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IEA Hydropower

Management Models for Hydropower Cascade Reservoirs

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Management mode of single series cascade reservoir group

Management Mode of Cascade Reservoirs in Wujiang Basin

1An overview of cascade reservoirs in a river basin

1.1Basic situation of river basin

The Wujiang River is the largest tributary on the south bank of the Sichuan River, with a catchment area of 87,920 km2, a river length of more than 1,030 km, and a natural drop of more than 2,120 m. About 80% of the entire basin is in Guizhou Province, and the rest are distributed in Chongqing, Yunnan, and Hubei.

The terrain of the basin slopes from southwest to northeast. The upper reaches of the river are located on the Yunnan-Guizhou Plateau, with gentle ground undulations; the upper section of the middle reaches of the Wujiang River is dominated by Zhongshan; the lower section of the middle reaches to the lower reaches of the Wujiang River, with low mountains or hills on both sides of the valley near the river.

The Wujiang River is an early rainy river in the upper reaches of the Yangtze River. Rainfall is mainly concentrated in May to September, with more rain in autumn. The distribution of rainfall in the basin is uneven, and the annual average annual precipitation of the whole basin is 900～1400mm. Due to the many mountains and hills in the basin, tributaries and section runoffs converge quickly after heavy rains, and floods fluctuate rapidly. The main flood peaks are generally dominated by a single peak shape, which is relatively thin. The annual average flow of Wulong Station at the exit station is 1690m3/s, the annual runoff is 53.4 billion m3, and the annual runoff variation coefficient is 0.20~0.30. Floods occur from May to September and often encounter the Qingjiang and Dongting Lake water systems. The maximum peak flow rate is 21000m3/s.

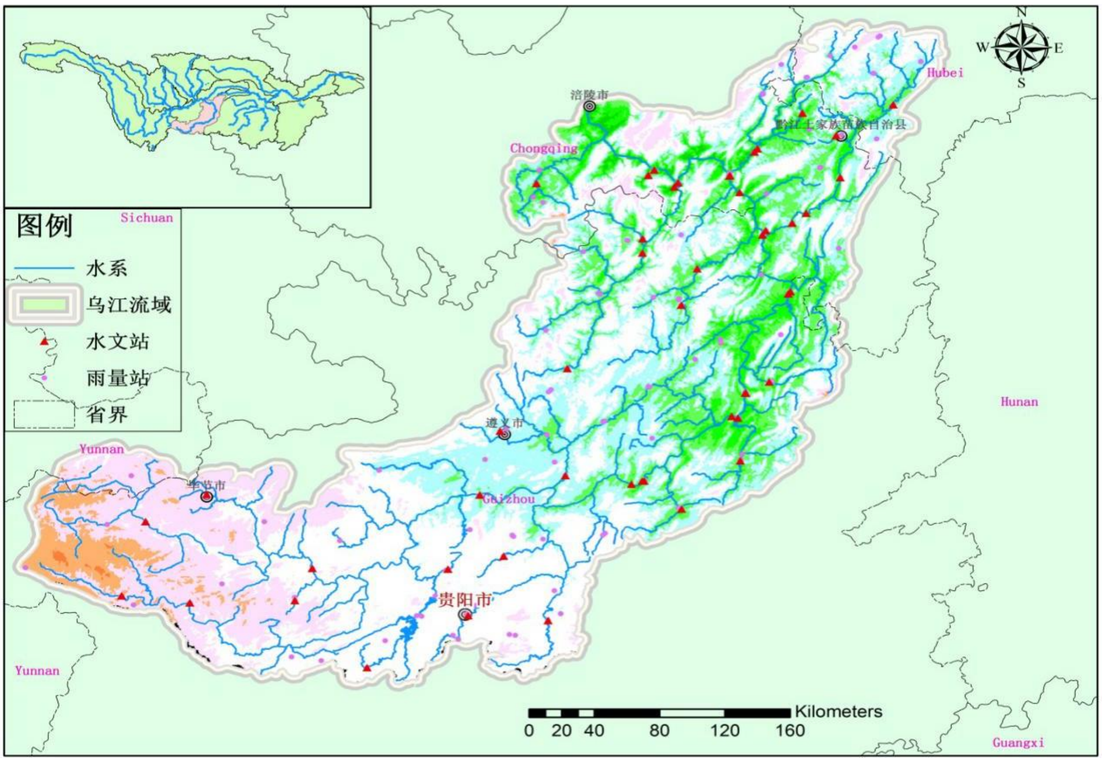

figure 1 Schematic diagram of Wujiang Basin water system

1.2 Development of Cascade Hydropower in the Basin

Located on the edge of the Yunnan-Guizhou Plateau and the Sichuan Basin, the Wujiang River Basin is a typical canyon-type river. The river has abundant and stable runoff, low sand content, concentrated natural drop in the river course, superior topography and geology of the dam site, and relatively small engineering volume and reservoir inundation losses , The theoretical reserve of mainstream hydropower is 10430MW, and the average power generation for many years is about 50.8 billion kW•h. Wujiang is one of the country's 13 largest hydropower bases, with abundant hydropower resources, good cascade regulation performance, excellent technical and economic indicators, and obvious location advantages.

The main power stations planned for the river basin have all been developed, with a total installed capacity of 12,782MW, which are mainly developed and operated by 5 different owners. The 7 cascade power stations on the main stream of Guizhou and the 2 cascade power stations on the tributary Qingshui River belong to Guizhou Wujiang Hydropower Development Co., Ltd. (hereinafter referred to as Wujiang Company, with an installed capacity of 8695MW, accounting for 68% of the total installed capacity of the Wujiang River Basin);

The three power stations belong to the Chongqing Branch of Datang International Power Generation Co., Ltd. (hereinafter referred to as Datang Chongqing Branch, with an installed capacity of 2920MW, accounting for 23%). The 2 cascades on the tributary Sancha River and the 3 cascade power stations on the tributary Furong River belong to Qianyuan Electric Power Co., Ltd. (hereinafter referred to as Qianyuan Company, with an installed capacity of 567MW, accounting for 4%). Both Wujiang Company and Qianyuan Company are secondary units of Huadian Group. The six cascade power stations on the tributary Maotiao River belong to Guodian Guizhou Electric Power Co., Ltd. (hereinafter referred to as Guodian Guizhou zCompany, with an installed capacity of 300MW), accounting for 2.5%. The Jiangkou power station on the tributary Furong River belongs to China Power Investment Corporation Chongqing Jiangkou Hydropower Co. Chongqing Jiangkou Company, installed capacity (300MW, 2.5%).

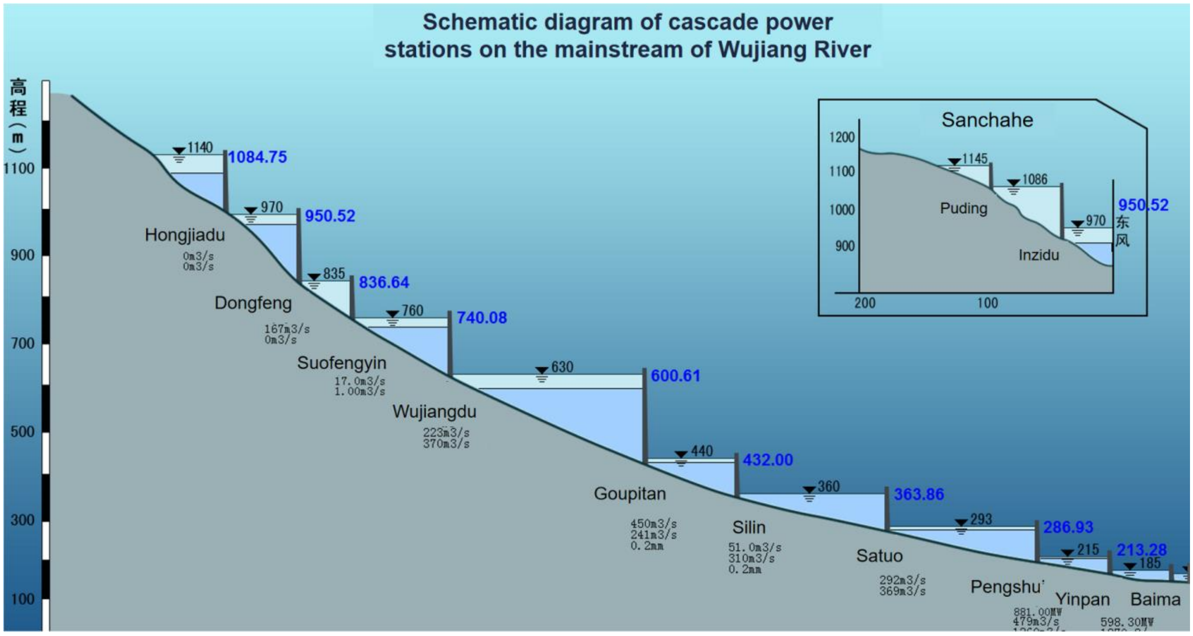

figure 2　Schematic diagram of cascade hydropower stations on the mainstream of Wujiang

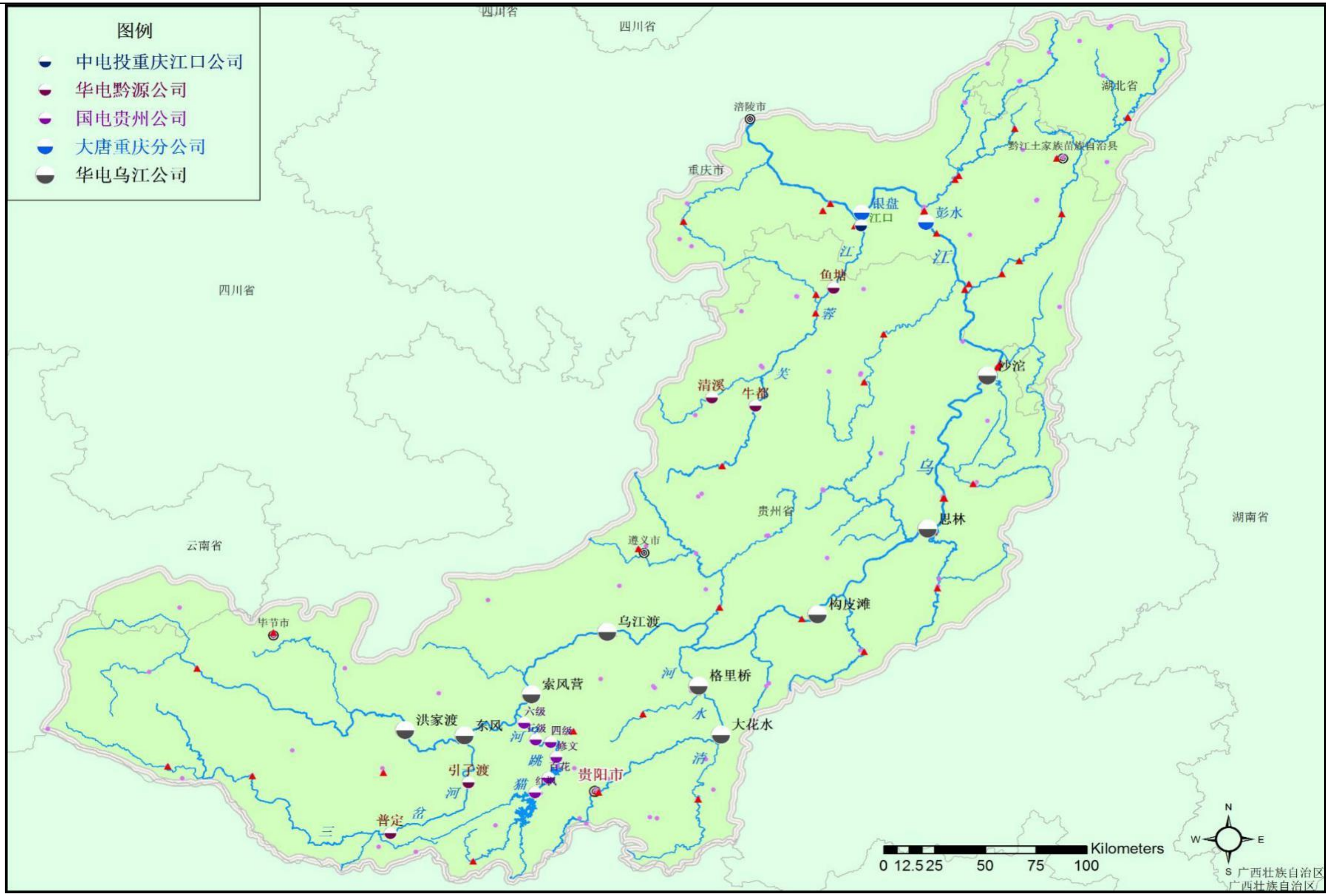

figure 3 Schematic diagram of the distribution of main hydropower stations in the Wujiang Basin

2 Basin management model and current situation

2.1 Management model and current situation

2.1.1 Dispatch management

The cascade reservoirs in the Wujiang River Basin are mainly used for power generation, followed by flood control and shipping. In general, power dispatch should obey flood control dispatch and shipping dispatch, and shipping dispatch shall obey flood control dispatch. The Wujiang River is a tributary of the Yangtze River. When there is a basin-wide flood on the Wujiang River, it will be coordinated and dispatched by the Yangtze River Water Resources Commission, the flood control authority of the Yangtze River Basin.

Flood control scheduling: Considering reservoir capacity and geographical location, most reservoirs in the Wujiang River Basin do not undertake flood control tasks. Reservoirs that undertake flood control tasks are Hongjiadu, a multi-year regulating reservoir, Wujiangdu, a seasonal regulating reservoir, and Goupitan, a daily regulating reservoir. Silin and Shatuo, Pengshui of Jitun Reservoir. The Wujiang River Basin spans Guizhou Province and Chongqing Municipality. The local flood control and dispatching units of the reservoirs are their provincial (city) flood control and drought relief command offices (referred to as the Prevention Office), and the provincial (city) prevention offices are subordinate to the Yangtze River Water Conservancy Commission (referred to as the Yangtze River Committee) Flood control dispatch. In addition, the flood control authority of some reservoirs is divided according to the water level of the reservoir. For example, the flood control of Pengshui Reservoir below the water level of 288.85m can be directly dispatched by the Chongqing Municipal Office of Prevention; the above shall be dispatched by the Yangtze River Committee.

Power generation dispatching: In Guizhou, except for the Goupitan Power Station, which belongs to the direct regulation of China Southern Power Grid, other power stations belong to the Guizhou Province Intermediate Power Station. The Goupitan Power Station is sent to Guangdong for consumption, and the other power stations are reserved for local consumption in Guizhou Province. The main and tributary hydropower stations in the lower reaches of the Wujiang River Basin in Chongqing belong to the Chongqing Municipal Commission. However, the Guizhou

Intermediate Transfer System belongs to the China Southern Power Grid Corporation and the Chongqing City Transfer System belongs to the State Grid Corporation of China. They are two different power grid systems.

Shipping dispatch: The traffic volume of the Wujiang River Basin is mainly concentrated in the lower reaches of Chongqing. The Pengshui-Yinpan Cascade Reservoir at the end of the basin takes into account shipping dispatch, and the navigable dispatching unit is Chongqing Port and Shipping Bureau. When conflicts arise, shipping dispatch is generally coordinated by the transportation department, power grid dispatching, and owner management units. When the outgoing flow of the Pengshui Hydropower Station is greater than 5000m3/s, it is necessary to notify the Chongqing Port and Shipping Bureau that the downstream river channel of the power station is closed; when the silver plate is greater than 5500 m3/s, it is necessary to notify the Chongqing Port and Shipping Bureau that the downstream river channel is closed Navigation; the minimum navigable flow downstream of Yinpan Power Station is 345m3/s, corresponding to the output of Yinpan Power Station's whole plant is not less than 100~110MW; when Pengshui and Yinpan Power Stations pass through the dam for navigation, application must be made one day in advance. It is required to cooperate with load control, including water level control; during the operation of the ship lift of Pengshui Power Station, the downstream water level is required to be stable, and the whole plant is required to operate with a fixed load.

2.1.2 Dispatching management of a typical single cascade reservoir

The installed capacity of the tributary reservoirs of the Wujiang River in Guizhou is relatively small. Therefore, it can be said that the Shatuo Reservoir and the 9 cascade reservoirs above are basin cascades developed and managed by a single company. The cascade power stations with a unified operation management unit carry out information collection and dispatch coordination through the centralized control center. The information communication between the cascade power stations is smooth, and the joint dispatch is performed efficiently, which can give full play to the power generation benefits of the cascade power stations. In addition, Wujiang Company's reservoir dispatching restrictions are less. The power dispatching agencies are relatively unified. Except for the Goupitan Power Station, which belongs to the South Grid Direct Transfer, the other 8 power stations belong to the Guizhou Intermediate Transfer. All reservoirs are mainly for power generation, and there are no important flood control tasks in the downstream. Except for Hongjiadu, Goupitan, Silin, and Shatuo, which have limited flood levels, the other four reservoirs have no flood control tasks. Moreover, none of its 9 cascade reservoirs have shipping requirements. As the hydropower stations of Wujiang Company have fewer scheduling restrictions and the combined operation of cascade reservoirs has many years of regulation performance, it is the main power supply and peak-shaving power station of the Guizhou Provincial Power Grid.

2.1.3 Upstream and downstream hydropower management and operation coordination

The Pengshui-Yinpan cascade reservoir of Datang Chongqing Branch is located at the end of the basin, and the upstream reservoir belongs to Wujiang Company. As the Wujiang Company's cascade reservoir plan is not rigid, the outflow flow changes greatly, and the Pengshui reservoir is a daily-regulated Shatuo Reservoir. The plan is changeable. Therefore, it is difficult to predict the inflow flow of the Pengshui Reservoir. -There are major constraints in the reservoir dispatching of Yinpan cascade power stations.

At present, the Central Control Center of Datang Chongqing Branch has established a relatively sufficient information sharing mechanism with upstream. One is to access the automatic water regime monitoring and reporting information of upstream reservoirs. The hour by hour reservoir water level, inflow and outflow of the reservoir and the surface rainfall of the reservoir are connected to the power station above Goupitan. In addition to the hydrological conditions of the power station below Goupitan, it also includes the information of the interval rainfall station; the second is the reservoir operation information, and the Wujiang Centralized Control Center regularly reports the weekly and monthly power generation plans of the Shatuo Power Plant to the Centralized Control of Datang Chongqing Branch Center; The third is daily communication. The upstream and downstream centralized control center has established a water regime sharing QQ group for daily communication. Since 2012, the Central China Regulatory Bureau of the National Energy Administration has organized an annual Wujiang Cascade Power Station

Joint Optimal Dispatching Coordination Meeting, which has further promoted the information sharing and dispatch coordination mechanism. The benefit distribution mechanism has not been established between the upstream and downstream of the Wujiang River. It is also due to the current status quo. The basic principle of upstream and downstream coordination and joint dispatch is: not detract from each other's interests, and make every effort.

2.2 Basin hydropower complements other multi-energy

In addition to hydropower energy in the Wujiang River Basin, there are other types of power sources, such as thermal power and wind power. The total installed capacity of the cascade reservoirs operated by Wujiang Company accounted for 68% of the Wujiang River Basin. Therefore, the Wujiang Company is mainly responsible for the operation and management of cascade reservoirs in the Wujiang River Basin. In addition, the company also owns thermal power, wind power, photovoltaic and other multi-energy power generation industries, including hydropower and thermal power installed capacity The largest, other energy installed capacity is smaller. Wujiang Company is the largest hydroelectric power generation company in Guizhou Province. Its installed hydropower capacity accounts for about 46% of Guizhou Province' s, and its power generation accounts for approximately 60% of the grid' s hydropower generation; there are 5 thermal power plants with an installed capacity of 4500 MW, which account for Guizhou' s power grid. 17% of the unified unit.

Wujiang Company has transformed the water and thermal power competition into complementary advantages. The optimal dispatch of hydro-thermal mutual aid is divided into annual hydro-thermal power distribution and mid-year hydro-thermal power optimization adjustments. This business is mainly based on the marginal contribution of thermal power as the initial criterion. In hydropower non-abandonment, water level control assessment and year-end cascade energy storage meet the group Under the premise of the company's requirements, combined with the supply of electricity and coal, hydro-thermal power maintenance plans and other factors, the following year's hydro-thermal power will be allocated in a coordinated manner to form a corresponding hydro-thermal mutual aid optimal scheduling plan to guide hydro-thermal power production. In the middle of the year, the actual water inflow has a large deviation compared with the forecast, the supply of electric coal is tight or the price of electric coal is rising, the non-stop and load limitation of thermal power units, and the administrative order intervention by higher-level units, in order to minimize the loss of power generation revenue and increase The principle of utilization rate of hydropower resources is to optimize the adjustment of hydro-thermal power.

2.3 River Basin Electricity Market Situation

Guizhou Province is a pilot province for comprehensive power reform and transmission and distribution price reform. In January 2016, Guizhou made clear regulations on transaction subjects and access conditions, transaction models, power generation planning arrangements, electricity tariff settlement, and safeguard measures. Thermal power and hydropower units with a single unit capacity of 100MW or more that comply with the national capital construction approval procedures can participate in market electricity trading, and promote hydropower to participate in power generation rights trading and surplus hydropower bidding online. In October of the same year, the Guizhou Provincial Development and Reform Commission clarified that the 500kV transmission price in the province for "West-to-East Power Transmission" was 2.76 cents/kW•h, of which the on-grid power price for thermal power was implemented at 0.3149 yuan/kW•h, and hydropower and others were deducted at the current on-grid power price 2.76 minutes/kW•h.

The thermal power industry mainly involves the coal market, power market and heating market. At present, part of Wujiang Company's thermal power is involved in the market-oriented transaction of electricity in the province, and the other part is supplied to the western power market as planned; the heat is supplied by region, and there is basically no competition with other companies.

The hydropower generation of Wujiang Company and Qianyuan Company accounts for about 80% of the hydropower generation of Guizhou Intermediate Transfer Project, which is a vital source of power generation for Guizhou Intermediate Transfer Project. Both Wujiang Company and Qianyuan Company are secondary units of Huadian Group. Therefore, they jointly deal with the hydroelectric power market in Guizhou Province to ensure that Huadian's hydroelectric power generation benefits in Guizhou are maximized. Mainly adopt measures to reduce power market losses by fighting for the priority of hydropower generation rights, reducing west-to-east transmission costs, energy-saving optimized dispatching, and undertaking peak and frequency modulation auxiliary services.

3 Key technologies of cascade dispatching in river basin

3.1 Meteorological and Hydrological Forecast Technology and System

None of the reservoir management and operation companies in the Wujiang River Basin conduct weather forecasting operations. This is because the Wujiang River is a tributary of the Yangtze River, with a relatively small drainage area, relatively concentrated reservoirs, and a relatively small power receiving area. The long-, medium- and short-term weather forecasts are mainly produced by entrusting other units, such as the Provincial Meteorological Center and the Hydrological Bureau of the Yangtze River Committee. In addition, Yangtze Power provides free weather forecasts for Wujiang Company to obtain water regime information in the Wujiang River Basin.

Hydrological forecasting is the key to lean reservoir operation. Although the operating companies of several major reservoirs and hydropower stations in the Wujiang River Basin do not have weather forecasting operations, they all carry out hydrological forecasts. The hydrological forecast system is generally integrated in the water dispatch automation system, including long-term hydrological forecast, daily runoff forecast, and flood forecast. Long-term inflow forecast: using 74 circulation index stepwise regression models and empirical forecasts to make quantitative predictions. After comprehensive analysis, annual inflow forecasts can be made. Annual runoff forecasts for the next 3-5 years in each interval can be made, monthly and ten-day runoff forecasts , The results are used in the production of annual and monthly power generation plans. Daily runoff forecast: The combination of system forecast and manual correction is applied to the production of weekly plans, which can predict the daily runoff of each section in the next 1-30 days. Flood forecasting: The combination of system forecasting and manual analysis is adopted, and the results are used in the making of 96-point plan and flood dispatching plan. Flood forecasting has the highest accuracy, with an average flood peak forecasting relative error of less than 10%; medium and long-term forecasting accuracy fluctuates greatly, with a minimum average relative error of less than 10% and a maximum of greater than 50%.

3.2 Joint dispatch technology and system

3.2.1 Remote centralized control technology of hydropower station

Wujiang Company, Qianyuan Company and Datang Chongqing Branch have all achieved a high degree of remote centralized control of hydropower stations. Each centralized control center not only performs remote measurement, remote signaling, remote adjustment, remote control, and remote viewing of the "five remote" control of the controlled power station units, but also implements unified scheduling and centralized management. The controlled power station has realized that the control room has no one on duty. Few people on site.

The remote centralized control system of the cascade power stations in the Wujiang River Basin is mainly composed of three parts: the power dispatching automation system, the water dispatching automation system and its advanced applications and auxiliary support systems. The power dispatch automation system of Wujiang Centralized Control Center mainly refers to the computer monitoring system. Its basic function is to realize the integration of the local functions of the upper computer system of each cascade hydropower station in the remote centralized control center. Functions include automatic power generation control (AGC), automatic voltage control (AVC), economic power generation operation (EDC), intelligent coordinated control, unit planning, unit commitment, load distribution within the station, safety constraint analysis, data communication, data acquisition and processing, and operation Monitoring and event alarms, human-machine communication and operation control, large-screen projection display functions, and power monitoring and control of the power transmission lines of each cascade power station.

The water transfer automation system is the foundation and technical support for ensuring the safety of cascade reservoirs and realizing economic operation. Its main purpose is to realize water regime analysis, joint reservoir dispatching and flood control decision-making command by automatically collecting real-time water regime, rain regime, meteorology, water quality, hydraulic building operation monitoring and other information in reservoirs, river basins and formulating areas. Its basic function is to replace the traditional single-reservoir hydrological information center system with a unified river basin water transfer center system, realize data collection, transmission and storage processing in the macroscopic scope of the whole river basin, and realize cascade water affairs calculation and comprehensive hydrological analysis. Advanced application is an important technical means to realize comprehensive utilization of water energy. Its functions include hydrological forecasting, flood risk analysis and short, medium and long-term economic operation.

Auxiliary support systems mainly include communication systems, industrial television systems, video conferencing systems and electric energy metering systems, etc.

3.2.2 Joint Optimal Dispatch of Cascade Reservoirs Regulated by Single Stream

The Hongjiadu and Goupitan reservoirs can change the annual runoff distribution of cascade reservoirs, so that the inflow of water is stable, which is conducive to reservoir power generation. In the non-flood season, "storage less and more use", orderly reduce the water level of reservoirs with regulating capacity, while maintaining high water level operation of daily regulating reservoirs, reducing the overall water consumption rate of the cascade. During the flood season, "storage more and less use", reasonably control the water level of cascade reservoirs, use flood resources to generate more power, coordinate upstream and downstream reservoirs, and reservoirs with regulating capacity can intercept floods as much as possible without affecting safety, and perform peak shifting or compensation scheduling , And create good flood control conditions for downstream cascade power stations and ensure the flood control safety of cascade reservoirs.

Wujiang Company is actively carrying out joint optimized dispatching of cascade hydropower stations, making full use of the regulating performance of the reservoir, greatly increasing the power generation efficiency of the main stream of the Wujiang River, and improving the power quality of the Wujiang cascades. According to the conventional operation mode, the average output of the Wujiang cascades during the dry season is 3634MW. When Hongjiadu operates in the mode of more storage and less release during the wet season and frequent dry seasons, the average output of the Wujiang cascades during the dry season can reach more than 4100MW, which can increase the Wujiang cascade. Power quality and annual average power generation. Before 2003, the Dongfeng Power Station had an average of 1 billion cubic meters of water discarded each year. After the completion of Hongjiadu, Dongfeng only had 300 million m3 of water not discarded each year. The benefits were significant. The completion of Hongjiadu made the cascade joint dispatching of the mainstream of the Wujiang River a reality. And it improves the peak shaving capacity of the power grid, and the effect is significant.

3.2.3 Complementary water and fire

Wujiang Company takes the competitive relationship of water and thermal power transformation in the same grid area as complementary advantages. During the dry season, while hydropower stations are responsible for improving the power supply guarantee capacity of the power grid, they also undertake more peak and frequency regulation tasks for the power grid, increase the power generation load rate of thermal power units, and reduce coal consumption of thermal power; Reduce the progress of hydropower station reservoir drawdown, and at the same time arrange for the maintenance of hydropower units, and maintain the thermal power load rate of Wujiang Company at around 68% during the dry season. Prior to the flood season, priority should be given to arranging hydropower stations with regulating capacity to generate electricity for elimination. During the flood season, thermal power is a concession channel for hydropower, and the thermal power load rate is reduced to about 60%, and the single unit load is reduced to a minimum of about 40%.

Such as Silin and Dalong Power Plants: Silin (hydropower, installed capacity of 1050MW) and Dalong Power Plant (thermal power, installed capacity of 600MW) belong to the eastern power grid area of Guizhou. Under certain demand, if Silin generates more power, Dalong Power Plant will generate less . Silin is the most downstream of the Wujiang cascade power stations that are put into production. Silin is more frequent, and the upstream cascade needs to be more frequent. In order to maintain the high water level operation of the cascade in the dry season, the optimization of hydropower requires Silin to generate as little as possible. In November 2012, Wujiang Centralized Control Center actively contacted and communicated with the Southern Power Grid, the Guizhou Intermediate Project, and Silin local governments to ensure that the downstream ecological water demand of Silin Power Plant was to be reduced as far as possible. Long Power Plant makes room for power generation. At the same time, we seized the opportunity of applying copper to the power grid for the first anti-icing reinforcement, coordinated the monthly arrangements for the Southern Power Grid and the Guizhou Intermediate Transfer, and gave priority to the Dalong full hair, so that the Dalong load rate quickly increased from 76% to 95% Around 60 million kW•h of power generation. The mutual aid of water and fire not only quickly and effectively increased the load rate of Dalong, but also controlled the overall power of hydropower, so that all reservoirs maintained high water level operation, and the water consumption rate was generally reduced by 10%-15%. Due to the reduced water consumption, the amount of water saved was equivalent to 4000. Million kW•h.

3.2.4 Optimal dispatch across river basins

Wujiang Company is responsible for the dispatch and management of 9 cascade hydropower stations in the Wujiang River Basin, and Qianyuan Company is responsible for the dispatch and operation of 5 hydropower stations on the tributaries of the Wujiang River and 4 hydropower stations in the Beipan River Basin (not belonging to the Wujiang River Basin). The two companies belong to the Huadian Group Corporation, and the power dispatching belongs to the Guizhou Intermediate Harmonization and the Southern General Harmonization. This time, it created favorable conditions for cross-basin optimal dispatch.

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The main scheduling measures are:

(1) Taking power grid energy-saving dispatch as an opportunity, build a harmonious "multilateral multi-layer" consultation mechanism for grid factories. The first is to establish a multi-objective collaborative optimization consultation mechanism; the second is to establish a

multi-agent information sharing mechanism for Wujiang and Beipanjiang; and the third is to establish a hierarchical consultation mechanism for Wujiang and Beipanjiang dispatch strategies.

(2) Guided by cascade synchronization and equilibrium, innovatively form a consensus on cross-basin optimal dispatching indicators. Based on the optimization goals of each subject, the Wujiang Centralized Control Center puts forward the "energy storage reduction consistency principle" and "abandonment risk consistency principle" through summarizing experience and in-depth research, finding the greatest common divisor and forming a consensus among multiple parties.

(3) With the goal of optimizing smooth communication, build a consultation and exchange platform for cross-basin joint dispatch.

Through scientific and technological investment, the Wujiang Central Control Center has developed a cross-basin optimal dispatch system for the Wujiang and Beipanjiang cascades, which effectively solved the problems of disagreement between multiple parties and complicated coordination and communication. Through optimized dispatching across river basins, the total additional power generation from 2014 to 2015 was 1.241 billion kW•h, and the direct economic benefit was 360 million yuan.

3.3 Decision Support Systems

3.3.1 Decision Support System for Power Generation Optimization and Consultation of Wujiang Cascade Reservoirs

The power generation consultation decision support system is an informationized electronic platform for Wujiang cascade reservoir scheduling. It realizes the modernization of power generation scheduling decision-making through digitalization and informationization, and is the main measure to improve the level of cascade scheduling. In order to meet the needs of power generation dispatch decision-making, according to the consultation process, the system has developed consultation assistance functions and program analysis and decision-making functions, which can comprehensively, quickly, accurately, flexibly and dynamically consult according to the various needs of the consultation personnel to achieve Effective management requirements.

For practical purposes, the system has built five consultation assistance functions: real-time water regime information, historical water regime query, forecast query, power generation plan and implementation, and power generation analysis. The first three functions are the water regime information query of cascade reservoirs. The power generation plan and implementation function are designed to analyze the implementation of the system power generation plan by the cascade reservoir, including historical plans and current plans. Power generation analysis can analyze the power generation status and subsequent power generation capacity of the hydropower station reservoir group at the present time, as well as the completion of a certain plan or virtual plan from different dispatch periods of the day, week, ten days, month, and year. The conference function mainly includes 2 modules. One is plan comparison. Plan comparison is the main method of consultation and decision-making. Through intuitive comparison of tables and graphs, consultation factors such as power generation, reservoir storage, later generation capacity of different incoming water, reservoir water level, power station output, etc. Compare. The second is decision output, including functions such as query and browsing of different types of plans, interactive calculations, plan reports, and plan result output.

3.3.2 Multi-energy complementary operation optimization big data intelligent decision-making platform

Based on the research results of virtualization, cloud computing, big data, mobile collaboration and other technologies, Wujiang Company is planning and developing a big data intelligent decision-making platform for multi-energy complementary operation and optimization business, which can be optimized through the integration of multiple energy information, operation complementation and integration. Improve the energy supply and demand coordination ability, the overall efficiency of the energy system, and the production and operation decision-making ability to achieve the goal of "optimal energy consumption, maximum benefit, and strongest comprehensive competitiveness".

From the perspective of the entire industry chain, the platform is divided into three major sections with "market-operation-production" as the main line of business content. Its platform architecture is shown in Figure 4. Market business: Mainly covers coal, electricity and electricity derivatives market analysis and customer information management. Operational business: It mainly covers the strategy formulation of coal procurement inventory, economic operation, electricity bidding, sales of electricity and heat, and electricity derivatives trading. Production business: Mainly covers lean remote control, intelligent monitoring, remote diagnosis and analysis of unit, intelligent power generation dispatching and benchmarking management. The entire platform will be built on the existing computer monitoring, water dispatch automation, thermal power centralized supervision, industrial TV monitoring and other subsystems, new energy remote diagnosis platform, power bidding decision support, multi-energy complementary optimization scheduling and other 11 subsystems.

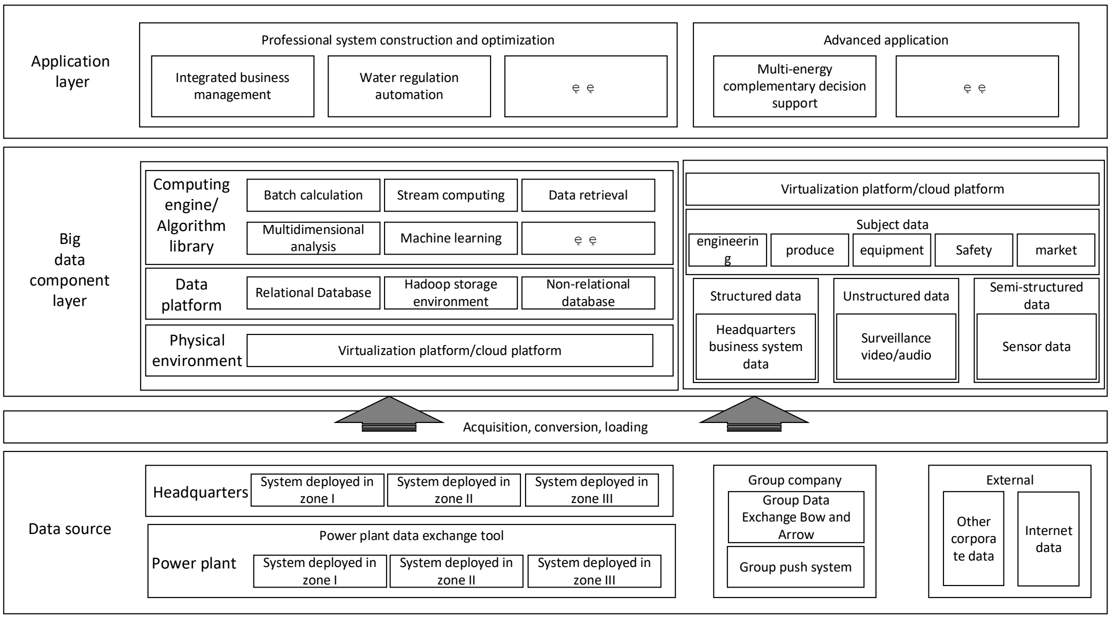

figure4 Multi-energy complementary operation optimization big data intelligent decision-making platform architecture diagram

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[1]Research and Application of Decision Support System for Optimal Dispatching and Consultation of Wujiang Cascade Reservoirs Yulan, Tang

[2]Research on planning of multi-energy complementary operation optimization big data smart decision platform for energy enterprises Peng, Peng

Management Mode of Cascade Reservoirs in Yalong River Basin

1An overview of cascade reservoirs in a river basin

1.1Basic situation of river basin

The Yalong River is a river in the western part of Sichuan Province, China. It is a tributary of the Jinsha River in the upper reaches of the Yangtze River. It is 1,187km long and has a drainage area of 144,000 km2. Originating from the southern foot of Bayan Har Mountain in Chenduo County, Qinghai Province, it flows from northwest to southeast through Nidakando and then enters Sichuan Province. It flows from north to south at the mouth of Lianghe River and flows into Jinsha River under Yajiang Bridge in Panzhihua City. It is a typical alpine valley river. The terrain of the basin is high in the north, west and east, and slopes to the south. The river source area is separated from the Bayan Har Mountains and the Yellow River Basin. The rest of the surrounding area is sandwiched between the Jinsha River and the Dadu River Basin. It is long and narrow, involving Qinghai and Sichuan. Province, 8.5% of the basin area belongs to Qinghai Province, and 91.5% of the basin area belongs to Sichuan Province. The natural drop from the source of the Yalong River to the estuary is 3,830 meters. Among them, from the Xiyi Temple to the estuary, the river is about 1,360 kilometers long, with a drop of 3180 meters, and an average drop of 2.34‰. The upper reaches of the main stream is the upper reaches, the mouth of the Nito-Litang is the middle reaches, and the lower reaches of the mouth of the Litang is the lower reaches. The upper reaches of the mountain and plateau landscape, the river valleys are mostly grassland wide valleys and a small number of shallow hills and valleys, and the runoff is dominated by ice and snow; the middle and lower reaches are plateaus, alpine valleys and rivers, the river is 100-150 m wide, and wide valleys and basins appear in the tributaries . The tributaries are distributed evenly on both sides of the main stream in a dendritic shape. There are 3 Xianshui River, Litang River and Anning River with a drainage area of more than 10,000 km2..

（1）Climate

The climate of the Yalong River Basin is mainly affected by the high-altitude westerly atmospheric circulation and the southwest monsoon, and due to the large topographical height difference and the large changes in the north-south latitude, the characteristics of both horizontal and vertical changes are large, resulting in very complex climate conditions in the basin , The northern plateau has a dry and cold continental climate, cold and dry, less clouds and fog, strong sunshine, long winters, four seasons are not obvious, dry and wet seasons are distinct, most areas can snow throughout the year, the annual average temperature is about 0℃, and extreme temperatures Below -35℃; the central and southern parts of the basin have a subtropical climate with distinct wetness and dryness, with obvious vertical climate changes. In the same area, the mountains are wet and rainy but the temperature is low, and the river valleys are dry and dry with little rain but the temperature is high. As the altitude increases, the temperature begins to decrease. . There are large differences in the temporal and spatial distribution of rainfall in the basin, mainly concentrated in the wet season from June to October. The spatial distribution is: 600～800mm in the upstream area (500～600 mm at the head of the river), 1000～1400mm in the middle reaches, and 900～900 in the downstream area. 1300 mm.

(2) Hydrology

The river runoff of the Yalong River Basin is mainly composed of rainfall, groundwater and snowmelt water. The annual average flow of the estuary is 1890m3/s. The interannual change of the runoff is small, abundant and stable. The annual runoff is 59.6 billion m3, accounting for the total runoff of the upper Yangtze River. November to May is the dry season, and the water volume accounts for about 24% of the annual runoff. June to October is the wet season, accounting for about 76% of the annual runoff. The middle and lower reaches of the Yalong River are located in two heavy rain areas in western Sichuan and Anning River. They are the main source areas of floods. The flood characteristics are peak height, small volume and short duration. The main flood season is from June to September, and major floods mostly occur from July to August, which are roughly synchronized with the floods in the middle and lower reaches of the Yangtze River. The middle and upper reaches of the basin have low sediment content. The lower reaches of Wali to Xiaodeshi are the main sediment producing areas in the Yalong River basin, with an average suspended load transport of 41.9 million tons.

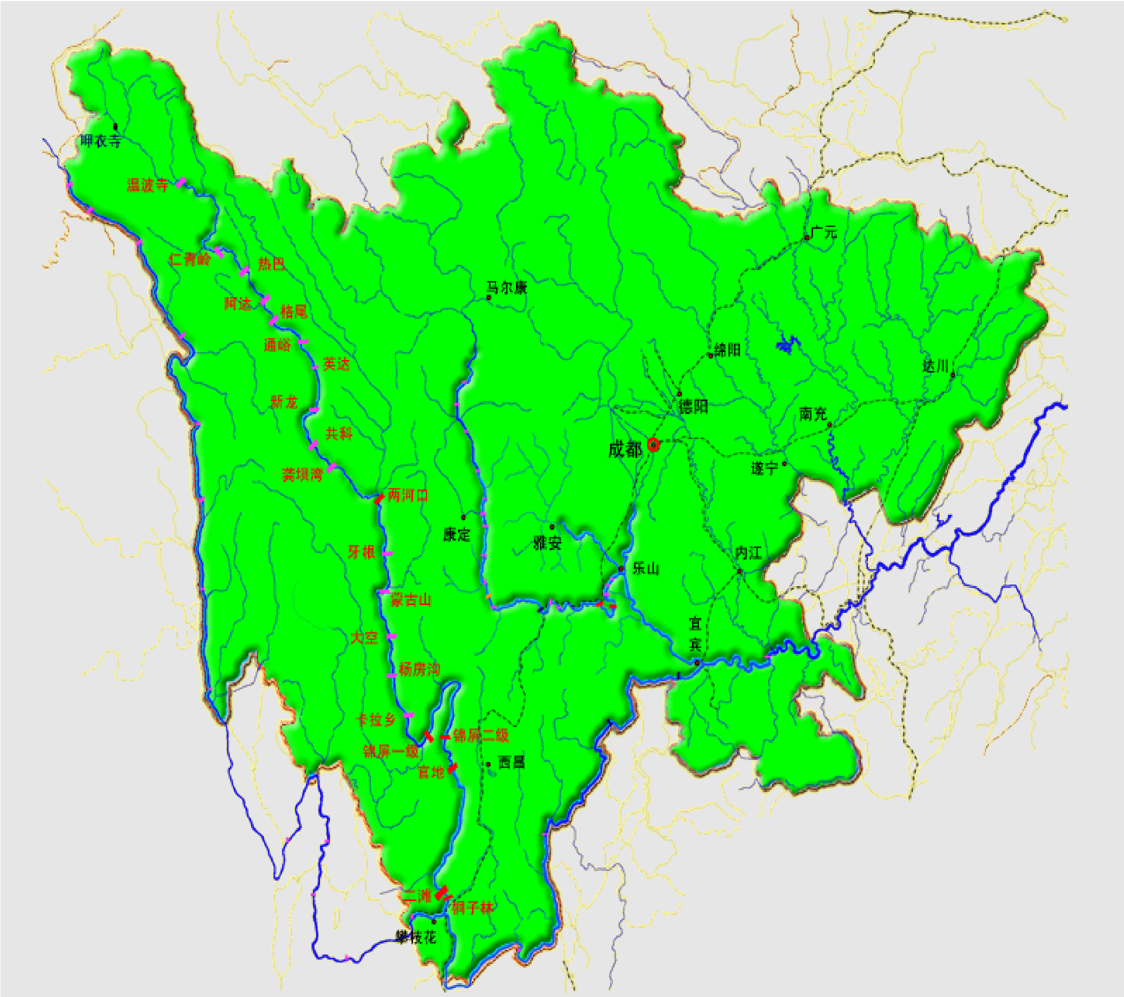


figure1 Schematic diagram of the geographical location of the Yalong River Basin

1.2 Development of Cascade Hydropower in the Basin

The Yalong River Basin is a high mountain and gorge. It is located in a precipitous zone. The population is small and the area of submerged cultivated land is small. The migration population and submerged cultivated land per 10,000 kilowatts are about 5% of the national average, which has minimal impact on project investment and construction period. It avoids a large number of social problems, undertakes fewer profit-making tasks, and makes the operation of cascade power stations less restrictive. In addition, the Yalong River valley is deep, the river has a large slope, good location conditions, superior power generation conditions, and higher overall efficiency of cascade power stations.

The Yalong River Basin Hydropower Base is one of the "China's 13 Largest Hydropower Bases". Its hydropower resource reserves rank third, second only to the Jinsha River Hydropower Base and the Upper Yangtze River Hydropower Base. It is a treasure house of China's energy supply. Only the main stream of the Yalong River Basin has a theoretical hydropower reserve of 22 million kW, and its tributaries are 11.44 million kW. The developable hydropower resources in the entire basin are 30 million kW. Based on the principles of rational utilization, orderly development, and comprehensive benefits, and taking advantage of the abundant water in the basin, the concentrated drop, and the small loss of reservoir inundation, the Yalong River plans to build 21 large and medium-sized cascades with good reservoir regulation performance. Hydropower station, with an installed capacity of 30 million kW, of which Lianghekou, Jinping I and Ertan are controlled reservoirs, with a total regulating storage capacity of 15.8 billion m3. The regulating capacity of other hydropower stations is not calculated. Only the regulating capacity of these three reservoirs has already been accounted for 27% of the 59 billion m3 average water inflow to the Yalong River for many years, with very good multi-year regulation ability.

The main stream of the Yalong River is divided into three sections for planning：

The upstream section is from Xiayisi to Lianghekou. The section is 688km long. It is planned to include: Wenbosi Hydropower Station (150,000kW), Renqingling Hydropower Station (300,000kW), Reba Hydropower Station (250,000kW), Ada Hydropower Station (250,000 kW), Gurney Hydropower Station (200,000 kW), Tongha Hydropower Station (200,000 kW), Yingda Hydropower Station (500,000 kW), Xinlong Hydropower Station (500,000 kW), Gongke Hydropower Station (400,000 kW) , Gongbagou Hydropower Station (500,000 kW) has 10 cascade power stations with an installed capacity of about 3.25 million kW.

The middle reaches from Lianghekou to Kara. The length of the river section is 268km. It is planned to include: Lianghekou Hydropower Station (3 million kW), Yagen Hydropower Station (1.5 million kW), Lenggu Hydropower Station (2.3 million kW), Mengdigou Hydropower Station (1.7 million kW) kW), Yangfanggou Hydropower Station (2.2 million kW), Kara Hydropower Station (1.06 million kW) 6 cascade power stations, with a total installed capacity of 11.26 million kW). Among them, the Lianghekou cascade power station is the middle reaches of the control "leading" reservoir.

The downstream section from Kara to the mouth of the river is 412 km long and has a natural drop of 930m. This section has good geological structure stability, low reservoir inundation loss, and single development target. It is a key development section. It has been basically completed and put into production at present, including: Jin Ping I Hydropower Station (3.6 million kW), Jinping II Hydropower Station (4.8 million kW), Guandi Hydropower Station (2.4 million kW), Ertan Hydropower Station (3.3 million kW, completed), Tongzilin Hydropower Station (600,000 kW) 5-level development plan, installed capacity of 14.7 million kW, guaranteed output of 6.78 million kW, and annual power generation of 69.69 billion kWh.

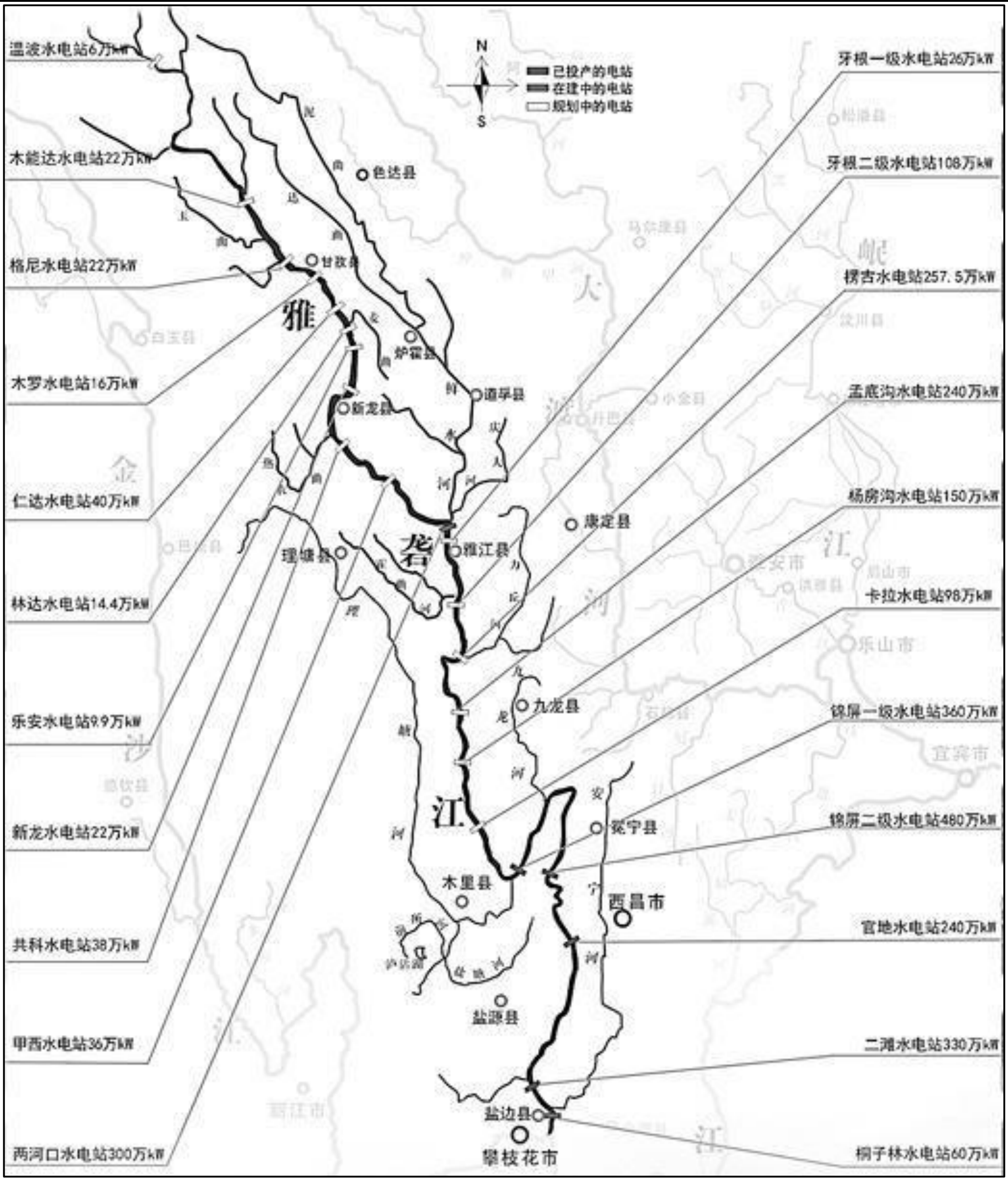
The development of hydropower resources in the Yalong River Basin is divided into "four stages". The first stage: Before 2000, the Ertan Hydropower Station was developed and constructed, and the installed capacity of 3.3 million kilowatts was put into operation, laying the foundation for hydropower development in the Yalong River Basin. The goal at this stage has been achieved, and the construction of Ertan Hydropower Station has achieved remarkable achievements recognized worldwide;

The second stage: before 2015, complete the Jinping I, II Hydropower Station, Guandi Hydropower Station, and Tongzilin Hydropower Station, and fully complete the development of the cascade hydropower stations on the lower reaches of the Yalong River. The company's power generation capacity will increase from 3.3 million kilowatts to 14.7 million kilowatts , The benefits of scale and cascade compensation have initially appeared, becoming an independent power generation enterprise with strong market competitiveness and sustainable development capabilities in the regional power market; basically forming the prototype of a modern basin cascade power station group;

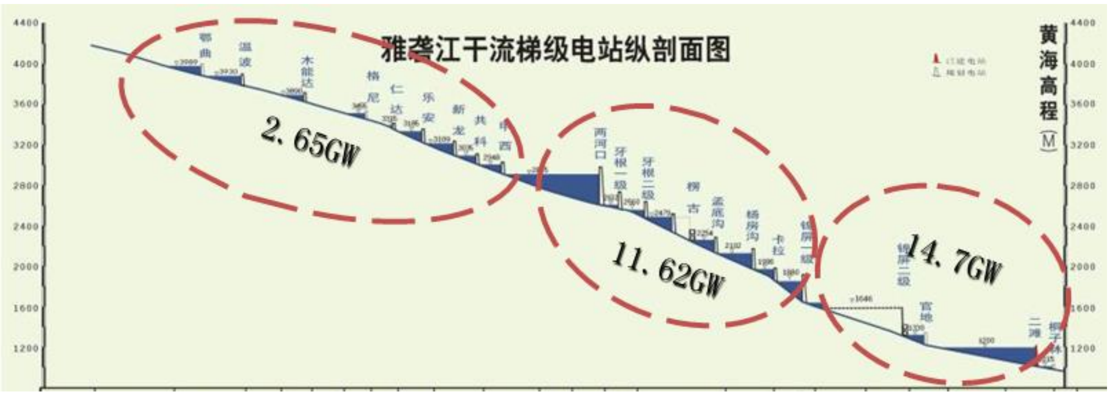
The third stage: by 2025, continue to further promote the development of hydropower in the Yalong River Basin, build 4-5 main cascade power stations in the middle reaches including Lianghekou Hydropower Station, achieve an additional installed capacity of about 8 million kilowatts, and have a power generation capacity of up to With more than 23 million kilowatts, the company will enter the ranks of world-class large independent power generation companies;

The fourth stage: project development and filling in the whole river basin, the hydropower development of the Yalong River basin is fully completed, and the company has a power generation capacity of about 30 million kilowatts.

Currently, the first and second phases have been completed: With Ertan Hydropower Station and Jinping Hydropower Station as the core reservoirs, including Tongzilin Hydropower Station, Jinping Hydropower Station II, and Guandi Hydropower Station, all have been completed and put into operation. The Lianghekou Hydropower Station and Yangfanggou Hydropower Station in the middle reaches have been approved to start construction. The preliminary work of the five hydropower stations in Kara, Yagen I, Yagen II, Lenggu, and Mengdigou is progressing in an orderly manner; the upstream "One Reservoir and Ten Levels" planning work has been launched. The focus of river basin development and construction shifts to the middle and upper reaches.



(a) Plan top view



(b) Planning profile

figure2 Plan of the main stream of the Yalong River Basin

The Yalong River Basin has a single development target and superior technical and economic indicators. There are many large power stations with large installed capacity and outstanding scale advantages. Among the 21 cascades planned in the main stream, there are 16 large power stations (installed capacity greater than 300,000 kW), with a total installed capacity of 27.51 million kW.

There are few migrants and submerged cultivated land, and the unit submerged index is low. The Yalong River cascade power stations are mainly located in Liangshan Yi Autonomous Prefecture and Ganzi Tibetan Autonomous Prefecture. The population density is small, the cultivated land is scattered, and the submergence loss of hydropower development is small. According to the statistics of the six cascade power stations currently under construction in the two river mouths, Jinping I, Jinping II, Ertan, Guandi, and Tongzilin, the total migrant population is only about 11,000 and the total inundated cultivated land is 16,000 mu. The average migrant population per 10,000 kilowatts is 8.5 people, and 11.9 mu of cultivated land is submerged; the average migration population is 15.8 people per 100 million kWh, and the submerged cultivated land is 22 mu, which is the lowest inundation index in the national hydropower development.

The overall regulation performance is good, and it has a great compensation effect on the downstream cascade power stations. The three large reservoirs at Lianghekou, Jinping I and Ertan have a large total regulating storage capacity. When all cascade power stations are completed, the whole basin capacity regulating coefficient can reach 0.32, which will become the best quality regulating performance among all rivers in Sichuan Province. Hydropower bases are also one of the few in the country. The 10 cascades below Lianghekou (the main stream of the Yalong River) operate separately, and the electricity of the entire cascade is 46.72 billion kWh during the dry period (November to May of the following year), and 65.95 billion kWh during the flood period (June to October). The ratio of the electricity to the electricity in the flood season is 1:1.41; the electricity of the entire cascade is 72.92 billion kWh during the dry season, the electricity of the flood season is 56.03 billion kWh, and the ratio of the electricity during the dry season to the electricity during the flood season is 1.3:1. The cascade compensation has huge benefits, which can effectively realize the optimal allocation and utilization of water resources.

2 River Basin Cascade Reservoir Management

2.1 Current management model

In the late 1980s, my country began to explore the rolling hydropower development mechanism and set up large-scale river basin hydropower companies. This method is a further deepening of the owner's responsibility system, that is, the owner uses the built power station as the parent power station, and uses the profit of the parent power station to develop a group of power stations in a river basin. The development model of "watershed, cascade, rolling, and comprehensive" began to emerge: The development and construction of a single hydropower station has evolved into the development and construction of hydropower clusters in the basin; the investment, construction and operation of a single hydropower station has evolved into a trend of rolling development of funds in the basin, that is, the "one river, one company" system. The "watershed, cascade, rolling, and comprehensive" development mechanism refers to a unified plan based on the characteristics of each cascade power station, geographical location, regulation performance, installed capacity, upstream and downstream relationship, and power demand analysis, combined with the development plan of the power grid. Orderly construction promotes the unified and orderly development of river basins and the unified dispatch of river basin cascades, realizes the maximization of regulation benefits and river basin benefits, and promotes the development of hydropower. At the beginning of the 21st century, the huge economic and social benefits of this river basin development model have been widely recognized by the industry. Promoted by the country's western development and power system reform, this new hydropower development model has been rapidly promoted.

In this context, in October 2003, the National Development and Reform Commission issued a document agreeing that Ertan Hydropower Development Co., Ltd. is responsible for the development of hydropower resources in the Yalong River Basin. In November 2012, according to the requirements of the National Energy Administration, Approved by the State

Administration for Industry and Commerce, "Ertan Hydropower Development Co., Ltd." was renamed "Yalong River Basin Hydropower Development Co., Ltd." (hereinafter referred to as Yalong River Company). At present, the Yalong River Company is the main body of the development of nearly 30 million kilowatts of hydropower installed capacity in the Yalong River Basin, and is fully responsible for the construction and management of the cascade hydropower stations in the basin. The overall cascade development model adopted has achieved remarkable results and has also ensured Yalong River Company is the sole development subject of Yalong River.

The Yalong River hydropower development management model is a typical "single owner, single control center" development management model, where the "single control center" is the Yalong River centralized control center. In recent years, the centralized control center is comprehensively promoting the joint optimized operation of the Yalong River cascade power stations and reservoirs, strengthening the research on joint optimized dispatching of reservoirs, and achieving the goals of maximizing power generation revenue, maximizing peak regulation capacity, and maximizing flood arrest during flood periods, and realizing the comprehensive benefits of cascade power plants.

figure3 Yalong River Basin Centralized Control Center

With the continuous deepening of the cascade development and construction of hydropower stations in the Yalong River Basin, in order to follow the development and management concept of "watershedization, groupization, and scientificization", to pursue the largest overall benefits of the cascade hub, optimize production and improve management levels, Yalong River The company formally established a centralized control center in 2009 to optimize power generation control and regulation of the power plant group under the premise of ensuring the requirements of the power grid. At the same time, the Centralized Control Center, as the hub for water regime forecasting in the Yalong River Basin, is responsible for water regime forecasting, construction and maintenance of related measurement stations, and centralized water dispatch management. Its responsibilities include 6 parts:

1. Make and implement unit production and maintenance plans;
2. Make long-term, medium- and short-term power generation plans for cascade reservoirs;
3. Provide meteorological and hydrological information services for the safe and efficient operation of cascade power stations;
4. Real-time scheduling of cascade reservoir operation;
5. Remote monitoring of each unit of cascade power station;
6. Build and manage automated communication systems.

The management of Yalongjiang Control Center has one director, one deputy director and one chief engineer. In order to be responsible for daily production and management, 5 major offices (departments) have been set up, including: Production and Technology Office, Power Plant Operation Management Office, Hydrological Information Office, System Maintenance Office, Comprehensive Management Office, etc. The organizational framework and details of each department The main responsibilities are shown in Figure 4.

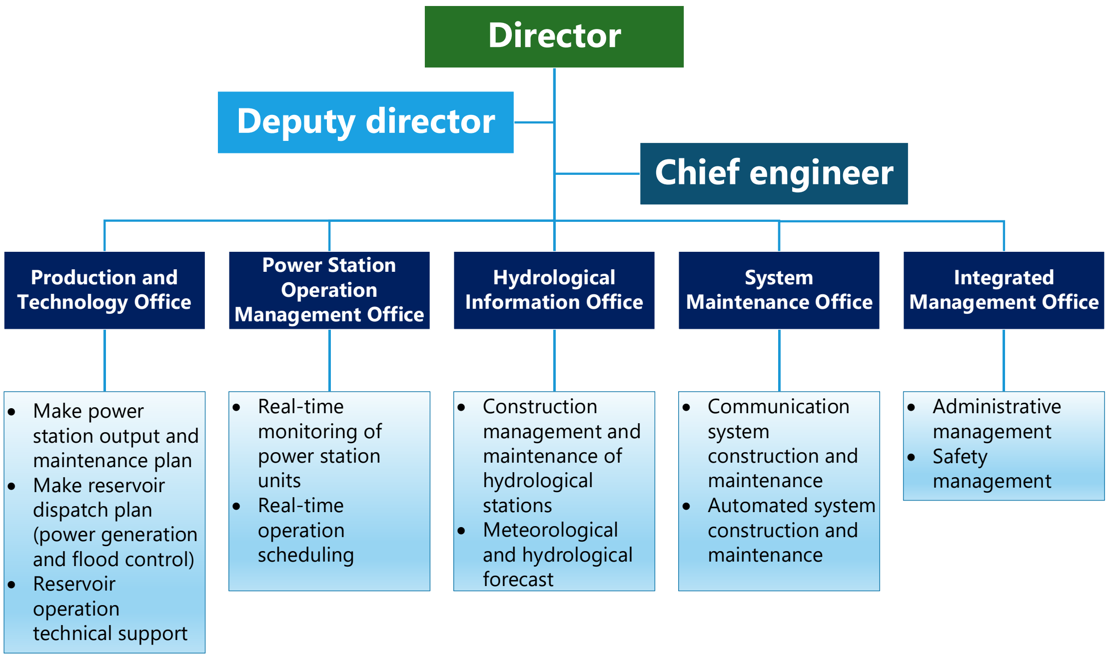


figure4 Management Organization Framework of Yalong River

Centralized Control Center

The Yalong River Basin is vast and sparsely populated, and it is also a deep mountain and canyon landform. The flood control and dispatching pressure of cascade reservoirs is not great. However, due to the close hydraulic connection between the Yalong River Basin and the middle and lower reaches of the Yangtze River, the cascade reservoirs are also included in the joint flood control dispatching of the Yangtze River Control. They need to undertake the overall flood control dispatching task of the Yangtze River Basin and share the flood control pressure for the middle and lower reaches. During the flood season, the conflict between flood control and power generation of the reservoir group in the basin is more prominent. In the actual flood control operation process, due to the special geographical and natural environment of the Yalong River Basin, the temporal and spatial distribution of rainfall is highly uneven and extreme, resulting in strong randomness of floods in mountainous areas, short flood forecast periods, and poor forecast accuracy. high. Because the flood peak process is relatively fast, from collecting rainwater conditions, making scheduling plans, reporting decisions to leaders or higher-level agencies, to issuing operational instructions to execute, and notifying the downstream of the cascade to prepare for flood control, time is very tight, and the scheduling process must comply with relevant scheduling procedures Especially in the flood season, while taking into account flood control and benefiting, we often face floods that actually occur but cannot be accurately forecasted, making decision-making difficult and arduous responsibilities.

At the same time of flood control, the main task of the Yalong River cascade reservoir dispatching is to coordinate the contradiction between flood control and benefit, allocate water resources rationally, and realize the maximization of social and economic benefits. The unified allocation and management of resources. The relevant water administrative departments of the river basin, the flood control and drought relief departments of the Yangtze River Basin, and the power grid departments are all managed according to their own responsibilities. There is competition in the distribution of water resources among the various regions of the river basin and among the water use departments. This has led to some ecological and environmental problems, management conflicts, and more acute contradictions in the beneficial operation of reservoirs, involving many departments and stakeholders in water resources management, and it is difficult to resolve and coordinate.

2.2 Comprehensive utilization and sustainable development of watershed

The Yalong River Basin is rich in hydropower resources, with a theoretical hydropower reserve of 33.72 million kW, accounting for 14% of the total amount of the Yangtze River Basin. It is one of China's large hydropower bases. According to the characteristics of the Yalong River Basin and comprehensively considering the requirements of economic and social parties in the basin for development, governance and protection of the river basin, the main tasks of the Yalong River Basin's governance, development and protection are determined as follows: hydroelectric power is the mainstay, while irrigation and protection Water supply (including water transfer across river basins), flood control, shipping, ecology and environmental protection, etc.

Based on the strategic deployment of the company's own development, Yalongjiang Company deeply analyzed the development of the State Grid and the power transmission from west to east, the development of hydropower in the river basin and the development of large independent power generation enterprises, the economic development trend of the river basin, and the need to revitalize the economic development of ethnic minority areas, etc. Factors, the use of centralized control center mode unified management of the Yalong River Basin cascade reservoirs. At present, the joint dispatch management model has been realized, the cloud computing center of cascade hydropower stations in the river basin has been established, and the particle swarm algorithm for optimized dispatching of multi-objective reservoirs has been used, the DP model of annual regulating reservoirs has been established, the artificial neural network model of reservoir dispatching, and the multi-objective and multi-stage fuzzy Advanced calculation methods such as optimization model, LP basic theory of optimal dispatching of reservoir group, SEPOA algorithm of optimal dispatching of reservoir group, etc., jointly developed and researched with well-known domestic universities and scientific research institutions, have concluded that the joint dispatching of Jinping I and II hydropower stations can achieve obvious Economic and social benefits. Through optimized operation and joint dispatching, the average annual power generation for many years, and joint dispatching hydropower stations guarantee a large year-on-year increase in output, water shortage in dry seasons, full utilization reached 100%, and water discarded at 0 (except for Jinping II Hydropower Station as designed to meet ecological flow It is required to discharge the flow outside), and optimize the power generation in different time periods of peak, flat and valley according to dispatch, greatly improving economic benefits.

2.3 Basin hydropower complements other multi-energy

In addition to huge hydropower resources, the Yalong River Basin also has unique wind and solar energy resources. The special topography and atmospheric circulation characteristics of the Sichuan Basin make Ganzi, Liangshan and Panzhihua where the Yalong River flows are the main centers of wind energy resources in Sichuan. Among them, Liangshan Prefecture and Panzhihua are located on the southwest branch channel, and the airflow on the channel is affected by the uplift of the terrain, resulting in a relatively high wind speed. The average wind speed of most wind farms in Liangshan prefecture is above 7m/s, and the average wind speed of some wind farms is even above 9m/s. Garze is located on the north branch of the westerly wind. Affected by the north branch, it also has good wind energy resources. According to preliminary estimates, the available wind power development in the Yalong River Basin is about 13 million kW, of which about 8 million kW in Liangshan Prefecture and Panzhihua. According to the measured solar radiation data from weather stations in the river basin and NASA data analysis, the total solar radiation in most areas of the Yalong River Basin exceeds 5500MJ/m2, the sunshine hours are 2000h～2500h, and most areas exceed 6000MJ/m2, which are solar resources. The second or third category areas have greater development value. According to preliminary estimates, the available photovoltaic power in the Yalong River Basin is about 18 million kW, of which about 7 million kW in Liangshan Prefecture and Panzhihua.

The wind and solar resources in the Yalong River Basin have obvious seasonal characteristics each year. Usually high wind speed and high light energy appear from November to May of the following year (dry season), and low from June to October (rainy season). The distinctive features of wind and solar resources in the region are naturally complementary to the characteristics of hydropower. There are many power stations in the Yalong River Basin with strong regulating capacity. After the completion of the

Lianghekou, Jinping I and Ertan Reservoirs, the total regulating storage capacity will reach 14.8 billion m3. The Yalong River Basin can be regulated for many years through the coordination of multiple energy sources. Operation and scientific dispatch can better optimize the power supply structure of the power grid, improve the power supply guarantee capacity and comprehensive development benefits.

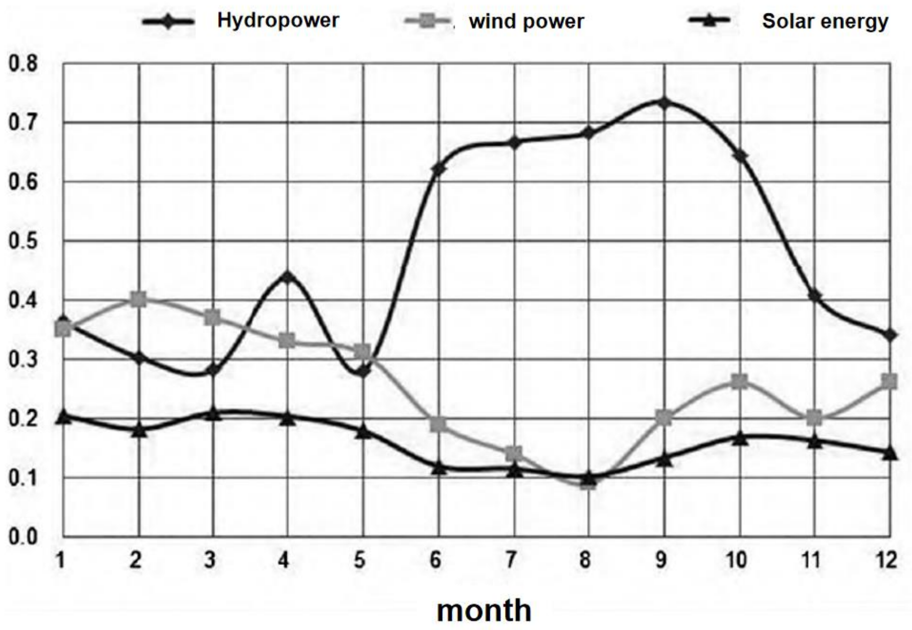


figure5 Annual load distribution of hydropower, wind power and solar power in the Yalong River Basin

The development model of wind, wind and water complementary bases can coordinate the construction of resources and accelerate the development of new energy. On the one hand, under the development model of wind-solar and water-complementary bases, wind power and photovoltaic consumption can use the transmission channel formed by the construction of hydropower stations. Especially in the current situation of difficulties in power consumption in Sichuan Province, the Yalong River Basin, wind-solar and hydro-complementary clean energy bases can use the existing and planned out-of-province transmission channels formed by hydropower development. On the other hand, the construction of a hydropower station is a complex and huge system project, in which construction resources such as transportation, factories, camps, and dispatching can be coordinated through the development model of the wind and water base, thereby saving construction resources and accelerating the development of new energy.

Utilize the overall regulation performance of river basin hydropower to improve the grid's ability to absorb wind power and photovoltaics. Hydroelectric power generation starts and stops quickly, operates flexibly, and has strong ability to track load. Especially in the basin-wide base model, through the centralized control of the basin, the overall adjustment ability is greatly increased. By monitoring the output changes of wind power and photovoltaics, adjust the opening of the hydroelectric generators of hydropower stations in real time to stabilize the amplitude and instantaneous rate of change of wind power and photovoltaic output, compensate for the output of wind power and photovoltaics, and adjust the random fluctuation of wind power and photovoltaics to smooth , Safe and stable high-quality power supply. This can greatly improve the power quality of wind power and photovoltaics, thereby alleviating or even eliminating the impact of wind power and photovoltaics on the grid system, and improving the ability of the grid to absorb wind power and photovoltaics.

The wind-solar complementary base development model can ensure the utilization of wind and solar energy. The wind-solar complementary base development model bundles out wind and solar water, which can not only provide a large amount of clean energy during the flood season, but also effectively ensure the safety of energy supply and the full utilization of the channel during the dry season. , Will explore an efficient, safe and sustainable development path of clean energy, and build a diversified clean energy supply system in the Yalong River Basin. Through the construction of wind, solar and water complementary bases, the rich wind and solar resources in the Yalong River Basin were avoided and the old path of "difficult to get online and a large amount of wind and solar abandonment" in some areas was avoided.

The Yalong River Basin Wind-solar Water Complementary Clean Energy Demonstration Base has a large construction scale and good construction conditions. Through the construction of a complementary clean energy base for wind, solar, and water, it can solve the current problems of wind power and photovoltaic construction, such as difficulties in grid connection, serious wind and solar abandonment, and is conducive to the comprehensive utilization of construction resources, saving construction and power transmission costs. Explore a new type of collaborative development model of renewable energy based on the "nearby access and local consumption" of new energy development, which will play an exemplary role in solving the problems of wind power and photovoltaic transmission and consumption.

2.4 River Basin Electricity Market Situation

The power generation operation dispatching of the Yalongjiang company power station group needs to meet the needs of three different levels of grid dispatching agencies. The Jinguan Power Supply Group composed of Jinping I, II and Guandi Hydropower Stations is dispatched by the State Grid Dispatching Center. It belongs to the national level, and the power receiving area is East China; Ertan Hydropower Station belongs to the Southwest Power Grid dispatching and belongs to the grid bureau dispatching At the level, the consumption areas are Sichuan Province and Chongqing City; the Tongzilin Power Station belongs to the Sichuan Provincial Network Dispatching and is consumed in Sichuan Province. The power generation dispatch of the cascade power station group in the river basin needs to be coordinated among the three-level dispatching agencies to meet the power demand of different regions. In the actual power generation plan implementation process, many interested parties are involved, the consumption situation is more complicated, and it is difficult for all parties to coordinate.

The Ertan Hydropower Station is the largest hydropower station with the most investment, the largest engineering, and the most technical difficulty in Sichuan Province in the 20th century. It is also the largest project in the world that has provided loans to a single project since the construction of the World Bank. However, since it was completed and put into production, the power generation has never reached the designed power generation, as shown in Figure 6. This is due to the historical problems caused by the backward development of my country's power grids and the emergence of overcapacity. For example, in the beginning of the 21st century, the grid was difficult to get online, the transmission facilities were lagging, the government, enterprises, and the grid were not separated, and the implementation of local protection of electricity prices, especially some Relevant policies virtually "encourage" market segmentation. Various vested interest groups including industry monopolies and local protectionism have become serious obstacles to Ertan's cross-regional electricity sales. At present, the power generation and sale of Ertan Power Station and the reduction of the loss of abandoned water have become the urgent problems for Yalongjiang Company to solve.

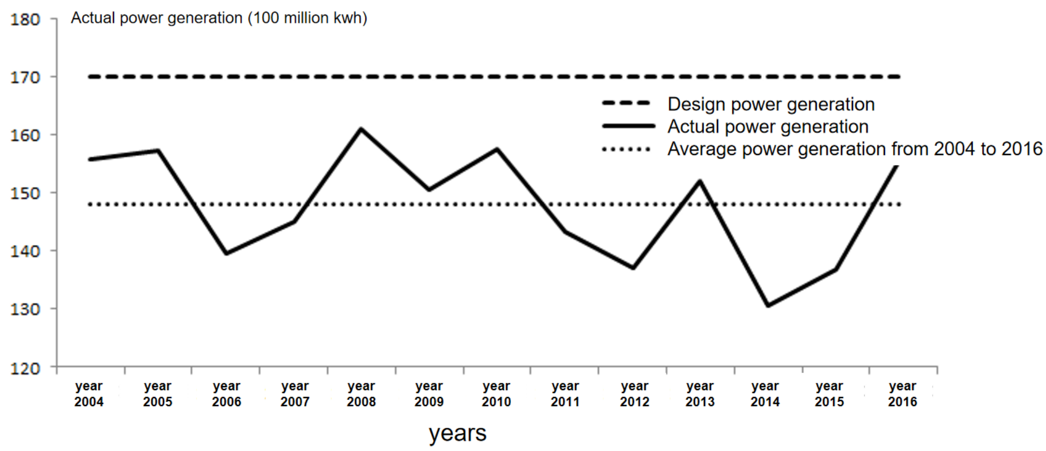


figure6 Power generation of Ertan Hydropower Station from 2004 to 2016

3 Key technologies of cascade dispatching in river basin

3.1Meteorological and Hydrological Forecast Technology and System

The Yalong River Basin has a large area, and there are many sub-basins and hydrological forecast control sections. According to the conventional method, the manual method is used to calibrate the hydrological forecast model parameters. Therefore, the hydrological forecast of the Yalong River Basin adopts the SCE-UA algorithm to calibrate the hydrology. Forecast model parameters. The optimization algorithm can search for the global optimal solution of hydrological model parameters in a consistent, effective and fast manner. Compared with some common algorithms, it has better robustness and efficiency. The application of automatic calibration technology for hydrological forecast model parameters not only fully reduces the workload of manual calibration of parameters, but also greatly improves the accuracy of hydrological forecast models.

There are many cascade power stations in the Yalong River Basin. At present, some power stations in the middle reaches are under construction. The downstream power stations are basically completed and put into operation. The unified management of hydrological forecasting needs to meet the needs of different construction periods and operation periods. In response to this practical problem, Yalong In the design and development of the automatic dispatching system, the Jiang Central Control Center completely separates the parameters and the calculation part; divides the reservoir flood regulation calculation during the construction period into the closure period, the cofferdam period, and the operation period. Different treatments; the conversion from the construction period to the operation period can be passed Adjusting the production and convergence parameters, setting the adopted rainfall station, water level station configuration and other methods to achieve the upgrade or expansion of the forecasting plan, without having to modify the program source code. In order to ensure the long-term stable and reliable operation of the hydrometeorological monitoring system, the basin company and the local hydrometeorological department jointly build and manage the model innovatively. The operation, maintenance and management of the telemetering station are respectively entrusted to the local hydrological and meteorological departments for unified management and resource sharing.

The software platform of the automatic hydrological forecasting system for the Yalong River Basin is a simple, complete and scalable enterprise-level application platform that provides an on-demand enterprise-level application for hydrological forecasting. This platform is also called a component platform, which divides all functions into "atomic components". Each functional component can be flexibly expanded, added, deleted, and updated, and it can ensure the stable and efficient operation of various business functions. When the system is upgraded and maintained, only the designated functional components or interfaces need to be updated, while other components remain unchanged, and the system can continue to operate. At the same time, the powerful integration function of the system can guarantee the inheritance and continuation of third-party system software.

3.2 Joint dispatch technology and system

As one of the few cases authorized by the state to develop a river, the Yalong River Company adheres to scientific planning and orderly development, and has formulated a "four-stage" strategy for the development of hydropower resources in the Yalong River Basin, and comprehensively promotes the construction of cascade power stations in the basin. Continuous progress in all aspects of development and management has achieved good results.

At present, the Yalong River Basin has formed a cascade power station group composed of Jinping I, Jinping II, Guandi, Ertan and Tongzilin reservoirs. In the future, there will be 4-5 main cascade power stations in the middle reaches including Lianghekou Hydropower Station. Will also be put into operation. In order to meet the needs of joint dispatching of cascade power stations in the river basin, the Yalong River Centralized Control Center has established a more advanced domestic water dispatching automation system. As a subsystem of the integrated automation system of the Yalong River Centralized Control Center, this system is mainly embodied in the collection and processing of water and rain information related to the Yalong River cascade power stations (Figure 7), including data acquisition and processing, database management, and data communication , Online alarm, information query management and release, etc. On this basis, carry out information display, water affairs calculation, cascade power station hydrological forecast, and combine the forecast results to carry out power generation, flood dispatch, risk analysis and economic operation evaluation, etc.

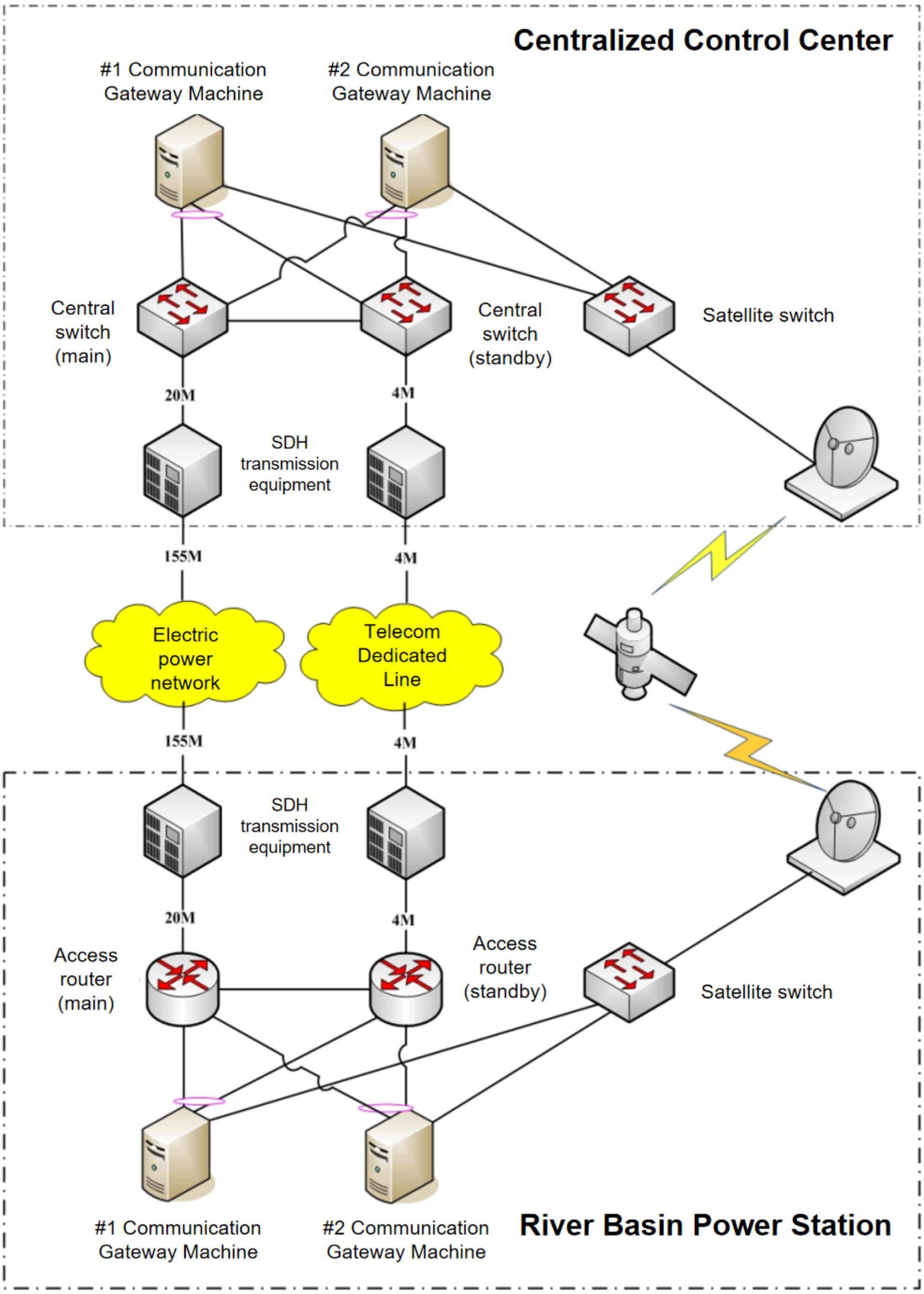


figure7 Information Transmission Automation Framework of Yalong River Centralized Control Center

(1) Basic data collection and processing. Basic data is the foundation of system operation and management. The completeness, consistency and accuracy of these basic data play a vital role in system operation and management. Data collection and transmission are mainly composed of four parts: the superior water regulation system, the EMS system, the integrated data platform and the flood reporting system. Data processing includes data inspection, retransmission control, data conversion, storage control, real-time data storage, conventional data processing, water affairs calculation, historical data extraction, water regime application data processing, etc., among which conventional data processing includes period data processing And data statistics, water affairs calculations include the calculation of common calculations and statistics such as reservoir inflow, outflow, power generation flow, flood discharge flow, power generation water consumption rate, various types of water volume, and unit capacity.

(2) **Basic application functions.** The basic application functions mainly include: data management, monitoring and query; event alarm; system monitoring function; editing of graphic reports; SMS publishing and query; data access service; WEB service; simulation training platform.

(3) **Advanced application functions.** The advanced application software of the water dispatching automation system is based on the reservoir dispatching automation system platform to realize the sharing of data sources, database access, authority management, and human-machine interface resources, as shown in Figure 8. It mainly includes water calculation, flood forecast during construction period, flood forecast during operation period, medium and long-term runoff forecast, accuracy assessment, power generation optimal dispatch, flood control optimal dispatch, economic operation evaluation, etc.

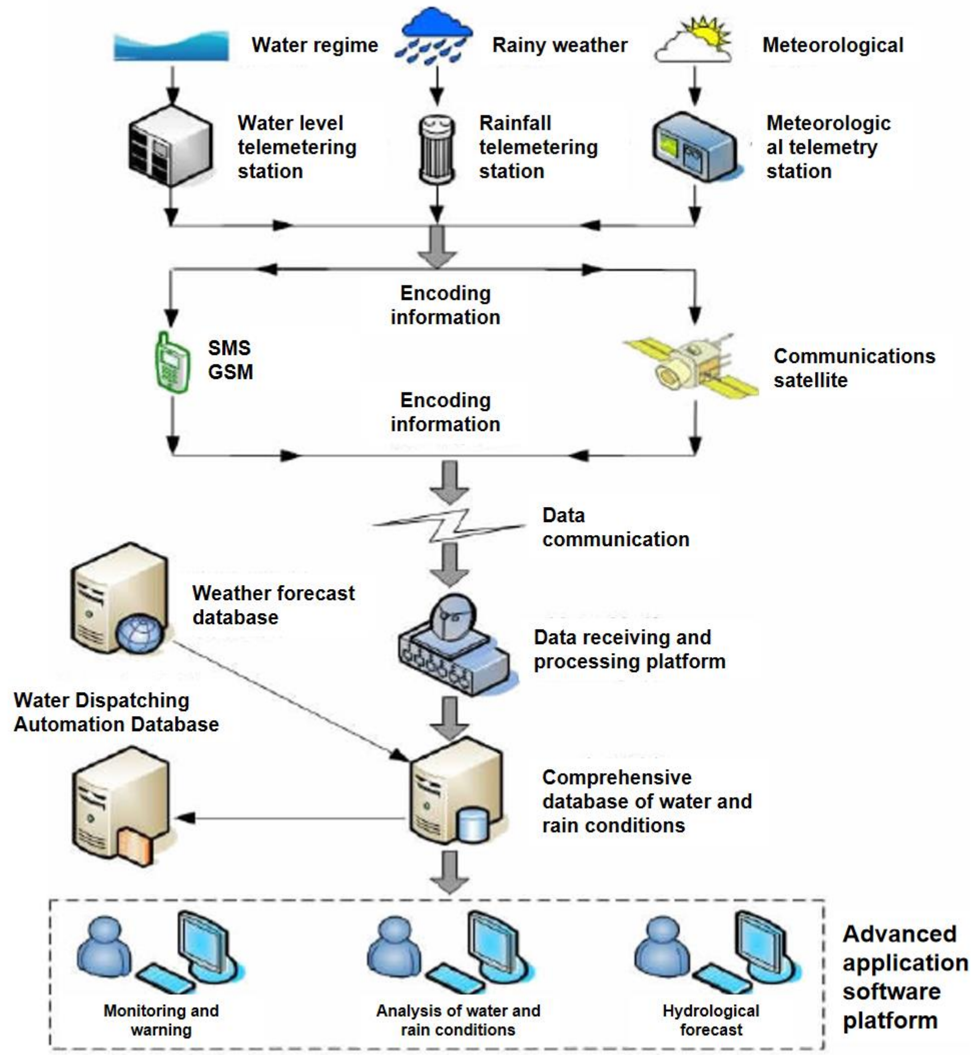


figure8　Yalong River Centralized Control Center Water Diversion System

The calculation of water affairs is divided into the calculation of the flow in and out of the storage during the period, and the calculation of the flow in the storage at sunrise. Time period is calculated as once per hour, and daily calculation is calculated as once per day. The algorithm is edited in the form of a report, and then stored in the database. The algorithm file is called by the water calculation program at a preset time interval to perform calculations and write the calculation results into the database. At the same time, it has a manual back calculation function.

The forecast during the construction period mainly forecasts the incoming water flow of the cascade power stations planned and under construction below Xinlong and the water level of the key parts of the construction area; the forecast during the operation period forecasts the flow of the dam sites of the cascade power stations in operation and the interval flow between adjacent power stations. Mid- and long-term runoff forecasting is based on the actual conditions of the basin and the convenience of obtaining data required for prediction. According to the different characteristics of mid- and long-term hydrological forecasting, the corresponding model is adopted. A single forecast model such as artificial neural network, threshold multiple regression and support vector machine is used as Based on the best combination of forecasting methods, complete medium and long-term hydrological forecasts and ensure the necessary accuracy.

Power generation dispatching is mainly based on real-time water regime data and hydrological forecasts of cascade reservoirs in accordance with the constraints of power system requirements, flood control safety, etc., and the use of joint dispatch methods to tap the economic operation potential of cascade hydropower stations in accordance with the actual needs of the Yalong River cascade reservoir dispatch , To quickly and accurately complete the preparation of the long-term joint power generation dispatching plan of the cascade hydropower stations and the short-term joint power generation dispatching plan, rationally use the water volume and head of the cascade hydropower stations, give full play to the compensation and regulation performance of the cascade reservoirs, increase power generation as much as possible, and improve power generation efficiency.

Flood control dispatching is based on flood forecasting, based on real-time data of river basin water regimes, flood discharge methods of each hydropower station gate, power generation flow, and under various constraints, the current flood is adjusted and calculated, so as to obtain the information of each hydropower station. The maximum water level, maximum discharge flow and corresponding reservoir storage and discharge process, rapid and accurate completion of cascade reservoir flood dispatching plan.

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Mixed or cross-regional cascade reservoir group management mode

Management Model of Cascade Reservoirs in American Basin

1Overview of U.S. Hydropower Development

1.1 Overview of the natural environment and rivers

The United States is located in the southern part of North America, bordering the Atlantic Ocean to the east, the Pacific Ocean to the west, Canada to the north, and Mexico and the Gulf of Mexico to the south. The territory also includes Alaska on the edge of the Arctic and Hawaii as far away as the equatorial Pacific Ocean. The mainland is 4,500 kilometers long from east to west, 2700 kilometers wide from north to south, and 22,680 kilometers long coastline. There are many rivers and lakes in the United States, and the water systems are complex. Generally speaking, they can be divided into three major water systems: All the rivers that are located east of the Rocky Mountains and which flow into the Atlantic Ocean are called the Atlantic water systems. The main ones are the Mississippi, Connecticut and Hudson. It is 6,020 kilometers long, ranking third in the world. The rivers that flow into the Pacific Ocean are called the Pacific Water System, and they mainly include the Colorado River, the Columbia River, and the Yukon River. The large lakes in central and eastern North America, including Lake Superior, Lake Michigan, Lake Huron, Lake Erie and Lake Ontario, with a total area of 245,000 square kilometers, are the world's largest freshwater waters and are known as the "North American Mediterranean". Lake Michigan belongs to the United States, and the remaining four lakes are shared by the United States and Canada. Lake Superior is the world's largest freshwater lake, with an area second only to the Caspian Sea and the second largest in the world.

1.2 Climate

The climate in most parts of the United States is temperate and subtropical. Only the southern tip of the Florida Peninsula is tropical. Alaska is located between 60° and 70° N latitude and is a cold climate zone within the Arctic Circle; Hawaii is located south of the Tropic of Cancer and is a tropical climate zone. However, due to the vast territory and complex terrain of the United States, the climate varies greatly from place to place, and it can be roughly divided into five climate zones. The temperate climate zone along the northeast coast is affected by the

Labrador cold current and the cold air in the north. The winter is cold. The average temperature in January is about -6℃, and the summer is mild and rainy. The average temperature in July is about 16℃. Rainfall is about 1000mm.

The southeast subtropical climate zone has a warm and humid climate due to the influence of the Gulf Stream. The average temperature in January is 16° C, the average temperature in July is 24-27° C, and the average annual rainfall is 1500 mm. The continental climate zone of the Central Plain is characterized by continental climate, with cold winters, with an average temperature of about -14° C in January and hot summers, with an average temperature of 27-32° C in July. The average annual rainfall is 1000～1500 mm. The arid climate zone of the Western Plateau has an inland climate. The plateau has a large annual temperature difference. The annual temperature difference on the Colorado Plateau is as high as 25° C. The annual average rainfall is below 500mm, and the rainfall in the plateau desert area is less than 250mm. The oceanic climate zone along the Pacific coast is warm in winter and cool in summer, with abundant rainfall. The average temperature in January is above 4℃, the average temperature in July is about 20-22℃, and the average annual rainfall is about 1500mm.

1.3 Overview of U.S. Hydropower Development

The United States is one of the first countries in the world to develop hydropower. Since the first hydropower station in the United States generated electricity in 1882, the history of hydropower in the United States has been more than 130 years. The peak period of hydropower development and construction in the United States was in the 1920s and 1970s. It was once the world's largest country in hydropower development and utilization, and it was also the largest country in hydropower development technology during that period, and it has always been a world leader. Hydropower was the main form of electricity in the United States in the first half of the last century. The early industrial and economic development of the country provided opportunities for hydropower development. In 1940, hydropower generation in the United States accounted for 40% of the country's total electricity consumption. However, since the 1970s, hydropower construction in the United States has begun to enter an era of steady development; since the 21st century, hydropower development has significantly slowed down.

The hydropower resources of the United States are mainly concentrated in the Tennessee River Basin, Columbia River Basin, Colorado River Basin, Missouri River Basin, etc., and its hydropower development is also concentrated in the above-mentioned basins. The Hoover Power Station on the Colorado River and the Grand Coulee Power Station on the Columbia River built by the United States in the 1930s played an important role during World War II and still generate electricity normally today. U.S. hydropower is mainly composed of the US Army Corps of Engineers (USACE), the US Bureau of Reclamation (USBR), public utility companies (Public utility District, PUD), and private energy companies (private power companies). companies) development.

U.S. hydropower accounts for a relatively small proportion, but it is currently the largest source of renewable carbon free energy in the United States; especially in the power system, it has multiple functions such as peak and valley filling, frequency modulation, etc., to ensure the safety and stability of the grid Pumped-storage power stations that operate, operate flexibly and respond quickly are particularly beneficial. According to the annual report of the U.S. Department of Energy, the total installed capacity of the United States in 2011 was 1.05 billion kW, and the total power generation was 410.656 billion kW•h, of which the installed capacity of conventional hydropower was 78.652 million kW, the installed capacity of pumped storage power plant was 22.293 million kW, and the annual hydropower generation was 3193.55 100 million kW•h, hydropower accounts for 7.8% of total power generation and 62% of renewable energy power generation. The United States currently has about 2500 power generation dams, which can provide 78 GW of traditional hydropower and 22 GW of pumped storage power at the same time, and there are more than 80,000 NPDs for water supply and inland navigation. The U.S. Department of Energy (DOE) "2016 Hydropower Outlook Report" predicts that the upgrading of existing dams will add 50 GW of installed capacity, increasing the country's total installed capacity by 50%. The dam construction and environmental costs calculated based on the NPD show that the use of the existing NPD to increase the power supply is cheaper and less risky, and it will take less time than building a dam. Therefore, NPD can play a better role in expanding the supply of renewable energy. In addition, NPD also has the advantage of small environmental impact, combined with the reliability and predictability of hydropower, so that these dams still have great development potential, including the development of private dams and their developers, and state-owned dams. The state-owned dam is jointly owned by the Tennessee River Basin Administration (TVA), the U.S. Army Corps of Engineers (USACE) and the U.S. Bureau of Reclamation (USBR) under the jurisdiction of the United Nations Commission on Natural Resources (CNR). These dams can all realize joint power generation through public-private partnerships. Missouri River Energy Services (MRES) is a municipal power supplier located north of the Midwestern United States. It is currently building a new hydroelectric power station on Red Rock Lake in Pella, Iowa. USACE Own the ownership and operation rights of the hydropower station. The dam was originally built for flood prevention and recreation, and now it will provide clean and cheap hydropower to about 18,000 residents. Also in Ohio, the Municipal Electricity Agency (AMP) will undertake the development of the Ohio River Project, which is the largest hydropower project in the United States in decades. It is planned to build on USACE’s existing sluices and dams. A radial hydropower station, the installed capacity will increase by 300 MW.

On the other hand, in the United States, there are fewer and fewer opportunities to implement large-scale hydropower development programs, but small hydropower has broad development prospects. As the world's emission reduction situation becomes increasingly severe and the energy structure is re-adjusted, the US Congress has decided to amend existing laws and regulations in order to quickly and effectively promote the development of small hydropower.

2 U.S. water resources management model

2.1 Overview of water resources management mode in river basin

In the United States, all states have great legislative powers, and the relationship between the state government and the federal government is relatively loose, which leads to the implementation of a state-based management system in water resources management.

According to the Constitution, the federal government is responsible for formulating the overall policies and regulations for water resources management, and the state is responsible for implementation. Interstate water resources development and utilization conflicts are coordinated by relevant federal government agencies. If coordination fails, they often resort to law and pass justice. Procedure to resolve.

The management of water resources in the United States involves three levels of agencies: federal government agencies, state government agencies, and local government agencies. In the United States, water resources are managed by the Natural Resources Protection Agency of the Ministry of Agriculture, the Water Resources Division of the National Geographic Survey, the Bureau of Reclamation (USBR) under the Ministry of the Interior, the Army Corps of Engineers under the Department of Defense and the National Environmental Protection Agency according to the federal government. The authorized functions are responsible. In 1969, the United States passed the National Environmental Policy Act, and in 1970 the National Environmental Protection Agency was established. It concentrated the environmental management powers that were originally dispersed in 5 federal government departments and held by 15 agencies to the National Environmental Protection Agency. , Making the National Environmental Protection Agency a core management department with unified water resources management authority. The National Environmental Protection Agency has established corresponding rules and regulations in accordance with the needs of environmental protection, and made unified arrangements for the rectification and management of water resources, so as to effectively avoid the waste and destruction of water resources. The National Environmental Protection Agency analyzes and studies the overall current situation of water resources, and divides different water resources regions in the United States, which greatly improves the efficiency of water resources control. At the same time, local offices are established in each region to replace the national Institutions to perform power. The authority of regional functional agencies includes approving the systems and standards prescribed by the state government, and monitoring the federal government's overall arrangement of water resources management funds.

The United States is a typical federal country, and all regions have certain powers to manage water resources. Each local jurisdiction delegates the right to manage water resources in the region to each state.

Therefore, water management in the United States is basically carried out on a state basis, and each state has its own corresponding functional departments for water resources management, and the federal government exercises the same legislative authority. The Natural Resources Environmental Protection Bureau is subordinate to the Ministry of Agriculture and is mainly responsible for the development and protection of water resources. The Water Resources Division under the jurisdiction of the National Geographic Survey is responsible for collecting, monitoring, and analyzing various hydrological information within the country, and at the same time provide policy advice for the development and utilization of water resources. The Bureau of Reclamation under the Ministry of the Interior is responsible for planning hydropower initiatives and maintaining water quality and quantity. The Army Corps of Engineers under the Ministry of National Defense is primarily responsible for the planning and commencement of large-scale water conservancy projects supported by government preparations. The establishment of these functional departments is mainly to prevent the phenomenon of efficiency waste caused by the repeated management of departments. The National Environmental Protection Agency is at the highest level and has the highest control and final decision power. Under the same leadership of the federal government, each department has clear responsibilities, can carry out a good division of labor and cooperation, and can also restrict and cooperate with each other well to form an efficient management system.

In addition, the United States is a relatively mature model of river basin management in the world. The management of the Tennessee River basin is regarded as a model for ensuring the successful implementation of water resources management and protection based on laws and regulations, and it has also been imitated by many countries. The Tennessee Administration (TVA), established in accordance with the Tennessee Watershed Management Act, implements comprehensive development and remediation of the Tennessee Watershed. The TVA organization is established in accordance with the situation of water resources, and has a board of directors. The members of the organization are nominated by the president and appointed after voting by the two houses. At the same time, they directly accept the leadership of the president and the Congress. TVA is recognized as a federal level agency. Its primary responsibilities include individual human resource management power, power to tax water resources, power to build water resources, and other areas of investment management matters, and perform on behalf of federal government agencies. Economic development and integrated control functions in the basin. The Tennessee River Basin Authority can modify and abolish some unreasonable or conflicting provisions with respect to the Tennessee River Basin Management Act in accordance with the principle of overall watershed development, and at the same time draft corresponding legal provisions.

2.2 Characteristics of river basin water resources management mode

(一) Tend to take the entire basin as the management object

The adjustment objects of the U.S. River Basin Management Law have all undergone a gradual evolution process, from simply focusing on the river itself to gradually changing to the management of the entire catchment area; from specifically regulating the water resources of the river basin to considering all the environmental resources in the basin, Basing management on the overall function of the basin ecosystem. And began to emphasize the relationship between watershed ecological protection and watershed socio-economic development, and comprehensive management of watershed ecosystems from the perspective of economic, environmental, and social issues. For example, the purpose of the Mississippi River Basin Alliance was to achieve watershed ecosystem management. The planning considers both the development and utilization of river basin resources and the protection of resources; not only the economic development of the river basin and the improvement of people's living standards, but also the protection of the ecological environment of the river basin. This overall management system is also the magic weapon for the success of Mississippi River Basin management.

(二) Cooperation between river basin management agencies and regional departments

The focus of water resources management in the United States is based on the state as the fundamental unit. Each state has established water resources management agencies, and the counties and cities under the state level also set up water bureaus with team members to deal with different types of water issues, such as water supply and drainage. , Pollution control and recycling reuse, etc. to carry out the same control, planning and deployment. However, the division of administrative regions will inevitably lead to a series of shortcomings such as blurring of the powers and responsibilities of water resources management. The US government has set up special federal management agencies for several major rivers in order to handle watershed remediation that is divided across administrative regions. River Basin Water Resources Management Committee. Typical representatives of the River Basin Water Resources Management Committee include the Tennessee River Basin Authority and the Mississippi River Management Committee. Adopting a water management system that combines administrative region management and river basin management, through the complementary advantages of the two, has greatly improved the efficiency of water management in the United States, and is of great significance in realizing the sustainable use of water resources. The cooperation between the United States Mississippi River Basin Management Agency and various departments and regions is a typical example. This cooperation and coordination model has even become a magic weapon for the success of Mississippi River Basin management. While specializing the water environment management power system, countries also pay attention to the role of other administrative departments, and centralization and decentralization are compatible with each other, rather than a unified power monopoly. However, in the process of power crossover, the environmental protection department has clearly established the dominant position in the power system of various departments, which has a great influence.

(三) Diverse and reasonable management methods

The U.S. River Basin Management Law focuses on strengthening the macro-control and overall management of the river basin, and gradually realizes marketization of resource management such as the development and utilization of river basin resources to improve the efficiency of resource utilization. For example, the development of the Tennessee River Basin is an optimal combination of a high degree of planning and commodity economic flexibility. The overall plan for river basin development approved by the Congress is a political law that all states and counties must follow. The specific resource development and the operation and management of industrial and mining enterprises are mainly handled in accordance with economic laws and coordinated by local governments at all levels and private capital. This kind of authoritative institution with government and enterprises, scientific research institutions and business entities is very conducive to the implementation and coordination of various measures, and is a reasonable solution to flood control, shipping, hydropower development, industry, agriculture, tourism, Urban development and other issues provide institutional guarantees and preconditions.

2.3 Main management organization of river basin water resources

At present, there are three larger water management agencies in the United States, namely the Bureau of Reclamation, the Army Corps of Engineers, and the Tennessee River Basin Administration. They are all set up to solve a specific problem and conduct water management under federal or congressional authorization. Among them, the Army Corps of Engineers manages the operation of more than 500 reservoirs across the United States, and is the only organization responsible for the construction and operation of large-scale, multi-target reservoir projects across the United States. The Bureau of Reclamation manages approximately 130 reservoirs in 17 western states, and a large number of water projects it builds are handed over to the local water conservancy department. The Tennessee River Basin Authority manages the operation of 50 reservoirs in 7 southeastern states. In addition, the responsibilities of each organization in reservoir management are determined by the project development goals. The Army Corps of Engineers builds, operates and manages large-scale shipping and flood control reservoirs, which play an obvious leading role in the United States; the Bureau of Reclamation is mainly responsible for the development and management of water resources in the western United States, and the expected projects are mainly irrigation, flood control, and water supply; the Tennessee River The River Basin Authority manages reservoirs in the southeastern state in accordance with the rights granted by the 1933 Congress Act.

3 Management of Cascade Reservoirs in the Tennessee Basin

The Tennessee Basin of the Mississippi River in the United States, the Tennessee Basin Authority, is a model of cascade development of hydropower stations.

3.1 Introduction to the Tennessee Valley

The Tennessee River in the United States is 1,050km in length and is a secondary tributary of the Mississippi River. It spans seven states including Virginia, North Carolina, Georgia, Alabama, Mississippi, Tennessee and Kentucky. The temporal and spatial distribution of rainfall in the Tennessee Basin varies greatly. Although the months with the largest and the smallest precipitation are different each year, usually December to March is the period of maximum precipitation, and September to November is the period of minimum precipitation. Heavy rains in winter will cover the entire basin for several days, sometimes the interval between heavy rains is only 3 to 5 days. 40% of the precipitation in the basin will become runoff, and the rest will be evaporated, absorbed by plants and soil, or turned into groundwater. In comparison, the runoff in summer and autumn is much lower than that in winter and spring, and summer rainstorms are usually only partial river basin rainstorms. Although the runoff caused by the summer rainstorm is relatively small compared to the winter rainstorm runoff, the flood problem must be considered, especially in local areas, because the reservoir usually has a higher water level and less effective flood control storage capacity.

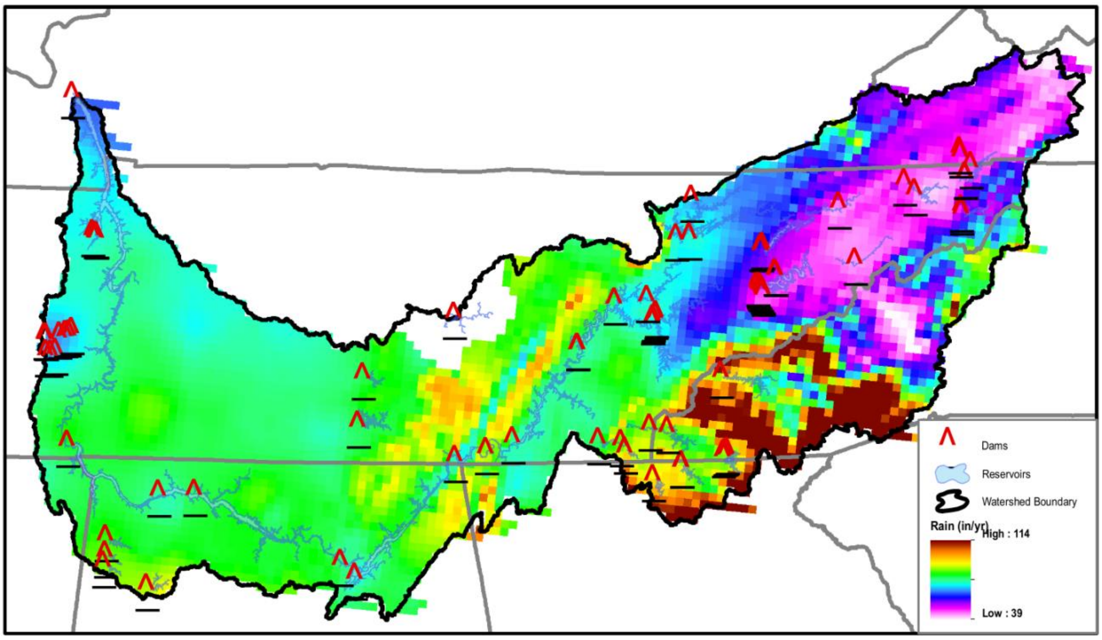

figure 1 Distribution map of annual precipitation in the Tennessee Basin

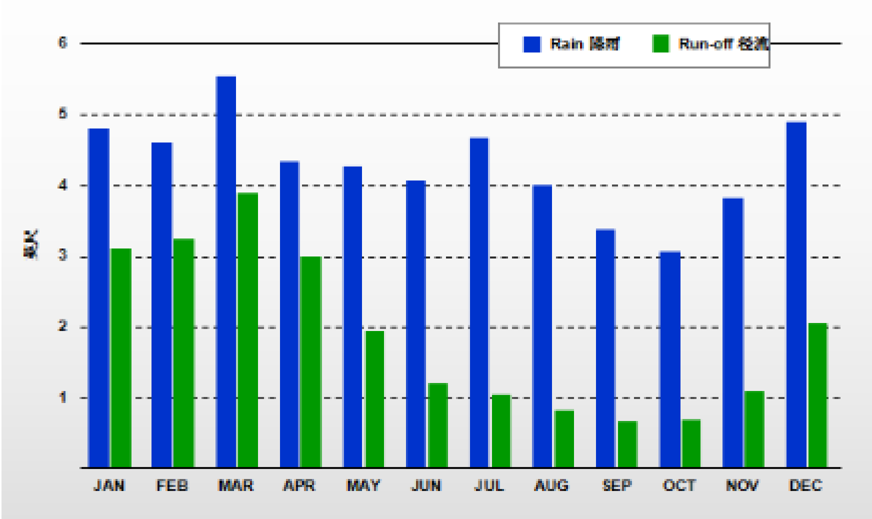

图 figure2 Map of average monthly rainfall and runoff in the Tennessee Basin

3.2 Tennessee Valley Administration (TVA)

In 1933, following President Roosevelt’s proposal, the United States Congress passed the Tennessee Watershed Authority Act, which established the Tennessee Watershed Authority, a special agency of the US federal government, to conduct comprehensive development and management of the Tennessee Watershed. The Tennessee Watershed Authority is an organization with government rights and flexibility for private companies, and it is also the world's first watershed management agency.

Tennessee Valley Authority (Tennessee Valley Authority, hereinafter referred to as TVA) is a multifunctional federal company responsible for managing the use, protection and development of water resources in the Tennessee Valley. TVA owns and operates 49 dams, of which 29 are for power generation, 1 is a pumped storage facility, and 5 are without power generation capacity but have controllable overflow gates and valves. The other 14 dams provide flood protection and tourism. The Tennessee River Basin covers an area of nearly 41,000 square miles, extending from the western reaches of the Appalachian Mountains to the Ohio River Basin near Paducah, Kentucky. It is the main resource and asset of the region’s economy. These 30 hydroelectric power generation facilities can provide 18% of the maximum possible power generated by all TVA power generation facilities. They are the most important energy source for TVA and can meet the daily peaks of power demand. Although power generation is usually the main factor that determines the operation of a reservoir, many reservoirs are regarded as multi-purpose reservoirs and need to meet many requirements such as navigation, water supply, residents' leisure, and nuclear power generation.

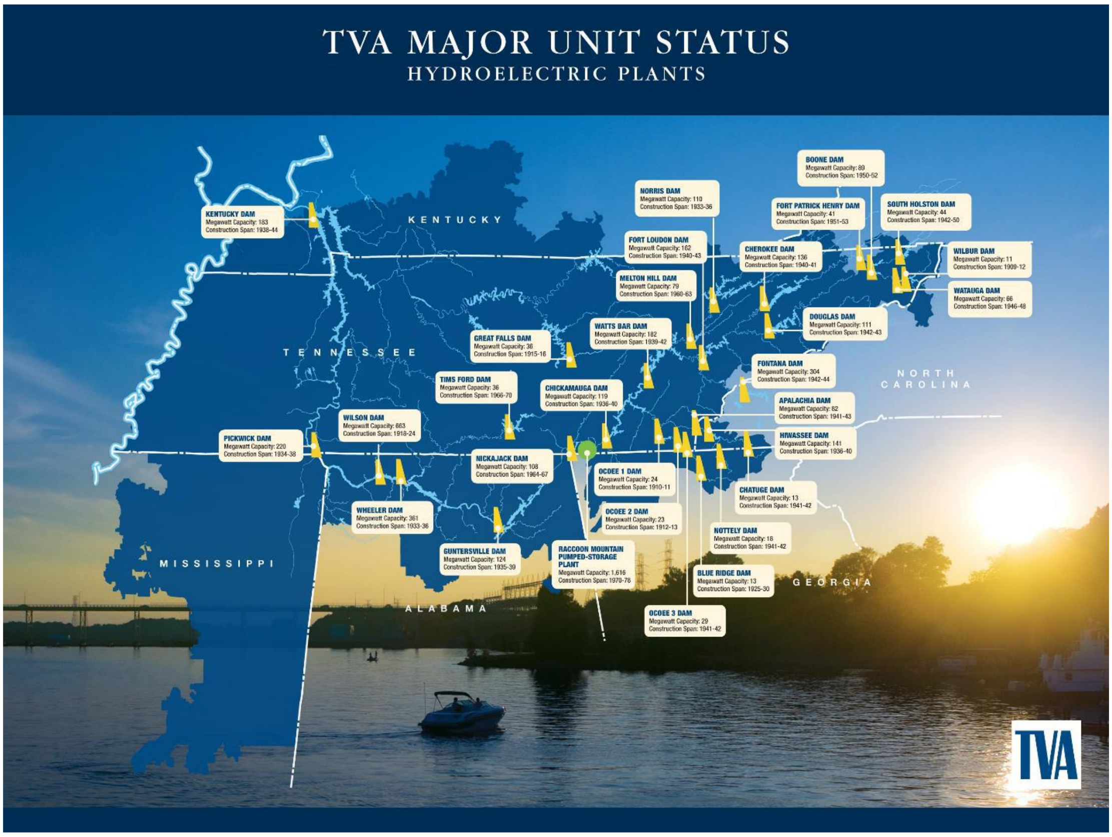

figure3 An important reservoir in the Tennessee Valley

The Tennessee River Basin Administration (TVA) is committed to improving the lives of river basin residents by providing affordable electricity and environmental management. TVA is in addition to dam safety and risk management in the Tennessee River Basin. The agency is also responsible for handling land management in the Tennessee River Basin, assisting local power companies and the economic development of state and local governments. Responsible for providing electricity to more than 9 million people in Alabama, Georgia, Kentucky, Mississippi, North Carolina, Tennessee, and Virginia, as well as satisfying the operation of these reservoirs by dispatching the reservoir systems under their jurisdiction Flood control and navigation needs.

TVA has an internal organization: the Power Generation Department is responsible for electricity production. The Operation Department is responsible for the safe and stable operation of the power grid, providing customers with reliable and cheap power; and is responsible for maintaining the stability and reliability of the eastern external line.

The External Relations Department is responsible for customer service. The Communication and Marketing Department is responsible for internal and external communication and coordination and market development. The Human Resources Department is responsible for human resources management. The Asset Finance Department is responsible for all matters related to finance, assets, and finance within the scope of TVA. The Legal Affairs Department is responsible for providing legal, regulatory and policy support.

3.3 Tennessee Watershed Management Model

The Tennessee River Basin Authority is a special institution of ″integration of government and enterprise″ established under specific historical, economic and political conditions. It has both government functions and corporate characteristics. It accepts the leadership of the president and the supervision of Congress to complete its specified tasks. There is a strong right to self-determination in river basin management, and can handle administrative and enterprise management issues on its own, and is less restricted in the process of hydropower dispatch, development, and implementation. Tennessee uses legislation as the basis for river basin management and provides legal guarantees for its management through the formulation and continuous revision of the TVA law.

The TVA organization is set up in the form of a company with a board of directors. Directors are nominated by the president and appointed after approval by the Senate and House of Representatives. The board of directors is directly responsible to the president and the Congress. TVA is determined as a federal level agency. Its main functions include independent personnel rights, the right to expropriate watershed land, watershed development and construction rights, and multi-field investment and management rights, and as a federal government agency to exercise economic development and comprehensive governance in the river basin And management functions.

The Tennessee River Basin Authority can amend or abolish local laws and regulations that conflict with the law in accordance with the purpose of basin-wide development and management, and formulate corresponding regulations. The Tennessee River Basin adopts a comprehensive arrangement of flood control, shipping, irrigation, power generation, afforestation, tourism, industry, and agriculture. Measures are taken to control river water pollution and protect water resources, and comprehensive utilization to improve water resource utilization Efficiency: In the process of development and utilization, coordinate the development of industry, agriculture and transportation, and coordinate the overall and partial, the main and tributary, upstream and downstream, and the left and right banks.

The Regional Resource Management Council, established under the Tennessee Watershed Management Act and the Federal Advisory Committee Act, aims to promote local participation in watershed management. The council can provide advisory opinions on TVA's watershed natural resource management. Although it is advisory in nature, it provides a channel for communication and consultation between TVA and various regions in the basin, and promotes the active participation of the public in the basin in the management of the basin.

3.4 Tennessee Watershed Management Decision Support System

TVA reduces the risk of flood and dam operation safety through a decision support system. The River Forecast Center under TVA continues to enhance its core capabilities, including data collection and quality control, hydrological and hydrodynamic modeling, reservoir operation simulation and optimization, and hydrothermal modeling (for water environmental management of nuclear power plants under its jurisdiction).

In 2012, TVA decided to start a pilot project and upgrade its current forecasting system to the Delft Flood Warning System (Delft-FEWS) platform. By improving its rainfall estimation processing, and embedding the hydrological model used by TVA into the Delft-FEWS framework to meet business needs.

Due to the successful implementation of the FEWS (Flood Warning System) pilot program, starting in 2013, the river management agency of TVA began to upgrade and modernize the river operation and decision-making system. These include new software frameworks, new hydrological and hydraulic models, unification of several independent applications running in various programming languages, and new data reporting and publishing systems. In February 2017, the system was put into use to improve system flexibility, simplify coordination with external agencies, improve business modeling, and recognize the continuous upgrade and maintenance of the system in the future.

The new framework Delft-FEWS (Flood Warning System), the Office of Water Prediction (OWP) of the National Weather Service, the Bonneville Power Administration (BPA) of the Department of Energy and other mission-related agencies Used jointly by the River Forecast Center under the Tennessee Basin Administration. Jointly provide opinions on the improvement of the system. In general, the Delft-FEWS framework allows TVA to focus on mission-critical modules, such as using standard model adapters to improve modeling. The flexibility of this "plug and play" structure reduces the burden of replacing models in the future, and at the same time enables TVA to stay ahead in the latest river modeling research and applications.

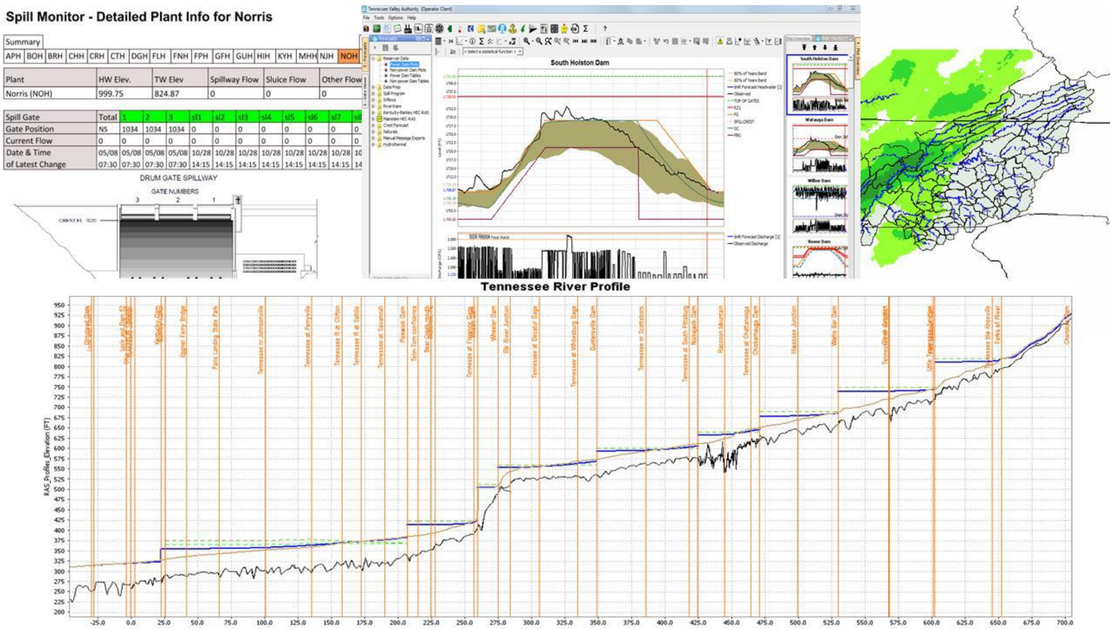

figure4 Interface of the system

Combined with the upgraded framework, TVA replaced its previous rainfall index (API) hydrological model with the Sacramento Soil Moisture Model (SAC-SMA). This includes a set of models and processes used by the OWP River Forecast Center. This upgrade facilitates the coordination of forecast results and processes between the Lower Mississippi Forecast Center (as the official data publisher for the Tennessee River Basin) and other agencies. In practical application, it improves TVA's ability to couple rainfall and inflow flow in hydrodynamic and reservoir optimization models.

TVA currently runs 10 HEC-RAS models, including the USACE/TVA combined reservoir model, most commonly used in key Ohio and Mississippi reservoirs. The RAS model covers approximately 700 miles, from the Cherokee Dam on the Holston River to the Ohio River in Cairo, Illinois. These upgraded hydrodynamic models can accurately predict the inflow of each dam and improve the prediction of important flows between dams. In the operating mode, TVA also designed an improved "natural" RAS model, which provides hypothetical forecasts for scenarios without existing reservoir structures. The predictions of these assumptions are incorporated into the model, which provides an assessment of the flood losses avoided during periods of high flow.

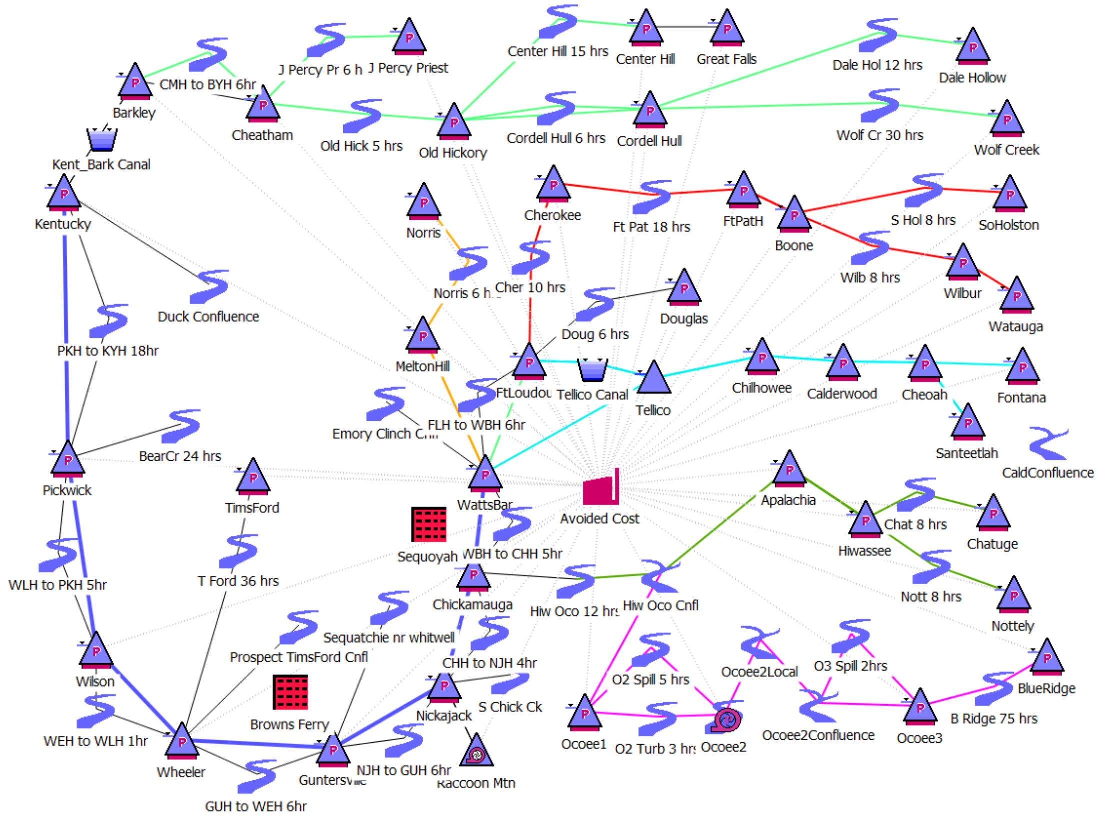

figure5 Reservoir topology of TVA in Riverware

As part of the project, the Riverware system, a decision model used by TVA for hydropower dispatching, was also integrated into the Delft-FEWS framework. The inbound flow from the OWP model module and a large amount of other data for optimization are passed to the Riverware system, where hydropower decision results are generated. This integration increases the possibility of emergency prediction and collective input in future development.

The traditional hydrothermal model is integrated into the framework to realize the fusion of two previously disjoint systems. This integration allows the sharing of data sets and inputs, and the shared basic framework increases the potential for in-depth integration of hydrothermal modeling and water quality in reservoir operations. These new models will rely on integration with FEWS and further utilize the flexibility and adaptability of the framework.

As an operating agency, TVA needs to continuously release various reports and information to its residents. TVA can send about 200 different report/message types, and during periods of high traffic, as many as 11,000 individual messages (many of which are scheduled updates to public media) are sent in one day. The project almost brings These different messages are reported under the Microsoft Business Intelligence tool suite, which uses SQL Server Data Warehouse, SQL Server Integration Services (SSIS) and SQL Server Report Services (SSRS). Now, reports are generated, published, recorded and archived under a unified framework.

As the river forecast system went live for one year, various other projects are being integrated. An evaluation system will be put into operation soon, allowing performance tracking, error evaluation, and prediction selection combined with machine learning algorithms. For TVA's other power generation systems, more frequent and iterative hydropower dispatch plans will be implemented in fiscal year 2019. Flooding mapping within the Delft-FEWS framework will also begin in fiscal year 2019. The project aims to produce real-time flooding maps for Mainstem Tennessee River within Delft-FEWS throughHEC-RAS.

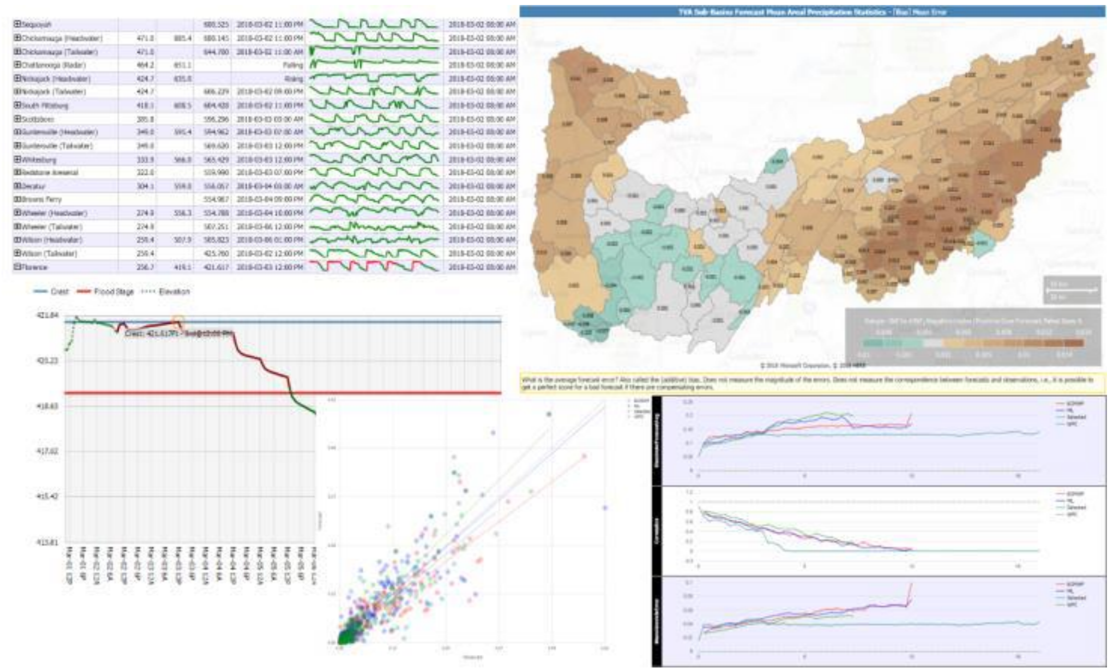

figure6 The evaluation system includes performance tracking, error

evaluation and intelligent forecast evaluation

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Management Model of Cascade Reservoirs in Canadian Basin

1 Overview of Hydropower Development in Canada

1.1 Overview of the natural environment and rivers

Canada is located in the northern part of North America, bordering the Pacific Ocean to the west, and the Atlantic Ocean to the east. It is approximately between 41° ~83° N and 52° ~141° W. The northwest is adjacent to Alaska, USA, and the northeast is separated from Greenland (actually controlled by Denmark). The West Strait and Baffin Bay face each other in the distance, and the United States is connected to the south (the eastern section is bounded by the four lakes and the Appalachian Mountains except Lake Michigan, and the middle and western sections are basically bounded by the 49° north latitude), To the north is the Arctic Ocean, and the Arctic Circle passes through the north. Canada is the country with the longest coastline in the world, with a coastline of more than 240,000 kilometers and a national border of 8892 kilometers, making it the longest undefended border in the world. With an area of 9.98 million km2 (the second largest in the world, after Russia), it is a country with a large area and sparsely populated area.

In Canada, 890,000 km2 is covered by freshwater, and sustainable freshwater resources account for 7% of the world. The main rivers in Canada are: St. Lawrence, Mackenzie, Yukon, Columbia, Nelson and Ottawa. The Mackenzie is the longest river in Canada, with a total length of 4241km, second only to the Mississippi, and is the Arctic Ocean. Water system. The St. Lawrence River is a navigation channel between the Great Lakes and the Atlantic Ocean, with a total length of 1287km. It is the river with the largest runoff in Canada and second only to the Mississippi in North America.

1.2 Overview of Meteorology and Hydrology

1.2.1 Climate

Because Canada has a large latitude span, Canada has a variety of climate types. The Gulf Stream in the Atlantic Ocean and the Alaska Current in the Pacific play an important role in the formation of climate. In the western region, the prevailing air currents in the Pacific Ocean blow from the sea to the land, causing heavy rainfall along the coast of British Columbia and mild winter and summer temperatures; in the inland regions, the Great Lakes eases the weather in southern Ontario and Quebec; in the east, it is cold. The Labrador Current meets the Gulf Stream on the coast of Newfoundland and Labrador, forming frequent foggy weather; about two-thirds of northern Canada has a climate similar to northern Scandinavia—winter climate It is cold and cool in summer for a short period of time; the plains in the central and southern inland have a typical continental climate, with cold winters, hot summers, and scarce precipitation; southern Ontario and Quebec have similar climates to parts of the Midwestern United States, with hot and humid summers and winters It's cold and snowy. With the exception of the West Coast, the average winter temperature in all regions of Canada is below freezing and will continue to accumulate snow.

1.2.2 Hydrological situation

Canada has a lot of water resources, about 9% of the world's freshwater resources, it owns a quarter of the world's wetlands, and has the third largest glacier (after Antarctica and Greenland). Due to the existence of glaciers in Guangfan, Canada has more than 2 million lakes, and more than 31,000 lakes have an area between 3 and 100 km2, of which 563 are larger than 100 km2.

The two longest rivers in Canada are the Mackenzie River and the St. Lawrence River. The Mackenzie River is more than 4200km long and flows into the Arctic Ocean from northwestern Canada; the St. Lawrence River is more than 3000km long, flows through the Great Lakes and finally flows out of the Gulf of St. Lawrence.

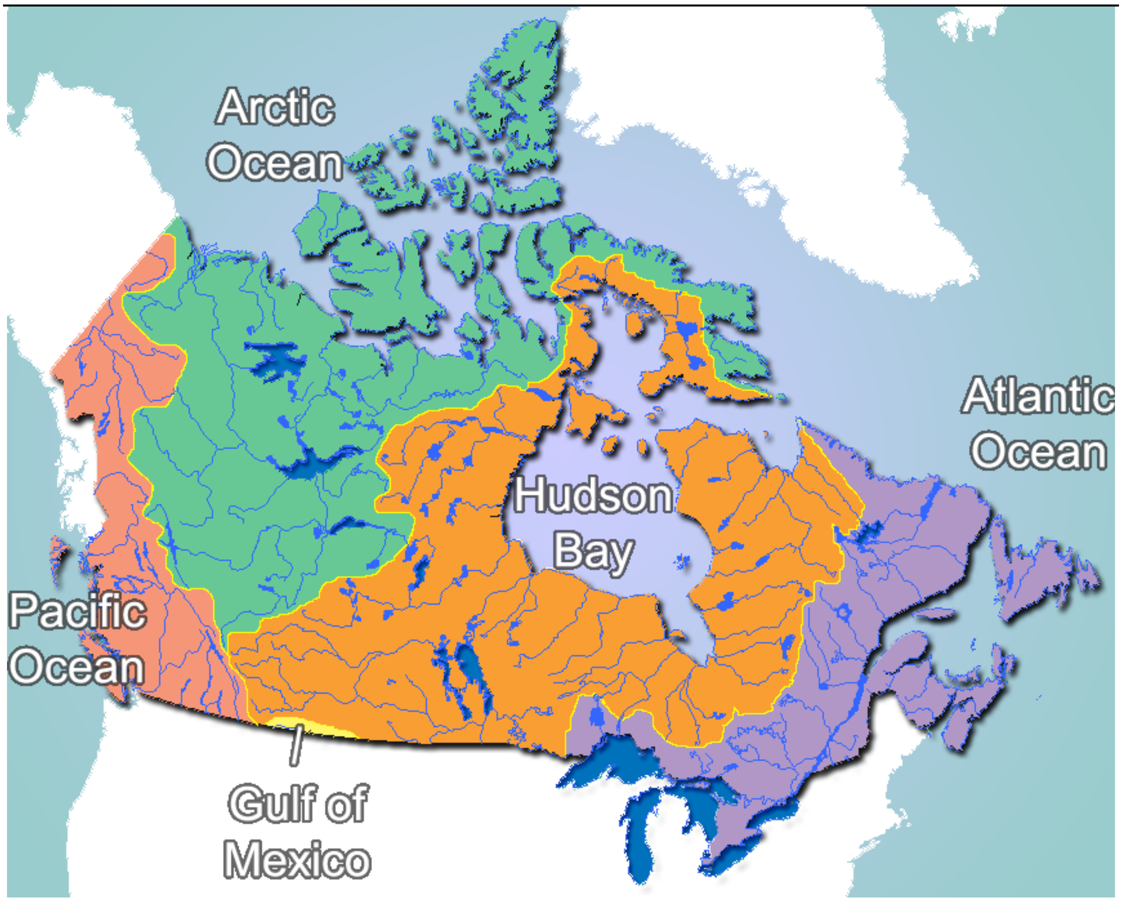

figure1-1 Major river basins in Canada

The Atlantic Basin covers the entire Atlantic Province (part of the Quebec-Labrador border is located on the Atlantic-Arctic Continental Divide), and is mainly located in most areas of Quebec and southern Ontario. The basin is mainly composed of the economically important Saint Lawrence River Drainage of its tributaries, especially the Saguenay River, the Manicouagan River and the Ottawa River, such as Lake Tai and Lake Nipigon from the St. Lawrence River. In addition, other important rivers in the Atlantic basin include the Churchill River and the St. John's River.

The Hudson Bay Basin drains more than one-third of Canada's total. It includes Manitoba, Quebec and northern Ontario, most of Saskatchewan, southern Alberta, and Nunavu Southwest Territories and southern Baffin Island. The basin has played an important role in combating grassland drought and hydroelectric power generation, especially in Manitoba, Quebec, and northern Ontario. The main waters of the basin include Lake Winnipeg, Nelson River, North Saskatchewan and South Saskatchewan Rivers, Assiniboine River and Lake Nettilling on Baffin Island. Lake Wollaston is located at the border of the Hudson Bay and Arctic Ocean basins. It is the largest lake in the world and drains into two basins at the same time.

The Continental Divide of the Rocky Mountains separates the Pacific Basin in British Columbia and Yukon from the Arctic and Hudson Bay Basin. The watershed irrigates the agriculturally important areas within British Columbia (such as the Okanagan and Kootenay Valleys), as well as hydroelectric power. The main rivers in the basin are Yukon, Columbia and Fraser.

The northern regions of Alberta, Manitoba, and British Columbia, most of the Northwest Territories and Nunavut, and parts of the Yukon are drained from the Arctic basin. Except for the Mackenzie River, the longest river in Canada, the basin is hardly used for hydropower. The Peace River, Asbasca River and Liad River, as well as Big Bear Lake and Great Slave Lake (the largest and second largest fully enclosed lakes in Canada, respectively) are important components of the Arctic basin. These rivers converge and drain most of the water in the Arctic basin.

The southernmost point of Alberta flows into the Gulf of Mexico through the Milk River and its tributaries. The Milk River originated in the Rocky Mountains of Montana, flows into Alberta and eventually flows into the United States and merges with the Mississippi River. A small area in southwestern Saskatchewan passes through the Battle Creek River and joins the Milk River.

1.3 Overview of Hydropower Development

Canada is the world's second largest producer of hydropower after China. In 2014, Canada's hydropower production was equivalent to consuming 85.7 megatons of oil, accounting for 9.8% of global hydropower consumption; in addition, hydropower accounted for 25.7 of Canada's total energy consumption (37.3% of non-oil sources), which is the second largest Canada's third largest energy consumption in oil and natural gas (oil and natural gas accounted for 30.9% and 28.1% of total energy consumption, respectively).

Some provinces and regions (such as British Columbia, Manitoba, Newfoundland and Labrador, Quebec and Yukon) more than 90% of their electricity comes from hydroelectric power, and they have large reservoirs and dams. Completed before 1990, after that, regardless of the scale of hydropower, most of them used run-off hydropower stations.

According to the statistics of the Canadian Department of Natural Resources, the currently installed small hydropower capacity is 3400MW, and the estimated potential capacity is 15000MW. However, the future development report of hydropower shows that due to the lack of public recognition, the remaining 78% of the potential capacity is expected to be available before 2050. Will remain undeveloped. The widespread use of hydropower has led to the fact that "hydropower" in Canadian English can refer to electricity in general regardless of the source of electricity, such as Toronto Hydro or BC Hydro. Data show that in 2017, Canada's installed hydropower capacity was about 81GW, and the annual hydropower generation was about 403TWh, second only to China.

Hydropower resources depend on the terrain and climate, and the development of energy is related to the size of the electricity market, the availability and price of competitive energy sources such as coal. The development of hydropower and its share of electricity production in Canada varies from province to province. Quebec, British Columbia, and Ontario account for most of Canada's hydropower generation. The installed hydropower capacity of each province (region) in Canada in 2014 is shown in Table 1-1.

table1-1 Installed hydropower capacity of Canadian provinces (regions) in 2014

Province/Area	Capacity (MW)
British Columbia	14210
Alberta	943
Saskatchewan	868
Manitoba	about 5000 or more
Ontario	about 10000
Quebec	about 40000
New Brunswick	about 950
Nova Scotia	about 376
Prince Edward Island (PEI)	0
Newfoundland and Labrador	6800
Yukon Territory	95
North-west region	56

The most practical hydropower stations are located close to the load centers. Canada has developed hydropower stations for most of these areas. However, there is still a large amount of hydropower potential untapped, mainly in northern Quebec, Manitoba, British Columbia and Las Vegas. In

Brado and Yukon, economic factors are the main factors affecting hydropower development in these areas. Therefore, reducing construction and financing costs, increasing the cost of other competitive energy supplies, expanding the power market, and expanding transmission channels are of great significance to the development of hydropower in these areas.

2 Canadian Water Management Model

Canada is one of the countries with the richest water resources in the world. It owns about 9% of the world' s freshwater resources, but its temporal and spatial distribution is inconsistent with population distribution. The north has 60% of the country' s freshwater resources, but 90% of the population lives in the south. The freshwater resources in the south are becoming increasingly tense due to pollution and increasing demand.

2.1 Basin water resources management concept

The main indicator of the transformation of water resources management in Canada from "basin water resources management" to "sustainable river basin water resources management" is the transformation of the concept of river basin water resources management. Taking the water law promulgated by Canada in 1970 as a watershed, water resources management in Canada's river basin has experienced three development stages: "water development", "water resources management in river basins" and "sustainable water resources management in river basins". Before 1970, it belonged to the water development stage, and its main feature was to emphasize the engineering construction of the development of water resources in the river basin; from 1970 to 1987 was the water resources management stage of the river basin, and its main feature was to emphasize the planning and evaluation of water resources in the river basin; after 1987 Entering the stage of sustainable river basin water resources management, this stage mainly focuses on the theme of sustainable development and emphasizes the sustainable use of water resources.

2.2 Basin water resources management measures

To ensure the sustainable development of Canadian water resources, Canada has implemented the following measures.

First, attach importance to legislation, clarify the rights of governments at all levels from the legal level, and use the force of law to manage water resources. For example, according to the Canadian Constitution, the provincial government owns most natural resources, including water resources. Therefore, the provincial government has the right to manage water resources within its boundaries. The provinces have legislative powers on various water issues, including civil and industrial water supply, pollution prevention, non-nuclear thermal power and hydropower development, irrigation and recreation and other water-related fields. The federal government has sovereignty over water resources in federally owned lands and territories, including national parks and Indian reservations. Congress has the supreme legislative power in the field of commercial navigation, which covers most large rivers. The Congress has supreme legislative power for the fisheries of inland rivers, including the protection of fisheries in various river basins. The federal government is responsible for relations with other countries. For water resources, this is an extremely important power, because many water resources in Canada are transboundary waters. In addition, Canada promulgated the "Canadian Water Act" in September 1970, which mainly made legislative provisions on the assessment of current and future needs of water resources, water quality management methods in polluted areas, and some responsibilities of the federal government and local governments.

Second, focus on cooperation and strive for a win-win situation. For example, the federal and provincial governments have established cooperative relations in water management. The Canadian Council of Ministers of the Environment is composed of environment ministers from the federal, provincial and territorial governments. The council meets regularly to discuss the country's environmental priorities (including water resources). However, in order to coordinate the respective roles and responsibilities of the federal and provincial water resources management, it is also necessary to rebuild cooperation mechanisms in budget cuts and rearrangement of their respective functions.

The Drinking Water Subcommittee of the Federal and Provincial Environmental and Resident Health Commissions has played an active role in protecting the quality of drinking water for more than 20 years. In order to maintain the quality of drinking water in Canada, the Drinking Water Sub-Committee, composed of representatives from the Federal Ministry of Health and various provincial or territorial health and environmental management departments, formulated national guidelines. The federal, provincial and territorial governments set their own drinking water quality standards based on the guidelines. Such as the maximum allowable content of microorganisms, chemicals and radioactive contaminants in the water.

2.3 River Basin Water Resources Management Agency

In order to meet the needs of sustainable management of water resources in the river basin, Canada has established some associations.

(1) Canadian Water Resources Association. The association is made up of individuals and organizations interested in participating in Canadian water management. The association promotes the sustainable development and utilization of water resources by providing forums for all parties to discuss various water issues, such as flood and flood detention area management, watershed restoration and water export, and other national and regional water issues.

(2) Water Commission. There are several committees that manage fresh water throughout Canada. For example, the Inter-Provincial Water Commission in the Prairie Region of Western Canada ensures that the provinces of Alberta, Saskatchewan, and Manitoba share the inter-provincial water resources equally according to the water control allocation agreement. The Water Commission encourages the use of an ecosystem approach to manage fresh water. The Mackenzie River Basin Commission is responsible for overseeing the implementation of the 1997 Mackenzie River Basin's cross-border water control and distribution agreement, which established the principles of protecting aquatic ecosystems and jointly managing water resources in the basin. The basin is Canada's largest basin, located between the provinces of British Columbia, Alberta, Saskatchewan, Yukon and the Northwest Territories. The water control distribution agreement emphasizes the importance of consultation with the public. It is required to publicize water allocation information to the public in an effective manner as soon as possible, and to share information on various development activities that have an impact on the integrity of ecosystems in other jurisdictions.

(3) Canadian Groundwater/Well Water Management Association. The association is a national industry association established in accordance with the Federal Charter. Various provinces have also established

groundwater/well water industry management associations. The provincial association is a member of the national association. Each member province has one vote on the board of directors of the Canadian Groundwater/Well Water Management Association. The provincial associations are responsible for communicating with the provincial policy and regulation departments on the standards for water well construction and the general regulations on groundwater and well water.

2.4 Water rights system

All water resources in Canada belong to the royal family (federation). To obtain the right to use surface water, one must hold a water use permit or obtain an approval certificate under the Water Law. The water laws of the provinces give all real estate owners the right to divert and use water on an equal basis in accordance with the principle of "time first, right first" for all real estate owners and water sources that belong to or adjacent to their territories. If the water use permit and approval certificate are not obtained in advance, it is illegal to take water from the source of water, but it is not illegal to use water without registration for residents' living, prospecting, drilling and fire fighting. The so-called unregistered water use refers to the use of water from various water sources, neither without permission, nor for other purposes, such as water reserved for fish habitat.

The water use permit is a legal document approved by the river basin water resources management agency, which stipulates the time limit and conditions of the right to use water. The terms of the water use permit include: the name and location of the water source of the water intake or storage area, the location of the water intake, the priority date of the permit, the purpose of the water intake, the maximum amount of water quoted or stored, the water use time in a year, and the water use permit The real estate to which it belongs, the authorization for the construction of water diversion and water delivery projects from the water source to the place of use, and the special terms for water diversion for special purposes. The water use permit belongs to the owner of the land, mine, and project. If the land and mine are sold or transferred to others, the water right is automatically transferred to the new owner. A very important clause of a water permit is its priority date. If multiple licenses are issued for the same water source, the license with the earliest priority date will get the first priority, the license with the second earliest priority date will get the second priority, and so on. Most water permits are issued for civil use, irrigation, and various water conservancy projects. Other uses include industry, electricity, environmental protection, mining, and land remediation. Permits are also issued for storage of water to support the right to divert water. This permit allows water to be diverted and stored in the wet season and released for use in the dry season. The water use approval certificate is a short-term water use authorization certificate issued by the water resources management department for a period of less than one year. The approval certificate includes the authorization of special projects such as river bank protection and pipeline installation at the water source.

2.5 Small hydropower development

The appeals of various provinces, autonomous regions and municipalities in Canada for the request for renewable energy proposals, project provision standards, and small hydropower grid access have indirectly promoted the development of small hydropower in Canada. Most people are more concerned about the impact of small hydropower projects on river runoff, ecological beauty, and ecological beauty. Compared with large-scale hydropower, run-off power stations can effectively reduce the impact on the ecological environment due to the impact of fish activities in their natural habitats. 15% of the proven small hydropower in Canada can be used as a strong candidate to promote the current socio-economic situation and the current technological level, with a total installed potential of about 15,000 MW. At the same time, the huge potential of low-head hydropower in Canada is also reflected in the economic efficiency and lower equipment costs.

The current run-off hydropower stations obtain energy from water flow with little or no storage, including small hydropower and low-head hydropower. Through complete design, multi-purpose planning and social participation, the development of these technologies can bring more environmental and social economic benefits. Most remote communities in Canada are currently still using high-emission, high-cost diesel power generation. In contrast, small water electrodes have development advantages and can be used as alternative options. Nowadays, Canada and the world are increasingly interested in the research of water flow patterns and flow patterns, and are working together to develop "zero head" power generation technology that does not require dams.

3 Canadian reservoir group management case-Ottawa river basin management

3.1 Overview of the basin

The Ottawa River is a tributary of the St. Lawrence River. Most of its river channels are located on the border between the two provinces. The river is more than 1130km long and has a drainage area of 146,300km2. It spans Quebec and Ontario, of which 65% is located in Quebec and 35% is located Ontario.

At the beginning of the 20th century, as downstream shipping and electricity demand continued to grow, Canada began to consider building reservoirs to store water resources in natural rivers. According to this, the federal government established the Quinze, Timiskaming and Kipawa reservoirs between 1911 and 1914, when Chaudi è re was the only hydroelectric power station in the river system. At present, 13 large reservoirs have been built in the basin, each with a storage capacity of at least 200 million m3. The total storage capacity of these reservoirs is approximately 12.155 billion m3, and is in accordance with ORRPB (Ottawa River Regulation Planning Board) policy Comprehensive management of reservoirs. The geographical location of major reservoirs in the Ottawa River Basin is shown in Figure 3-1.

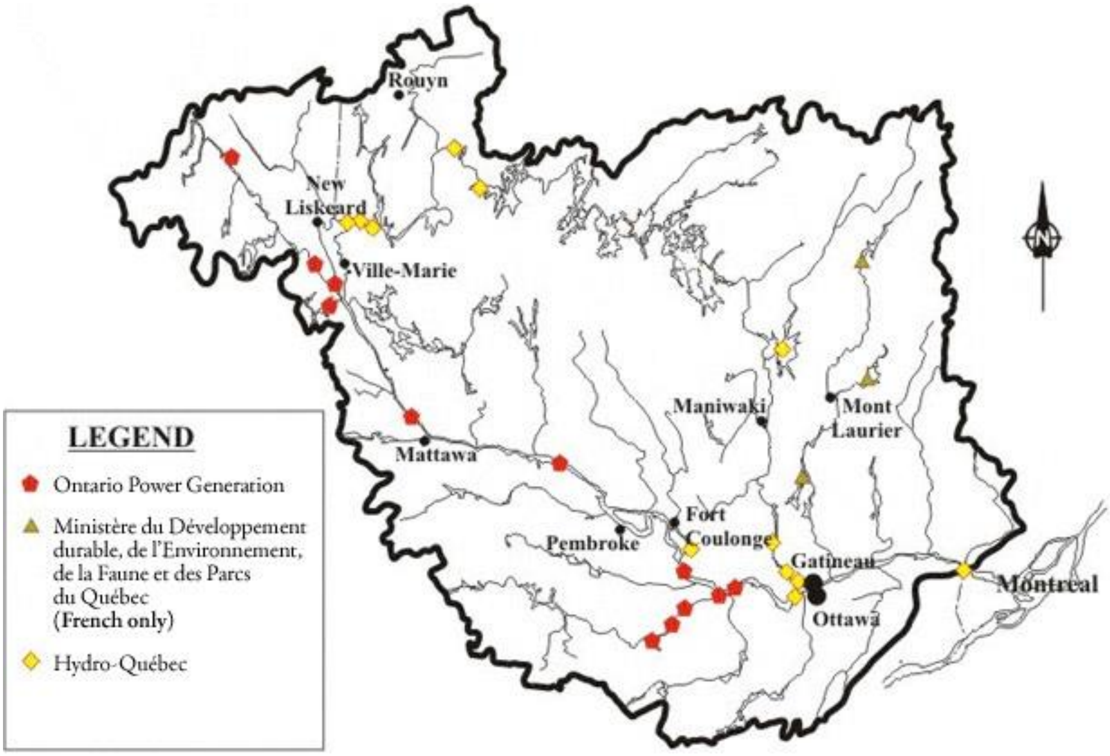

figure3-1 Geographical map of major dams in the Ottawa River Basin

In addition to these 13 large reservoirs, there are 14 small reservoirs, but they provide less storage capacity overall, so they are not included in the Ottawa River Basin Decision Support System.

3.2 River Basin Management Agency

The main purpose established by the Ottawa River Regulation Planning Board (ORRPB) and the Ottawa River Regulating Committee (ORRC) is to ensure the comprehensive management of large reservoirs in the Ottawa River Basin. The main objectives of management are Flood prevention and maintenance of the interests of users, especially for parties involved in hydropower production.

After a devastating flood in the Montreal area in 1974, both the federal and provincial governments began to take measures to reduce the damage caused by the flood. After another major flood in 1976, government departments clearly further increased their flood control efforts. The first step taken by the government is to establish a Commission on Flow Regulation (Montreal area). The purpose is to determine various possible conditions without damaging the existing water resources and the environment in the Montreal area to reduce Risk of flooding and low water levels. The committee put forward a series of recommended measures in 1976, including measures for the St. Lawrence River, integrated management of the Ottawa River Basin reservoir, and various engineering measures, such as the construction of a dam at the entrance of the Milk River and other control projects. In addition, it also proposes to expand the existing Ottawa River Regulating Committee so that it can include other stakeholders.

In March 1983, government departments and other relevant agencies signed the "Canada-Quebec-Ontario Agreement Respecting Ottawa River Basin Regulation" (Canada-Quebec-Ontario Agreement Respecting Ottawa River Basin Regulation) and established the Ottawa River Basin Planning Commission (The Ottawa River Regulation Planning Board (ORRPB), the Ottawa River Regulating Committee (ORRC) and the Ottawa River Regulation Secretariat (ORRS), including the federal and provincial governments and hydropower companies, have joined Planning committees such as Hydro-Qu ébec and Ontario Power Generation (OPG).

The responsibility of the Planning Board (ORRPB) is to formulate policies and standards for the integrated management of reservoirs in the agreement. The responsibility of the Management Committee (ORRC) is to formulate appropriate supervision and operation practices and procedures to ensure that the operation of the reservoir complies with the regulations and standards set by the Planning Committee. As the executive body of the Planning Committee, the Secretariat's main task is to perform the tasks of the Planning Committee by collecting and analyzing data, reporting and predicting the hydrological conditions of the Ottawa River Basin, and developing and operating mathematical models.

3.3 Joint management of hydropower stations and reservoirs

The integrated management of hydropower stations and reservoirs in the Ottawa River Basin mainly includes various steps of data collection, meteorological and hydrological models, and decision support systems for optimal operation of the reservoir.

data collection

The first step is to obtain data through real-time observation. After data collection is complete, data verification must be performed. After data verification is completed, the observed hydrological and meteorological data can be used for meteorological and hydrological forecasting.

Weather forecast

Meteorological forecast is the source of uncertainty in hydrological forecast, so it is very important. The weather forecasting process is as follows:

(1) Analyze the current and past meteorological background.

(2) Analysis of future weather conditions.

(3) Meteorological scene construction.

(4) Interpolate based on the grid to calculate the average value of the watershed, and then construct the probability weather forecast in 85% and 15% based on the error in historically similar situations.

Hydrological forecast

The HSAMI model is a watershed conceptual model developed by Hydro-Québe (Bisson and Roberge, 1983). The HSAMI model uses the following inputs: daily minimum and maximum temperature, rainfall, and snowfall. Figure 3-2 shows the interaction of various processes in the HSAMI model. In the HSAMI model, the physical processes and their interactions are controlled by parameters set during model calibration.

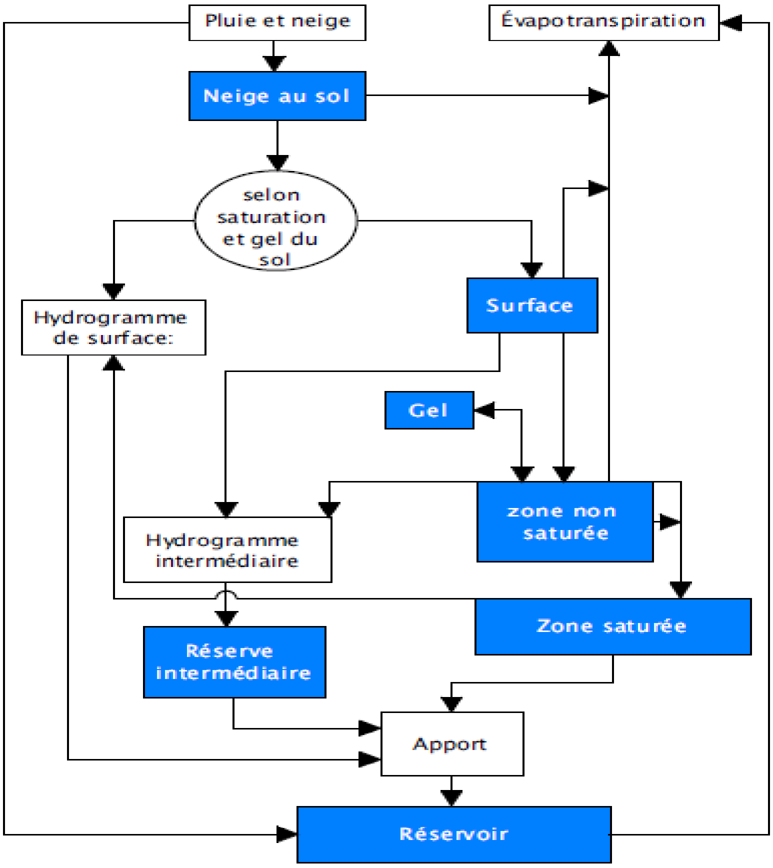

figure3-2 HSAMI conceptual model

The HSAMI model contains 23 parameters, which can be combined in thousands of ways. The parameters are optimized in the iterative process to find the optimal solution. The optimal solution is the parameter combination that maximizes the Nash - Sutcliffe coefficient (NSE) within a year .

$$C_N = 1 - \frac{\sum_{i=1}^{n}(Q_{obs,i} - Q_{sim,i})^2}{\sum_{i=1}^{n}(Q_{obs,i+1} - \overline{Q}_{obs})^2}$$

Among them , $Q_{obs,i}$ s the inflow on the i-th day of observation , $Q_{sim,i}$ simulated inflow on the i-th day , $Q_{obs,i+1}$ is the inflow on the i+1-th day of observation , $\overline{Q}_{obs}$ is the average inflow of the entire series of observations。

The hydrological forecast process mainly includes:

(1) Quantify the evolution of the hydrometeorological situation.

(2) If necessary, verify and compare the weather forecast plan with

the output results of other weather forecast models on the website of the Meteorological Center.

(3) When the observed flow data is abnormal, raise questions in time to prevent potential undetected problems.

(4) Search for situations with similar conditions in the historical database (observed flow, weather conditions, current time, snow volume on the ground, etc.).

(5) Use the hydrological model to simulate the flow process under the conditions of "low water" (85%), "flat water" (50%) and "high water" (15%).

(6) If the simulation structure is not ideal, the forecast plan needs to be adjusted. Adjustments may involve the following aspects: adjustments to observations or predicted values; changes to the historical process of reference; adjustments to the initial conditions to change the difference between the three situations; adjustments to model parameters (such as reduced snow cover or lower groundwater level).

In ORRC, it is important to communicate the predicted inflows and certainty/uncertainty levels of each sub-basin, especially when it comes to public and facility protection.

3.4 Decision Support Systems

The Ottawa River Basin currently uses the HEC-ResSim model for integrated watershed management, which is related to the HSAMI model. The HSAMI model is a natural flow forecast model developed by Hydro-Québe. The forecast results of the HSAMI model will be input into the HEC-ResSim model , In order to carry out river course evolution calculation and reservoir flood regulation calculation. At the same time, the calculation of the HEC-ResSim model must provide an estimated dispatch plan of the reservoir to determine the amount of runoff stored in the reservoir, and then to calculate the evolution of the river.

The HEC-ResSim model was developed by the US Army Corps of Engineers and is the next generation model of the SSARR model. Since the establishment of ORRPB in 1983 until January 2016, ORRC has been using the SSARR model. Since then, the SSARR model has been used as a backup for the HEC-ResSim model.

The schematic diagram of the HEC-ResSim model used in the Ottawa River Basin is shown in Figure 3-3. As shown in the figure, the Ottawa River

Basin is conceptualized into 46 basins, each producing natural runoff, starting from the source area, evolving and converging along the river channel, and reaching the outlet of the basin at the Carillon Dam.

In order to facilitate the evolution calculation, the physical river system is simplified into a set of interconnected nodes, including three types. Transmission points are nodes in the system that do not undergo river evolution. They are usually used to aggregate runoff from different tributaries and to facilitate data measurement. The flow passes through the remaining two types of stations: reservoir points and reach points. For computer simulation, the combination of these three station types are connected together.

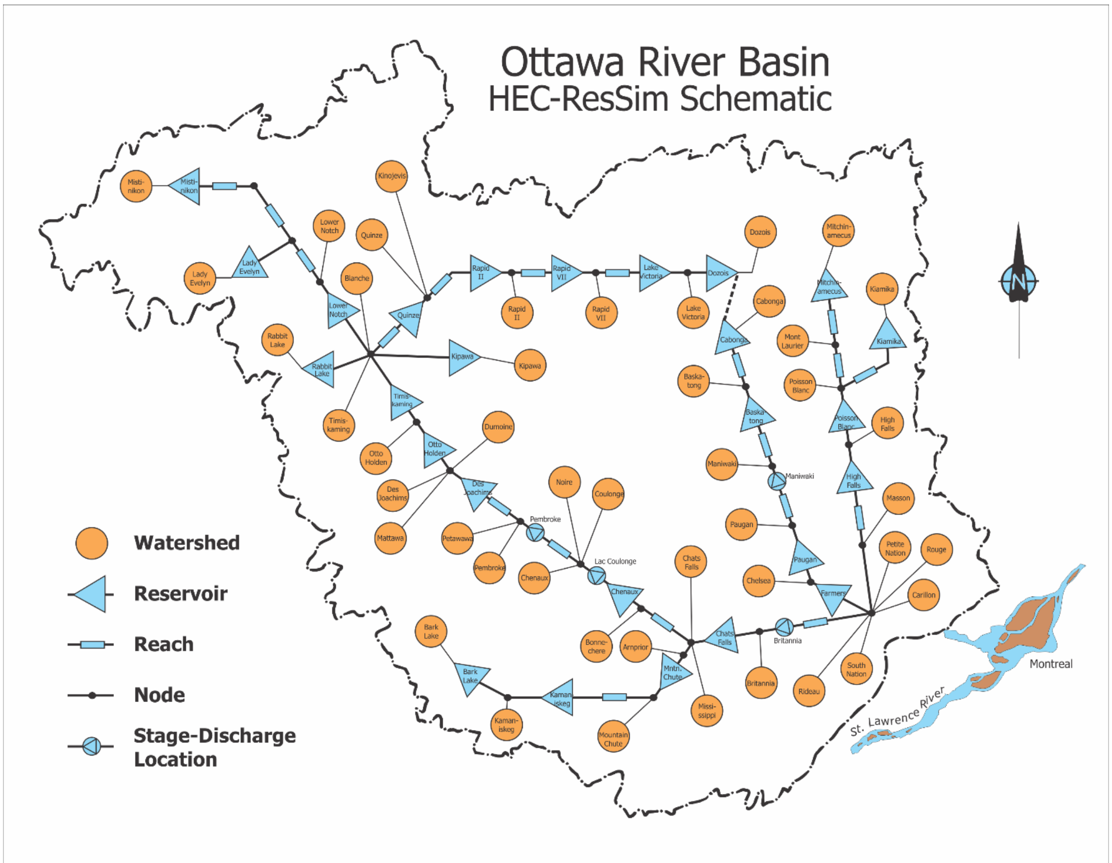

figure3-3 Application of HEC-ResSim Model in Ottawa River Basin

4 Canadian Electricity Market

Canada's electricity market reform began in the mid-1990s. In order to adapt to market competition, the Canadian government first introduced a competition mechanism on the power generation side, and then reformed the regions that exchanged electricity with the United States, opened the electricity market, and participated in competition in the United States using low-cost electricity provided by abundant water resources. For states without this advantage, the degree of openness of the electricity market is subject to a vote by the state assembly, which ultimately decides whether to open the electricity market for competition.

Canada's regulatory agencies are divided into national and provincial levels. National regulatory agencies mainly include the Ministry of Natural Resources (NRC) and the National Energy Board (NEB). Among them, the NRC is the competent authority for energy management on behalf of the Canadian government. It is mainly responsible for energy development and security policy guidelines and related policy research, and reports to the Canadian Parliament through the Minister of Natural Resources. NEB is mainly responsible for the supervision of the electric power industry. It is directly managed by the Minister of Natural Resources of Canada and has the power to make independent decisions and exercise supervision. Each province has an energy management department, usually an energy committee or a public utility committee, which is responsible for implementing provincial energy policies, reviewing the income permits of regulated companies, issuing business licenses for electric power companies and power sales companies, reviewing or arbitrating the scale of wholesale markets, and regulating retail sales Market etc.

Electricity market overview

Canada's existing transmission grid is divided into two parts: the western power grid uses 500 kV and 138 kV tie lines to connect the grids of British Columbia and Alberta; the central and eastern regions use 115 kV and 735 kV tie lines to connect Manitoba, Ontario, Quebec and other regions are connected to the grid. In addition, the 6 provinces in southern Canada and the 10 states in the United States have also been connected to each other through ties.

In terms of cross-border transactions, Canada has close cross-border power transactions with the western United States, the Midwest, PJM, New England (ISO-NE) and New York State (NYISO), mainly exporting clean and cheap power to the United States. In 2016, Canada's total exported electricity was 73.1 billion kWh, an increase of 4.3 billion kWh over 2015; the total imported electricity was 9.3 billion kWh, an increase of 600 million kWh over 2015. In terms of price, in 2016, the average price of electricity exports from Canada to the United States was $0.0385 per kWh, and the average price of electricity imports was $0.0263 per kWh. In 2016, net income from cross-border transactions was approximately US$2.7 billion.

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Management Model of Cascade Reservoirs in Norwegian Basin

1 Overview of River Basin Hydropower Development

1.1 Overview of Norwegian River Basin

Norway is located in the northwest corner of the European continent, including the surrounding Svalbard and Jan Mayen islands, with a land area of 385,000 km2. Norway has a long and narrow terrain, starting from the southernmost latitude 58° N, spanning more than 1,700 kilometers in the northeast direction, reaching 71° N latitude.

More than 30% of the land area of Norway is between 0 and 300m above sea level, another 30% is between 300 and 600m above sea level, and the rest are valleys or plateaus with an elevation of 600 to 1200m above sea level. The highest peak is close to 2500m above sea level. There are 18 larger rivers, the largest being the Glomma River.

1.2 Status of hydropower development in Norway

Since 1965, the Norwegian economy has continued to develop, and energy requirements have continued to grow. Science and technology continue to innovate, and new ideas and new methods continue to emerge in design and construction. In the early 1960s, the new Austrian method was widely adopted in underground engineering, and a new understanding and practice of rock was gained. It was no longer regarded as a simple load, but at the same time as a load-bearing structure. Give full play to its self-supporting ability. As a result, hydropower projects have developed greatly.

In the layout of the hub, a series of innovations in tunnels, shafts, inclined shafts, and waterway linings were proposed. In terms of factory buildings, the ground factory was turned to the underground factory, and the design of rock wall crane beams, shotcrete anchor support, and minimized factory span was proposed. Finally, an air-cushion type pressure regulator was used on the waterway system to turn the waterway system into a deep-buried, one-slope-to-bottom method, and attention to environmental protection requirements in the entire hub. As of 2020, the total installed hydropower capacity in the country has reached 37 GW, and the annual power generation has reached more than 150 TWh. National hydropower accounts for 90% of the normal annual power production, continuously meeting the high standards of industrial, commercial, and residents' living standards, and it is also connected to the Nordic and European power markets. The total installed hydropower capacity accounts for more than 98.8% of the total installed capacity of various energy sources across the country.

2 River Basin Cascade Reservoir Management

In terms of river basin cascade reservoir management and power market, Norway has promulgated a series of related laws and established related organizations and institutions to establish hydropower development and power market on a standardized, scientific and orderly basis. The main features are as follows: :

1. Norwegian water resources management responsibilities are clearly divided, with government departments, water resources management associations, and power generation companies performing their duties.

2. Establish a hydropower development permit system through the law to ensure that hydropower resources are managed in the country' s best interests through public ownership of hydropower resources.

3. Establish river basin water resources management organizations, manage water resources in a unified manner in different river basins, and implement unified planning for the entire river basin.

4. Successfully carry out the reform of the electricity market, so that electricity production and supply enter the liberalized market competition.

2.1 Management model and current situation

Norway has promulgated a series of laws on hydropower development, so that hydropower development is established on a standardized, scientific, and orderly basis. In 1917, the "Waterfall Rights Act" was passed by the Norwegian Parliament.

In Norway, private ownership of the right to utilize water resources for hydropower production is restricted. Although domestic private investment is allowed, the licensing system introduced in 1917 has had strict deadlines for private investors. That is, the BOT system is adopted. After 60 years of operation, the power station must be handed over to the country intact and unconditionally (because Norway is basically free of sediment and the problem of wear and tear, the power station can generally run for 70 to 80 years). Under the current rules, licences may only be issued to public bodies, i.e. state-owned enterprises, municipalities and county authorities. Still, private actors may own up to one-third of a company that holds a licence under the Waterfall Rights Act. The license system also stipulates that a series of links such as dam construction, power station construction, power generation, power transmission, distribution, and electricity sales must be separately licensed. The licensing system is one of the most important elements of Norwegian hydropower development regulations. It ensures the country’s ownership and development control of water resources and maximizes the use of water resources. Unified management of watersheds is another characteristic of Norwegian water resources management. Without a unified plan for the entire watershed, no power station can be constructed.

Norway attaches great importance to the impact of hydropower development on the environment, such as building dams based on topography, not deliberately seeking to maximize installed capacity, but putting the comprehensive benefits of economy, society, environment and ecology first; they pay special attention to the protection of natural ecology For example, it is required to set up fish gates for the rivers rich in salmon so that the salmon can go back and spawn, and developers are also required to set up salmon juvenile fish cultivation ponds; even the development of certain rivers is prohibited to protect the environment the goal of. Hydropower development has brought huge tax revenues to Norway (it is Norway’s second largest tax revenue source after petroleum), and has also spurred the development of other industries and local economies, helping local residents get rid of poverty and become rich.

According to Norwegian law, the responsibility for energy management and development in Norway is divided among several agencies. The Ministry of Petroleum and Energy and its subordinate body, the Norwegian Water and Energy Directorate (NVE), as a government department, is responsible for the management of water and energy resources in Norway. , And under the supervision of the national government agency NVE, there is an original and important organization-Water Resources Management Association (WMA), which effectively coordinates the interests of all parties involved in the water resources of the river basin, and solves the contradictions in the daily water use process. And conflicts play an important role in the optimal use of water resources in the Norwegian basin. In different river basins, the optimization and management of water resources are managed by the corresponding river basin water resources management associations, such as the Glomma and Laagen River Basin Water Resources Management Association (GLB), which is the management agency of Norway’s largest river and is responsible for the management of Gromma. And Lajian River Basin. The centralized control and daily management of the power station are responsible for the corresponding energy groups, such as the Eidsiva Energy Group in the Glomma and Laagen River Basin. The centralized control center of Eidsiva Company is responsible for the remote monitoring, control, and control of more than 40 hydropower stations in the basin. Regulating work, the power station realizes closed operation. Only the regional maintenance center conducts regular or irregular inspection, maintenance and operation of the power station, which not only improves management efficiency, satisfies the safe production of the power station, but also reduces the operating cost of the enterprise.

Norwegian water resources management and development are inseparable from the government's legislative support. Representative legislation such as "The Watercourse Regulation Act" (1917) established the establishment of the Watercourse Management Association WMA, clarified its business objectives and control scope, etc.

2.2 Electricity Market

2.2.1 Electricity market overview

The Norwegian Parliament passed the Energy Act (Norwegian: Energiloven) at the end of 1990, and it became effective on January 1, 1991. The "Energy Act" has become the main basis for the reform and restructuring of the Norwegian power industry and has been used for reference by other Nordic countries. The total wind and hydropower generation capacity of Norway is 84% owned by the state, municipalities and counties., 16% owned by foreign or private Norwegian entities. In the process of reforming the electricity system in Norway, the State Electricity Authority were divided into three parts: Statkraft owns the generator sets owned by the former State Electricity Agency and accounts for 30% of the country's power generation capacity. Statnett is the system operator (TSO) in the Norwegian energy system. The Norwegian Water and Energy Directorate is a directorate under the Ministry of Petroleum and Energy and is responsible for the management for Norway's water and energy resources. One of their main tasks is to process license applications for the construction of power plants. The responsibilities of the State Grid Corporation are: operation and development of the state-owned power transmission system; planning of the Norwegian power transmission system; responsible for the joint operation of the Norwegian power system, formulating system operation procedures; and organizing the Norwegian power market.

In addition to owning 80% of the main network, State Grid Corporation also signs lease contracts with the property owners of the remaining 20% of the main network. Norway's management policy is mainly to compete in the power generation market and the user market, and the network is separated and operated by the State Grid Corporation. The government department controls the State Grid Corporation to ensure that the network is open to all market members.

The State Grid Corporation of China has also established a subsidiary organization: Power Market Ltd to perform tasks related to the operation and trading of the electricity market. In terms of power supply, the power distribution company retains the responsibility of connecting users, but does not have the right to increase power supply. That is, for a new user, when it needs to be connected to the distribution network, it must be completed by the distribution company in the area where it is located. However, the user is not necessarily supplied by the distribution company in his area. Users can choose a suitable power supplier from distribution companies in the region, power suppliers in other regions, power retailers, and power markets. In other words, in the Norwegian electricity market, the networking and power supply business are separated.

Looking at the reform of the electricity market in Norway, the purpose is to introduce competition, not to privatize. Therefore, although the electricity industry in Norway is still publicly owned, all the power companies in large provinces and cities no longer have a monopoly in the local area. The core characteristics of the electricity market reform include the following five aspects: 1) Opening up the transmission network, whether it is a national, regional or local transmission network, must be opened to all market participants to achieve free competition at the retail end of electricity, and distribution providers No longer have exclusive rights to local power supply services, and need to compete with new distributors in the market for price; 2) Electricity supplyers can participate in electricity spot market transactions, or buy directly from the producers. The consumers enter into agreements to purchase electricity form a power supplier of their choice. Market participants may also enter bilateral forward transaction contracts. For reference, because traders in bilateral forward transaction contracts can enter the spot market at the same time, the expected spot market price becomes the reference price of the bilateral transaction contract; 3) a transmission fee system independent of distance is established for transmission; 4) Separate power generation business from transmission and distribution services, and public power companies with transmission and distribution networks and generating sets must establish separate departments for power generation, transmission and distribution services.

After the reform of the electricity market, Norway has introduced complete competition in the field of competitive wholesale and retail electricity. The transmission field still maintains a monopoly, but all transmission networks must be open to all users to ensure the openness of the network and control the efficiency of natural monopoly [5].

2.2.2 Trade forms in the Nordic electricity market

In 1996, the Norwegian power transaction database system was extended to Sweden, then to Finland and Denmark, and was organized as a new Nordic power transaction database, jointly owned by Norway and the Swedish Grid Corporation. The Nordic electricity trading database includes three markets, namely the spot market, the regulated market and the futures market. The first two markets are the physical market for electricity trading, and the futures market is the financial market for avoiding and managing risks.

Spot market: The physical market for electricity trading. Contracts are bought and sold on a daily basis for the delivery of the second day. The basic unit of time for market clearing and settlement is hour. In principle, there should be 24 price units each day and night, but only 6 price units are released daily and 4 price units are released on weekends. This information is calculated by the equilibrium price determined by the electricity trading database based on the supply plan and demand plan. Since the spot market is cleared on an hourly basis, traders must have the necessary equipment to measure hourly electricity transactions.

Intraday market: Transactions that deviate from the contract quantity are carried out on the regulated market. This market is established in response to changes in the actual production and consumption by market participants from their position in the day-ahead market. Because the production plan based on the price formed in the spot market in advance may deviate from the actual delivery power production plan. The intraday market plays a large part in ensuring the balance of power generation and transmission in the power system. Power generation capacity is obtained in the intraday market through the auction process.

Futures market: Provides participants with organized electricity market price avoidance and risk management. The market uses spot market prices as a reference for potential prices. In the futures market, there are market makers who publish buying or selling prices, which allows participants to make quick adjustments to their strategy or asset portfolio.

2.2.3 Norwegian power grid and other power grids

The four Nordic countries: Sweden, Norway, Finland and parts of Denmark form a unified Nordic synchronous area sharing the same frequency. The power system in each of these countries are very different and highly complementary. Among them, Norway is basically a pure hydropower system. In Sweden, hydropower, nuclear power and wind power make up almost 90% of the power production. In Denmark most of the power production come from wind and thermal power plants. Finland is mainly thermal power and nuclear power, and the proportion of hydropower is about 15%. The difference in power structure is the main reason for the interconnection of the Nordic power grids and the formation of the electricity market. Norwegian power companies have signed long-term trading contracts with power companies in other Nordic countries. The contract power is based on Norway's daily peak load, and its price is based on current electricity prices and costs.

Today, Norway and the Nordic countries are part of the European market coupling through a price coupling mechanism, and it is expected that the exchange capacity between the Nordic countries and other Euroean countries will increase significantly between 2020 and 2030.

3 Key Technologies of Cascade Dispatching in Norwegian Watershed

Norway has special geographical and climatic conditions. For more than 100 years, a hydropower-dominated power system has been developed based on these unique natural conditions. In the dispatching and operation of hydropower stations, based on ice and snow hydrology, they have carried out runoff forecasts and research on hydropower dispatching operations. And integrated the development of a river system simulator, forming a unique water resources forecasting and dispatching method system.

3.1 Ice and snow hydrology

Norway is located in a high latitude area. Snow accumulation and melting play an important role in Norway's hydrological cycle. Generally, several physical parameters can be used to describe the characteristics of snow. Norwegian hydrologists are most concerned about the parameters describing the water content of the snow cover and the parameters that affect the melting of the snow, such as the water equivalent (mm), depth (cm), and density (g/cm3 or kg/m3) of the snow cover. , Liquid water content (weight or volume percentage), etc.

3.2 Runoff forecast

Weather forecasting is an important input for short-term runoff forecasting. If the weather forecast is quantitative and the time step is consistent with the runoff forecast model, the application is very convenient. If the weather forecast is only qualitative, the qualitative forecast needs to be converted into quantitative data based on experience. The Norwegian Meteorological Institute (DNMI) has published a quantitative forecast model, LAM, which is suitable for the meteorological characteristics of Norway, with a forecast period of 36 hours and a 6-day qualitative forecast based on the European Meteorological Center ECMWF global forecast model. The forecast includes temperature and precipitation, and the weather record includes air pressure, wind (wind direction and speed) and cloud cover. The above quantitative forecast content is only released to relevant users such as the River Basin Management Association, and transmitted by fax, etc. The weather record data can be viewed and saved through terminal software.

The hydrological model is a generalization of the hydrological system to simulate the hydrological cycle processes such as precipitation, evaporation, snow melting, infiltration, and runoff. In order to solve the problem of flood forecasting in hydropower plants, the Swedish Hydrometeorological Research Center developed the HBV (Hydrokogiska Byrans avdeling for Vattenbalans) model for river flow prediction and river pollutant transmission in the 1970s. This model was used in the Nordic region. It is widely used in hydropower station runoff forecasting and is considered the most important precipitation runoff model in hydropower utilization in Norway [8].

The typical short-term forecast forecast period is within one week, which is generally used for short-term reservoir operation and management. The forecast value is closely related to the quality of the weather forecast and the initial state of the system.

In Norway, medium- and long-term forecasts are usually related to snowmelt runoff. This is a situation in which snowmelt affects medium- and long-term forecasts in the hydrological system. The other is a long-term small flow situation that has nothing to do with snowmelt. The flow is controlled. In view of the above two situations, the Norwegian forecast department uses precipitation runoff models or regression models to calculate medium and long-term forecasts.

In the application of precipitation runoff model, the important initial state is described as accurately as possible, and then a set of typical data (in the low flow state without snow melting) or historical series data (in the case of snow melting, with Precipitation and temperature series) run the model to obtain the runoff forecast results.

Establish a total snowmelt calculation model based on precipitation or accumulated snowfall at different stations in winter, use the total snowmelt data to establish a regression equation, and use stepwise regression methods to concentrate the selected forecast data on several important data. In actual operation, the regression equation can be established by using snowmelt on different dates, and then the forecast value can be calibrated by actually observing the snowmelt runoff flow.

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Management Models of Cascade Reservoirs in the Brazilian Basins

1 Overview of Hydropower in Brazil

1.1 Abundant hydropower resources

Brazil is one of the countries with the richest hydropower resources in the world, with superior hydropower resources and development conditions. The average annual precipitation is 1,954mm, and the average annual river runoff is 6.950 billion m3, the largest in the world.

Brazil has three major river systems: Amazon, Parana and San Francisco, and water resources are mainly distributed in these three river basins. The Amazon River in the north is 6751km in length and traverses northwestern Brazil. It has a drainage area of 3.9 million km2. It is the largest river in the world. Water resources account for 46.3% of the country. Most areas in the basin have a tropical rainforest climate with annual rainfall above 2000mm, the flow during flood period can reach more than 280,000 m3/s. The Parana river basin in the southeast region, flowing through the southwest, is rich in torrents and waterfalls, and is rich in water resources, accounting for 24% of the country total water resources. The average annual precipitation in the basin is 1240mm and the total precipitation is 3700 billion m3. (November to February of the following year) The average flow rate is 45000m3/s, and the average flow rate during the dry season (August to September) is 6,200m3/s. The San Fransico river system in the northeast is 2,900km in length and flows through the arid northeast. It is the main source of irrigation water in the region. Water resources account for 8.6%. The annual average flow is 2810m3/s and the annual runoff is 88.6 billion m3.

1.2 Mature hydropower development

After the end of the Second World War the power industry in Brazil has been dominated by hydropower. As the most mature technology and the most stable supply of renewable clean energy, hydropower occupies an important position in Brazil's energy supply. In terms of installed capacity, the theoretical installed capacity of hydropower in Brazil is 248 million kW, the theoretical installed capacity of the Amazon River Basin is 97 million kW, the theoretical installed capacity of the Paraná River Basin is 63 million kW, and the theoretical installed capacity of the San Francisco River Basin is 23 million kW.

The development of hydropower resources in Brazil began by the end of the XIX century, and in the 1970s, it began to expand the development area and reached a climax in the 1980s. As of 2018, Brazil' s total installed capacity in the country was about 158 million kW, of which hydropower was 104 million kW, accounting for 64%; hydropower generation accounted for about 73.6% of the total power generation, showing the core position of hydropower. For hydropower installed capacity, the Paraná River has developed installed capacity accounting for 56%, the San Francisco River has developed installed capacity accounted for 13.4%, and the Amazon River Basin has developed installed capacity accounted for 30.5%.

1.3 Representative power station

Itaipu Binacional (Itaipu Dam), located on the Paraná River (the fifth largest river in the world), was jointly built by Brazil and Paraguay. The power generation unit and power generation were divided equally between the two countries. The first unit generated electricity in 1983 . There are currently 20 generating units (each 700,000 kW) with a total installed capacity of 14 million kW and an annual power generation of 90 billion kWh. It is the second largest hydropower station in the world with installed capacity, second only to the Three Gorges Power Station. Itaipu Hydropower Station has been in operation for more than 30 years and has provided sufficient energy for social development and produced huge social benefits.

The Belo Monte Power Station in Brazil is the second largest hydropower station in Brazil, with an installed capacity of 11 million kW. It adopts a ±800 kV UHV DC transmission project. It is the first UHV DC transmission line in the Americas and can directly transport hydropower resources from northern Brazil to the southeast. Load center. During the construction of the Belo Monte power station, there was a lot of controversy on energy and environment. The construction company invested 13% of the total project, 3.7 billion reais for environmental protection, infrastructure, immigration and other social projects, making the Belo Monte project recognized by the society , Played a great role in promoting the development of the country.

2 Basin hydrological forecast

All hydropower stations in Brazil accept unified dispatch and share hydrological risks. Therefore, hydrological monitoring is the supervision obligation of all hydropower stations, and the monitoring data is also shared with the whole country. Brazil's hydrological forecast combines meteorological forecasts and shared hydrological monitoring information to produce reservoir water forecasts. According to whether the information source is open or not, it is divided into the following two categories.

2.1 Use public information to predict

The Brazilian Meteorological Forecasting Agency carries out weather forecasts and mid- to long-term climate research for the next 7 days nationwide

It can provide qualitative judgments on the water inflow situation in Brazil and various river basins, which is a common reference for many power companies. However, for the quantitative analysis required for hydropower station operation scheduling and market forecasting, more accurate weather and rainfall data and subsequent model conversion in inflows are required. The Brazilian National Electric Power Dispatching Center has a professional team to collect the above-mentioned public information and make water forecasts for weekly optimization of the short-term reservoir dispatch model and daily dispatch reference.

3 Operational Planning and Dispatch of the Brazilian Interconnected System

The Brazilian generating system is hydro dominated and characterized by large reservoirs presenting multi-year regulation capability, arranged in complex cascades over several river basins. For example, the hydro generation represents more than 80% of the installed capacity and the generating system comprises 162hydro plants and 114 thermal plants. The hydro plants use stored water in the reservoirs to produce energy in the future, replacing fuel costs from the thermal units. For these reasons, the operation scheduling in Brazil ranges from long term multi-year reservoir optimization (five years horizon divided in monthly steps) to short term hourly dispatch.

The generation dispatch and trading arrangements in the Brazilian interconnected system - thus including cascade reservoirs - are based around a tight, centralized system optimization, scheduling and dispatch scheme, that allows to better capture the diversity of the hydrological behaviour of the main country river basins [1]. Based on the received technical data, the National System Operator (ONS) establishes a generation schedule which defines which generation plants should be dispatched and the associated generation target in order to achieve least cost operation of the whole system. This schedule is obtained through the chain of optimization models developed by CEPEL [2] that also calculates the water values. The water values form the basis for determining the spot price, i.e., the Settlement Prices for Differences - PLDs in each period, calculated by the Whole Sale Energy Market Entity (CCEE) [1-3].

In this way, since 1998 expansion and operation planning studies in Brazil, have been carried out with the support of a chain of optimization and simulation models [2]. The year of 1998 marks the first official use of the NEWAVE program, which has been used in the routine and official activities of sector entities: generation dispatch by ONS; calculation of the spot prices by CCEE; expansion planning by the Ministry of Mines and Energy (MME) and the Energy Research Company (EPE); parameters of public auctions for the purchase of electricity by the Electricity Regulatory Agency (ANEEL); as well as by utilities of the power industry to develop corporate strategies [4-5].

The chain of optimization and simulation models developed by CEPEL is presented in Figure 3.1. It extrapolates the operation planning and also encompasses the expansion planning the activities, covering the long-term generation expansion planning (30-40 years ahead), the short-term generation expansion planning (so called ten year expansion planning), long/medium/short-term operational planning and unit commitment. It considers distinct planning horizons and degrees of detail in system representation and allows for a smooth and coordinated transition between decisions making in each of the time horizons.

The main mathematical models comprise stochastic optimization models (NEWAVE, DECOMP), mixed integer linear optimization models (DESSEM, MELP), linear optimization model (MATRIZ), simulation model (SUISHI), synthetic inflow scenarios generation model (GEVAZP), streamflow and wind power forecasting models (PREVIVAZ, VENTOS), short-term load forecasting models (PrevCargaPMO, PrevCargaDessem), reliability model (CONFINT), flood control models (CHEIAS system), hydropower inventory of river basins model (SINV) and investment risk analysis model (ANAFIN). Additionally, methodologies and software to include the environmental issues in the generation expansion planning are also part of the tool chain.

Priorities for improvements in methodologies of the official computer programs are defined by the Standing Committee for Analysis of

Methodologies and Computational Programs of the Electric Sector - CPAMP, chaired by MME. Besides, CPAMP also validates new developments, releases and key parameters of the official models, which holding workshops followed by public consultations with interested parties on the improvements implemented in the computational models that will come into force in the near future. Thereafter, new functionality and improvements in the operational planning models of the Brazilian toolchain are thoroughly tested before their use has been approved through a rigorous validation process organized by a task force coordinated jointly by ONS and CCEE, with the supervision of ANEEL, and the participation of all interested market participants in the electricity industry [2-3].

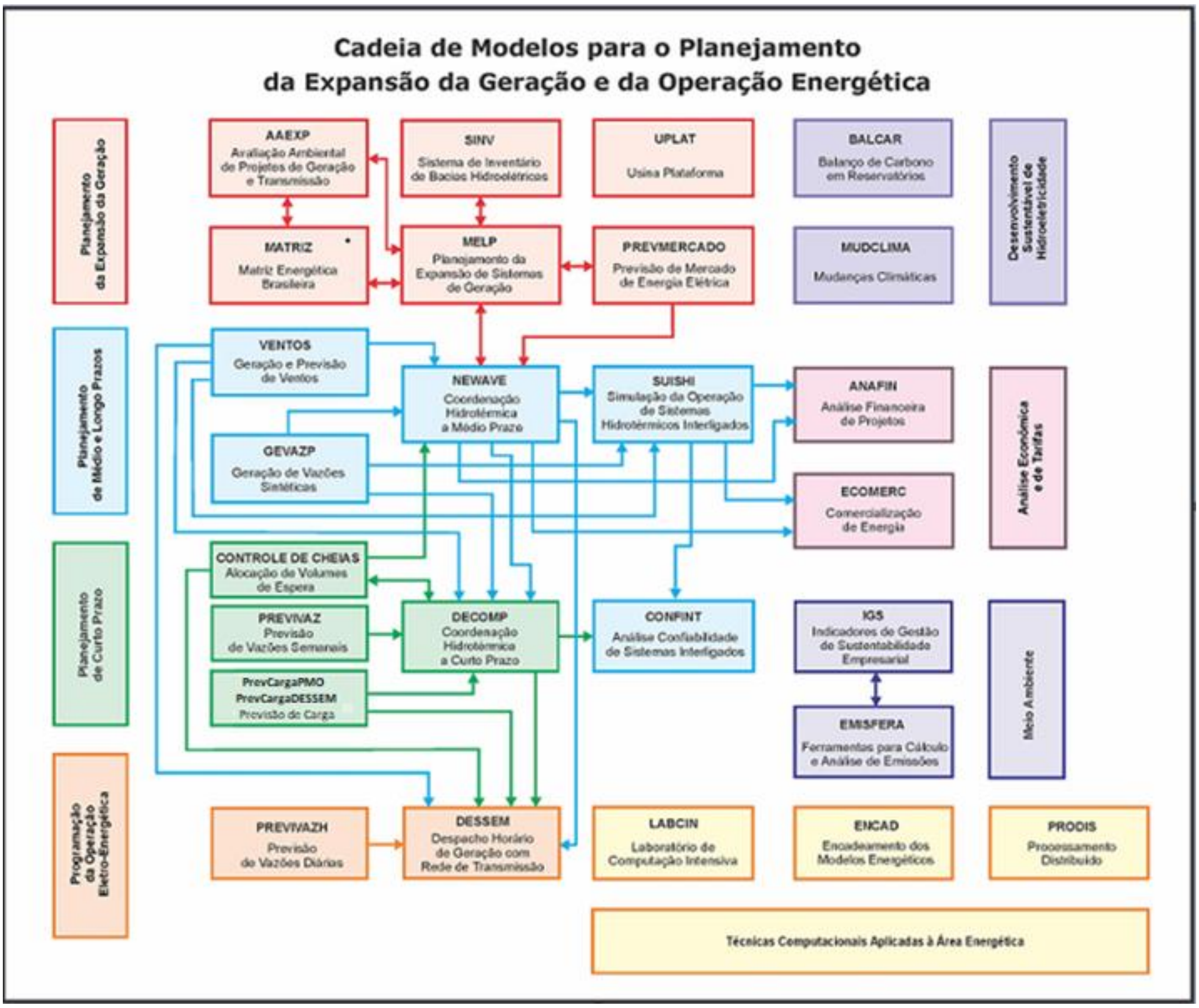

Figure 3.1 - Chain of Optimization Models for the Brazilian Generation Expansion and Operational Planning [2]

The power plants dispatch is decided though the Monthly Energy Operational Plan (MOP), carried out by ONS, which main objective is to establish short-term guidelines for the system operation in order to assure the optimal use of the generation resources. The main outcomes from the MOP include: hydro and thermal generation dispatch; fuel consumption estimation; reservoirs storage targets; decision about generator maintenance schedule; energy interchange among systems; operation marginal costs, etc. These studies also provide guidelines to be followed by the daily system operation programming and the real time operation.

The procedure for executing MOP and the day ahead scheduling of the SIN is depicted in Figure 3.2. At the end of each month, ONS runs GEVAZP [5-8] that generates energy inflow sequences to each energy equivalent reservoir based on recent observed energy inflows. These sequences will be utilized by NEWAVE to construct a multivariate cost to go function for each month of the five-year horizon. These functions provide the expected system operation cost over the entire horizon, given the storage level of the subsystems at the beginning of the month and the previous observed energy inflows. Then, ONS runs DECOMP [9], which considers at the end of its two-month horizon the expected cost-to-go function produced by NEWAVE. In the first month, which is discretized in weekly steps, DECOMP model utilizes just one streamflow sequence for each hydropower plant of the system, produced by a runoff model for the first week and by a stochastic streamflow forecasting model PREVIVAZ [10] for the remaining weeks. In the second month an ensemble of streamflow sequences for each hydropower plant are generated by GEVAZP, conditioned to the streamflow forecasts of the previous month and the recent observed ones. At the end of this process DECOMP produces the weekly goal dispatch for all thermal and hydropower plants and the energy interchanges among subsystems. Additionally, it produces a multivariate cost-to-go function for each time step horizon which will be utilized by DESSEM [11] model at the end of its horizon, to determine the hourly dispatch with a time horizon of up to one week and a time discretization of up to half-an-hour. Therefore DECOMP is run at end of each week of the month, always considering the cost-to-go function of NEWAVE model obtained at the end of the previous month while DESSEM is run every day taking into account the cost-to-go function of DECOMP obtained at the end of the previous week.

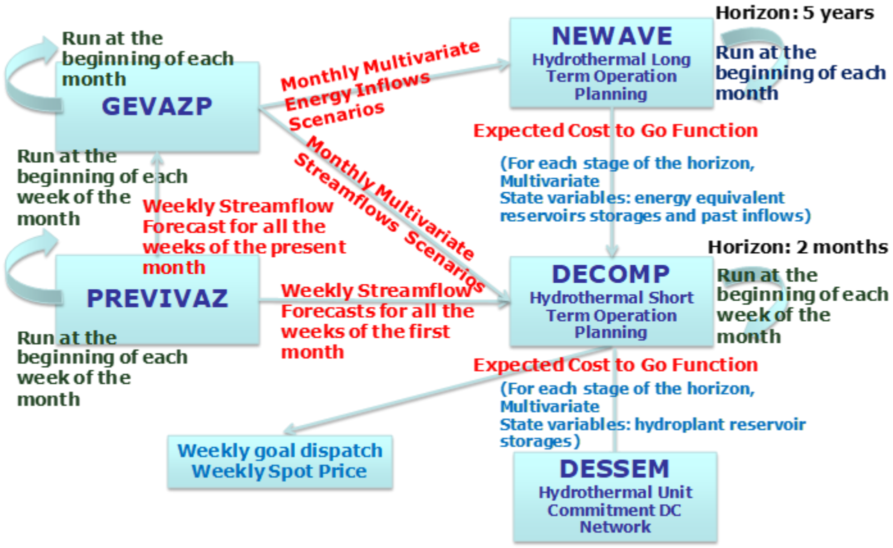

Figure 3.2 - Computer Models for executing the Monthly Energy Operational Planning [2]

The key components in the current Brazilian operational scheduling toolchain are shown in Figure 3.3, ranging from the long- and medium-term NEWAVE model, through short-term DECOMP model to the short-term DESSEM model. This figure also summarizes the main features of these optimization models and the rolling horizon scheme that is applied to coordinate them, by running them for each month m (NEWAVE), week w (DECOMP) and day d (DESSEM), with the time horizon and discretization shown in the table and updated information on reservoirs storages, inflows, load forecasts, etc. [11].

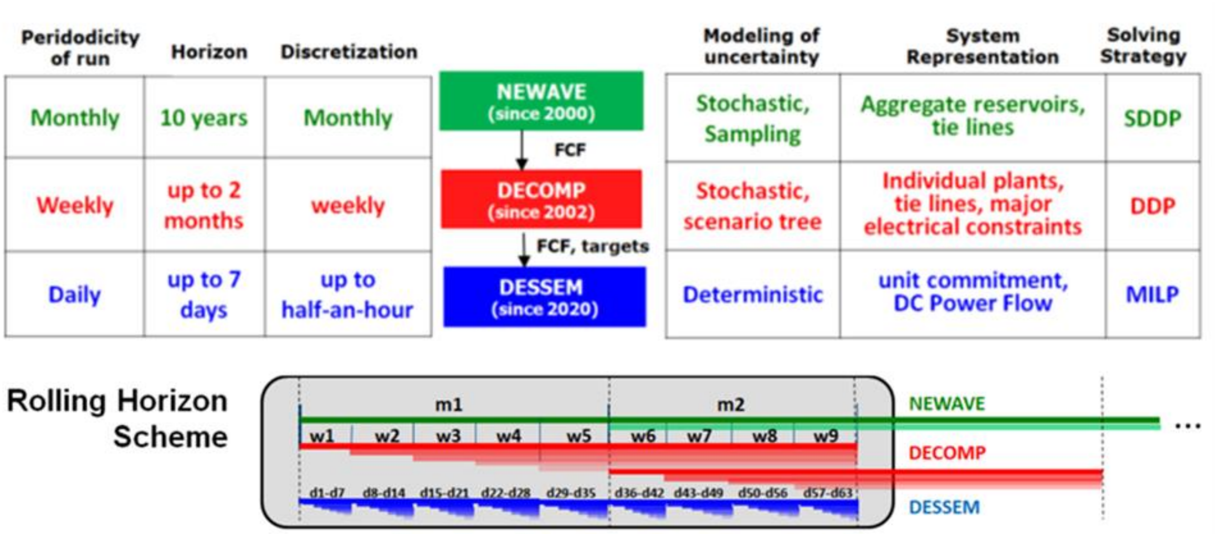

Figure 3.3 - Rolling horizon scheme for NEWAVE, DECOMP and DESSEM models [11]

A brief description of the three backbone optimization models, i.e., NEWAVE, DECOMP and DESSEM are presented next.

3.1 Long- and Medium-Term Operational Planning – the NEWAVE Model [4-5]

In1991, researchers at CEPEL, the Brazilian Electric Energy Research Center, developed the stochastic dual (SDDP) algorithm to determine the optimal allocation of the generation resources, especially hydro and thermal sources, in the long and mid-term operation planning [12]. Unlike the stochastic dynamic programming (SDP), there is no need to discretize the state variables with the SDDP method. In 1993, CEPEL extended the original SDDP formulation in [4] to take into account serial correlations of the inflows to the reservoirs [13], which led to considering another state variable (hydrological trend) in addition to the original one (reservoir storage level in each energy equivalent reservoir). Consequently, the SDDP method paved the way for considering multiple reservoirs in the long-term scheduling without compromising the computational complexity. This development triggered the development of the SDDP-based NEWAVE model in 1993, which has later become the cornerstone of long-term scheduling in the Brazilian system [3].

In 1998, an institutional framework for the Brazilian electrical sector was issued leading to the need of calculating the so-called “initial contracts” to align the existing contracts from the former to this institutional model; these initial contracts were computed by solving long-term hydrothermal coordination problems within a specific procedure. On the other hand, a new transmission line started its operation in that year, connecting the North/Northeast and South/Southeast subsystems, which were independently operated until that date. Due to the dimensions of these now four large and interconnected subsystems, the only existing methodology capable of dealing with the associated long-term hydrothermal coordination problem in a tractable way was the SDDP approach. Therefore, the year of 1998 is the milestone for the first official use of the NEWAVE model in Brazil.

The Brazilian National System Operator (ONS) and Whole Sale Energy Market (MAE/CCEE) were then created and since the year of 2000 the NEWAVE model has been officially used by the ONS to dispatch the hydro and thermal power plants and by MAE/CCEE to calculate the electricity spot prices.

A new institutional framework was issued in 2004. A new entity (EPE) was created which is in charge of the studies associated to the energy expansion planning, under the coordination of the Ministry of Mines and Energy; and NEWAVE program was kept as the official tool in these expansion studies. A key feature was the introduction of competition for the long-term market, and the implementation of public auctions as a procurement mechanism to guarantee capacity expansion, resulting in the establishment of PPAs between generators and distribution companies; again, the NEWAVE model was adopted to calculate associated figures of merit. Because of the strategic uses of this model, in 2007 the National Council for Energy Policy (CNPE) issued an act calling MME to establish a Standing Committee for Analysis of Methodologies and Computational Programs of the Electric Sector - CPAMP; CEPEL takes part of the meetings and provides technical support for this Committee.

3.1.1 Outline of NEWAVE model [4-5]

The main objective of the operation planning in a hydrothermal system is to compute a so-called operation policy, that estimates the water values in the reservoirs and allows to determine monthly generation targets for each plant of the system which meets the energy demand and at the same time minimizes the expected operation costs throughout the planned period, also considering a risk aversion criterion. This cost is composed by the variable fuel cost of thermoelectric plants and the cost assigned to power supply deficits, represented by an energy deficit penalization function.

The decision regarding when to use the stored energy, represented by the water stored in reservoirs, is intrinsically linked to the uncertainty of future inflows, and must be the result of a probabilistic analysis of inflow behavior. Moreover, the most adequate operational decision for each moment depends on the system's conditions. Thus, it is necessary to take operational decisions as a function of the possible states of the system. In systems with large participation of hydroelectric power plants, two types of information compose the system's state: reservoir storage levels and the future hydrological trend of the system, which may be represented by the inflows to the reservoirs during the previous months, using a stochastic model called periodic autoregressive model - PAR(p).

The existence of interconnections among subsystems (system areas) allows reducing operating costs through energy interchanges, and increasing supply reliability through the sharing of reserves. In hydro-dominated systems, it is necessary to determine the value of the hydropower generation, given by the value of thermal generation that could be replaced now or in the future.

This value is not measured separately for each plant, since it depends on the joint operation of the system. In order to obtain maximum operational gains in an interconnected hydrothermal system, it is necessary to operate the system in an integrated manner, jointly optimizing the operation of all plants - hydropower, thermal, biomass, wind and solar power, and the energy interchanges decisions with the aim of minimizing total operation costs. In Brazil and many other countries [1,3,14], the solution to this problem is obtained in stages. These stages use models with different degrees of detail to represent the system, covering study periods with different time horizons - NEWAVE model for the long and medium term, DECOMP model (Short-Term Operation Planning Model for Interconnected Hydrothermal Systems) for the short term, and DESSEM model (Short-Term Hydrothermal Dispatch Model) for daily operation scheduling.

The NEWAVE model was developed by Cepel for application in long- and medium-term operation and expansion planning of interconnected hydro dominated systems, also considering intermittent renewables such as wind and solar power. As the operating strategy should be calculated for all combinations of storage levels and hydrological trends, in large systems such as Brazil, the problem of optimal system operation, depending on the study horizon, becomes rapidly intractable from the computational point of view if high quality results are desired. Thus, in the NEWAVE model, the hydropower plants can be represented in an aggregated form through energy equivalent reservoirs (EERs), in an individualized way or in a hybrid way - in the first years of the study period hydropower plants are individually considered and in the other years they are represented by EERs, providing the benefits of an individualized representation in the horizon closer to the decision making, without too much computational time.

Therefore, the NEWAVE system boundary comprises the whole of Brazil, currently with 12 EERs within the four subsystems connected through a transmission grid. The four subsystems are the same for which spot prices are computed. A schematic diagram of the hydropower in the Brazilian system and its aggregation into the 12 ERRs is presented in Figure 3.4, whereas Figure 3.5 shows the four SIN subsystems and the 12 EERs, where the EERs are distributed as follows: 3 in the North subsystem, 1 in the North-East, 6 in the South-East and 2 in the South.

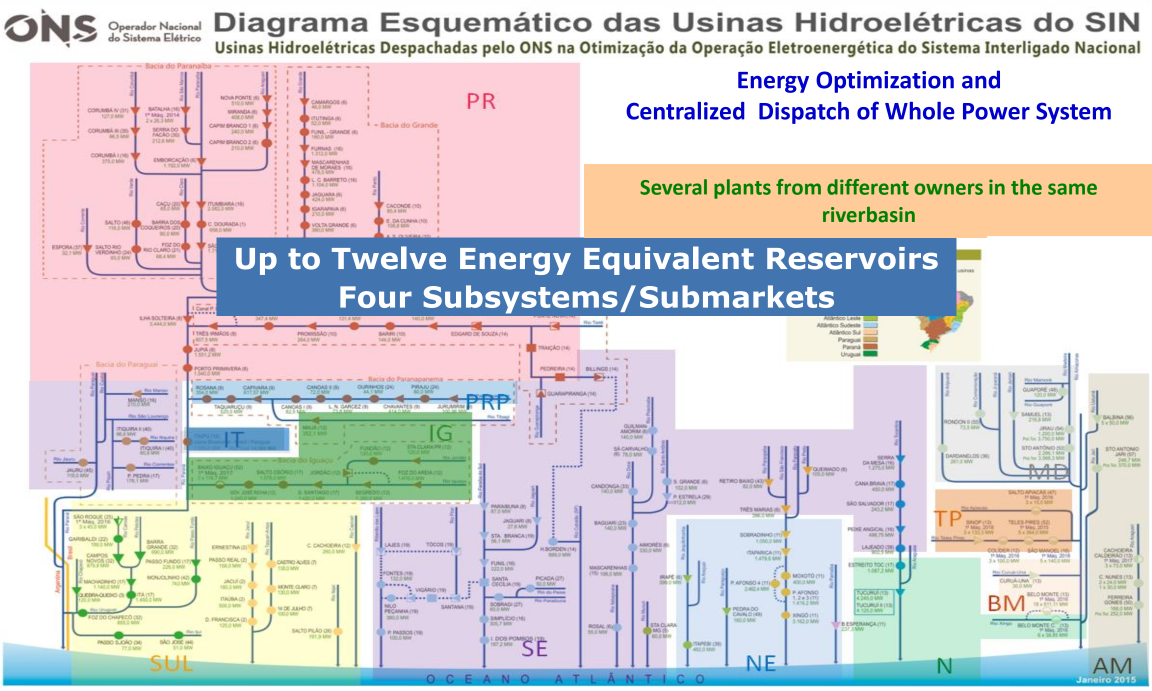

Figure 3.4 - Schematic diagram of the hydropower plants composing 12 ERRs [5]

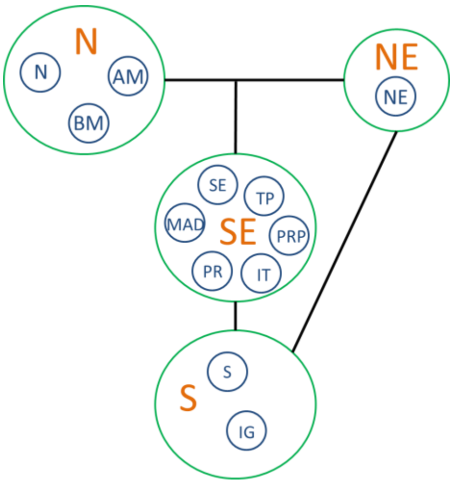

Figure 3.4 - Subsystems and EERs in the NEWAVE model [3]

In NEWAVE model, the operation planning problem is represented as a multi stage stochastic linear programming problem. The objective is to minimize the expected value of the operation cost during the planning period considering risk aversion mechanisms, given a known initial state of the system. Fuel costs and penalties for failure in load supply compose the operation cost. The solution of this problem results in an operation strategy which, for each stage of the planning period, given the system state at the beginning of the stage, produces generation targets for each plant and energy interchanges targets between systems.

The calculation of the operation policy employs the stochastic optimization technique called Stochastic Dual Dynamic Programming (SDDP), considering the uncertainties in the future inflows, represented explicitly through scenarios of inflows generated synthetically by using a periodic autoregressive model and a selective sampling process - the GEVAZP model.

In the long / medium term operation planning studies of the Brazilian interconnected system, where the typical horizon considered is five years discretized in monthly periods, with 20 hydrological scenarios in each period, the complete tree representing the uncertainties has about 1078 scenarios, which makes the resolution of the problem computationally unfeasible. Thus, the SDDP strategy, instead of going through all the subproblems of the scenario tree during the forward simulation, solves only a subset of scenarios (subtree), which are chosen from the original distribution of the random variable. The Benders cuts that represent the cost-to-go function are constructed iteratively during each backward recursion for all subtree nodes traversed in the last forward simulation, and in the next forward simulation, new values for the state variables related to the storage levels in the hydropower plants are obtained. The operation policy, represented by the expected-cost-to-go function at each stage of the study horizon, is calculated accurately, and considers the same constraints used in the simulation of the system operation. It also considers the representation of anticipated dispatch restrictions for LNG plants.

In order to ensure theoretical convergence and increase the number of scenarios of the sampled sub-tree for the forward simulation without compromising the computational time to solve the problem, and thus to enable an improvement of the future cost function, the NEWAVE model allows the use of scenario re-sampling techniques during the calculation of the optimal operating policy.

Two risk aversion mechanisms were developed and embedded in the model with the aim of providing greater supply reliability: (i) CVaR (Conditioned Value at Risk), where a component related to the cost of the most expensive hydrological scenarios is added to the objective function; (ii) SAR (Risk Averse Surface), which represents an extension, for the multivariate case, of the minimum energy storage constraints in EERs.

Based on the obtained operational policy, the NEWAVE model simulates the system operation over the planning period, for distinct hydrological scenarios – either from the historical record or generated by the GEVAZP model, calculating performance indices, such as average operational costs, deficit risks and expected values of unsupplied energy. The model also provides a cost to-go-function that acts as a boundary condition for the optimization of the system in shorter time horizons, where a more detailed time discretization is used.

To increase computational performance in large scale systems, two approaches have been developed. The first was the release of the executable version of the NEWAVE model in a high performance environment – it was the first program of the Cepel ′ s Chain of Energy Optimization/Simulation Models to use parallel processing techniques. The second is an iterative process to solve each linear programming subproblem, where the cuts already constructed in past iterations of the SDDP algorithm are inserted progressively, as they are needed. Thus, a reduction in the computational time is obtained for the resolution of the LP problems and, consequently, of the convergence process as a whole, but maintaining the same precision in the results.

3.3.2 Decision Support – NEWAVE Model

For more than 20 years, the NEWAVE model have been an official decision support tool by in several tasks of the Brazilian Electrical Sector, and have been routinely utilized by Government and Agencies (MME, ANEEL, EPE, ONS and CCEE) as well as by concessionaires (e.g., Eletrobras) and power industry in corporate decisions.

The application of NEWAVE includes the following routines:

- Expansion planning – MME, EPE
- Physical guarantee – MME
- Assessment of energy supply conditions – CMSE
- Public auctions for purchasing electricity in the ACL – ANELL, EPE, CCEE

- Operational planning (Monthly Operation Program and Annual Operation Plan) - ONS
- Spot price (PLD) calculation - CCEE.

This justifies the need of a very rigorous validation procedure of the CEPEL toolchain by CPAMP as well by a task-force coordinated jointly by ONS and CEPEL with supervision of ANEEL [3].

3.2 Short-Term Operational Planning – the DECOMP Model [9]

The DECOMP objective is the same as in NEWAVE, i.e., to minimize the cost of system operation over the period of analyses, subject to uncertainty in inflow and a risk measure. The modelling of risk aversion is an integral part of the model, similar to the treatment in NEWAVE. The overall problem formulation can be seen as a multi-stage stochastic linear programming problem. The scenario tree is defined to have a limited number of nodes, making explicit solution of the full problem viable. The solution strategy is based on multi-stage Benders decomposition to solve the large-scale stochastic linear programming problem, but without the sampling that is done in SDDP.

DECOMP is run on a weekly basis with weekly time steps for the first month and monthly steps from the second month on. The planning horizon can be up to one year, but is usually 2 months. Each time step is further divided into load blocks to represent the load duration curve within the week. Uncertainty in inflow is represented in a scenario tree with monthly resolution, typically provided by a statistical model [6]. The scenario tree is illustrated in Figure 3.5, which also shows the coupling to the NEWAVE model: each DECOMP leaf node receives a description of the future cost function calculated by NEWAVE.

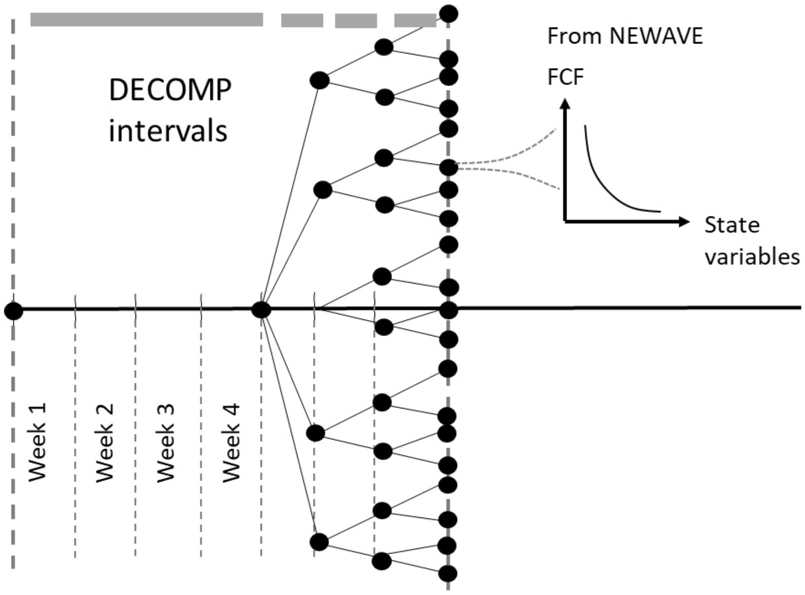

Figure 3.5 - DECOMP scenario tree with coupling to the NEWAVE model [9]

The DECOMP model represents in a detailed way the hydropower plants and waterways, including water balances for each reservoir per decision stage, release decisions taken per load bloc; time-delays in rivers; hydropower production function by four-dimensional piecewise linear model; explicit modelling of evaporation and irrigation; maintenance schedules. Also, the energy exchange between subareas are represented by a transportation model and grid constraints are used to represent bottlenecks and security constraints.

The mathematical model is linear and needs to be convex due to the decomposition algorithm. Certain constraints do not preserve convexity, e.g., maximum discharge which depends on water head. These are linearized around operating points obtained in an iterative way.

3.2.1 Decision Support – DECOMP Model

The DECOMP model has served as the official model for setting the spot price (PLD) and to provide the weekly centralized dispatch of the Brazilian system from 2002 to 2020. With the introduction of the shorter-term DESSEM model, the use of DECOMP has changed into a linkage between NEWAVE and DESSEM, as a medium-term model.

3.3 Day-Ahead Dispatch – the DESSEM Model [11]

The DESSEM is a deterministic mixed integer linear optimization model aiming at minimizing the costs of operating the system for a short period of time provided a future cost function from the DECOMP model. A model horizon of up to ONE week can be applied with a time discretization of down to 30 minutes. DESSEM does not explicitly incorporate any risk measure, but the CVaR measure considered in the NEWAVE and DECOMP models is embedded in the future cost function provided by DECOMP.

Some details are briefly described below [3]

Component modelling:

Generation from hydropower plants are represented as a function of volume, discharge and spillage. The convex envelope of this function is calculated a priori. Continuous variables are used when modelling the hydropower system, and start-up costs are not considered.

Water balance in reservoirs and along rivers is accurately represented by fixed travel times or propagation curves, according to.

The transmission grid is considered in a DC power flow model, including pre-defined security constraints. It is possible to include explicit computation of active power losses.

Thermal units are modelled with their marginal costs, generation capacity and a set of constraints constraining the flexibility of operation. In particular, ramping constraints both in regular and start-up/shut-down mode, minimum up and down times and start/stop costs are considered.

System-wide constraints:

Power balances for each subsystem

Reserve requirements per control area. Reserves can be delivered by both hydropower and thermal units

Transmission corridor constraints represented by individual line flow limits, summation of line flow limits and additional pre-defined security constraints.

A function describing the future cost as in terms of reservoir volumes and volumes in transit.

The consideration of the unit commitment on hydropower units is under development in DESSEM, to represent, for example, the operating range (discharge and minimum generation) in which each generating unit cannot operate and possible costs and constraints associated with for starting / stopping the units.

3.3.1 Decision Support － DESSEM Model

Since starting in January 2020, DESSEM model has been taken into operational use by ONS for dispatch of the semi-hourly operation and from

January 2021 by CCEE to establish hourly prices in Brazil.

CCEE is in charge of setting the spot prices in the short-term market, running the same models as ONS, but neglecting some inner system transmission constraints. Both for system dispatch and spot price calculation, the DESSEM model works together with the DECOMP and NEWAVE models as a decision support toolchain.

4 Regulatory Framework and Market Design of the Brazilian Power System

The regulatory framework in force in Brazil until mid-1990s introduced many of the fundamentals of a competitive market; also, issues related to the operational planning and dispatch, as well as the electricity trading, were outlined.

However, the planning function was left to be discussed and detailed in a second moment, which did not happen. Hence, there was a broad breakdown of these activities. In addition, the establishment of long-term contracts between generators and loads failed, leading to a situation where the generators were unable to obtain financing to build the plants.

Consequently, the lack of investment in new generation and transmission capacities led to a rationing of electric power of great scope from June 2001 to February 2002. It generated new debate about how to ensure adequate investment, leading to revise the institutional framework of the electrical power sector in 2004 [15,16].

4.1 Environments for Electricity Trading in Brazil

The introduction of competition for the long-term market in the Brazilian 2004 Electrical Sector Reform was a milestone towards the creation of a more stable investment environment for new generation capacity, with positive impacts on the security of electricity supply [15].

Now loads have to be 100 % contracted and two environments for electricity trading were initially established: a Regulated Contracting Environment (Ambiente de Contratação Regulada - ACR) and a Free Contracting Environment (Ambiente de Contratação Livre - ACL), as depicted in Figure 4.1.

ACR - Generators must participate in centralized public auctions to be able to sign PPAs with the regulated (captive) consumers supplied by the Discos, which must provide self-declaration of its forecasted loads for the next five years.

ACL - Free consumers can procure their energy needs as they wish, as long as they are 100% contracted. Hence, supply and demand are free to negotiate the features of the contract, such as the electricity price, end of term, etc.

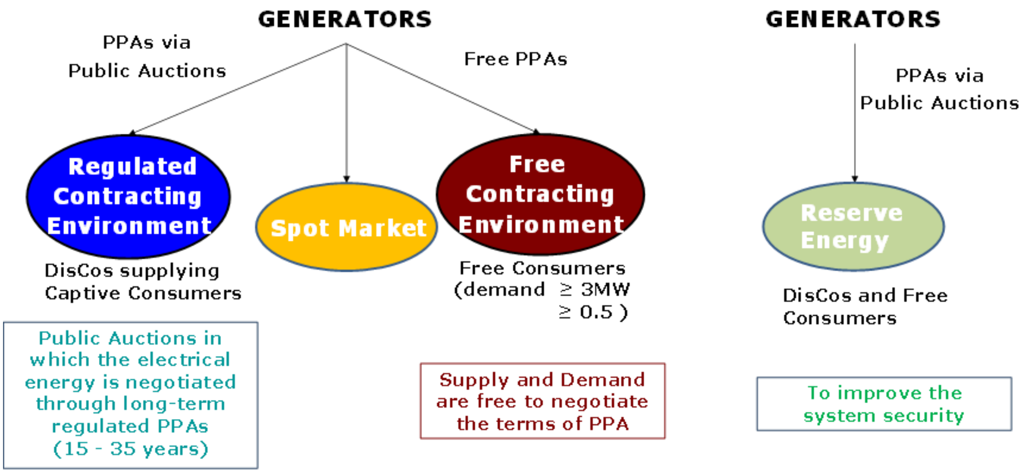

Figure 4.1 - Environments for Electricity Trading in Brazil

The introduced public auctions are a procurement mechanism for purchasing energy for captive consumers. Each winner in auctions is that one which offers the lowest price per kWh also limited to ceiling prices. In exchange, all distribution companies have an obligation to enter into PPAs (15 to 35-year duration) with each auction winner in proportion to their declared load forecasts. The successful generators can offer an assured future cash flow to obtain loans from banks to develop their projects, including the Brazilian National Development Bank. This auction scheme may occur at different times: 3 to 5 (nowadays, 7) years ahead for new generation, and 1 year ahead for existing ones. Auction prices are then passed on to electricity tariffs.

MME offers to bid a set of projects (hydroelectric and thermal) studied by EPE and considered the most economical to meet demand. Any generator is able to freely offer, for tenders, alternative projects to the set proposed by MME. Regarding hydropower projects (HPPs), as illustrated in Figure 4.2, in order to be eligible to participate in auctions, it is necessary to obtain the approval of the optimal dimensioning of the project with the Electricity Regulatory Agency, the preliminary environmental license from the Environmental Agency, and water use rights from the Water Regulatory Agency [17]. Also, all contracts, which are financial instruments, must be covered by real power production capacity defined by a "plate number" called Assured Energy Certificate or "Physical Guarantee ", which will be described later. In case of thermal power plants, there is also need to present Fuel Supply Purchase Agreement.

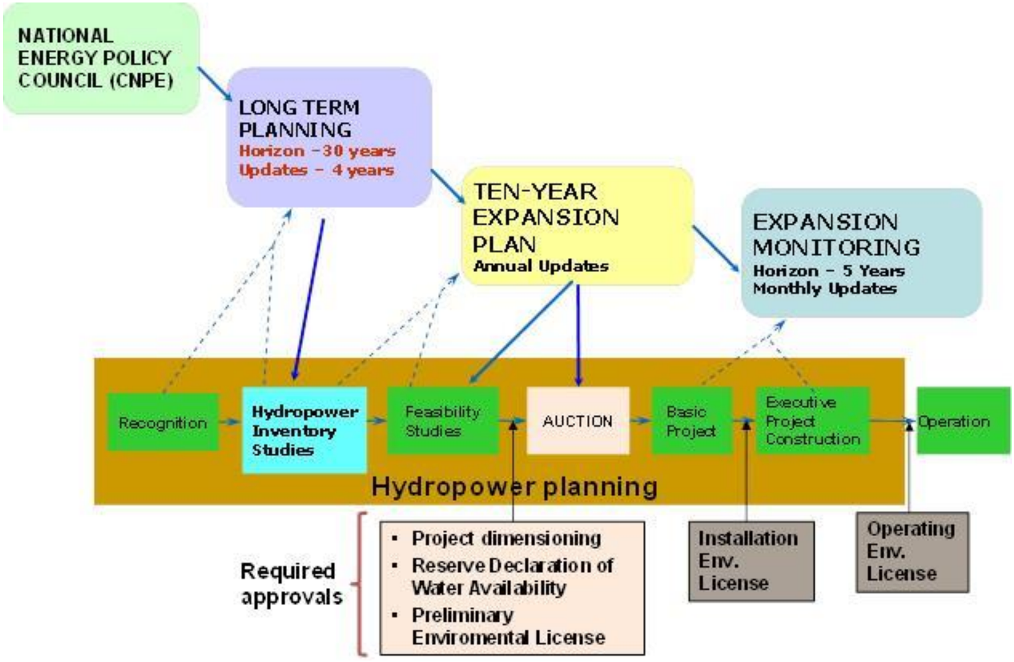

Figure 4.2 - Stages of hydropower development in Brazil [17]

Besides the winners signing direct bilateral contracts with the Discos, there is another contract attached called Guarantee Linked Contract (CCG) which transfers the money from the final customers to the generator, thus preventing the Discos from making discretionary payments and, therefore, minimizing the default risk of the generators.

The Government does not interfere with the demand forecasts, which are directly declared by Discos nor does it take ownership for the energy contracts or provides payment guarantees. Also, Discos are allowed to enter into contracting adjustments to the Regulated Market one and two years in advance, re-contracting existing energy in annual auctions and receiving, or transferring, free of charge, surplus energy contracts from other Discos.

In addition, the differences between the production or consumption of energy in relation to the contracts held are settled on the spot market by the PLDs. Finally, there is also the possibility to procure energy through Reserve Energy Auctions aiming at to improve the system security; the contracted energy must be paid for both distribution companies and free consumers.

4.2 Institutional Arrangement in the Brazilian Power System

In the restructuring of 2004, new institutions were created and some existing ones had their roles and responsibilities redefined. Below are brief descriptions of some entities (and their acronyms) that are central in the Brazilian electricity sector and relevant in the remaining text. These entities are also depicted in Figure 4.3 [3].

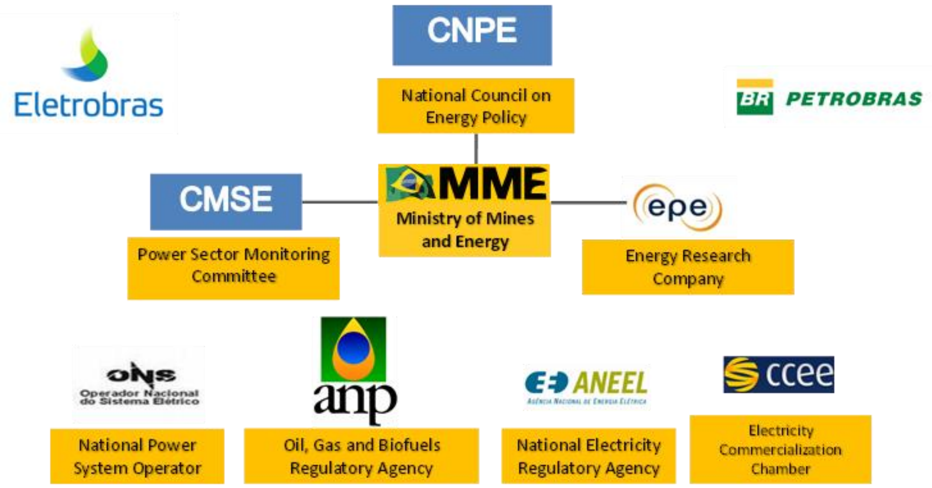

Figure 4.3 - Institutional Arrangement in the Brazilian Power System [3]

National Energy Policy Council (CNPE): an advisory body to the President of the Republic, in charge of the following duties: proposal of the national energy policy to the President of the Republic, in articulation with other public policies; proposition of individual bidding for special projects in the Electric Sector, recommended by MME and proposition of the structural supply guarantee criterion.

Ministry of Mines and Energy (MME): formulation and implementation of policies for the Energy Sector, according to CNPE guidelines; exercise of the sector planning function; exercise of granting power; monitoring the security of supply in the Electricity Sector, through the CMSE and definition of preventive actions to restore security of supply in the case of conjunctural imbalances between supply and demand, such as demand management and/or contracting the conjunctural energy reserve of the interconnected system.

Electric Energy Regulatory Agency (ANEEL): mediation, regulation and inspection of the functioning of the Electric System; holding auctions for the concession of generation and transmission projects by delegation from the MME and bidding for the acquisition of energy for Discos.

National Agency for Petroleum, Natural Gas and Biofuels (ANA):

responsible for regulating the oil and natural gas and biofuels industries in Brazil. It executes the national policy for the sector, with a focus on guaranteeing fuel supply and defending consumer interests, while also ensuring the quality of fuels sold to the final consumer. It also promotes bids and signs contracts on behalf of the Union for exploration, development and production activities.

Brazilian Independent System Operator (ONS): responsible for coordinating and controlling the operation of the electricity generation and transmission facilities in the National Interconnected System (SIN) and for planning the operation of the country's isolated systems, under the supervision and regulation of ANEEL. It's main objectives are: to promote the optimization of the operation of the electric energy system, aiming at the lowest cost for the system, observing the technical standards and reliability criteria established in the Grid Procedures approved by ANEEL; and ensure that all agents in the electricity sector have access to the transmission network in a non-discriminatory manner. The SIN operation is based on a centralized system optimization, scheduling and dispatch scheme, which is further described in Section **Error! Reference source not found.**.

Chamber for Commercialization of Electrical Energy (CCEE): took the role of MAE in managing the wholesale market and began to exercise the functions of accounting and financial settlement in the spot market; calculation of the Difference Settlement Price - PLD, used to value energy purchase and sale operations in the spot market; contract management of the Regulated Contracting Market and the Free Contracting Market; recording of generated energy and consumed energy data; hold power purchase and sale auctions at ACR, under the delegation of ANEEL; hold Reserve Energy auctions, under the delegation of ANEEL, and effect the financial settlement of the amounts contracted in these auctions.

Energy Research Company (EPE) - created with the main objective of developing the necessary studies so that the MME can fully exercise its role of executing energy planning, and with the following duties: studies to define the energy mix with an indication of the strategies to be followed and the goals to be achieved, within a long-term perspective; studies of integrated planning of energy resources; expansion planning studies for the electrical system (generation and transmission); foster studies on energy potential, including inventory of hydrographic basins and elaboration of technical, economic and socio-environmental feasibility studies for plants and obtaining the Preliminary License for hydropower projects.

Power Sector Monitoring Committee (CMSE): instituted within the scope of MME, with the function of permanently monitoring and evaluating the continuity and security of the electric energy supply throughout the national territory. Its duties include: monitoring the development and supply conditions of the activities of generation, transmission, distribution, commercialization, import and export of electric energy, natural gas and oil and its derivatives; periodically carry out an integrated analysis of security of supply for the electricity, natural gas and oil markets, considering the demand, supply and quality of energy inputs, the hydrological conditions and the prospects for gas and other supplies fuels. In addition to the MME, which presides, ANEEL, ONS, CCEE, EPE and the National Petroleum Agency for Petroleum, Natural Gas and Biofuels (ANP) also participate.

Inspired in the strategic uses of NEWAVE model in 2007 the National Council for Energy Policy issued an act calling MME to establish a Standing Committee for Analysis of Methodologies and Computational Programs of the Electric Sector - CPAMP, which was put in place by MME in 2008. The key objective of CPAMP is ensure consistency and integration of methodologies and computer programs used by MME, EPE, ONS and CCEE, in the following activities: expansion planning; operation planning and scheduling; electricity commercialization; definition and calculation of the physical guarantee and assured energy of the generation projects; and preparation of guidelines for conducting auctions for the purchase of electricity [5]. Also, any changes in methodologies and computer models must comply with the principles and guidelines proposed by MME and approved by CNPE. Besides discussing and defining priorities for improvements in methodologies and computer programs, CPAMP also validates new developments, releases and key parameters of the official models, including the scheduling models.

4.3 Physical Guarantee and the Energy Reallocation Mechanism

In the central dispatch scheme, owners of controllable power plants do not decide the physical output of their generation assets. Despite the synergistic gains from integrated operation, there are at least two relevant complexities with the central dispatch scheme for the Brazilian hydro-dominated system:

The long-term energy security. The dispatch of both hydropower and thermal plants depend on hydrological conditions, which are uncertain. A question that arises is what is the maximum amount of energy that a power plant can trade in the long-run, i.e., through PPAs. In Brazil this is called Assured Energy or Energy Physical Guarantee, which is calculated by a specific procedure, taking into account the overall system optimization; see [18] for more details.

The strong impact of hydrological conditions on the energy production of hydroelectric plants. The centralized dispatch scheme imposes a significant hydrological risk to the revenue streams of the plant owners and hinders the adoption of individual hedge strategies against hydrological risk. This is compensated through the Energy Reallocation Mechanism (MRE), see [19] for more details.

4.4 Centralized Dispatch and Settlement [1,3]

As illustrated in Figure 4.4, ONS collects technical data from generators and loads to perform a centralized cost-based dispatch of the system. Hydro and thermal generators submit their technical data to the ONS, such as reservoir levels, inflow, availability of equipment/facilities, thermal efficiency, fuel and operating costs, etc.

ONS is responsible for physical dispatch across the entire system, with the objective of minimizing operating costs while ensuring system security. ONS uses the suite of computational models developed by CEPEL to determine the most efficient hourly production schedule for each plant. This means that hydropower plants are dispatched based on their expected opportunity costs.

As described in Section 3.3.1, generators are obliged to sell their energy through the ACR and ACL markets. Contractual differences between generation and consumption are settled according to a difference settlement price (PLD). Thus, the generators receive a fixed payment for financial contracts through the markets and deviations in physical delivery are settled according to the PLD.

The PLD is often referred to as the "spot price". Currently, CCEE computes the PLD on a weekly basis for light, medium, and heavy load levels in each of the four SIN subsystems. The PLD are computed ex ante, in the sense that computations are done for the week ahead based on expected values of inflow, equipment availability, loads, etc. The PLDs are found using the same mathematical models and data as for the ONS dispatch, and thus represents a sound estimate on the expected marginal costs of operating the system. CCEE runs the model toolchain developed by CEPEL to obtain the PLDs.

To determine the spot market price, only the major transmission constraints are taken into account. Therefore, the Brazilian interconnected system is divided into a small number of price zones (currently four), denoted as “submarkets” or “subsystems”, which reflect the effects of these more important transmission limitations. The PLDs are determined for each submarket and transmission loss allocation factors are used to calculate the final price for each generator and load inside each submarket.

Wholesale competition is facilitated through CCEE and is compulsory for all generators larger than 50 MW and loads with more than 100 GWh per year [1,16].

Figure 4.4 also illustrates the financial settlement in the Brazilian market. Generators and Loads contract their energy in the ACL and/or ACR markets. Then they submit their technical data to ONS, which in turn determines the actual system dispatch. CCEE accounts for the differences between actual production and consumption, and the respective contracted amounts. Differences are settled in the market through the PLD.

Generators and loads also pay a yearly fixed transmission use of the system charge - TUOS ($/installed kW for generators and $/yearly peak for loads), which depends on their location.

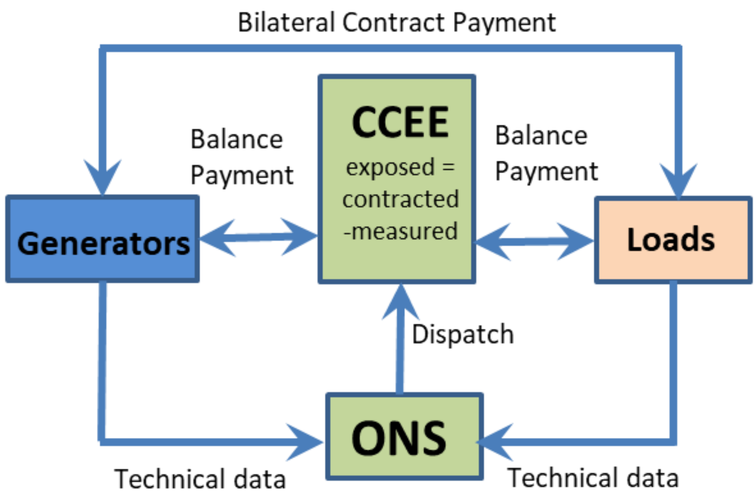

Figure 4.4 - Relationship between ONS, CCEE and market participators[1,3]

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Management model of cascade reservoirs in the upper reaches of the Yangtze River

1 An overview of cascade reservoirs in the upper reaches of the Yangtze River

1.1 Basic situation of the basin

The upper reaches of Yichang City on the main stream of the Yangtze River is the upper reaches, with a length of 4504km, accounting for 70.4% of the total length of the Yangtze River, and a controlled drainage area of 1.1 million km². The Jinsha River above Yibin City is 3464km long, with a drop of about 5100m, accounting for about 95% of the total river drop. The river bed has a large slope and has many shoals. The main tributary is the Yalong River; the length from Yibin to Yichang is 1040km, the main tributary added , There are Minjiang River and Jialing River on the north bank, and Wujiang River on the south bank.

The upper reaches of the Yangtze River are mainly located in the alpine climate zone of the Qinghai-Tibet Plateau and the subtropical monsoon climate zone. The vast area and complex topography determine the diverse regional climate characteristics of the Yangtze River Basin. The Qinghai-Tibet Plateau in the upper reaches of the Yangtze River is a typical plateau alpine climate zone, with high altitude, low temperature and pressure, cold winter and cool summer, thin air, large temperature difference between day and night, less precipitation and evaporation, and insignificant monsoon climate. Located in the subtropical monsoon climate zone, the summer is hot and rainy, the winter is mild and drier, the four seasons are distinct, the rain and heat are in the same season, and the monsoon climate is very obvious.

The average annual precipitation in the upper reaches of the Yangtze River is 988.7mm (1981-2010). The Jinsha River Basin is 865.6 mm, the Mintuo River Basin is 965.6 mm, the Jialing River Basin is 995.0 mm, the Wujiang River Basin is 1107.9 mm, the Yibin-Chongqing section is 1046.2 mm, and the Chongqing-Yichang section is 1133.8 mm.

The distribution of precipitation in the upper reaches of the Yangtze River is extremely uneven, with the main rain belt trending from southeast to northwest. The general trend is: decreasing from southeast to northwest, with more mountainous areas than plains, and more windward slopes than leeward slopes. The annual precipitation in the source area of the Yangtze River and the upper reaches of the Jinsha River is less than 400mm, which belongs to the arid zone; the middle reaches of the Jinsha River and the upper reaches of the Luotuo River have an annual precipitation of 400~800mm, which belongs to the semi-humid zone; the annual precipitation in other areas of the basin is above 800mm, which belongs to the humid zone; The particularly humid zone with a volume greater than 1600m is mainly located in the Western Sichuan Basin.

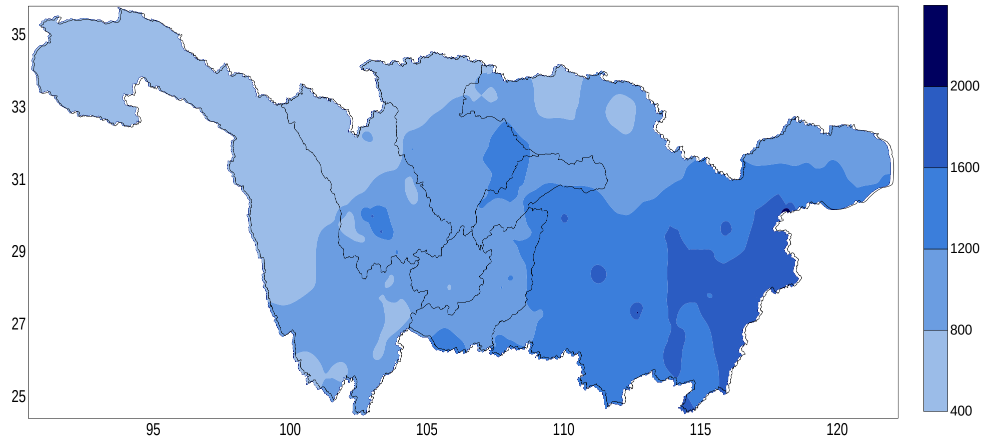

figure1 Spatial distribution of annual average precipitation in the Yangtze River Basin (mm)

There are two precipitation centers in the upper reaches of the Yangtze River, which are located in western Sichuan and Sichuan Wanyuan to the east of Wujiang River. The rainy areas with annual precipitation of more than 1600mm are distributed in the Emeishan and Ya'an areas of the western Sichuan Basin. The area is relatively small and is the strongest precipitation center in the basin. It is mainly related to the effect of climbing terrain.

The main tributaries of the upper reaches of the Yangtze River include the Yalong River, Jialing River, Mintuo River and Wujiang River. The annual average runoff of the Yichang Control Station on the mainstream of the Yangtze River is $4457 \times 108m^3$, and the annual average flow is about $14123m^3/s$; the annual average runoff of the Cuntan Station on the mainstream is $3461 \times 108m^3$, accounting for 77.7% of the runoff of the Yichang Station; the mainstream Jinsha River The annual average runoff of Duanpingshan Station is $1441 \times 108m^3$, accounting for about 32.3% of the runoff of Yichang Station; the runoffs of the four main tributaries of Yalong River, Mintuo River (including Dadu River), Jialing River and Wujiang River respectively account for the total runoff of Yichang Station. 11.4%, 22.3%, 14.8% and 11%.

1.2 Development of Cascade Hydropower in the Basin

The Yangtze River is rich in water resources, with a total hydropower reserves of 305,000 MW, accounting for 39.6% of the country. The upper reaches of the Yangtze River above Yichang account for about 84% of the total hydropower resources of the Yangtze River. Five hydropower bases are planned for the Jinsha River, Yalong River, Dadu River, Wujiang River and the upper reaches of the Yangtze River. The installed capacity is 175.64 million kilowatts, accounting for the 13 largest hydropower in the country. 59.23% of the total installed capacity of the base. There are a total of 119 large-scale reservoirs planned for the upper reaches of the Yangtze River and main tributaries, including 27 on the Jinsha River, 23 on the Yalong River, 29 on the Dadu River, 12 on the Wujiang River, 5 on the upper reaches of the Yangtze River (Yibin to Yichang), and the main stream of the Minjiang River 4, 19 Jialing River. The status of the power stations that have been put into production, under construction and planned in each basin is shown in Table 1.

As of the end of 2015, the five hydropower bases on the upper reaches of the Yangtze River had built hydropower stations with an installed capacity of 89,642,400 kilowatts, accounting for 50.2% of the technologically developable volume. The development status of each hydropower base is shown in Table 1.

talbe1 Development of five hydropower bases in the upper reaches of the Yangtze River（Ten thousand kW、%）

River	Technologically developable installed capacity	Built in 2015	Under construction in 2015	Undeveloped scale	Development scale
Jinsha River	8140	2996	1260	3884	52.3
Yalong River	2896.34	1440.64	480	1125.7	61.1
Dadu River	2518.86	895.2	1036.8	786.86	68.8
Wujiang	1163.4	1110.9	0	52.5	95.5
Yangtze	3127.5	2521.5	0	606	80.6

River					
SUM	17846.1	8964.24	2776.8	6455.06	63.8

2 Management of Cascade Reservoirs in the Upper Yangtze River Basin

2.1 Management authority

The dispatching management of the upper reaches of the Yangtze River is implemented by the National Flood Control and Drought Relief Headquarters (hereinafter referred to as the "National Headquarters"), the Yangtze River Flood Control and Drought Relief Headquarters (hereinafter referred to as the "Yangtze River Headquarters"), and the Provincial (City) Flood and Drought Relief Headquarters (hereinafter referred to as "Province (city) defense index"), reservoir management unit and other hierarchical dispatch management. Among them, the first three are the administrative management units in charge of flood control and the superior reservoir dispatching agencies of the reservoir management units. Reservoir management units include China Three Gorges Corporation, Jinsha River Midstream Hydropower Development Co., Ltd., Guodian Daduhe Company, Yalong River Basin Hydropower Development Company, Guizhou Wujiang Hydropower Development Company and more than ten different development owners. For reservoirs with comprehensive utilization tasks, the participating departments of reservoir management include grid dispatching departments, shipping departments, environmental protection departments, etc., which put forward demands on the use of reservoirs in terms of power generation, shipping, and ecology. The power dispatching department is the superior power generation of the reservoir management unit. Dispatching agency.

Except for large floods in the middle and lower reaches of the Yangtze River during the flood season and large-scale droughts in the middle and lower reaches of the special drought years, the Yangtze River Defense Headquarters will uniformly dispatch the flood control storage capacity and emergency water supply of the controlling reservoirs. Dispatching with each reservoir management unit in accordance with the requirements of the comprehensive utilization of the project and the requirements of the power system, with the main goal of maximizing the power generation benefits of the project.

The specific scheduling management authority is as follows:

1. When the water level of the reservoir during the flood season is

not higher than the flood control limit water level, and there is no need to undertake flood control tasks, or the comprehensive utilization of the non-flood period of the reservoir has no special requirements for the discharge flow of the reservoir, the reservoir management unit shall dispatch. When undertaking flood control tasks, the reservoir operation management unit shall be responsible for the specific scheduling and operation of the reservoirs or cascade reservoirs under its jurisdiction in accordance with the approved scheduling plan and scheduling instructions.

2. Reservoir flood control dispatching affects only the dispatching of the province (city) where the reservoir is located, and the relevant provincial (city) defense authority shall be responsible for dispatching and report to the Yangtze River Defense for the record.

3. Reservoir flood control dispatch may affect two provincial-level administrative regions, or when upstream reservoirs are required to cooperate with the Three Gorges Reservoir to undertake flood control dispatching in the middle and lower reaches of the Yangtze River, the Yangtze River Flood Control Dispatching shall be carried out.

4. The National Defense General Administration is responsible for the organization, coordination, guidance and supervision of joint reservoir dispatch.

5. The flood control and drought relief command agency is responsible for the reservoir water storage and dispatch during the flood season (end). Reservoir operation and management units prepare annual water storage implementation plans based on the prevailing flood control situation, water and rain trend forecasts and the above-mentioned reservoir group storage plans, and implement them after the approval of the Yangtze River Prevention Bureau; the annual water storage implementation plans of the Three Gorges Reservoir are reviewed and approved by the State Council .

6. The reservoir dispatch management unit proposes an emergency dispatch plan, which shall be implemented after the approval of the flood control and drought relief command agency with dispatch authority.

7. The reservoir dispatch management unit proposes a power generation plan, and implements it after submitting it to the power dispatching department for approval.

2.2 Management responsibilities

2.2.1 Responsibilities of reservoir dispatch management unit

1. Responsible for the forecast of the inflow of the reservoir, prepare the reservoir dispatching plan and power generation plan according to the water and rain conditions, and organize the implementation after the approval of the flood control dispatching agency and the power grid dispatching department.

2. Responsible for the implementation of the dispatching instructions of the superior authority, and the implementation of daily dispatching work such as power generation and flood discharge.

3. Responsible for coordinating the requirements of flood control, power generation, shipping, environment and other departments on the operation of the reservoir to give full play to the comprehensive benefits of the reservoir.

4. Responsible for the safe and reliable operation of reservoirs, dams, and power station facilities and equipment. When abnormal phenomena and unsafe factors are found, necessary safety measures shall be taken in time, and relevant departments shall be notified.

5. Responsible for the establishment of operation dispatching technical support system, with functions such as flood control dispatching, power generation dispatching, automatic hydrological monitoring and reporting, AGC, information services, etc., and capable of maintaining good intercommunication with dispatching systems of flood control and power grid departments.

2.2.2 Responsibilities of administrative management units

1. Organize the formulation of river flood prevention plans, flood dispatch plans and water emergency dispatch plans.

2. Responsible for reviewing and approving the flood prevention plan, flood dispatch plan and authorized reservoir dispatch plan and water emergency dispatch plan for rivers in the basin, and coordinate and supervise the implementation.

3. Responsible for the management of the main stream of the Yangtze River, the main tributary channels and lakes, the management of large and medium-sized comprehensive utilization reservoirs in the basin, and the management of water resources.

4. Responsible for flood control and drought fighting in the river basin, and coordinate the joint flood control and water dispatching of the reservoirs in the Yangtze River basin.

5. Responsible for the dispatch and command of emergencies such as

extreme low water, water pollution, water safety accidents, and engineering accidents in the basin.

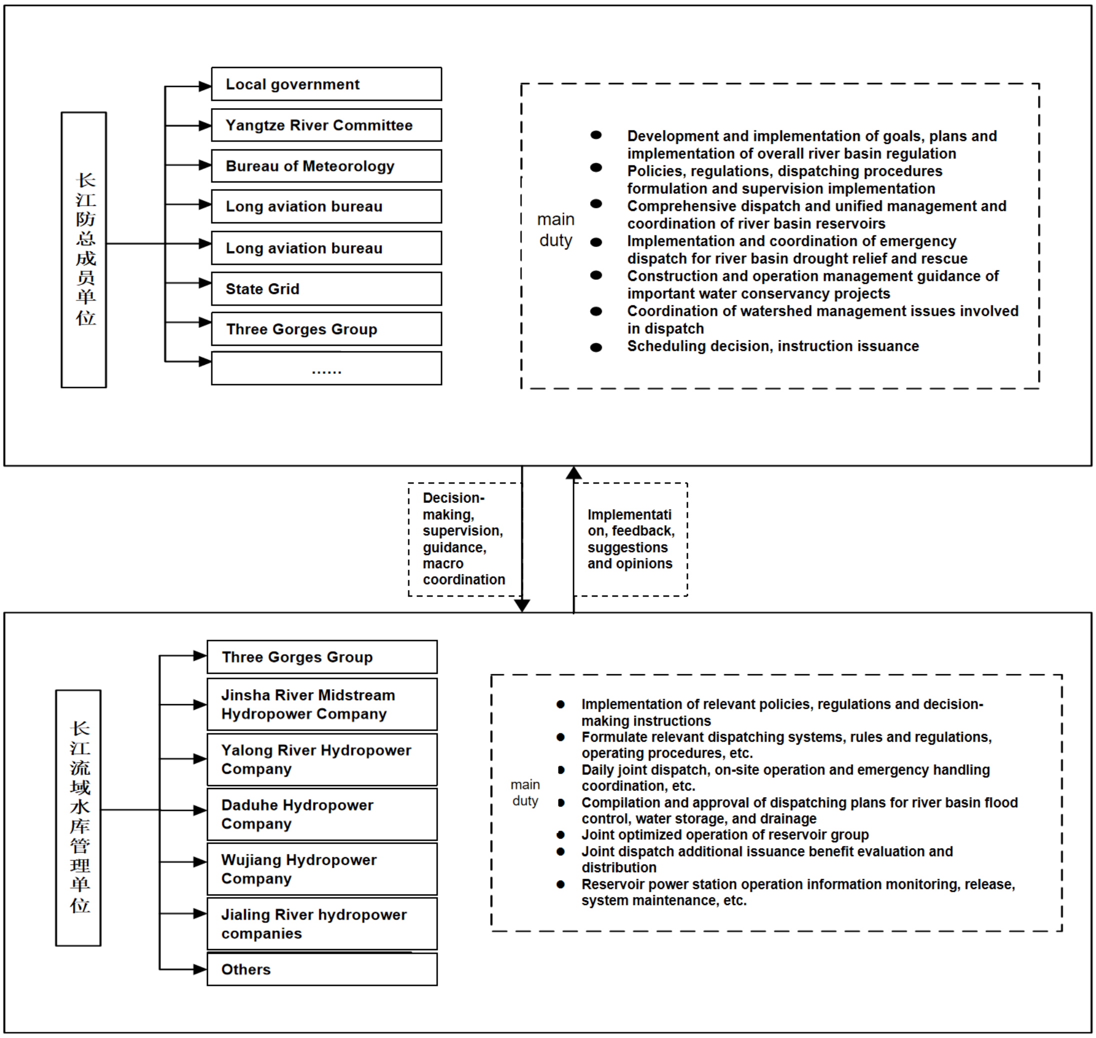

figure3 Management Model of Cascade Reservoirs in the Yangtze River Basin

2.3 Dispatch management

2.3.1 flood dispatch

According to the "Water Law of the People's Republic of China", "Flood Control Law of the People's Republic of China", "Regulations of the People's Republic of China on Flood Control", "Regulations of the People's Republic of China on Drought Relief" and other relevant laws and regulations, and the "Comprehensive Plan for the Yangtze River Basin (2012-2030)" and "Flood Control in the Yangtze River Basin" "Planning", "Yangtze River Flood Dispatching Plan", "Yangtze River Flood Defending Plan", and "Joint Dispatching Plan for Reservoir Groups in the Upper Yangtze River", the Yangtze River Defense Headquarters implemented joint flood control dispatch for 21 reservoirs in the upper reaches with the Three Gorges Reservoir as the core, and issued flood control requirements in consideration of flood control requirements in the river basin. Dispatch instructions to the reservoir management unit, and implement flood blocking, peak cutting, and peak shift scheduling for floods. All reservoir scheduling management units strictly implement it to ensure the safety of flood control in the river basin. The Upper Three Gorges Reservoir will raise the level of Panzhihua, Yibin, Luzhou, Chongqing's main urban area, Leshan, Cangxi, Langzhong, Nanchong, Hechuan, Sinan, Yanhe, Pengshui, Wulong and other important towns and The flood control capacity of important infrastructure; The Three Gorges Reservoir guarantees that the flood control standard of the Jingjiang River reaches a once-in-100-year flood. In the event of a once-in-1000 flood or similar to the 1870 flood, the flood storage and detention area shall be used to ensure that no devastating flood disaster occurs in the Jingjiang area; The upstream reservoir cooperates with the Three Gorges Reservoir to intercept floodwaters to reduce the amount of flood flowing into the Three Gorges Reservoir, and further reduce the flood diversion volume of the middle and lower Yangtze River and the probability of using flood storage and detention areas.

Reservoirs in the upper reaches of the Yangtze River adhere to the principle of benefiting from flood control, and electric regulation (aeronautical regulation) to water regulation. Each reservoir reserves sufficient capacity for flood control during flood seasons, and flood control and water dispatch obey the unified dispatch of the Yangtze River. During joint flood control and dispatching of reservoir groups, first ensure the safety of each pivot project; for reservoirs that both serve as river flood control and share flood control tasks in the middle and lower reaches of the Yangtze River, rationally allocate the flood control storage capacity of the reservoir and coordinate the relationship between flood control in the river and flood control in the middle and lower reaches of the Yangtze River. Under the premise of meeting the flood control requirements of the river where it is located, share the flood control tasks in the middle and lower reaches of the Yangtze River as needed; flood control dispatching takes into account the requirements of comprehensive utilization, combined with hydrometeorological forecasts, and under the premise of ensuring flood control safety, rational use of water resources and correct treatment of flood control in reservoir groups Significant relationship with benefit, part and whole, flood season and non-flood season, single storage and multiple storage. Through the joint dispatch of the reservoir group, the upstream and downstream coordination of the river basin and the balance between the main and tributary streams can be realized, and the flood control safety, water supply safety, and ecological safety of the river basin can be guaranteed, and the comprehensive benefits of the reservoir group can be fully utilized.

2.3.2 Power generation dispatch

The controlled reservoirs in the upper reaches of the Yangtze River have multiple development tasks such as flood control, power generation, irrigation, and shipping. The established controlled reservoirs are under the jurisdiction of the Three Gorges Corporation, Datang Corporation, Yalong River Hydropower Development Corporation, and Jinsha River Middle Reaches Hydropower Corporation. There are different development owners, showing multiple development tasks and multiple owners. Reservoir management units implement beneficial dispatching to the reservoirs under their jurisdiction. For example, the Three Gorges Corporation is responsible for the power generation dispatching of the Three Gorges, Xiluodu and Xiangjiaba reservoirs on the mainstream of the Yangtze River, and the Yalong River Basin Hydropower Development Company is responsible for the Jinping I and Ertan of the Yalong River. For the power generation dispatching of the reservoirs, Guizhou Wujiang Hydropower Development Company is responsible for the power generation dispatching of the Wujiang Goupitan, Silin, Shatuo and Pengshui reservoirs.

Reservoir management units perform dispatching, management and coordination functions in reservoir dispatching, power generation dispatching, reservoir hub operation management and shipping coordination, uniformly accept and execute dispatching instructions from administrative management units with jurisdiction, and participate in the coordination of relevant professional dispatching plans And formulate. Based on the incoming water forecast, the reservoir dispatch management unit comprehensively considers the needs of flood control, shipping, water supply, ecology, etc., prepares a reservoir dispatch plan, coordinates the power grid dispatching agency to implement power generation, optimizes the dispatch of the reservoir, reduces the loss of abandoned water, and makes full use of the power generation benefits .

2.3.3 Ecological dispatch

Consider the needs of organisms and their habitats, water environment and sensitive targets for reservoir operation, clarify the ecological operation requirements parameters of main and tributary reservoirs and reservoir groups, and determine the ecological operation plan, coordinate the operation of the reservoir group and the relationship between the ecological environment, and maintain the biodiversity of the Yangtze River Basin It plays an important role in habitats, ensuring ecological flow, and protecting water quality in important areas. At present, the research foundation of ecological regulation demand in the Yangtze River Basin is relatively weak. There are only some accumulations in the regulation demand research and practice of the natural reproduction of the four major home fish under the Three Gorges Dam, and the regulation demand for important species protection, important ecological function areas and wetland protection. It is still unclear, and it is urgent to carry out related scheduling requirements research and scheduling practice.

2.3.4 Dispatching coordination

In terms of dispatch coordination, in order to smoothly implement flood control dispatch, drought-resistance dispatch and emergency dispatch of reservoir groups, clarify dispatch objectives, dispatch content, dispatch conditions, implementation subjects, supervision and management of dispatching process, and division of responsibilities and powers of the participating parties, etc. The inter-departmental dispatch coordination mechanism including water conservancy, electric power, transportation and other departments and reservoir management units coordinate and guide major issues in the unified dispatch process. The current implementation effect is good. In the future, more water-related units and departments should be included in the coordination mechanism, increase related powers, take into account the needs of all parties, and strengthen coordination effects.

2.3.5 Information sharing

There are 4 tributaries in the upper reaches of the Yangtze River with an area of more than 80,000 km2, with annual runoffs of more than 49 billion m3, and 285 large-scale reservoirs (with a total storage capacity of more than 100 million m3) have been built, which are responsible for comprehensive utilization. In order to improve the accuracy of the inflow of cascade reservoirs, extend the forecast period, reduce the management cost of cascade reservoirs, give full play to the adjustment and compensation capabilities of cross-regional and mixed reservoir groups, and improve the comprehensive benefits of cascade reservoirs in the basin, it is necessary to share the dispatch and operation information of the basin reservoirs .

Since the beginning of 2014, the General Organization of the Yangtze River Defense has carried out the construction of an information sharing platform for reservoir groups jointly dispatched by the upper reaches of the Yangtze River, and has compiled and issued the "Management Measures for Information Sharing of Controlled Reservoirs in the Yangtze River Basin (Trial)". At present, the information sharing platform of the upper Yangtze River reservoir group has been put into trial operation, and 21 large-scale reservoirs in the upper river basin have been included. The basic information on the operation of the reservoir group has been shared, and it has played an important role in flood control during flood season and water supply in dry season. However, the existing results are far from the requirements of realizing the comprehensive sharing of information of the cascade reservoirs in the river basin and optimizing resource allocation. It is necessary to combine the current status of the development and management of the reservoirs in the river basin, and establish a comprehensive, open, and comprehensive information sharing mechanism on the basis of the existing information sharing mechanism. A mutually beneficial information sharing model.

2.4 Comprehensive utilization and sustainable development of watershed

The cascade reservoirs in the upper reaches of the Yangtze River are responsible for the functions of flood control, power generation, shipping, ecology, water replenishment, and emergency dispatch.

In accordance with relevant laws and regulations, the Yangtze River Commission implemented joint flood control and dispatch for 21 reservoirs in the upper reaches with the Three Gorges Reservoir as the core. Taking into account the flood control requirements of the river basin, it issued flood control dispatch instructions to the reservoir management unit, and implemented flood control, peak reduction, and peak shift dispatch. All reservoir dispatching management units strictly implement it to ensure the safety of flood control in the basin. The Upper Three Gorges Reservoir will raise the level of Panzhihua, Yibin, Luzhou, Chongqing's main urban area, Leshan, Cangxi, Langzhong, Nanchong, Hechuan, Sinan, Yanhe, Pengshui, Wulong and other important towns and The flood control capacity of important infrastructure; The Three Gorges Reservoir guarantees that the flood control standard of the Jingjiang River reaches a once-in-100-year flood. In the event of a once-in-1000 flood or similar to the 1870 flood, the flood storage and detention area shall be used to ensure that no devastating flood disaster occurs in the Jingjiang area; The upstream reservoir cooperates with the Three Gorges Reservoir to intercept floodwaters to reduce the amount of flood flowing into the Three Gorges Reservoir, and further reduce the flood diversion volume of the middle and lower Yangtze River and the probability of using flood storage and detention areas.

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3 Key technologies of cascade dispatching in river basin

3.1 Meteorological and Hydrological Forecast Technology and System

3.1.1Weather forecasting technology

1.Multi-scale rainfall forecast method

1) Short-term forecast. Introduce foreign advanced mesoscale weather model WRF (the Weather Research & Forecasting model) to construct short-term quantitative rainfall forecasts for the Yangtze River Basin. Through the selection of important rainfall processes during the flood season to conduct historical case studies, focusing on the comparison and discussion of the microphysical processes and cumulus parameterization processes that have a greater impact on rainfall, to find out the ideal parameterization scheme combination suitable for the Yangtze River Basin, and establish a future-oriented Yangtze River Basin 1-3 days short-term quantitative rainfall forecast.

Based on the above-mentioned WRF model for the research of quantitative precipitation forecast technology in the Yangtze River Basin, a mesoscale WRF numerical weather forecast system for the Yangtze River Basin was developed to realize the real-time operation of the WRF model. The model should be able to automatically collect and process the initial field, automatically generate rainfall information in different periods according to the needs of meteorological and hydrological forecasters, and complete the visualization of the weather element forecast products of the WRF model. The software system can be installed and run elsewhere, while leaving an input interface for obtaining short-term quantitative rainfall forecast results in the Yangtze River Basin based on the WRF model directly from the Hydrological Bureau of the Yangtze River Committee.

At the same time, the received rainfall data of the European Center fine grid is used as backup data for short-term rainfall forecasts, and they are stored in the database in time every day, and the regional rainfall is calculated according to the hydrological forecast requirements.

2) Medium-term forecast. The rainfall forecast results of the CFS model of the United States are mainly used as the medium-term rainfall and input into the medium-term hydrological model for medium-term flood forecasting. Extract the rainfall forecast products for the next 30 days in the Yangtze River Basin for use in the medium-term forecast of the Yangtze River Basin. Taking into account actual business requirements, the four sample forecast results at 12 o'clock (UTC) are interpreted and applied.

In order to improve the accuracy and reliability of the forecast, the downloaded and processed rainfall forecast results are corrected and interpreted in different regions of the Yangtze River Basin. It is also necessary to consider the problem of using another model product to replace when the data is not available. Comprehensive consideration and comparison, it is more appropriate to adopt the rainfall forecast products of the European Center. Due to intellectual property issues, the results of this model can only be obtained remotely from the Hydrological Bureau of the Yangtze River Committee. This requires post-processing of the model of the European Center, including a series of work such as partition processing, interpretation and application, and correction, similar to CFS.

3) Long-term forecast. Interpretation and application of the CFS products of the Climate Forecast System of the US Environmental Forecast Center, extracting forecast products such as rainfall and high-altitude fields in the Yangtze River Basin in the next 30 days for daily, ten-day and monthly forecasting in the Yangtze River Basin in the next 30 days. At the same time, it can realize the automatic download of data, map out and calculation of regional rainfall.

Introduce the regional climate model RegCM4, and combine the characteristics of weather, climate and natural environment in the Yangtze River Basin to study short-term climate numerical simulation prediction technology and model development in the basin. First, establish a real-time numerical forecast model (RegCM4) for the Yangtze River Basin, and realize that the RegCM4 model can at least meet the reanalysis of historical and forecast background fields such as the European Center and the United States NCAR as the initial and boundary conditions of the model. By comparing and analyzing the difference in return results, the optimal parameterization scheme and land surface process suitable for the Yangtze River Basin are selected. At the same time, the real-time prediction results of the RegCM4 model need to be quantitatively evaluated and tested after accumulating for a certain period of time. Through the comparison and analysis of the simulation results and the observed values, the possible causes of the simulation errors are found to help adjust the model. Based on the above research, a short-term climate numerical simulation prediction model for the Yangtze River Basin was developed in the Hydrological Bureau of the Yangtze River Committee to realize the real-time automatic operation of the model.

According to the hydrological forecast requirements, the Yangtze River Basin is divided into regions, and statistical method models are established for each region of the Yangtze River Basin. The models include analysis of variance and gray prediction G(1,1) model to forecast the monthly rainfall in each region.

3.1.2 Hydrological forecasting technology

According to the 82 flood control forecasting and dispatching nodes in the Yangtze River basin, based on the existing forecasting scheme system in the basin, flood forecasting is required for 404 stations (intervals) for the above nodes, 467 sets of runoff generation schemes (rainfall runoff models) need to be constructed, and river flood evolution There are 256 plans, and 63 sets of reservoir static storage capacity flood regulation plans. Among them, for the 20 new flood control forecasting and dispatching nodes such as Shuangjiangkou, 36 sets of new runoff generation schemes, 17 sets of confluence schemes, and 11 sets of static storage capacity flood regulation calculation schemes are needed. The rest of the schemes are revised on the existing basis.

Compilation of multi-scale water quantity forecasting plan

According to 130 important control sections of water volume in the Yangtze River Basin, select important control sections with good data conditions to construct 60 short-term and medium-term water volume forecasting systems (some engineering sections above and below the dam are combined into one node), and 30 long-term water volume forecasts Scheme system. For short and medium-term forecasts (1-7d), the SWAT model or Xin'an River daily model is used to carry out daily water forecasting; for long-term forecasts (1 month), a two-parameter monthly water balance model is used to carry out monthly runoff forecasts. Therefore, it is necessary to construct 10 sets of SWAT forecasting plans, 66 sets of Xin'an River daily model plans, 45 sets of Muskingen or synthetic flow plans, 38 sets of two-parameter monthly water balance model plans, and 31 sets of reservoir flood regulation calculation plans. Considering that there is no water forecasting model in the Yangtze River Basin, water resources forecasting is realized using flood forecasting schemes, and the accuracy and rationality of the forecasts have yet to be verified. Therefore, in the above water forecasting schemes, except for the revision of the reservoir flood regulation calculation scheme on the basis of the existing schemes, All other plans need to be newly built.

3.1.3 Meteorological and Hydrological Forecast System

1. Watershed simulation system

Develop rainfall forecasting, flood forecasting, water volume forecasting, forecasting evaluation and forecasting results management functions to provide basin simulation results for various dispatch applications.

2. System composition and function

1) Rain forecast. It mainly includes short-term, medium-term and long-term rainfall forecasts. The short-term rainfall forecast realizes 1～3d short-term rainfall forecast and provides 6h and 24h time scale products; the medium-term rainfall forecast realizes 3～7d medium-term rainfall forecast and provides 6h and 24h time scale products; the long-term rainfall forecast realizes long-term rainfall forecast. Provide 7-30d daily (24h time scale) rainfall forecast products, as well as ten-year and monthly time scale products.

2) Flood forecasting. It mainly includes two functions: automatic flood forecasting and manual intervention interactive flood forecasting. The two forecasting methods can be operated simultaneously, and the forecast results can be compared.

The automatic forecast is based on the forecast stations and forecast plans set up in accordance with the definition of the river system. The program automatically completes the forecast calculations of each plan and model one by one. Automatic forecasting can realize the automatic forecasting of each forecasting station in the defined river section, or the forecaster can modify and confirm the calculation results of the forecasting station, and then transfer to the forecast of the next station. The models used by the forecasting station are all lack of system. Provincial configuration, forecasters cannot make choices. The final results can be saved in the database, output in tables, and saved as needed.

For manual intervention interactive forecasting, the forecaster chooses the forecast site by himself, and the configured forecast plan and model can also be selected, complete the forecast calculation of the selected plan and model, and embed the real-time correction function to correct the calculation results.

When the forecast period rainfall needs to be considered, the preset forecast period rainfall can be extracted from the database and participate in the forecast calculation.

The final results can be saved in the database, output in tables, and saved as needed.

3) Multi-scale water volume prediction. It mainly includes three functions: short-term water quantity forecast, medium-term water quantity forecast, and long-term water quantity forecast.

The short-term water volume forecast realizes the short-term water volume forecast of all water resources prediction sections in the basin, and provides data support for the analysis of the water available in the non-flood season and the formulation of water resources dispatching plans. The method of coupling quantitative rainfall forecast and hydrological forecast model is adopted to realize the daily average flow forecast of the water resources forecast section of the river basin for 1 to 3 days, providing automatic, semi-automatic and interactive calculation methods.

The medium-term water volume forecast realizes the mid-term water volume forecast of part or all of the water resources forecast section of the basin, and provides data support for the analysis of the water available in the basin during the non-flood season and the formulation of water resources dispatching plans. The medium-term water quantity forecast mainly realizes the daily average daily flow forecast of the water resources forecast section of the river basin for 3 to 7 days.

Long-term water volume forecasting realizes the long-term water volume forecasting of some water resources prediction sections in the basin, and provides reference for the implementation of water resources dispatching plans and the most stringent water resources management in the basin. By coupling the long-term monthly rainfall forecast information, the forecast of the daily average daily flow of some water resources in the basin in the next month is realized, and the output (forecast) value of ten-year and monthly inflow is provided.

For time scales above the month (flood season, dry season, and annual), the forecast and forecast of the inflow of water on a longer time scale such as seasons (dry seasons, flood seasons) and years on a monthly scale are mainly based on mathematical statistics.

4) Forecast evaluation. It mainly includes three functions: flood forecasting result evaluation, water quantity forecasting result evaluation and experimental forecasting result evaluation.

Flood forecasting results evaluation Carry out flood forecasting accuracy evaluation analysis, statistical error probability, and rolling forecast based on accuracy evaluation, to provide a basis for consultation and decision-making. Realize automatic flood forecasting results evaluation and storage storage; manual interactive forecasting results evaluation and storage storage.

Water volume forecasting results evaluation Carry out water volume forecasting accuracy evaluation analysis, statistical error probability, and rolling forecast based on accuracy evaluation, providing basis for consultation and decision-making. Realize short-term water volume prediction results evaluation and storage storage; mid-term water volume prediction results evaluation and storage storage; long-term water volume prediction results evaluation and storage storage.

5) Forecast results management. It mainly includes four functions: rainfall forecasting achievement management, flood forecasting achievement management, water forecasting achievement management and experimental forecasting achievement management.

Rainfall forecast results management mainly realizes the release, query, modification and preservation of short-term, medium-term and long-term rainfall forecast results.

Flood forecasting results management mainly realizes the release, query, modification and preservation of automatic flood forecasting and artificial interactive flood forecasting results.

The management of water volume prediction results mainly realizes the release, query, modification and preservation of the short-term, mid-term and long-term water volume prediction results of the water resources prediction section of the river basin.

The results display is based on a water conservancy sheet, which integrates water and rain monitoring information, flood warning information, low water warning information, water and rain query analysis, water and rain forecast information, and water and rain special reports (referring to bulletins, briefings and other types of analysis reports). Provide services in a combination of charts.

3.2 Joint dispatch technology and system

3.2.1 Joint flood control and dispatching technology

Based on the river basin digital simulation service, construct a river basin flood control dispatch model. The Yangtze River Basin flood control and dispatch model is constructed in three levels on a spatial scale: First, the large-scale system decomposition and coordination theory is adopted to coordinate the flood control dispatch requirements of various important areas within the basin, mainly the flood control storage capacity reservation requirements, and the construction of large-scale basin flood control storage capacity Configure the model to evaluate the effectiveness of flood control in the river basin. Second, divide each river section in the area into several sections based on the important flood control section as the node, and use the allowable discharge flow of the river channel as the constraint condition to further subdivide the dispatching requirements of each control section in the area. Regional flood control optimization dispatching model for each main and tributary of the river basin; combining long, medium and short flood forecasting and forecasting models, and using inter-regional historical flood correlation knowledge and dispatching rule bases, constructing control projects (reservoirs) or cascade reservoirs in consideration of flood control in different regions The internal coordination model of its own flood control storage capacity during the mission.

3.2.2 Joint Flood Control Dispatching System

By integrating part of the functions of the National Flood Control and Drought Relief System, and providing support services based on the digital simulation of the river basin, the flood control dispatching rule library is further enriched, and the function of flood control dispatching models is improved; and new technologies are used to build new flood control plans intelligently push, flood control dispatch plan analysis, and dispatch effects Simulation and other functions provide plan decision support for flood control dispatching.

1. System composition and function

1) Flood control dispatching rule base. Define the operating boundary conditions of water conservancy projects such as reservoirs, dikes, flood storage and detention areas in the river basin flood control engineering system, and important parameters such as the allowable flow capacity of flood control nodes; digitize the relationship between each flood control control node and each water conservancy project in space and flood control scheduling tasks Relationships, including the spatial relationship between flood control points and river channels, the reservation requirements of flood control points for reservoir flood control capacity, and specific flood control dispatching methods for various encounter types and magnitudes, etc.

2) Push flood dispatch plan. Realize the reservoir flood regulation model of the dynamic combination of river courses, reservoirs and dispatch nodes, and realize the flood dispatch plan inversion based on dispatch node target regulation, and sort according to dispatch indicators, and intelligently push flood control dispatch plans.

3) Flood dispatch simulation simulation. Based on river basin numerical simulation and important flood control dispatching nodes as the boundary, using hydrodynamic simulation, calling the program simulation function in public application services, constructing a flood deduction system for important flood control areas of the Yangtze River basin, realizing its two-dimensional and three-dimensional visualization expression.

4) Comprehensive evaluation of flood control plan. Realize the comparative analysis of multiple dispatching plan indicators, and conduct a comprehensive evaluation of the comprehensive benefits of dispatching plans.

5) Management of flood control dispatching plan. The selected scheduling plan is stored in the database, and the template is prepared, the scheduling order is generated in real time, and the committee's

integrated office system interface is called to review the scheduling order.

4 Outlook

The 21 large-scale reservoirs on the main and tributary streams of the upper reaches of the Yangtze River have achieved joint flood control operations, and significant results have been achieved in flood control of the rivers where the reservoirs are located and the middle and lower reaches of the Yangtze River. During the flood season of 2016, the middle and lower reaches of the Yangtze River experienced the largest flood since 1998. The three-gorges reservoir centered on the upper reaches of the Yangtze River trunk and tributary reservoirs carried out joint flood control operations, which effectively reduced the flood peak water level of the middle and lower reaches, shortened the duration of high flood levels, and reduced The flood control pressure has been greatly reduced, and flood losses have been greatly reduced. Through the joint water storage of cascade reservoirs, the water storage plan of main and tributary reservoirs can be considered as a whole, avoiding the disorderly storage of upstream reservoirs, ensuring the full storage rate of the reservoir group, and effectively guaranteeing the shipping and ecology of downstream rivers during dry seasons. Wait for water demand. Under the premise of ensuring flood control safety, the joint flood control dispatching of the upper reaches of the Yangtze River takes into account the requirements of comprehensive utilization of reservoirs, rationally utilizes water resources, guarantees flood control safety, water supply safety, and ecological safety in the basin, and gives full play to the comprehensive utilization benefits of reservoirs for power generation and shipping.

However, with the country's economic and social development and the continuous changes in the operating environment of reservoirs, especially the implementation of the national "Yangtze River Economic Belt" strategy, higher and newer requirements have been put forward for the operation of river basin reservoirs. The current reservoir operation and management model of the Yangtze River Basin cannot meet the higher requirements of the new situation in terms of top-level design, laws and regulations, management systems and mechanisms at the national level, which restricts the comprehensive benefits of the river basin and the ecological environment of the Yangtze River to a certain extent. Great protection.

The specific manifestations are as follows:

1. Multi-headed dispatching operation management, overall planning and insufficient communication and coordination

The "Comprehensive Plan for the Yangtze River Basin (2012-2030)" approved by the State Council stipulates the dispatching principles of "prosperity is subject to flood control, electric power dispatch is subject to water dispatch, professional is subject to integration, and locality is subject to the whole". The main body and multiple river basin management departments lack effective cross-industry, cross-regional, and cross-departmental communication and coordination mechanisms in actual operation, which affects the efficient implementation of decision-making, as well as the ecological environment of the river basin, the safety of hub operations, and the play of comprehensive benefits. For example, due to the lack of communication and coordination between water conservancy, hydrology, electric power, and meteorological departments, the lag in the construction of power transmission channels, and hydrological and power demand forecasts, the power loss of major power stations in the upper reaches of the Yangtze River in 2015 and 2016 exceeded 22 billion. 32 billion kilowatt hours, resulting in a lot of waste of clean energy.

2. Incomplete laws and regulations, lack of comprehensive system protection at the top

At present, most laws and regulations related to reservoir dispatching and operation focus on various industries and regions, considering the overall situation of the basin, and the comprehensive system from the top level is not enough, which causes difficulties in the implementation of operation management units, unclear dispatch and operation responsibilities, and risk control methods Limited issues. For example, there are currently no unified and clear regulations on the management of large navigable buildings on the mainstream of the Yangtze River. The Xiangjiaba ship lift is located in the boundary river and is divided by province. Navigation management is divided into Yunnan and Sichuan based on the Zhonghong line of the river. It will bring complexity and management difficulty for Xiangjiaba to transfer to normal operation in the future, which will affect the unified operation of the hub.

3. The upstream hydropower development subjects are diverse, and

joint dispatch and coordination are difficult

The reservoirs and power stations in the upper reaches of the Yangtze River are developed, constructed, operated and managed by multiple entities, and the benefit-sharing mechanism has not yet been established, which has affected the formation of joint dispatch and information sharing mechanisms in the basin. In the daily dispatch operation, due to the interests of different subjects, the comprehensive functions and coordination effects of the reservoir group are not well coordinated, which restricts the maximum utilization of the comprehensive benefits of the river basin. For example, due to the lack of uniform and specific arrangements for the storage of reservoirs in the basin during the impoundment period, it is easy to cause disorderly impoundment, decrease in downstream inflows, and decline in the water level of downstream rivers and lakes, which will affect the normal water use for daily life and production, as well as the ecology of the Yangtze River and the "two lakes" regions. surroundings.

Management Model of Cascade Reservoirs in the Yellow River Basin

1 An overview of cascade reservoirs in a river basin

1.1 Basic situation of river basin

The Yellow River originates from the northern foot of the Bayan Har Mountain in Qinghai Province, flows through 9 provinces (regions) including Qinghai, Sichuan, Gansu, Ningxia, Inner Mongolia, Shaanxi, Shanxi, Henan, and Shandong, and flows into the Bohai Sea in Kenli County, Shandong Province. The main stream has a total length of 5464km, second only to the Yangtze River, the second longest river in China and the fifth longest river in the world. The basin area is 752,400 km2, and the average annual runoff is 58 billion m3, ranking eighth among Chinese rivers.

According to the geographical, geological and hydrological conditions of the basin formation and development, the main stream of the Yellow River can be divided into upper, middle, lower reaches and 11 river sections. Heyuan to Hekou Town in Tuoketuo County, Inner Mongolia Autonomous Region is the upper reaches. The river is 3471.6km long and the drainage area is 428,000 km2, accounting for 53.8% of the entire river basin area. The tributaries of this river reach less, and the river channel has slight siltation. Floods mainly come from Lanzhou and above. In order to protect the plains from flood disasters, dikes were built in Ningxia and Inner Mongolia. The Yellow River runs from Hekou Town to Taohuayu in Zhengzhou City, Henan Province. The middle reaches of the river is 1206.4km long, with a basin area of 344,000 km2, accounting for 43.3% of the total basin area, with a drop of 890m and an average drop of 7.4%. From Taohuayu to the mouth of the Yellow River is the downstream. The watershed area is 23,000 km2, accounting for only 3% of the entire watershed area. The river is 785.6km long, with a drop of 94m and a drop of 1.11%. The downstream river channel traverses the North China Plain, and most of the river sections are restricted by dikes. The total area of the river is 4240km. Due to the accumulation of a large amount of sediment, the river course has been raised year by year. At present, the river bed is 3~5m higher than the back surface of the river. Some river sections, such as Fengqiu Caogang in Henan Province, are 10m higher. It is a world-famous "overground river" and has become the Huaihe River. The watershed of the Haihe River system.

figure1-1 Schematic diagram of the Yellow River Basin

1.2 Development of Cascade Hydropower in the Basin

A total of 49 reservoirs and hydropower stations are planned to be constructed on the main stream of the Yellow River, including 13 on the Yellow River above Longyangxia, 26 from Longyangxia to Hekou Town, and 10 on the middle reaches of the Yellow River below Hekou Town. As of June 2017, a total of 33 reservoirs and hydropower stations have been built on the mainstream of the Yellow River and 16 are to be constructed.

1.2.1 Above Longyangxia

13 hydropower stations are planned to be built above Longyangxia. As of June 2017, the Yellow River Source, Banduo and Yangqu hydropower stations have been built.

table1-1 Basic situation table of planned hydropower stations above Longyangxia on the mainstream of the Yellow River

Serial number	project name	Construction site	Control area (ten thousand km2)	Normal water storage level (m)	Storage capacity (100 million m3)	Tuning performance	Effective storage capacity (100 million m3)	Installed capacity (ten thousand kw)
1	●Source of the Yellow River	Qinghai Maduo	1.9	4270	15.12	Many years	14.6	2.5
2	○Tehetu	Qinghai	3.74	4140	21		6	8

3	○ Jianshe	Qinghai	4.12	4080	25		10	15
4	○ Guancang	Qinghai	5.25	3920	45		15	54
5	○门 Mentang	Qinghai	5.96	3775	70		16	58
6	○Tajike	Qinghai	6.19	3635	11.5		5.3	26
7	○ Duosong	Qinghai	9.04	3440	81	year	31	110
8	○ Duoergen	Qinghai	9.72	3320	3.75	day	1	126
9	○ Maerdang	Qinghai	9.83	3160	1.4	day	0.5	57
10	○尔 Erduo	Qinghai	9.98	3070	1.6	day	0.4	72
11	○茨 Ciha	Qinghai	10.58	2980	2.78	day	0.58	100
12	● Banduo	Qinghai Bando	10.75	2845	2.69	day	0.43	36
13	● Yangqu	Qinghai Xinghai	12.33	2680	3.79	day	1.31	65
sum					284.63		102.12	793.5
●built ⊚building ○will build								

1.2.2 Below Longyangxia

36 water conservancy hubs and hydropower stations are planned to be constructed below Longyangxia on the main stream of the Yellow River. The total storage capacity under the check water level is 104.6 billion m3, the storage capacity under the normal storage level is 101 billion m3, the effective storage capacity is 50.3 billion m3, and the installed capacity is 23.94 million kW. As of June 2017, 30 buildings have been completed.

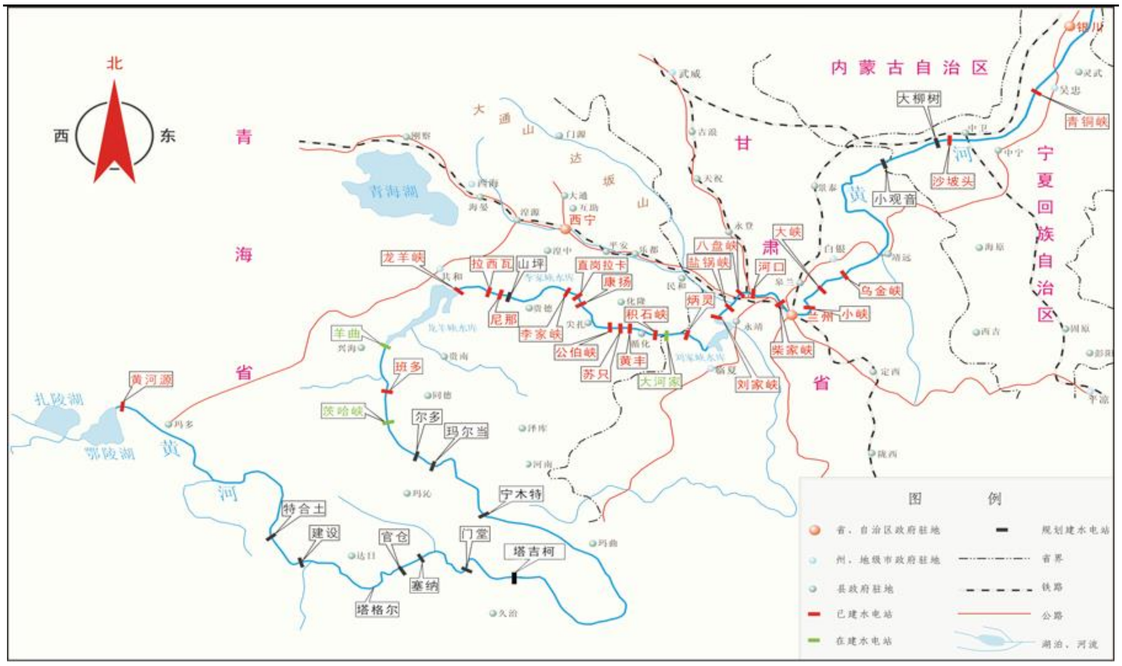


figure1-2 Distribution map of cascade power stations below Longyangxia

①Reservoirs and hydropower stations built

The upper reaches of the Yellow River is a “rich mine” in the development of hydropower resources in China. In terms of hydropower resource development, it has the characteristics of good natural geographical conditions, resource concentration, stable water volume, small submergence loss, superior engineering conditions, low investment, and large benefits. It is the main stream of the Yellow River. The most concentrated river section of water conservancy project construction. Reservoirs in the middle reaches of the Yellow River are mainly used for flood control, silt reduction, snow prevention, water supply, irrigation and power generation.

There are 30 reservoirs and hydropower stations built below Longyangxia on the main stream of the Yellow River, of which 24 are in the upper reaches of the Yellow River and 6 are in the middle reaches. The total storage capacity of the 30 reservoirs that have been built is about 61.3 billion m3 under the checked water level, the storage capacity is about 58.8 billion m3 under the normal storage level, the effective storage capacity is about 36.3 billion m3, and the installed capacity is 16.68 million kW. They account for 58%, 72%, and 68% of the total storage capacity of the 36 reservoirs under the normal storage level of 101 billion m3, the total effective storage capacity of 50.3 billion m3, and the total installed capacity of 24.48 million kW.

table1-2 Table of basic conditions of built reservoirs and hydropower stations below Longyangxia on the mainstream of the Yellow River

No	name	location	Total storage	Adjust storage	Tuning perform	Installed capacity	Management unit
1	Longyangxia	Qinghai. Republic	276.30	193.5	years	128	Huangshang Hydropower Development Company
2	Laxiwa	Qinghai. Guide	10.79	1.50	day	350	Huangshang Hydropower Development Company
3	Nina	Qinghai. Guide	0.288	0.086	day	16	Hydropower Fourth Bureau Co., Ltd
4	Lijiaxia	Qinghai. Jianzha	17.5	0.6	Day, week	20	Huangshang Hydropower Development Company
5	Zhiganglaka	Qinghai. Jianzha	0.154	0.03	day	19.2	Datang International Power Generation Co., Ltd
6	Kangyang	Qinghai. Jianzha	0.288	0.05	day	28.4	Qinghai Sanjiang Hydropower Development Company
7	Gongboxia	Qinghai. Xunhua	6.2	0.75	day	150	Huangshang Hydropower Development Company
8	Suzhi	Qinghai. Xunhua	0.5	0.142	day	22.5	Huangshang Hydropower Development Company
9	Huangfeng	Qinghai. Xunhua	0.84	0.2	day	22	Qinghai Sanjiang Hydropower Development Company
10	Jishixia	Qinghai. Xunhua	2.63	0.40	日	102	Huangshang Hydropower Development Company
11	Dahejia	Qinghai. Gansu	0.1	0.039	日	14.2	Qinghai Sanjiang Hydropower Development Company
12	Bingling	Gansu. Jishi	0.568	0.1	日	24	Gansu Electric Power Investment Company
13	Liujiaxia	Gansu. Yongjing	57	41.9	year	169	Gansu Electric Power Company
14	Yanguoxia	Gansu. Yongjing	2.7	0.07	day	47	Huangshang Hydropower Development Company
15	Bapanxia	Lanzhou	0.49	0.09	day	22	Huangshang Hydropower Development Company
16	Hekou	Lanzhou	0.16	0.02	day	7.4	Gansu Electric Power Investment Company
17	Chaijiaxia	Lanzhou	0.17	0	day	9.6	Chaijiaxia Hydropower Company
18	Xiaoxia	Lanzhou	0.5	0.14	day	23	Yellow River Small Three Gorges Company
19	Daxia	Lanzhou	0.9	0.55	day	30	Yellow River Small Three Gorges Company
20	Wujinxia	Gansu. Jingyuan	0.2	0.1	day	14	Small Three Gorges Hydropower Development Company
21	Shapotou	Ningxia. Zhongwei	0.26	0.1	runoff	12.03	Shapotou Junction Co., Ltd.
22	Qingtongxia	Ningxia. Qingtongxi	6.06	3.2	day	30.2	Huangshang Hydropower Development Company
23	Haibowan	Inner Mongolia	4.6	1.8	day	9	Haibowan Water Conservancy Project Management Bureau
24	Sanshenggong	Inner Mongolia	0.8	0.2	day	0.2	Inner Mongolia Yellow River Engineering Administration
25	Wanjiazhai	Shanxi. Inner	9.0	4.5	day	108	Wanjiazhai Hub Co., Ltd.
26	Longkou	Shanxi. Inner	1.96	0.71	day	42	Wanjiazhai Hub Co., Ltd.
27	Tianqiao	Shanxi. Shaanxi	0.7	0.4	day	12.8	Shanxi Tianqiao Hydropower Co., Ltd
28	Sanmenxia	Shanxi. Henan	96.4	60.4	day	41	Sanmenxia Hub Administration
29	xiaolangdi	Henan	126.5	50.5	year	180	Xiaolangdi Construction Management Bureau

No	name	location	Total storage	Adjust storage	Tuning perform	Installed capacity	Management unit
30	Xixiayuan	Henan	1.62	0.5	day	14	Xiaolangdi Construction Management Bureau
	sum		612.66	362.54		1667.53	

②Proposed reservoir and hydropower station

Six reservoirs and hydropower stations are proposed to be built below Longyangxia on the main stream of the Yellow River, including two upstream, namely Shanping and Daliushu, and four in the middle reaches, namely Qikou, Guxian, Guxian, Ganzepo and Taohuayu. The total storage capacity of the 6 normal storage levels is about 42.17 billion m3, and the effective storage capacity is about 14.07 billion m3, which respectively account for 42% and 28% of the total storage capacity of the 36 reservoirs at normal storage levels of 101 billion m3 and the total effective storage capacity of 50.3 billion m3 , The installed capacity accounts for 27% of the total installed capacity of 24.48 million kW.

The proposed Daliushu, Qikou, and Guxian water conservancy projects are three large-scale water conservancy projects proposed to be built among the seven key projects of the Yellow River water and sediment control system, and their status and role are huge.

table1-3 Table of basic conditions of proposed reservoirs and hydropower stations below Longyangxia on the mainstream of the Yellow River

No	name	location	Normal water storage level (m)	Storage capacity (100	Tuning performance	Effective storage capacity (100	Installed capacity 10 000 kW
1	Shanping	Qinghai	2219.5	1.2	day	0.1	16
2	Daliushu	Ningxia.	1377.0	107.4	year	50.2	200
3	Qishi	Shanxi.	785.0	125.7	years	27.9	180
4	Guxian	Shanxi.	645.0	165.7	years	47.8	210
5	Ganzepo	Shanxi.	423.0	4.4		2.8	44
6	Taohuayu	Henan	110.0	17.3		11.9	
	sum			421.7		140.70	650

2 River Basin Cascade Reservoir Management

2.1 Management model and current situation

The Yellow River Basin has a vast area and few water resources. With the development of society and economy, the water consumption of the Yellow River Basin has increased sharply, and the overall situation of "resource water shortage" is present. The relationship between water supply and demand among provinces is extremely tense. At the same time, topography, geology, climate and other factors have brought problems such as sediment deposition and anti-freezing problems for the management of the Yellow River Basin. To cope with these problems, the Yellow River Basin implements unified management of water resources in the basin led by the Yellow River Conservancy Commission. The operation of various power stations in the basin relies on the overall arrangement of the Yellow River Conservancy Commission, which is highly planned.

Currently, the construction of the three power stations in Daliushu, Qikou, and Guxian has not yet begun. Among the reservoirs in the Yellow River Basin, there are only four power stations with annual (multi-year) regulation performance in Longyangxia, Liujiaxia, Sanmenxia, and Xiaolangdi. It is a daily regulating power station or a radial power station, and its power station operation depends on the operation and management of these four power stations. As a result, the Yellow River Basin has formed a basin-wide comprehensive utilization engineering system with the four power stations of Longyangxia, Liujiaxia, Sanmenxia and Xiaolangdi as the main body.

2.2 Comprehensive utilization and sustainable development of watershed

2.2.1 Administrative management

(1)Yellow River Conservancy Commission of the Ministry of Water Resources

The Yellow River Water Conservancy Commission of the Ministry of Water Resources is the dispatched agency of the Ministry of Water Resources in the Yellow River Basin. It represents the Ministry of Water Resources to perform the responsibilities of water administration in the basin where it is located. At present, the state implements a system that combines basin management and administrative area management in the Yellow River Basin, and implements a management model that combines macro management (or indirect management) and direct management. Macro-management refers to the implementation of river basin-wide planning, flood control, water resource allocation, water volume scheduling, water resource protection, and water and soil conservation by river basin agencies through certain coordination organizations or mechanisms. Direct management refers to the water activities of the river basin organization on the main stream below

Yumenkou, including the construction and management of flood control projects and facilities, the management of water, water areas (including estuaries), and water projects, and important to the main stream and across provinces (regions). For the management of water intake permits above the designated amount of tributaries, the Yellow Committee shall establish directly affiliated management agencies at all levels to implement direct management (or unified management) in the above-mentioned areas.

(2)Yellow River Flood Control and Drought Relief Headquarters

Based on the needs of the new situation of flood control and drought relief of the Yellow River in the new period, with the approval of the State Council, the National Defense General Administration approved the addition of drought relief functions to the Yellow River Control Division, and established the Yellow River Flood Control and Drought Relief Headquarters in 2007. The duties of the Yellow River Flood Control and Drought Relief Headquarters are:

(1) Implement national guidelines, policies, laws and regulations on flood control and drought relief. Organize the formulation of relevant regulations and systems for flood control and drought relief in the Yellow River Basin and supervise their implementation.

(2) Organizing, coordinating, supervising, and guiding the flood control and drought relief work in the Yellow River Basin, focusing on strengthening the mainstream of the Yellow River and important cross-provincial (regional) tributary rivers, dikes, flood storage and detention areas, reservoirs and other major projects and non-projects in conjunction with relevant provinces (regions) Measures for flood prevention and drought management.

(3) Organize the formulation of flood dispatch plans for the Yellow River Basin and flood prevention plans for important trans-provincial (regional) rivers in the basin, examine and approve flood dispatch plans for important trans-provincial (regional) rivers in the basin, and coordinate and supervise their implementation.

(4) Responsible for the implementation of flood control and drought relief dispatching for important water conservancy and hydropower

projects, flood storage and detention areas, culvert gates, etc. in the Yellow River Basin in accordance with regulations and authorizations.

(5) Coordinate and resolve water disputes involving major flood control and drought relief work in the mainstream of the Yellow River and its inter-provincial (regional) tributaries.

(6) Grasp important flood conditions, working conditions, drought conditions and disasters in the Yellow River Basin, put forward the Yellow River flood control and drought relief decision-making deployment and dispatching opinions, guide, coordinate and supervise major flood relief and drought relief work in the Yellow River Basin.

(7) To undertake other tasks assigned by the State Defense Administration.

2.2.2 Multi-objective scheduling management

(1)Flood management

The focus of flood prevention and protection in the upper reaches of the Yellow River is Lanzhou City, Ningxia, Inner Mongolia Hetao Plain, Baolan Railway and industrial and mining enterprises. Flood control in the plains along the banks of the Yellow River in Lanzhou, Ningxia, and Inner Mongolia relies on dikes and control and guidance projects. Liujiaxia Reservoir regulates the flood during the flood season, and the discharge peak discharge under control does not exceed 6000m3/s, which is equivalent to a 50-year encounter. Longyangxia Reservoir focuses on power generation, combined with flood control, irrigation and water supply, and can also improve the flood control standards of Liujiaxia Reservoir, Yanguoxia Hydropower Station, Bapanxia Hydropower Station and Lanzhou City. During the flood control period of the Ningmeng and the lower reaches of the Yellow River, Liujiaxia Reservoir, Sanmenxia Reservoir and Xiaolangdi Reservoir respectively control the discharge flow of the upper reaches of the Yellow River in Ningxia, Inner Mongolia and the lower reaches of the Yellow River, reducing the increase in trough storage during the closure period to reduce ice melting Ling Feng at the time of thawing. If necessary, the downstream can also use the widening area of the river channel and the culvert gates on both sides of the Yellow River to divert the floodwater and reduce disasters.

(2)Water dispatch management

Approved by the State Council, in December 1998, the State Planning Commission and the Ministry of Water Resources jointly promulgated and implemented the "Measures for the Management of Yellow River Water Dispatching", authorizing the Yellow River Conservancy Commission to implement unified water dispatching of the Yellow River. The "Regulations on Yellow River Water Dispatching" passed and promulgated by the executive meeting of the State Council in July 2006 are the basic measures and guarantees for realizing the optimal allocation of water resources of the Yellow River, alleviating the contradiction between supply and demand of the Yellow River water resources, and resolving the Yellow River's dry-flow crisis.

The regulations stipulate that the Yellow River Water Conservancy Commission shall be responsible for the organization, implementation, supervision and inspection of the Yellow River water regulation. The Yellow River water volume is subject to unified dispatch, following the principles of total volume control, section flow control, hierarchical management, and hierarchical responsibility. The Yellow River water volume control should first meet the needs of urban and rural residents for domestic water use, and rationally arrange water for agriculture, industry, and the ecological environment to prevent the Yellow River from drying up.

(3)Anti-blink scheduling management

After the Longyangxia and Liujiaxia reservoirs were jointly operated in 1987, the Ningmeng and Ningxia sections of the Yellow River were heavily siltated and the main trough shrank severely. The contradiction between the power generation dispatching and the snowing prevention dispatching of the upper reaches of the Yellow River during the flood season intensified. The main manifestations are: on the one hand, to ensure the safety of snowing prevention, the river is closed. The flow cannot be too large. The discharge flow of the reservoir is further reduced during the opening period (generally controlled by 300m3/s at the Lanzhou section), and the discharge flow and water volume of the reservoir are restricted during the freezing flood period (November to March of the following year). On the other hand, the hydropower installed capacity of the Qinghai power grid accounts for a large proportion of the total installed capacity. There are 9 hydropower stations in the interval from Longyangxia to Liujiaxia Reservoir. The 8 hydropower stations except Liujiaxia Reservoir are all located in Qinghai Province. At peak power generation, water requirements for power generation are very urgent. With the economic and social development of Qinghai Province, the contradiction between the requirements for anti-freezing safety discharge and the discharge requirements for power generation has become more and more prominent. Under the premise of ensuring the safety of blizzard prevention, in order to give full play to the blizzard prevention function of the upstream backbone reservoirs and the Ningmeng River section, and to give full play to the river' s flood discharge and bludge removal capacity, to better meet the water demand for power generation of the reservoirs during the freezing flood period, the Yellow River Long and Liu Reservoirs will be flooded. Scientific scheduling played an important role.

After more than 20 years of dispatching practice, the Yellow River Control Group has experienced repeated processes such as research, application, summary and re-practice in reservoir control and dispatching, and accumulated rich dispatching experience, and initially formed a relatively complete method for flood control dispatching in the upper reaches of the Yellow River. The risk of flood prevention in the reservoir is reduced, and the loss of life and property of the people along the Yellow River is minimized. Measures to maintain an appropriate flow rate before the river is closed in the Lingling River have reduced the flow fluctuation caused by the retreat water in the interval, shaped the appropriate flow rate of the river closure in line with the actual conditions of the river, and reduced the probability of ice jams and ice dams. During the freezing period, the discharge flow of the reservoir is appropriately reduced, while maintaining a certain flow capacity of the frozen river channel, it effectively restrains the excessive increase of the tank storage increment and reduces the pressure during the opening period. Appropriate reduction of flow regulation during the opening of the river effectively reduced the peak flow of the Kaihe River during the flood period, and the situation of the opening of the river changed from "Wukai River" to "Wenkai River", which improved the initiative of anti-freezing work and effectively reduced the ice disaster during the opening period. In the past ten years, on the basis of fully studying the characteristics of the under-ice flow capacity of the river and the law of water flow propagation, the flood prevention and dispatching of reservoirs has developed in a more refined direction.

(4)Water and sand regulation and management

The main tasks of constructing the Yellow River water and sediment control system: scientifically control, use and shape floods, coordinate the relationship between water and sand, and provide important guarantees for flood control and blizzard safety; use the storage capacity of backbone reservoirs to hold and store sediment, especially the most harmful to river sedimentation. Coarse sand; reasonable allocation of water resources, ensure continuous flow of rivers, guarantee water for sand transportation and ecological water, and ensure the safety of water supply for life and production.

2.3 Basin hydropower complements other multi-energy

The sunshine conditions of the Yellow River Basin are sufficient in the whole country. The annual sunshine hours generally reach 2000-3300 hours; the annual sunshine percentage is mostly between 50% and 75%, second only to Qaidam, which has the most abundant sunshine. basin. Abundant light energy resources provide an opportunity for the vigorous development of the new energy industry in the Yellow River Basin, and the Upper Yellow River Hydropower Development Company is a leader in the photovoltaic power generation industry.

In accordance with the requirements of the Qinghai Provincial Party Committee and Government to build the largest photovoltaic power generation base, the Yellow River Upper Hydropower Development Company has become the largest photovoltaic power station operator in China and even the world. At present, 35 photovoltaic power stations have been built, with a total installed capacity of 2.86 million kW, and 16 wind power projects have been built with an installed capacity of 940,000 kW. Among them, the Longyangxia water-light complementary base has become a multi-energy complementary benchmark project.

The Longyangxia Hydro-Photovoltaic Complementary Photovoltaic Power Station Project is located in Talatan, Gonghe County, Hainan Prefecture, Qinghai Province. The annual average solar radiation in this area is above 6381.6MJ/m2, the annual average sunshine hours are above 2719 hours, and the annual average sunshine percentage Between 55%-80%.

figure2-1 Longyangxia water and light complementary base

2.3.1 Overview of Longyangxia Hydropower Station

The Longyangxia Hydropower Station is a cascaded "leading" reservoir power station in the Longyangxia-Qingtongxia section of the upper reaches of the Yellow River. The normal storage level is 2,600m, the dead water level is 2,530m, the storage capacity below the normal storage level is 24.7 billion m3, and the regulating storage capacity is 19.35 billion m3. Excellent adjustment performance for many years. The installed capacity of the power station is 1280MW, and the average annual power generation capacity for many years is 5.942 billion kWh. The first unit was put into production in September 1987, and all four units were put into operation in June 1989. The 363 kV GIS equipment of Longyangxia Hydropower Station has 6 outlet intervals, of which 5 outlet intervals have been used and 1 is reserved.

2.3.2 Overview of water and light complementary photovoltaic power plants

The photovoltaic power station is located on Tala Beach, Gonghe County, Hainan Prefecture, Qinghai Province. It covers an area of 24 km2 and is approximately 30 km away from the Longyangxia Hydropower Station in a straight line. The installed capacity of the first phase is 320 MWp, the designed average annual power generation is 498 million kWh, and the static investment of the project is 3.457 billion yuan. It was put into operation in December 2013; the installed capacity of the second phase is 530 MWp, and the designed average annual power generation is 936 million kWh. With a static investment of 4.960 billion yuan, the power generation was put into operation in December 2014, and all production was put into operation in August 2015. The total installed capacity of the two phases is 850MWp, the annual average power generation capacity is 1.434 billion kWh, and the annual utilization hours are 1687 h.

The coordinated operation and adjustment of water and light complementary operation is mainly based on the daily compensation of the Longyangxia Hydropower Station to the photovoltaic power station. The Longyangxia Hydropower Station is used to adjust the storage capacity to make up for the lack of power generation during the day and night of the photovoltaic power station. The photovoltaic power generation is compensated to obtain a stable and reliable Combination power supply. Basically does not change the role and status of Longyangxia Hydropower Station in the power system, does not affect the power generation efficiency of Longyangxia Hydropower Station, and satisfies the comprehensive utilization of Longyangxia and its cascade power stations for flood control, power generation, and irrigation, and the stable operation of Longyangxia Hydropower Station Under the requirements, following the principle of water balance, the fluctuation of hydropower flow after water and light complementation is completely reversed by the downstream Laxiwa Hydropower Station, which has little impact on the operation of Longyangxia Hydropower Station and downstream cascade power stations.

On the basis of comprehensive weather changes, temperature, seasons and other factors, according to the solar power forecasting system, the power generation of the photovoltaic power station on the second day is reported to the Northwest Grid at the same time as the dispatched power of Longyangxia Hydropower Station. The power output curve of the complementary combined power source is sent to the Longyangxia Power Station and the photovoltaic power station respectively. When the water and light are complementary to operate, according to the power generation output curve issued by the dispatch, if the photovoltaic is not generating power, the hydropower will generate electricity according to the power generation output curve; if the photovoltaic power generation output is large, the hydropower will reduce the output and adjust the hydropower and photovoltaic power generation output. And meet the requirements of power generation output curve.

The water-light complementary power supply combination undertakes system backup and maintenance, etc. The situation varies slightly depending on the daily power generation of photovoltaic power plants. When the photovoltaic power generation is average or small, it will basically not affect the system backup and maintenance capacity, but when photovoltaic power generation When the amount is large, adjustments are needed to undertake system backup and maintenance. If the system cannot be accepted after adjustment, appropriate load reduction of photovoltaics needs to be considered, and the safe and stable operation of the power system is the premise for water and solar complementary operation.

2.4 River Basin Electricity Market Situation

The Longyangxia Hydro-Photovoltaic Complementary Photovoltaic Power Station has participated in the power market of the Northwest Power Grid, and conducts electricity trading through the Northwest Power Grid Qinghai Province inter-provincial power market system. As photovoltaic power generation still enjoys the national new energy power generation subsidy policy, at present, Huangshang Hydropower Development Company adopts the strategy of ultra-low quotation when participating in the power market bidding and strives to complete the online transaction. The intraday quotation is 0.01 yuan/kW•h, the final transaction price is 0.1 yuan/kW•h-0.2 yuan/kW•h, and the national photovoltaic power generation subsidy is about 0.4 yuan/kW•h. After calculation, the final photovoltaic power station is sold The price is nearly 0.5 yuan/kW•h.

3 Key technologies of cascade dispatching in river basin

3.1 Joint dispatch technology and system

The Yellow River water and sediment control system consists of engineering systems and non-engineering systems. Take the backbone of Longyangxia, Liujiaxia, Heishan Gorge, Qikou, Guxian, Sanmenxia, Xiaolangdi and other key water conservancy projects as the main body, and take the main river’s Haibowan, Wanjiazhai Reservoir and tributaries of Luhun, Guxian and Hekou villages , Dongzhuang and other controlled reservoirs are supplemented to form a complete Yellow River water and sediment control engineering system. Among them, Longyang Gorge, Liujiaxia, Heishan Gorge and Haibowan Water Conservancy Projects constitute the upstream control sub-system, Qikou, Guxian, Sanmenxia, Xiaolangdi and Wanjiazhai, Luhun, Guxian, Hekou Village, Dongzhuang and other water conservancy projects constitute the midstream control sub-system; the Yellow River water and sediment control non-engineering system is formed by water and sediment monitoring, water and sediment forecasting, and reservoir scheduling decision support systems. Provide technical support for the Yellow River water and sediment joint operation.

(1) Upstream regulatory sub-system joint operation mechanism

The Longyangxia and Liujiaxia Reservoirs have jointly adjusted the water volume of the Yellow River and the volume of water entering the Yellow River from the west route of the South-to-North Water Transfer Project to compensate for the dry season and increase the water supply capacity of the Yellow River in dry years, especially continuous dry years. The Heishan Gorge Reservoir mainly counter-regulates the discharge of upstream cascade power stations, improves the relationship between water and sediment in the Ningmeng River section, and supplements the water and sediment adjustment of the middle reaches of the reservoir; regulates the flow during the freezing flood period to ensure the safety of the Ningmeng River section; regulates the runoff, Timely water supply in the industrial, agricultural and ecological irrigation areas of the Ningmeng River section. The Haibowan Water Conservancy Project mainly cooperates with the upstream key reservoirs to prevent ice, and cooperate with the upstream key reservoirs to adjust water and sediment during the flood season.

(2) Joint Operation Mechanism of Midstream Regulatory Subsystem

The joint application of the midstream regulation and control sub-systems is to jointly manage the Yellow River floods. In the event of a catastrophic flood in the Yellow River, the peak flow is reasonably reduced to ensure the safety of flood control in the lower reaches of the Yellow River; when the Yellow River occurs in the middle and regular floods, the process of high sediment flooding in the middle reaches is jointly regulated. Give full play to the sediment-carrying capacity of the water flow, transport sand into the sea, reduce the siltation of the main channel of the river, and shape suitable water and sand conditions for the siltation of the middle and lower beaches; in order to prevent the main channel of the river from silting and shrinking when there is no flood in the Yellow River for a long time, Jointly adjust the water volume to shape the artificial flood process and maintain the flood and sediment transport capacity of the middle water channel. The second is the joint use of the reservoirs for coarse and fine drainage, as far as possible to intercept the coarse sediment that is the most harmful to river sedimentation; the third is to jointly regulate the runoff, give full play to the benefits of comprehensive utilization of water supply and power generation, and ensure the safety of the lower Yellow River.

Before the completion of the Guxian Reservoir, the Xiaolangdi Reservoir was mainly used for the combined water and sediment diversion of the main and tributary backbone projects, and the Wanjiazhai Reservoir, Sanmenxia Reservoir and tributary reservoirs in the middle reach were used in conjunction.

(3) Joint operation mechanism of upstream sub-system and midstream sub-system

According to the water resources allocation requirements of the Yellow River, the upstream sub-system reasonably arranges the amount and process of water discharge during the flood season to provide hydrodynamic conditions for the joint water and sediment regulation of the midstream sub-system; when the middle-stream reservoir needs to flush and discharge sediment and restore the storage capacity, the upstream sub-system discharges a large amount of water , Forming a water-sediment process suitable for river channel sediment transport; the midstream sub-system readjusts the water-sediment process discharged from the upstream sub-system, the sediment adjusted by the river channel scouring and silting, and the inflow and sediment process of the interval, forming a favorable downstream river channel The water-sand process of sand reduces siltation in reservoirs and downstream rivers.

3.2 Decision support system or system platform

The General Office of the Yellow River Prevention has completed the cooperation between China and Finland-the Yellow River Flood Control and Dispatch System, the Yellow River Flood Control Forecast Dispatch and

Management Coupling System, the first phase of the National Flood Control and Drought Relief Command System-the Yellow River Flood Control Dispatch System (Phase 1), and continue to build and upgrade the system Transformation to form the current flood control dispatching system in the middle and lower reaches of the Yellow River.

(1) Guiding ideology of system construction

The water-sediment joint regulation of the middle and lower reservoir groups can effectively control the water-sediment relationship entering the downstream rivers, and solve the problems of shrinkage of the main channel of the downstream rivers and river siltation. At the same time, the joint operation of these reservoirs can also use the means of shaping artificial density flow to reduce sedimentation in the reservoir area and extend the service life of the reservoir.

Focusing on system construction, one is to use analysis to sort out various information resources involved in flood control and dispatching of the Yellow River. The second is to analyze the characteristics of flood control work such as forecasting, flood evolution, and reservoir scheduling, pay attention to the unified management of water and sand, and gradually realize the calculation of the water and sediment process in stages. The third is to introduce new technologies and new concepts, such as "coupling" thinking, risk decision-making, and multi-objective optimization decision-making concepts to solve the problems of system separation and single function in a unified way.

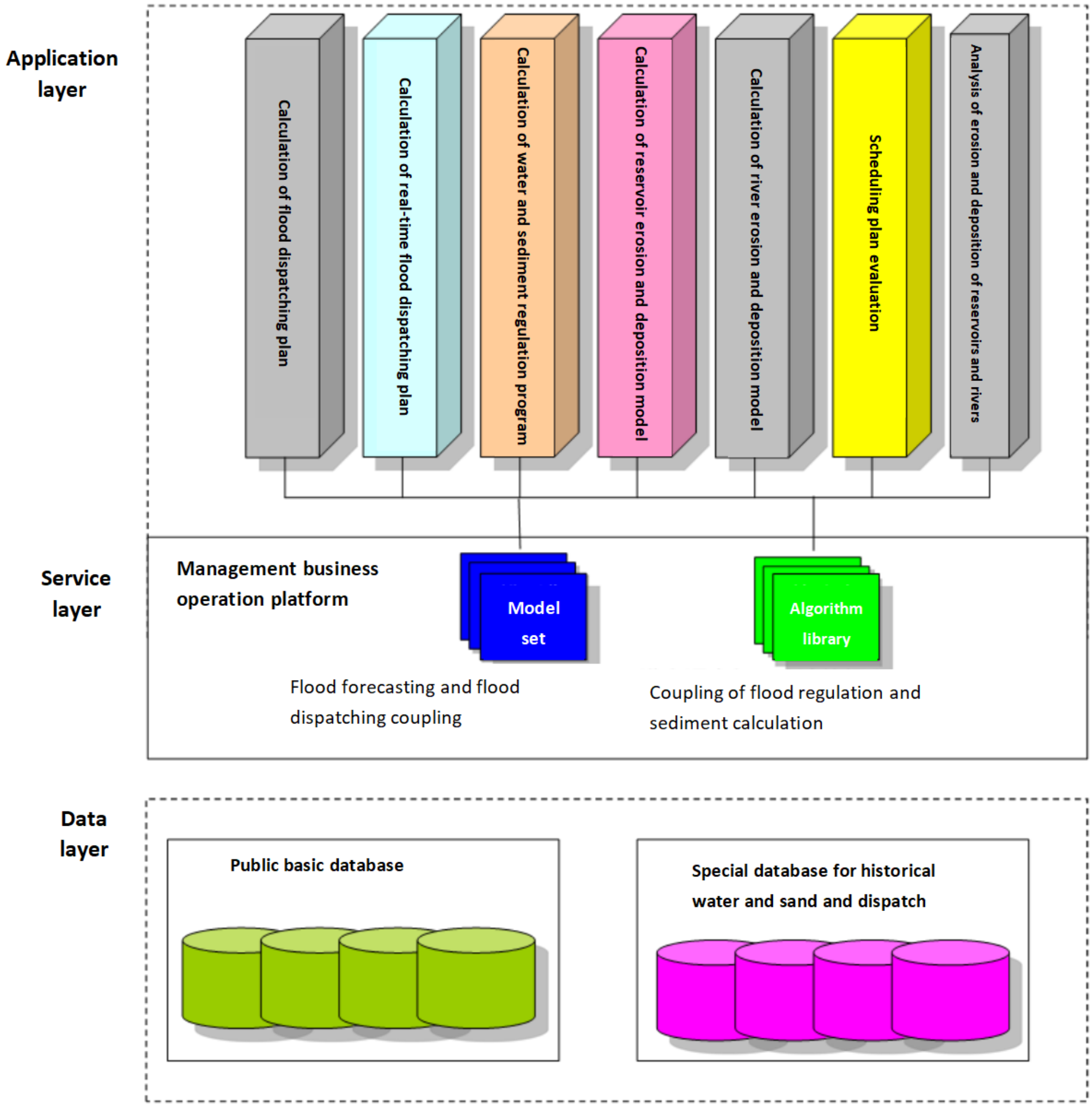
(2) The overall idea of system design

The overall idea of the system design is to take flood dispatch as the main line, focus on water-sediment joint dispatch, and penetrate the coupling thought to realize the coupling of flood forecasting and flood control dispatching, the coupling of reservoir dispatching and reservoir area scour and silting model calculation, and the flow and sediment evolution of downstream rivers. Calculation coupling of erosion and deposition model.

(3) Main features of the system

In the development process, the particle swarm optimization scheduling technology and the sediment model were introduced for the first time, which realized the combined water and sediment scheduling and solved some key technical problems. The main features include: standardized overall model packaging; task chain hierarchical management to realize the flexibility of processing task additions and reductions and selection; organic coupling of forecasting and scheduling; coupled processing under complex conditions of water and sand processes.

figure3-10 verall framework of the decision support system for water and sediment regulation in the middle and lower reaches of the Yellow River



Management Model of Cascade Reservoirs in Pearl River Basin

1.An overview of cascade reservoirs in a river basin

1.1 Basic situation of river basin

The Pearl River is the largest river in southern China. Ma Xiong Mountain, originating from the Yunnan-Guizhou Plateau, traverses the land of South China from west to east. Together with the Yangtze River, the Yellow River, the Huai River, the Haihe River, the Songhua River, and the Liao River, it is called the seven major rivers in China. It is composed of the Xijiang, Beijiang, East River and the Pearl River Delta. After entering the Pearl River Delta, Beijiang and East River will enter the South China Sea via Humen, Jiaomen, Hongqimen, Hengmen, Modaomen, Jichaomen, Hutiaomen, and Yamen, forming Hong Kong and Macau Special Administrative Regions. And northeastern Vietnam.

figure1 Schematic diagram of the Pearl River Basin

The Pearl River has abundant runoff and abundant hydraulic resources. There are 570 rivers with a theoretical reserve of 100,000 kW and above, and a theoretical reserve of 46.454 million kW. The technology of a single station with an installed capacity of 5,000 kW and above can develop 2504 hydropower stations. The total installed capacity is 39.005 million kW, and the annual power generation is 168.2 billion kWh; there are 2,263 economically developable hydropower stations, the total installed capacity is 37.321 million kW, and the annual power generation is 160.6

billion kWh. Among them, the Hongshui River on the Xijiang River has a concentrated drop, large flow, and superior development conditions. It is known as the "rich mine" of hydraulic resources.

(1) Climate

The Pearl River is located on the north and south sides of the Tropic of Cancer, and is close to the South China Sea. Affected by the southeast monsoon and southwest monsoon, the spring is overcast and rainy; summer is hot and humid with concentrated rainstorms; tropical cyclones invade frequently in autumn; and warm and drier in winter. It belongs to the tropical and subtropical monsoon climate zone, the climate is mild and rainy, and the annual average temperature is between 14℃ and 22℃, with little inter-annual change. The rainfall is abundant, with an average rainfall of 1525.1 mm for many years. The rainfall decreases from east to west. The time distribution of precipitation is unbalanced, and precipitation in the rainy season (April to September) can account for more than 80% of the year. The turn of spring and summer is often the period when rainfall is most concentrated, which can easily lead to flood disasters. Disastrous climate hazards are serious. The wet season rainfall is too concentrated, and the rainfall intensity is high. In some areas, a continuous rainfall can reach more than 400 mm. Even river valleys and plains are prone to flood disasters, and mountains are prone to water and soil erosion. The dry season rainfall is significantly less. , The spring drought is prominent and has a greater impact. The southeast coastal area is a high-frequency area through which tropical cyclones pass, which are affected 6-9 times a year on average. July-September is the high-frequency season for tropical cyclones. Tropical cyclones bring storms, heavy rains and storms, which are more destructive, but they also bring abundant rains, which have a positive effect on alleviating summer and autumn droughts, and also have a positive effect on eliminating pests and diseases. The dry season is from October to March of the following year, and the runoff accounts for about 22% of the whole year. The average flow of the driest month often occurs from December to February of the following year, and mostly occurs in January.。

(2) Hydro

The Pearl River Basin has abundant rainfall, which is characterized by long duration and high intensity, but its temporal and spatial distribution is uneven. The Pearl River has an average annual runoff of 336 billion m3, of which the Xijiang River is 238 billion m3, the Beijiang River is 39.4 billion m3, the East River is 23.8 billion m3, and the delta is 34.8 billion m3. It is the second largest river in China, second only to the Yangtze River, and the total amount of the Yellow River. 4 times the flow rate. The distribution of runoff during the year is extremely uneven. The flood season from April to September accounts for about 80% of the total annual runoff, and the three months from June, July and August account for more than 50% of the annual runoff.

1.2 Development of Cascade Hydropower in the Basin

(1) West River

The Xijiang River is the main water system of the Pearl River Basin. It originated from the Maxiong Mountain in the Wumeng Mountains in Qujing City. The main stream is divided into five sections of Nanpan River, Hongshui River, Qianjiang River, Xunjiang River and Xijiang River from west to east. It enters Guangdong via Guizhou and Guangxi, and enters the Pearl River Delta river network area after Sixianjiao Huihui Beijiang. The main stream is 2075km long from the source to Xijiaokou of Sixianjiao, with an average river slope of 0.58‰ and a rain-collecting area of 353,120 km2.

table1 Basic situation of the main rivers of the Xijiang River

River name	level	Catchment area (km^2)	starting point	End point	length (km)	Average gradient (‰)	Annual average runoff (100 million m3)
West River	Main stream	17970	Jiangkou Town, Fengkai County	Mimizu basement west exit	208	0.58	2330
He River	Primary tributary	3091	Nanfeng Town, Fengkai County	Fengkai Jiangkou Town	104	0.47	118
Luoding River	Primary tributar	4493	Xinyi Kaopaili	Yunan Nanjiang	201	0.87	39

	y		ng	kou			
Xinxing River	Primary tributary	2355	Enping Tianlu Mountain	Gaoyao Xinjiang kou	145	0.98	23

There are 12 rivers with theoretical reserves of not less than 10MW in the Xijiang River Basin in Guangdong Province (including transboundary rivers greater than 10MW). The theoretical reserves of hydraulic resources of the rivers have an average power of 741MW and an electricity of 6.49 billion kWh, accounting for the province's theoretical reserves. 6.5%. The main stream of the Xijiang River in Guangdong Province is relatively flat, with a total river length of 208km and a total drop of 6m. The theoretical total average power of hydropower resources is 410MW, and the electricity is 3.592 billion kWh, which accounts for 30% of the theoretical reserves of the Xijiang River Basin. Within the statistical scope of the theoretical reserves of the Xijiang River Basin in Guangdong Province, there are 239 rivers of less than 10MW. The theoretical reserves of hydraulic resources of the rivers are 624.4MW, and the electricity is 5.47 billion kWh, accounting for 5.5% of the province's theoretical reserves.

Although the main stream of the Xijiang River is rich in water and has a large runoff, it is located in the lower reaches of the river. The river bed is flat and the drop is small. Although the tributaries that merge along the two banks of the main stream have a large drop, the basin area is small and the local water volume is small. Therefore, the Xijiang River Theory The reserves are not large. Coupled with the densely populated towns and populations on both sides of the river section, only low-head power stations should be arranged. Power generation is not the main task of the main stream of the Xijiang River. The tributaries of the He River, the upper reaches of the Luoding River, the upper reaches of the Xinxing River and other tributaries at all levels with rich hydropower resources, such as Yulao River, Datan River, Luojing River, Silun River, Baishi River, Huanghua River, Qianpai River, are developed by hydropower Mainly, combined with other requirements such as flood control and irrigation. Among the hydropower stations that have been developed, there are only 4 power stations with an installed capacity of more than 10MW, namely Duping, Baigu, Jiangkou, and Fucao. Among them, Duping, Baigu, and

Jiangkou are located on the main stream of the Hejiang River.

(2) North River

Beijiang is a major river in the Pearl River Basin. It originated from Damao Mountain, Shijie, Xinfeng County, Jiangxi Province. The main stream is 468km in length from the source to Sixian River in Sanshui, Guangdong Province, with an average slope drop of 0.26% and a drainage area of 46710km2. The upstream water was called Beijiang after the confluence of Shaoguan City, Guangdong Province and Wushui originating in Hunan Province. From below Shaoguan to Feilai Gorge in Qingyuan City is the middle reaches, and the Feilai Gorge to Sixianjiao is the lower reaches. It is 253km, the drop is about 50m, and the average gradient is 0.2%. The main tributaries of the Beijiang River are Wushui, Nanshui, Manjiang, Lianjiang, Xiejiang and Binjiang, which are plume-shaped on both sides of the main stream.

The general topography of the basin is high in the north and low in the south. Three rows of arc-shaped mountains constitute the geomorphic features of the area. There are valleys and basins between the rows of mountains. The main stream of the North River cuts the arc-shaped mountains longitudinally. After the Feilai Gorge, the terrain on both sides Flat and open. The Qingyuan Plain in the lower reaches of the Beijiang River is the northern terrace of the Beijiang River Delta. The main stream of the Beijiang River circulates on the plain. There are embankments along both sides of the river. The more famous ones are Beijiang Dike, Qingdongwei, Qingxiwei, Qingcheng Lianwei, Qingbeiwei Wait. Among them, the Beijiang Dike is the flood control barrier of Guangzhou City and one of the seven major river dikes in the country.

In the 1990s, with the start of construction of Feilaixia Water Control Project, Mengzhouba, Baishiyao and Mengli cascade power stations also started. So far, the Feilaixia Hydropower Project and the Mengzhouba and Baishiyao Hydropower Stations have been put into operation for many years. The Mengli Hydropower Station has achieved benefits in 2005, and the development of the reach below the Feilaixia River has also been on the agenda.

(3) East River

The East River is one of the main rivers in the Pearl River Basin. It originated from Yajibo, Xunwu County, Jiangxi Province. The upstream is called Xunwushui, and it is called East River after Heheba in Longchuan. The Xinfengjiang Reservoir, Fengshuba Reservoir and Baipenzhu Reservoir have been built in the basin, referred to as the "Three Reservoirs on the East River". The total rain collection area of the three major reservoirs is 11740km2, accounting for 43.1% of the control area above Shilong, the total storage capacity is 16.992 billion m3, and the controlled water volume is 11.29 billion m3, which is equivalent to 41.3% of the average annual runoff of the East River; the comprehensive average storage capacity of the three major reservoirs The coefficient is 0.71, which has a high degree of control over the river basin, and is the main controlled water storage project in the East River basin. Through the joint optimization of the three reservoirs, it can meet the water demand inside and outside the lower reaches of the East River, and together with the middle and lower reaches of the river, it forms a flood defense system that combines the main stream of the East River with dykes and reservoirs to ensure the safety of people's lives and properties along the middle and lower reaches.

The hydropower technology available for the main stream of the East River is 537,700 kW. The cascade layout plan below Fengshuba is a 14-level cascade development. Except for a small amount of dredging to meet the channelization of the channel, the water level between the cascades can basically be connected. . At present, 13 of them have undergone various levels of development (including Fengshu Dam), all of which are low-head runoff power stations. The total installed capacity of the power stations that have been and are being developed has reached 477,700 kW, accounting for 88.51% of the technologically developable volume of the main stream of the East River. The degree of development is relatively high. The scale and power generation capacity of other hydropower stations in the East River Basin are much smaller than those of Xinfengjiang and Fengshuba.

The location of the main cascade reservoirs on the East River is shown in Figure 2.

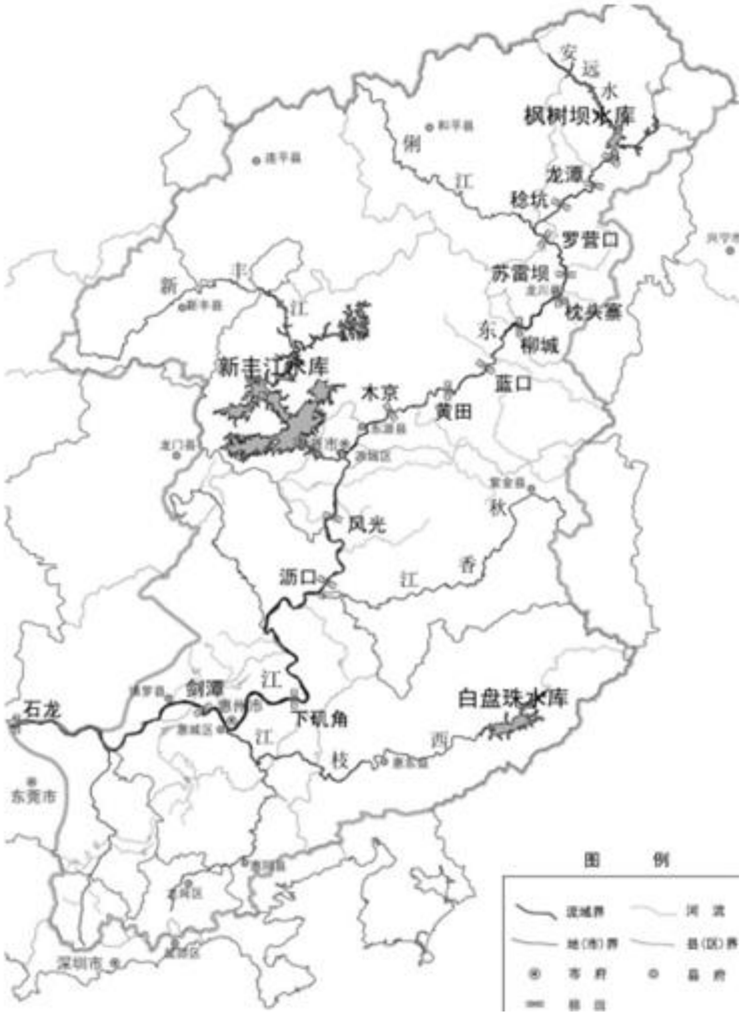


figure2 Schematic diagram of the location of the main steps of East River

The original plan of 15 cascade power stations on the main stream of the East River only left Jijiao and Shilong cascades undeveloped. With the increasingly prominent contradiction between water supply and demand and water environment problems, future cascade development should pay more attention to water resources allocation and water environment improvement And other comprehensive utilization needs.

2. River Basin Cascade Reservoir Management

2.1 Current management model

(1) The overall situation of dispatching management in the Pearl River Basin

The Pearl River Water Conservancy Committee (hereinafter referred to as the Pearl River Committee) of the Ministry of Water Resources was established in 1979. It is a river basin management agency dispatched by the Ministry of Water Resources. It operates in the Pearl River Basin, the Han River Basin, the international rivers east of the Lancang River (excluding the Lancang River), the coastal rivers of Guangdong and Guangxi, and Hainan Province. The region shall exercise water administrative responsibilities in accordance with the law, be responsible for ensuring the rational development and utilization of water resources in the river basin, be responsible for the management and supervision of water resources in the river basin, and coordinate the life, production and ecological water use of the river basin. Since the establishment of the Pearl River Defense Headquarters, it has continuously strengthened the management of river basin reservoir dispatching, gradually standardizing the dispatching management authority and responsibilities of key river basin reservoirs and provincial boundary reservoirs, continuously expanding the field of river basin dispatching, and strengthening the unified dispatch and management of the basin. Through the practice of dispatching in recent years, the Pearl River Basin dispatching plan and pre-plan system have been continuously improved, and dispatching management has been gradually standardized, precise, and rationalized, ensuring the safety of flood control, water supply and ecological safety in the basin.

Before the flood, the Zhuhai Prevention Office organized the review and approval of the flood season scheduling and operation plans of key river basins and provincial boundary reservoirs, held a flood coordination meeting involving cross-provincial rivers and key reservoirs, and urged key reservoirs in the river basin to cut down the reservoir water level to cope with the flooding process during the flood season . During the flood season, scientifically regulate the key reservoirs of the river basin, give full play to the role of reservoirs in flood interception, peak cutting and peak shifting, reduce the pressure on flood control in the middle and lower reaches of the basin, and ensure the safety of flood control in the basin. Starting in 2016, the Pearl River Defense General Organization has implemented the water regulation (experimental) during the fish breeding period in the mainstream of the Xijiang River. Through the implementation of the reservoir group scheduling in the upper and middle reaches of the Xijiang River, it has created a flow process suitable for the reproduction of target fishes in the mainstream of the Xijiang River, and is the four major spawners in the downstream The spawning and reproduction of fish provide better ecological conditions. In the latter flood season, under the premise of ensuring the safety of flood control, we will coordinate the implementation of risk-controllable key reservoirs at the end of the flood season, rationally utilize rain and flood resources, reserve water sources for the implementation of dry season water dispatch, and realize seamless connection between flood season and dry season water dispatch. During the dry season, coordinate the implementation of the Pearl River water dispatch during the dry season. Through the practice of dispatch, dispatching technologies such as "starting and suppressing the end", "avoiding fluctuations and falling", and "dynamic control" have been put forward, forming pre-storage and post-replenishment, node control, upper and lower linkage, and total Scheduling ideas for volume control.

In the flood season of 2017, three numbered floods occurred on the main stream of the Xijiang River. The Pearl River Defense Association and the relevant provinces (autonomous regions) have implemented fine dispatches for many times. They have issued 12 dispatch orders with a dispatch period of up to 83 days, effectively reducing the number of floods in the Xijiang River. The flood control pressure of the downstream, Datengxia Water Control Project and Gaobei Water Control Project successfully avoided flooding Nanfeng Town and Chayang Town in the lower reaches of the Hejiang River in Guangdong Province and ensured the safety of flood control in the upper and lower reaches of the basin. From late June to early July, in response to the No. 1 and 2 floods of the Xijiang River, the Pearl River Defense General Organization implemented the joint dispatching of key reservoirs in the main river basins such as Tianshengqiao I, Longtan Hydropower Station, Yantan Hydropower Station, and Baise Water Conservancy Project to give full play to the cascade. Reservoir's effects of blocking flood, peak cutting and peak staggering. In early and mid-August, in response to the Xijiang River No. 3 flood, the Pearl River Defense Group once again scientifically dispatched the Longtan, Yantan and Baise reservoirs. At the same time, under the premise of ensuring the safety of the reservoir, the reservoir should give full play to the role of flood blocking and peak staggering, and make overall arrangements for the implementation of the storage and dispatching of the backbone reservoirs at the end of the flood period to prepare sufficient water sources for the Pearl River water dispatch during the dry season. Through water volume scheduling, the process of controlling the cross-section flow generally meets the needs of fish reproduction, significantly improving the fish reproduction habitat and migration channel conditions, and the scale of fish resources in the trunk and tributaries of the Xijiang River is effectively maintained. In the post-flood season, under the premise of ensuring the safety of flood control, the Pearl River Defense President plans to implement risk-controllable key reservoirs at the end of the flood season. After water storage scheduling, the key reservoirs of the Xijiang Tianshengqiao I, Longtan, Yantan, Baise, Changzhou and other river basins increased their water sources by about 3.16 billion m3. At 8 o'clock on September 30, the Tianshengqiao I, Longtan and Baise three The effective water storage capacity of the backbone reservoir is 17.8 billion m3, and the effective water storage rate is 91%. Since the start of water scheduling, the Zhuhai Prevention and Control Office has closely monitored the rainfall in the river basin and the salt tide activity in the Pearl River estuary, rolling analysis of the water supply safety situation, scientifically dispatching the upstream backbone reservoirs, and promptly urging relevant units in Zhuhai to seize favorable opportunities to grab fresh water to replenish the reservoirs , The work of water scheduling in winter and spring was carried out in an orderly manner.。

（2）Small Hydropower Management Mode in the Pearl River Basin

The geographical topography of the Pearl River Basin has created abundant and widely distributed small hydropower resources. In remote mountainous areas, the development and utilization according to local conditions has not only developed the local economy, but also solved the problem of local power consumption. Due to the small investment, low risk, stable benefits, and low operating costs of small hydropower stations, state-owned, collective, and private enterprises and other economic entities have invested in small hydropower construction everywhere, realizing the coordinated development of economic, social and environmental benefits.

China's small hydropower management entities mainly include state-owned power generation group companies, state-owned local power generation companies, centralized power generation companies, joint-stock power generation companies, and private power generation companies. Different management entities adopt different management modes, and each management mode has its own advantages and disadvantages. China Datang Group Guangxi Branch's small hydropower stations are mainly distributed in the Pearl River Basin in Guangxi. There are 24 small hydropower stations with an installed capacity of less than 50,000 kW [1], and their management modes are mainly as follows:

1) The original single-station operation and management mode of power enterprises

The operation and maintenance are separated. Generally, there are operation, electromechanical, and hydraulic workshops (departments and safety supervision departments, as well as finance, human resources, party and government work groups and other departments. Due to the small scale of small hydropower, the annual power generation is low , It is difficult to withstand its operation, and there is a serious "big pot meal" problem.

2) Management mode of collective joint-stock power generation company

Affected by state-owned power enterprises, their management basically follows the original power enterprise operation and management model, which is large and comprehensive, and the enterprise has a heavy burden. There is also the problem of "big pot of rice", management responsibilities are not clear, income equalization assessment is formalized, and posts are set up according to people, etc., and the enthusiasm of enterprises to promote is not high.

3) Private joint-stock management model

Its management is completely different from that of state-owned power enterprises. In order to maximize the benefits, the organization is simple, the staffing is small, and the management mechanism cannot meet the normal safety production needs. There are many loopholes in operation management, some basic production management rules and regulations have not been established and perfect, and there are serious hidden dangers in safe production.

4) Watershed management model

For cascade power stations in the same river basin, the management mode of basin cascade centralized control is implemented. The corresponding production management departments such as safety supervision, equipment and operation are set up at the company level. Workshop-style management is implemented for the power stations under its jurisdiction. Operation and maintenance personnel are assigned by the basin. The company deploys uniformly, and the personnel are relatively fixed.

5) Regional management mode

Small hydropower stations (10-50MW) in the same management area, with geographical proximity advantages, implement regional management mode. The regional company set up a relatively complete production and operation management organization, equipped with full-time production management personnel such as safety supervision, equipment, and operation, and coordinated to guide the production management of the subordinate power stations; the organization of the subordinate power stations was relatively simplified, and the workshop style under the factory director responsibility system was implemented. Management, only set up operation and maintenance teams, responsible for the daily operation and maintenance of the power station.

6) Private management model

Because its assets are privately owned by shareholders, due to lack of experience in power station construction and operation, unreasonable investment during the construction period, saving project investment and inferior project quality, etc., bring hidden dangers to the safe operation of the power station; institutions, personnel, and systems are not sound, eager Production, focus on marketing, and lack of management are common problems of private small hydropower stations.

7) Entrusted management mode

Some small hydropower companies entrust professional operation and maintenance management companies affiliated to large and medium-sized power stations to undertake power generation operations. Technical strength and management capabilities are guaranteed, which reduces the operation risks of small hydropower stations. However, the inability to control the management process makes the owners worry about the loss of profits in the process, and the investment in entrusted management also weakens the profit space.

8) Company operation, power plant management mode

Establish a management company and implement the general manager responsibility system. Clarify the management authority of the general manager (factory director) for people, finances, and materials, and set up functional departments to supervise, coordinate and guide the power plants, including safe production and technology. Its advantages lie in clear responsibilities, standardized management, fewer intermediate links, direct and effective command, etc.; the main disadvantages are less staffing, large management scope and span, long business approval process, and low efficiency.

2.2 Comprehensive utilization of watershed

The comprehensive utilization of the Pearl River Basin includes flood control, navigation, power generation, water resources allocation, irrigation and ecological protection. Except for the few backbone cascade power stations such as Longtan and Datangxia Water Control Project, which have flood control and navigation functions, most of the other cascade power stations are mainly for power generation.

In terms of power generation and transmission, the cascade power stations in the Pearl River Basin are under the jurisdiction of the China Southern Power Grid. China Southern Power Grid is the highest leadership and management organization of China Southern Power Grid. The China Southern Power Grid Electric Power Dispatching Control Center (hereinafter referred to as the Southern Power Grid Corporation of China) is a direct agency of China Southern Power Grid Corporation and the highest dispatching and commanding organization for the operation of China Southern Power Grid. China Southern Power Grid implements a four-level dispatch system of "unified dispatch and hierarchical management", that is, the power dispatching organization is divided into four levels in the order of superiority and superiority: the first level dispatch is the China Southern Power Grid power dispatch control center; the second level dispatch is the province (autonomous region) level Dispatching agency; the third-level dispatching is the district (city, state)-level power dispatching agency; the fourth-level dispatching is the city and county-level power dispatching agency. The Southern Power Grid General Commissioner is responsible for the organization, command, guidance, and coordination of the entire network operation, as well as 9 major management of power grid dispatch, operation mode, hydropower dispatch, relay protection, power communication, dispatch automation, safety supervision, technical economy, and comprehensive management. Work hard to improve the safe, economic, high-quality, and environmentally-friendly operation of the power grid. Among them, the Longtan Hydropower Plant is one of the top ten landmark projects of the country's "Western Development" and one of the strategic projects of "Power Transmission from West to East".

Regarding water dispatching, it is dispatched by the Pearl River Water Conservancy Commission. The occurrence time of floods in the Pearl River Basin is the same as that of heavy rains, mostly from April to October. According to the differences in the weather systems that form heavy rains and floods, the flood period can be divided into the first flood season (April to June) and the latter flood season (July to October)). The floods mainly came from the west and north rivers. Due to the long duration, high intensity, and wide range of heavy rains, the water system in the basin is developed, the upper and middle reaches are many hills, and the flood confluence is fast, and it is easy to gather into the main stream at the same time. In addition, the lack of lake regulation and storage makes the middle and lower reaches and delta floods have high peaks and large amounts. , The characteristics of long duration, local areas are prone to form mountain torrents, debris flow.

The Datengxia Water Control Project, a flood control control project on the mainstream of the Xijiang River, has not yet been completed. The main tributaries of the Liujiang River, Yangxi, Luojiu, Mudong and other reservoirs have not been built; the Hanjiang Gaobei Reservoir has not yet been completed, and the Beijiang River flood storage and detention area has not been safely constructed. The construction of dikes and sea dikes for part of the trunk and tributaries of the basin has not been completed. The imperfection of the flood control engineering system has resulted in insufficient flood control capacity in the middle and lower reaches, making it difficult to withstand major floods. According to laws and regulations such as the Flood Control Law and Flood Control Regulations, flood control and water resource dispatching are subject to the management of local water conservancy (flood control) departments at all levels in accordance with the territorial management principle. The dispatching is also similar to power dispatching, and there is a multi-level management or dispatching relationship. 1. Longtan and Yantan are mainly dispatched by the Watershed Prevention Directorate (Pearl River Control Directorate) and supervised by the provincial prevention indicator. Other power plants mainly receive the provincial prevention indicator dispatch and also accept the leaders of the city and county flood prevention departments. Water resources dispatch is currently being implemented mainly by river basin prevention and control. Starting from 2005, the Pearl River Water Conservancy Commission in the dry season will consider the basin water allocation according to the water and salt conditions, mainly from the upstream Tianyi, Longtan, Yantan and other reservoirs. To alleviate or eliminate seawater uptracking in the Pearl River Delta region, and ensure the safety of water supply in Zhuhai and Macau.

In terms of shipping, it is uniformly dispatched by the Pearl River Navigation Administration Bureau of the Ministry of Transport. The abundant river water and numerous tributaries of the Pearl River have brought superior conditions for shipping. The Pearl River is the main waterway of China's inland river transportation after the Yangtze River. The freight volume accounts for about 20% of the country's inland river transportation freight volume. Among them, the Pearl River foreign trade container transportation accounts for about 70% of the country's inland river container traffic. It is a veritable "golden waterway". . The main ports along the Yangtze River are Guigang, Wuzhou and Guangzhou. Among them, Guangzhou is a river port, which is the largest river port on the main stream of the Pearl River and the largest sea port in the South China Sea. Other important river ports include Guiping, Shilong, Guilin, Liuzhou, Nanning, etc., all of which are accessible by small ships. Over the years, the Pearl River inland navigation infrastructure has been continuously strengthened, which not only promotes the sustainable development of shipping, but also promotes the development and construction of cities and towns along the river, the formation of industrial belts along the river, and the development of the national economy in the hinterland. Connecting Yunnan-Guizhou, traversing Guangdong and Guangxi, reaching Hong Kong and Macau, and radiating ASEAN, the Pearl River is the second largest navigable river in China. It is an important water transportation channel in South China and Southwest China.

2.3 River Basin Electricity Market Situation

As a regional power trading platform, the Guangzhou Power Exchange Center is mainly responsible for implementing the national strategy for power transmission from west to east, implementing national mandatory plans, framework agreements between local governments, conducting cross-regional and cross-provincial market transactions, and promoting inter-provincial surplus adjustment and clean energy consumption. It will gradually promote market integration in the southern region. Adhere to our own responsibilities, seek breakthroughs through innovation, constantly explore new mechanisms, new systems, and new models, and make the greatest efforts to promote the role of a platform for adjusting the surplus and deficiencies of the provinces and the clean energy consumption platform.

First, the task of surplus hydropower consumption in Yunnan has been exceeded. Implementing the strategy of power transmission from west to east and ensuring the completion of the annual mission of power transmission from west to east are the core tasks of the Guangzhou Electric Power Trading Center, especially when the task of absorbing surplus hydropower in Yunnan in 2017 is very difficult, relying on the large platform of China Southern Power Grid. In accordance with the "plan + market" model, we will make every effort to promote the consumption of surplus hydropower in Yunnan. On the one hand, strengthening the management and control of the west-to-east power transmission plan and promoting the decomposition of the west-to-east power transmission plan into specific power plants has increased the rigidity of plan implementation. At the same time, we will closely follow the changes in natural water, electricity supply and demand, and hydropower consumption in Yunnan, and optimize and adjust the west-to-east power transmission plan in time, especially taking advantage of the shortage of electricity and coal in Guizhou from January to May to effectively reduce the pre-flood water levels of various reservoirs in Yunnan. On the other hand, actively carry out incremental market-oriented transactions. Utilizing the market-oriented model to flexibly coordinate and solve the transaction of additional power delivery outside of the plan, successively organized 2 negotiation transactions, 12 monthly listing transactions, 6 power generation contract transfer transactions, and 1 Yungui hydro-thermal power replacement listing transaction. The total transaction power was 26.8 billion KW. Time. At the same time, vigorously tap the space for additional delivery. On the basis of the existing west-to-east power transmission and market-oriented mechanism, we have researched and formulated the Yunnan-Guizhou hydro-thermal power replacement plan, and the Yunnan-Guangxi market-oriented transaction plan for additional transmission to Guangxi, and successfully launched the Yunnan-Guizhou hydro-thermal replacement listing transaction in September, realizing the original mechanism Breakthrough. Through unremitting efforts, in 2017, the National Development and Reform Commission's 20 billion KW surplus hydropower consumption target in Yunnan was exceeded.

Second, the construction of inter-provincial and inter-regional power markets has achieved remarkable results. Adhering to establishing rules, building platforms, and attracting the main body, the "four beams and eight pillars" of the inter-provincial and inter-regional power market in the southern region have basically been built. The trading rules were officially issued and implemented. The "Southern Regional Cross-regional and Cross-provincial Monthly Electricity Trading Rules" were officially issued and implemented in June 2017 after being approved by the National Development and Reform Commission and the National Energy Administration, clarifying the types of transactions, transaction timing, settlement processing, and transaction fees Basic matters such as market operation. The trading functions of the trading platform have been gradually improved. After being launched in September 2016, the development of monthly power generation contract transfer transactions, monthly incremental listing transactions, and centralized bidding transactions have been completed. A breakthrough has been made in the cultivation of market entities. After repeated communication and negotiation, the barriers between provinces have been successfully broken, and 49 power generation companies in Guangdong and 16 power generation companies in Yunnan have been promoted to enter the cross-regional and cross-provincial market. At present, relevant entities have completed registration on the Guangzhou power trading platform. The Market Management Committee was formally established, and related matters such as the rules of the management committee meeting, the director of the management committee, and the establishment of the secretariat were successively clarified and entered into normal operation.

The third is to effectively strengthen the synergy of the two-tier power market. Pay attention to strengthening the guidance and coordination of provincial-level trading institutions, and promote the orderly connection and standardized development of the two-level power market. The preparation of the sequence diagram and the settlement connection algorithm of the southern regional electricity transaction connection ensures the effective connection of the two-tier market power transaction. In cooperation with the China Southern Power Grid Corporation, it has compiled guidance on the orderly promotion of power trading business, and further clarified the responsibility interface and management and control requirements of two-level trading institutions. Actively promote the business synergy in the construction of the credit system in the southern region, establish a credit evaluation coordination agency, and formulate unified standards for the registration and credit evaluation of electricity sales companies. At present, all provinces and autonomous regions have established medium- and long-term market mechanisms based on annual and monthly transactions, forming a multi-period, multi-variety trading system. A total of 592 electricity sales companies, 12,194 electricity purchase customers, and 607 power supply companies have registered in the southern region. A diversified market structure has been formed.

Later key work arrangements: First, continue to improve the cross-regional and cross-provincial power trading mechanism to ensure the completion of the west-to-east power transmission and hydropower consumption tasks. At the same time, consolidate and improve the hydrothermal power replacement trading mechanism, expand the scope of replacement transactions, and organize the development of cloud and cloud Gui, Yungui hydro-thermal power exchange transactions, to maximize the potential of surplus hydropower consumption; second, continue to promote the construction of a unified power market, gradually realize the integration of the power market, pay attention to the preparation and implementation of the 13th Five-Year Plan for the construction of the power market in the southern region, and standardize all provinces Transaction rules and types of transactions, and gradually promote the development of the power market towards a unified market, unified rules, unified platform, and unified management; third, continue to strengthen lean management, promote standardized and efficient operation of trading institutions, implement lean management requirements, and continue to strengthen Internal management of trading institutions has further improved management efficiency and effectiveness.

3 Key technologies of cascade dispatching in river basin

3.1 Meteorological and Hydrological Forecast Technology and System

The Pearl River Basin is a hot, humid and rainy tropical and subtropical climate zone. The annual average temperature is 14° C to 22° C, the annual average precipitation is about 1200 mm to 2000 mm, and the annual average runoff is 338.1 billion m3 (surface water resources). The general trend of the regional distribution of precipitation in the basin is decreasing from east to west, and many high and low rainfall areas are formed due to factors such as topographic changes. The precipitation is unevenly distributed throughout the year. The precipitation from April to September accounts for about 70% to 85% of the annual precipitation. The annual runoff modulus increases from upstream to middle and downstream; the distribution of runoff during the year is uneven, and the runoff period is from April to September each year, accounting for 78% of the annual runoff; October to March of the following year is the dry period, runoff It accounts for about 22% of the whole year. The average flow of the driest month often occurs from December to February of the following year, and mostly occurs in January.

At present, there are four main methods used in the mid- and long-term hydrological forecasting of the Pearl River Basin, namely, historical evolution method, periodic mean superposition method, transition probability method, and mathematical statistics correlation analysis method. The following is an example of Datang Guangxi Branch to introduce key technologies and systems.

At present, the hydropower stations under the jurisdiction of Datang Guangxi Branch have completed automatic hydrological forecasting systems on the Hongshui River, including Pingban, Longtan, Yantan, Dahua, Bailongtan, Letan, and Xijin, a total of 7 power stations. Qikong simply built 3 rain measurement stations, and other power stations have not yet built automatic hydrological forecasting systems. Among the 7 automatic hydrological forecasting systems that have been built, except for the Longtan system which is large in scale (nearly 100 field observation stations), the other 6 are all small and medium scale, and the number of field observation stations is less than 20. Telemetry communication

Except that Longtan uses satellite, ultra-short wave and GSM hybrid communication, the other systems are all GSM-based, with a small amount of ultra-short wave auxiliary, and the water level before and after the dam and the data collection of the unit are all wired.

The main content of the water regime monitoring and reporting and water dispatching automation system construction of the centralized control center includes: data interface with the existing system of the hydropower station to realize data collection and data exchange. According to the construction of the existing automation system of the hydropower station, through the development of data interface with the hydropower dispatching automation system, the automatic hydrological monitoring system, the MIS system, the computer monitoring system, etc., the communication channel from each power station to the center is established to realize the power station to the center. Data transmission in the center. Complete the branch company's collection of hydropower and power generation information. For hydropower plants where data exists at multiple locations, the priority order is water dispatch automation system, water regime automatic measurement and reporting system, MIS system/computer monitoring system, etc. According to the application requirements of the center, software development is carried out to provide an operating platform for the center's water diversion business. Realize the basic application functions of water regulation including database system construction, information management, data monitoring, water affairs calculation, water regime analysis, query, alarm, on-duty management, as well as short message publishing, water regulation Web application and other functions. Install a set of satellite cloud image receiving device in the center to directly receive meteorological satellite cloud image information. Through the integration and development of public meteorological information, commissioned professional meteorological service information, and meteorological information obtained from other channels, comprehensive management, application and service of meteorological information are realized.

The water regime forecasting and water regulation automation system can be divided into three parts: data collection and transmission, basic application functions and advanced application functions. The system function module structure is shown in Figure 3.。

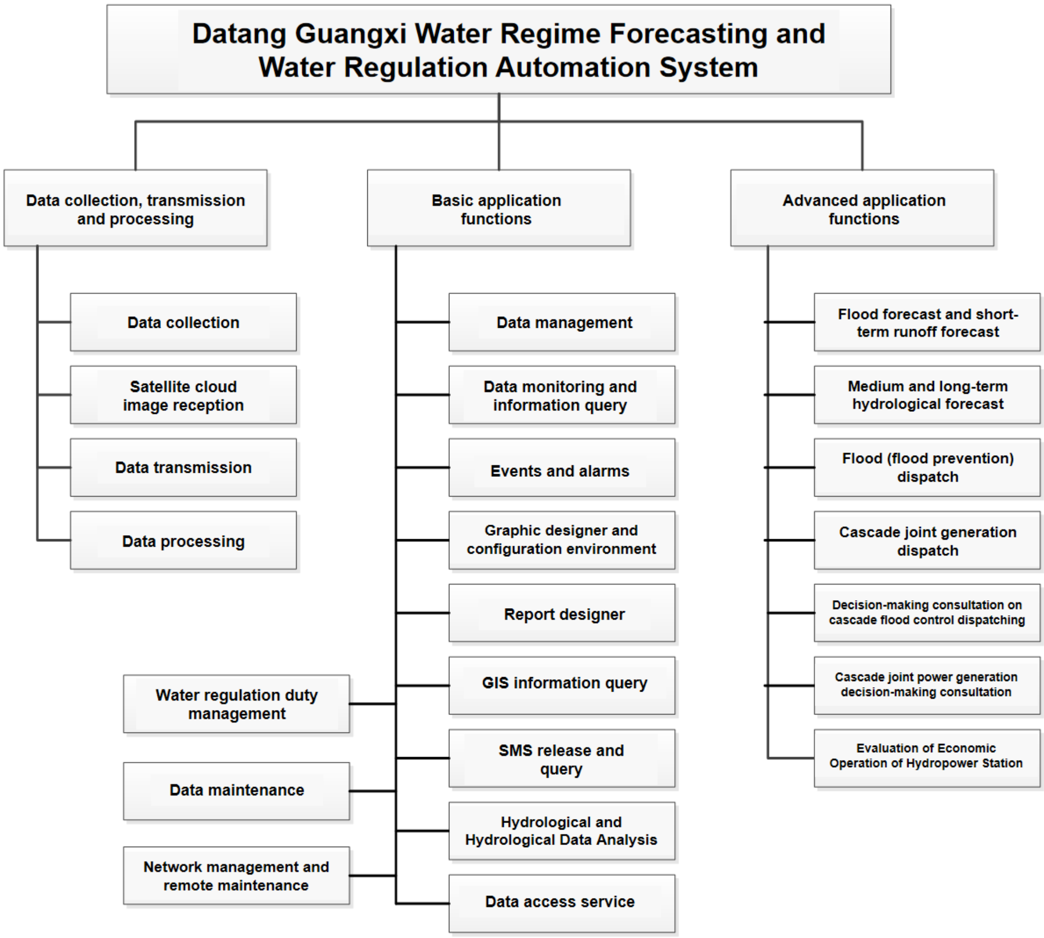


figure3 The functional module structure diagram of the water regime and water regulation automation system of the centralized control center of Datang Guangxi Branch

3.2 Joint dispatch technology and system

(1) Joint dispatch of Guangxi Datang Hongshuihe Centralized Control Center

The construction of a centralized control center is the need for the country to vigorously develop a low-carbon economy. In particular, the development of hydropower as a renewable energy is of great significance in optimizing the energy structure, achieving sustainable energy development, and responding to climate change. The cascade centralized control and unified dispatch of the Shi river basin provide a strong policy guidance basis for promoting the transformation of power grid dispatching mode.

Since on the same river, the inflow of the next-level power station not only depends on the runoff inflow from the river section, but also depends on the water release of the upper-level power station. Therefore, the power stations of the cascade must be coordinated to operate, comprehensively and accurately calculate the cascade The output and discharge of each power station can make the most economical use of water resources and generate more power, without the reservoir being forced to abandon or be emptied. Through the joint centralized control, optimized dispatching and economic operation of cascade power stations, considerable power generation benefits can be produced, the safe and stable operation of the power station can be improved, and the production and living standards of employees can be improved, and certain social benefits can be generated.

The construction of a centralized control center is also the need to maximize social and economic benefits. The realization of unified cascade dispatching, centralized control, and scientific and reasonable optimal dispatching configuration will greatly improve the flood control standards, economic benefits, water supply and power generation capacity of the river basin during dry periods, thereby creating huge social and economic benefits. The centralized control management mode can also effectively save manpower, material resources and system investment. The unified planning and control of the river basin can centralize the various dispersed systems for effective resource integration, realize centralized optimization and unified dispatch under the situation of extremely rich data, and improve the efficiency of personnel. Only under the centralized control and unified dispatch mode can the advantages of river basin cascades be realized.

(2) Practice of joint dispatch technology in the Pearl River Basin

There are many reservoirs and hydropower stations in the Pearl River Basin. As the current flood control engineering system in the river basin is not yet complete, in order to give full play to the comprehensive benefits of the project’s flood control and disaster reduction and reduce the downstream flood control pressure as much as possible, after careful analysis and research, the "Pearl River Flood Dispatching Plan" provides joint dispatching of the main and tributary reservoirs The principles and objectives are stipulated, including the admission of some large reservoirs and hydropower stations without flood control tasks, overall consideration of project flood control safety and downstream flood control needs, combined with weather and flood forecasting, implementation of the potential tapping of large reservoirs and hydropower stations. Joint reservoir dispatch mainly includes two types: First, when a regional flood occurs, combined with meteorological and hydrological forecasts, upstream and downstream reservoirs are used to implement joint compensation dispatch, and main and tributary reservoirs are used to implement joint staggered dispatch. The second is to use the Xijiang and Beijiang reservoirs in a timely manner to ensure the safety of flood control in the delta area when a basin flood occurs in the Pearl River. [2]

The Pearl River Reservoir Dispatching Technology Research and Dispatching Practice have proved that giving full play to the role of water conservancy projects in ensuring the safety of water supply in the river basin, improving the water environment, and increasing the water resources and water environment carrying capacity of the river basin are effective methods and approaches. It is not only a short-term expedient and emergency measure, but also an irreplaceable measure and task that should be adhered to for a long time. The Pearl River Reservoir dispatch involves many fields such as water supply, power generation, shipping, water environment, water ecology, engineering construction, etc. Due to the special geographical location of the Pearl River basin and special dispatch requirements (water transfer to Hong Kong and Macao), relevant units have carried out multi-reservoir cooperation Experimental innovation topics such as water supplement dispatching, salty conditions forecasting and salt pressure avoiding technology, hydrological forecasting technology, water supply system joint dispatching technology, and rolling optimization technology for dispatching plans.

3.3 Decision Support Systems

(1) Pearl River Flood Control Decision Support System

The main task of the Pearl River Flood Control Decision Support System is to complete the processing of flood control and drought relief information to generate analysis and calculation results such as flood analysis for flood control decision-making, flood forecasting and flood prediction, for use by decision-making departments. The flood control decision support system includes 8 subsystems including information receiving and processing meteorological product applications, flood forecasting, flood monitoring and information services, flood control dispatching, flood control management and disaster assessment, and a decision support data center. Planning and construction of the Zhujiang Flood Control Decision Support System, Guangdong, Guangxi, Yunnan, and Guizhou Flood Control Decision Support Systems, focusing on the establishment of flood control command for key rivers and sections of the Xijiang River, Beijiang, East River, Liujiang, Yujiang, Pearl River Delta, Hejiang, and Guijiang Decision Support Systems.

(2) Guangxi Datang Hongshuihe Centralized Control Center Decision Support System

China Datang Group Corporation Guangxi Branch is the secondary responsible entity of China Datang Group Corporation. It is mainly responsible for the production, operation and management of the enterprises affiliated to Datang Group Corporation in Guangxi. The current asset distribution of Datang Group Guangxi Branch has expanded to Guangxi. Others include Sichuan, Guizhou, Yunnan, Shandong, etc. Currently, the main hydropower stations in service in Guangxi include Pingban, Longtan, Yantan, Dahua, Bailongtan and Letan in Guangxi' s Hongshui River Basin, Yujiang River Basin and Guijiang River Basin. , Xijin, Shanxiu and Jinjitan power stations. By the end of 2013, the total installed capacity of hydropower plants under the jurisdiction of the branch was 9975.96 MW, with an annual power generation capacity of approximately 35 billion kW•h.

The centralized control center divides the forecast section according to the distribution characteristics of the hydropower station/reservoir basin, the regulation performance of the reservoir, and the needs of reservoir operation, and selects the appropriate hydrological forecast model according to the characteristics of each reservoir basin and river channel, and has designed and developed the corresponding Hydrological forecasting scheme and software.

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