A Discussion on Adaptive Applications of Some Chinese Design Codes in Guinea and Localization of Flood Standards

Une discussion sur les applications adaptatives de certains codes de conception chinois en Guinée et la localisation des normes d'inondation

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Abstract. Chinese engineering team participated in the construction of several water conservancy and hydropower projects in areas which have differences in climate characteristics from China. Due to a lack of hydrological and climatic data and the absence of systematic design specifications in these areas, considering construction safety, most of the Chinese designs and constructions are based on the extreme values with the Chinese design codes. The S Project in Guinea established a rainfall-runoff model through open-source remote sensing satellite precipitation data and limited hydrological station measured runoff data, allowing to refine local hydrological data. Based on these data series, it was then possible to calculate flood control standards with more local hydrological characteristics in order to promote the progress of the project scientifically. In addition, combining the refined discharging curve of the outlet hole with the latest arc gate online monitoring technology, and the joint dispatch with the downstream hydropower station, permitted that the downstream K Hydropower Station created historic power generation in 2019 with significant economic and social benefits.

Résumé. L'équipe d'ingénierie chinoise a participé à la construction de plusieurs projets de gestion de l'eau et d'hydroélectricité dans des zones présentant des différences de caractéristiques climatiques par rapport à la Chine. En raison d'un manque de données hydrologiques et climatiques, et de l'absence de spécifications de conception systématiques dans ces domaines, lorsqu'il s'agit de la sécurité de la construction, la plupart des

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conceptions et constructions chinoises sont basées sur des valeurs extrêmes avec des codes de conception chinois. Le projet S en Guinée a établi un modèle pluie-débit grâce à des données de précipitations satellitaires de télédétection open source et à des données limitées de débit mesurées par des stations hydrologiques ce qui a permis d'affiner les données hydrologiques locales. Sur la base de ces séries de données, il a ensuite été possible de calculer des normes de lutte contre les crues avec des caractéristiques hydrologiques plus locales afin de promouvoir scientifiquement l'avancement du projet. En outre, le fait de combiner la courbe de décharge raffinée du trou de sortie avec la dernière technologie de surveillance en ligne de la porte d'arc, une gestion coordonnée avec la centrale hydroélectrique en aval a permis à la centrale hydroélectrique de K en aval de créer une production d'électricité historique en 2019 avec de significatifs avantages économiques et sociaux.

1 Introduction

Adapting the reservoir regulation to local hydrological characteristics is the best way to maximize the effectiveness of hydropower stations [1-2]. In addition, extending the management of reservoirs to the construction period is of great significance for West Africa which suffers from an uneven distribution of water resources. According to the latest project progress, the water storage requirements in the contract, as well as the real-time water inflow, combined with regional runoff characteristics, we have to determine the reservoir scheduling method scientifically, which is the key to ensure the safety of the project and guarantee the construction progress during the flood season. At the same time, Utilizing the preliminary storage capacity of S Water Control Project with the precise control of the drain flow, can increase the downstream K water storage and power generation on the premise of meeting the water storage goal.

According the above analysis, the way to control the speed and rhythm of the water level rise based on the incoming water situation and the discharge flow of the two bottom discharge holes as much as possible is the sticking point. Solve this crux perfectly will give impetus to solving more power shortage problems for the local area under the premise of ensuring the safety of the dam under construction while maintaining the construction schedule. All these points are the focus of this paper.

2 Background of the project

The S Water Control Project is located in the middle reaches of the Kon River in Guinea and is a secondary hydropower station in the cascade development system of the basin. The catchment area is 10800km^2, the normal storage level has a storage capacity of 6.317 billion m^3, and it is a multi-year regulating reservoir with a total installed capacity of 450MW. This project started in April 2016, and it is planned to realize the first generator in order to generate electricity in 2020, and it will be completed in the first half of 2021. There are four-level hydropower stations in the hydro-level development plan of the Kon River Basin, among which the G Hydropower Station upstream of the S Hydropower Station and the K Hydropower Station downstream have been put into operation. As the secondary hydropower station in the basin, the S Hydropower Station is the most important and urgently needed hydropower station for the Guinea government.

During the construction of the project, appropriate construction measures were taken according to the unique climatic conditions of Guinea, and the construction progressed smoothly. However, in the initial stage of water storage, considering the current flood control standard (3410 m^3/s) and the flood discharge capacity when the two discharge bottom gates are fully opened logically, the full section of the overflow dam section needs to be shut down for the whole flood season from June to December to ensure the construction safety.

The long-term suspension of the overflow dam section will then seriously influence the construction progress of the overflow dam section and the bottom dam section, at the same time restricting the scheduled power generation goal achieved.

3 Research method

3.1 Build the data foundation

The original hydrological data of the basin of Guinea's hydrological department is incomplete, and there is a small part of the basic hydrological data in the design stage that is relatively rough. Considering the premise of construction safety, the flood design standard was determined as 3410 m^3/s in the design stage. While in the construction phase of the project, in order to make more reasonable use of seasonal water resources and reduce the waste of construction period, we made pioneering use of open source rainfall data measured by meteorological satellites [3-4] in water conservancy projects in West Africa in order to establish a rainfall-runoff model to improve hydrological data. According to the results of the model and the measured data of the downstream K power station in the past 4 years, the daily runoff data from 1981 to the present are refined.

The methods used mainly include [5-6]:

(1) **Rainfall-runoff Model:** Make use of historical data of daily rainfall, evaporation capacity and runoff to calibrate the parameters of the Rainfall-runoff Model, and evaluate the model's simulation consequents on daily runoff;

(2) **Rainfall Scenario Simulation:** Employ the historical data of rainfall for multi-year to calculate the total rainfall from August to October under different guarantee rates, and use a weather generator to produced daily rainfall and evaporation capacity from monthly rainfall as a hypothetical rainfall scenario in 2019;

(3) **Water Storage Simulation:** Input the daily rainfall and evaporation capacity from the Rainfall Scenario Simulation into the Rainfall-runoff Model to obtain the daily flow from August to October in 2019.

Since the simulation of daily rainfall is random, multiple rainfall simulations should be used here and then choose the successful schemes to do further evaluation. And this will improve the accuracy of the simulation. The method flow chart is shown in **Figure 1**.

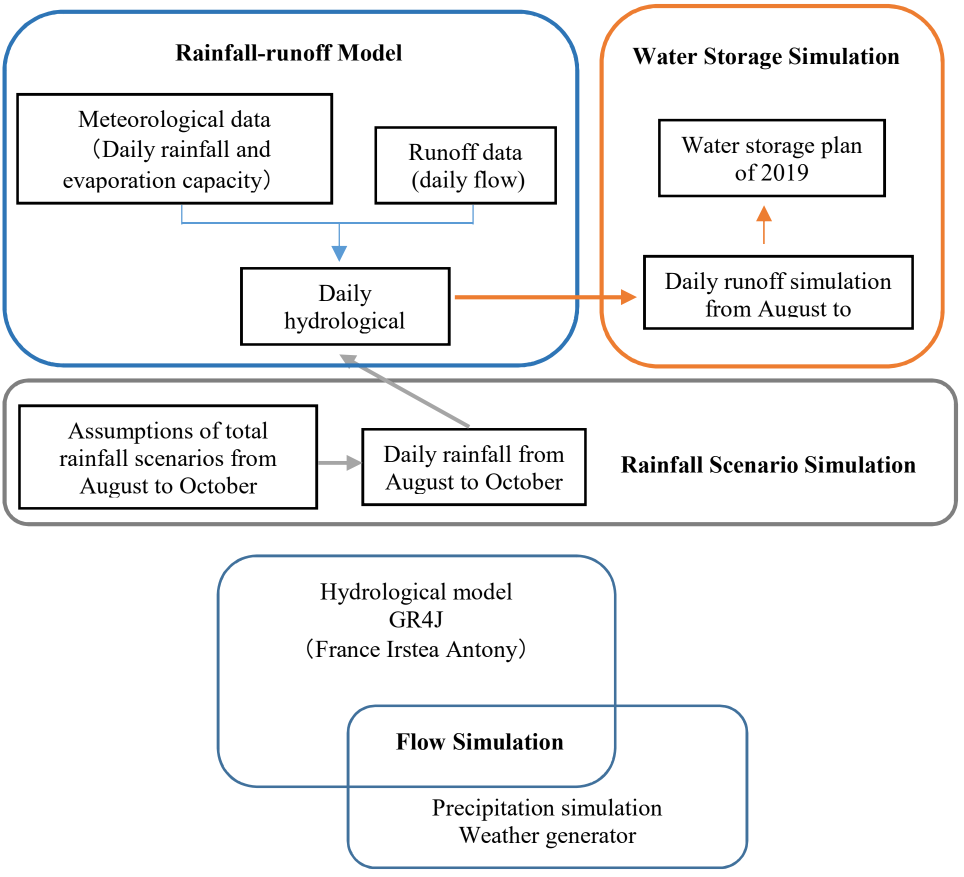


Fig. 1. Method flow chart.

This involves determining the "false watershed" required by the Rainfall-runoff Model according to the characteristics of the watershed, and selecting relatively reliable data sources and measured data for simulation and reproduction of the missing flow data. In 1998 and before, the inflow of S was not affected by the G power station. The inflow of the dam site was natural incoming water. Therefore, the GR4J Rainfall-runoff Model was directly constructed on the exact scale of the S basin. The simulation results for this first period are shown in **Chart 1**, where NSE=0.85 (NSE is the Nash efficiency coefficient, and it is used to evaluate the effectiveness of Rainfall-runoff Models. When the NSE is greater than 0.8, the effect of the model is considered to be fine). The inflow of S in 1999 and later was affected by the G Power Station. Although there are actual measured data from 1999 to 2003, it is relatively rough. We choosed the flow data from 2015 to 2019 for model calibration as the data in the past 5 years has been measured by K Power Station with high accuracy. The simulation effect of S from 2015 to 2019 is shown in **Chart 2**, where NSE=0.84. In general, whether it is a period of natural inflow or affected by G, the model's simulation of daily-scale incoming flow at the S dam site meets the needs.

Using this model with input rainfall and evaporation capacity data from 1981 to 2019, the missing daily flow at the S dam site from 1981 to 2019 can be reproduced with a certain degree of accuracy. The results are shown in **Chart 3**.

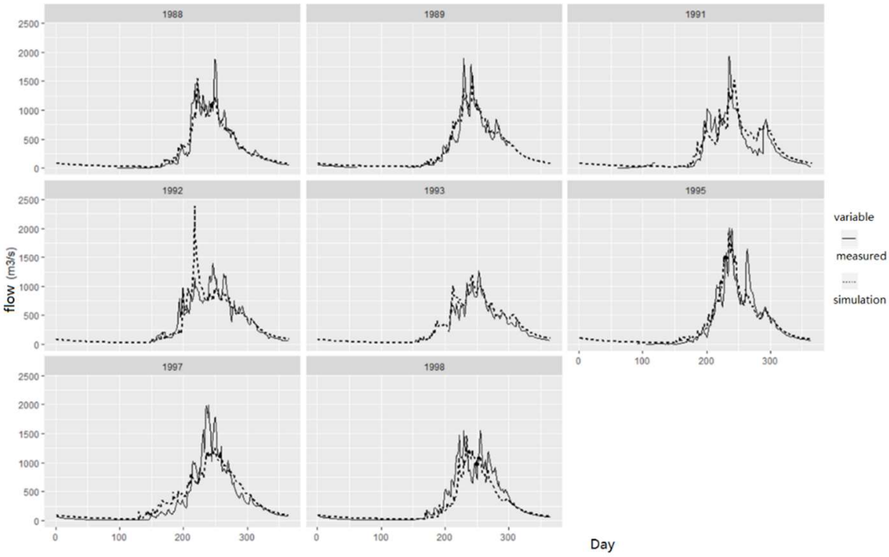


Chart 1. Comparison of simulated and measured flows at the S dam site in 1998 and before (the period of natural flow). Years without measured data are not shown in the figure.

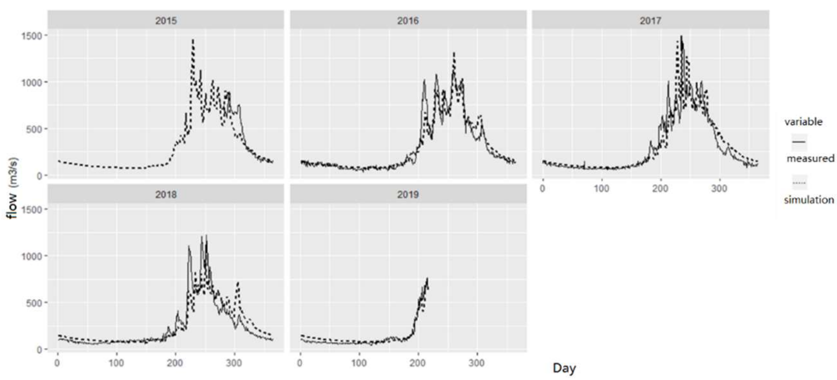


Chart 2. Comparison of simulated and measured flow rates at the S dam site in 2015-2019 (during the period under the influence of G which was measured by the K Hydropower Station)

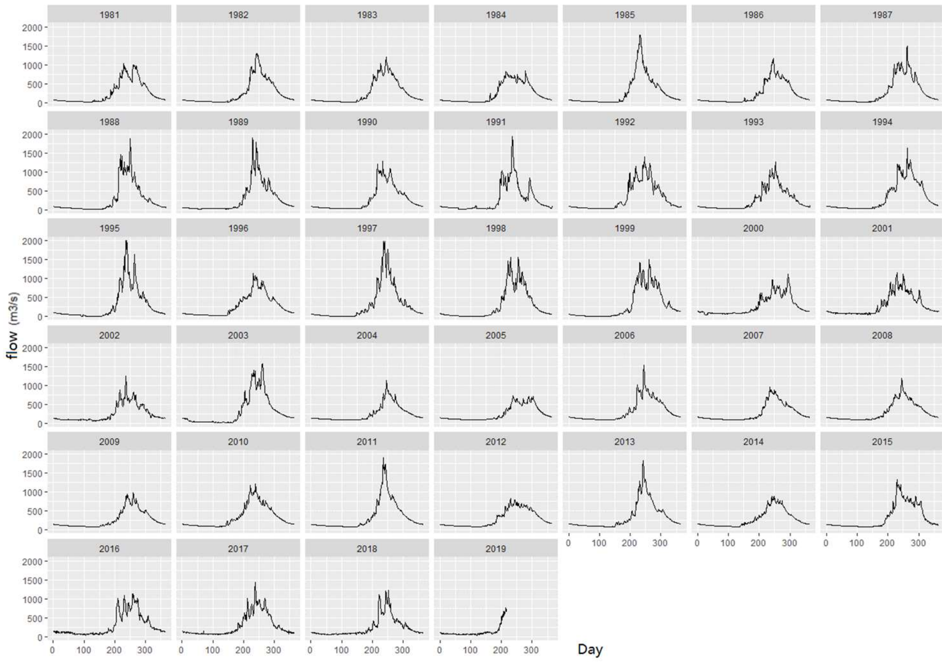


Chart 3. Daily flow of S dam site from 1981 to 2019. We use the actual measurement value when there is an actual measurement value, and replace it with a modelled-value when there is no actual measurement value to form a continuous and complete flow process line.

According to the calculation of rainfall data from 1981 to 2018, the result of the total rainfall guarantee rate from August to October is shown in **Table 1**. Through the simulation of the whole process on water storage, the range of gate closing time under different rainfall guarantee rates is obtained, as shown in **Table 2**. Among them, the earliest closing time ensures that the overflow dam does not produce overcurrent, and the latest closing time ensures that the dam can store water to 167m, avoiding insufficient subsequent total water flow. According to conservative estimates, the 95% guaranteed rainfall scenario is used, as the final recommended closing time is before August 21 [7].

Table 1. Total rainfall guarantee rate in August to October.

Guarantee rate	95%	75%	50%	25%	5%
August-October precipitation (mm)	865	950	1012	1050	1127

Table 2. The earliest and latest closing time under different guarantee rates from August to October.

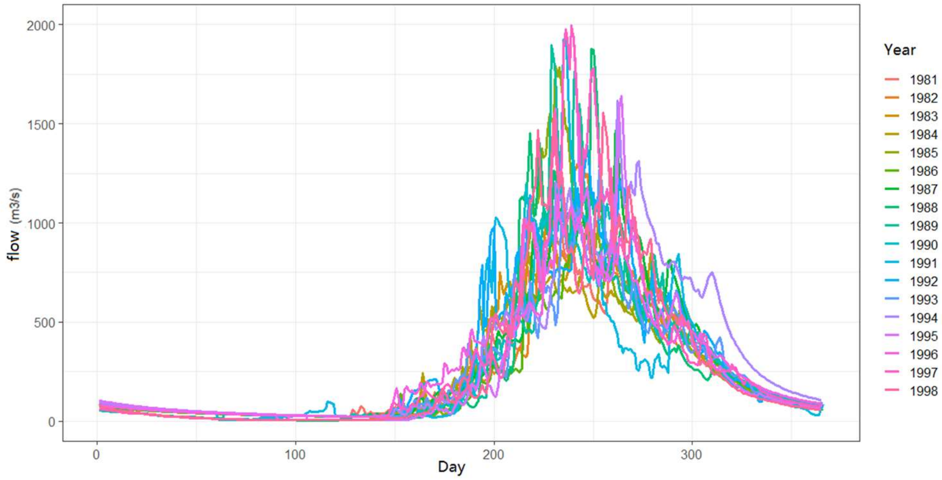
Rainfall guarantee rate	95%	75%	50%	25%	5%
The earliest closing time	-	-	08-20	08-20	09.06
The latest closing time	08.21	09.01	09-05	09.12	09.13

(**Note:** There is no over-current situation in the simulation at 95% and 75% guarantee rate without earliest closing time.)

3.2 Analysis of hydrological characteristics

Sufficient data foundation is a prerequisite for research, while the internal connections and laws expressed by data are of more practical significance in improving scientific research capabilities and management levels. Based on the obtained daily average flow data, combined with the distinct characteristics of the precipitation in the dry and rainy seasons in tropical areas, as well as the strong regularity of the inflow process in the rainy season, at the same time considering the absence of sudden factors such as typhoons and rain, we do the further analysis and summary of local hydrological characteristics.

We first analyse the inflow process of the basin during the year according to the inflow process line (**Chart 4.** Incoming water process line during 1981-2018), The summary rules are as follows: Divided by a natural year, the dry and rainy seasons during the year have obvious characteristics, and the dry season (from the end of December of the previous year to the end of May of the current year) is arid and has very little water; In the rainy season (June to December of the current year), the incoming water process line is generally parabolic, which is basically symmetrical and has strong regularity. It can be seen from **Graph 1** that there are "double peaks" in the incoming water process line of some individual years, that is, there are sometimes two points that can be regarded as peak flows, and the absolute value of the secondary peak exceeds the peak flood that occurs during the main flood season and with a small proportion, that means the value of the second flood peak is preventable if we know the first one. Although it is not completely consistent with the parabolic pattern, its overall law has not yet broken through, and the parabolic law is still basically available.



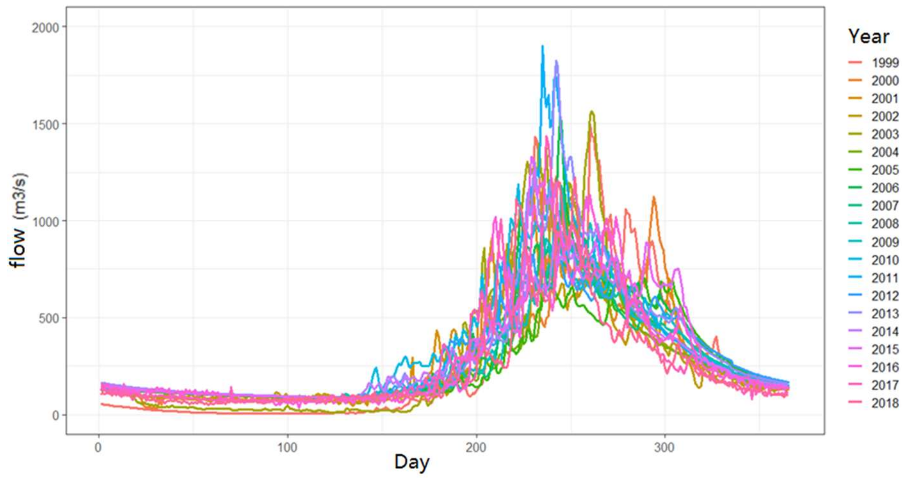
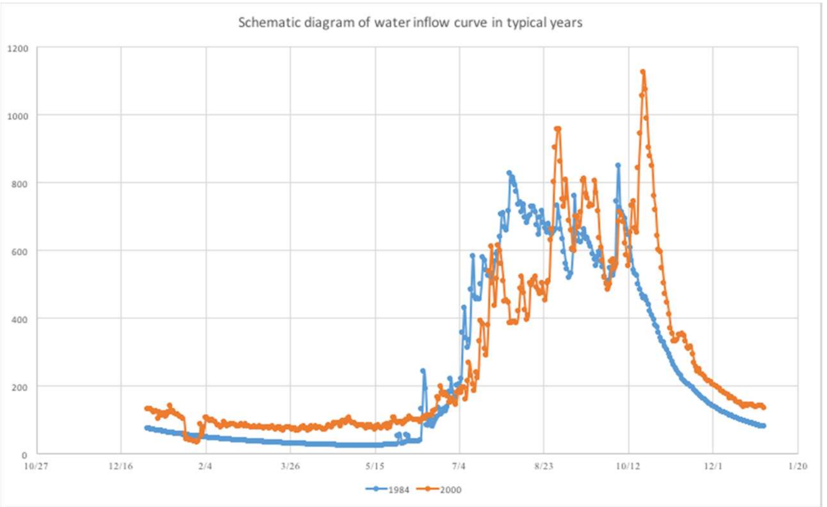


Chart 4. Incoming water process line during 1981-2018.



Graph 1. Schematic diagram of incoming water process line in typical years.

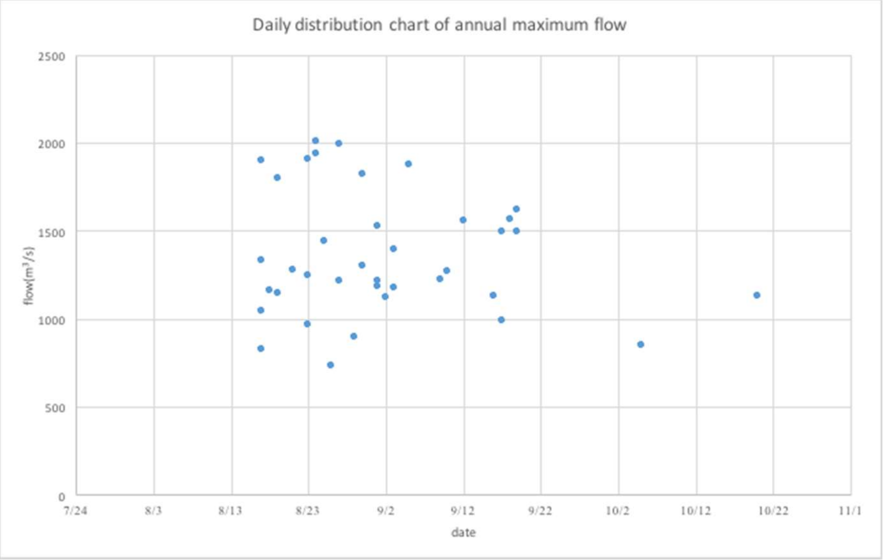


Chart 5. Daily distribution of the largest flow during 1981-2018.

It is considered that the most worthwhile characteristic point on the incoming water process line is the extreme point of the annual incoming flow (**Chart 5**), which is approximately regarded as the symmetry point of the incoming water characteristics, it can reflect the water situation of the year and provide reference for flood peak data to formulate safe and reasonable flood standards. Although the law of the maximum flood peaks and the total amount of floods vary greatly and is currently hard to find, the date of annual flood peak is relatively fixed, with a probability of more than 97% of occurring between August 15 and September 20 during the main flood season; The situation where the two largest flood peaks appear after October 2 in **Chart 5** is the typical water year in **Graph 1**. They belongs to the form of "double peaks", and there are secondary peaks in the main flood season.

3.3 "Localization" of flood standard

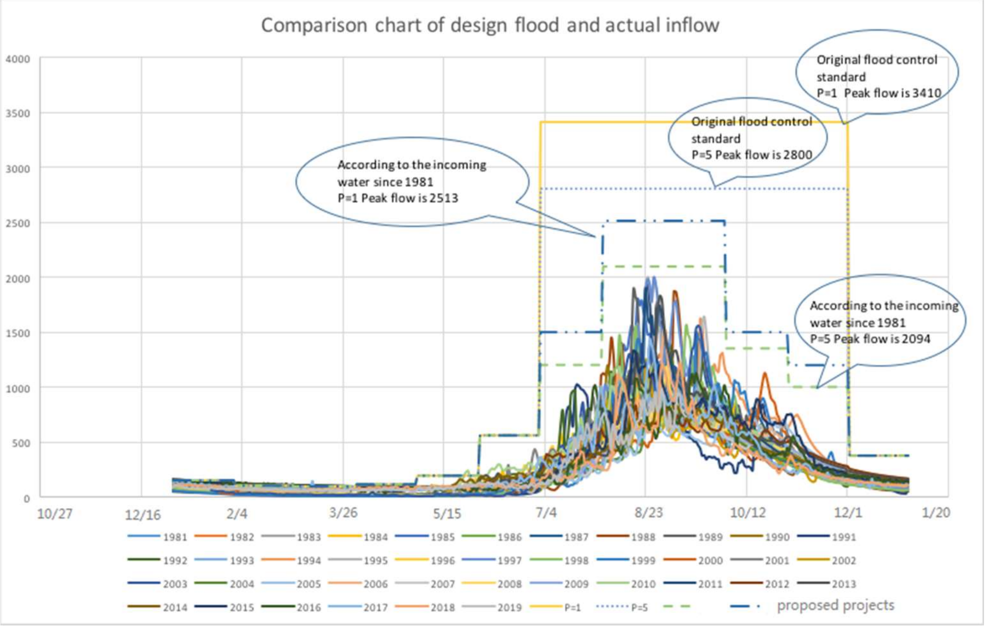
The analysis of runoff characteristics aims to better serve the operation of the multi-year regulation reservoir. For reservoir operation, reasonable flood prevention is a compromise between safety and power generation. If we continue to follow the flood control standard (3410 m^3/s) in the initial design as the control basis, we can see that the safety is guaranteed with the existing runoff situation in 2019. However, the shutdown of the overflow gap needs to last for nearly 50 days. Due to the feeding form and construction characteristics of the RCC gravity dam, the suspension of the overflow gap will have a certain degree of impact on the progress of the entire project.

Refining the October-November flood control standards under the premise of safety can make it possible to resume construction of the overflow gap early. Analysis based on the above data basis, according to the flood process line in the basin from 1981 to 2018, it can be preliminarily determined that the Kon River Basin has basically passed the peak period of inflow from October to November, while the runoff will show a downward trend in the next two months as the calculation results of probability statistics shows.

Based on the relatively complete data composed of satellite data, hydrological data reproduced by rainfall-runoff models, and some measured data, we then review the accuracy, consistency and representativeness of the information [8-9]. We select the 1954-2003 actual measurement series with relatively complete actual measurement data, and remove part of the year in the series that are missing or missing in October. Thus, with a total of 35 actual test samples were selected. According to the actual measurement series, the frequency calculation of the maximum daily average flow in October is performed, and the calculated design value of the once-in-a-hundred-year flood is 1870m^3/s.

Combining the typical overcurrent curve and the peak annual overcurrent flow (**Graph 1 & Chart 5)**, the most characteristic year 2000 is selected as the typical overcurrent curve for further flood regulation calculation. Using the October 2000 flood process as a model, we zoom in to get the 100-year design flood process. At the same time, combined with the current water storage situation of S Reservoir, this calculation starts from the reservoir water level at 165.2m. The flood regulation process is shown in **Chart 6**. In the process of flood regulation, when the inbound flow is less than the two-hole fully opened discharge flow, the discharge flow is adjusted by adjusting the opening of the discharge hole to maintain the balance of in and out of the storage; When the inbound flow is greater than the full open discharge flow of the two holes, the discharge hole is adjusted to the maximum discharge flow, and the reservoir stores the flood at the same time with the water level rises. The highest water level is calculated to reach 172.5m.

With reference to relevant domestic design standards [10], taking the established principles of codes and standards, and combining the characteristics of local climate and precipitation, the original once-in-a-hundred-year flood control standard from October to November is changed from 3410 m^3/s to 1870 m^3/s (**Graph 2**). With the support of this key data, the rectangular cross-section of the overflow gap was optimized to a trapezoidal cross-section, with the resumption of construction after the gap flooded nearly 30 days ahead of schedule, which effectively promoted the progress of the main line project and provided a compliance basis for the safety of the project. It has laid a solid foundation for early power generation.



Graph 2. Comparison chart of design flood and actual inflow (measurement m^3/s).

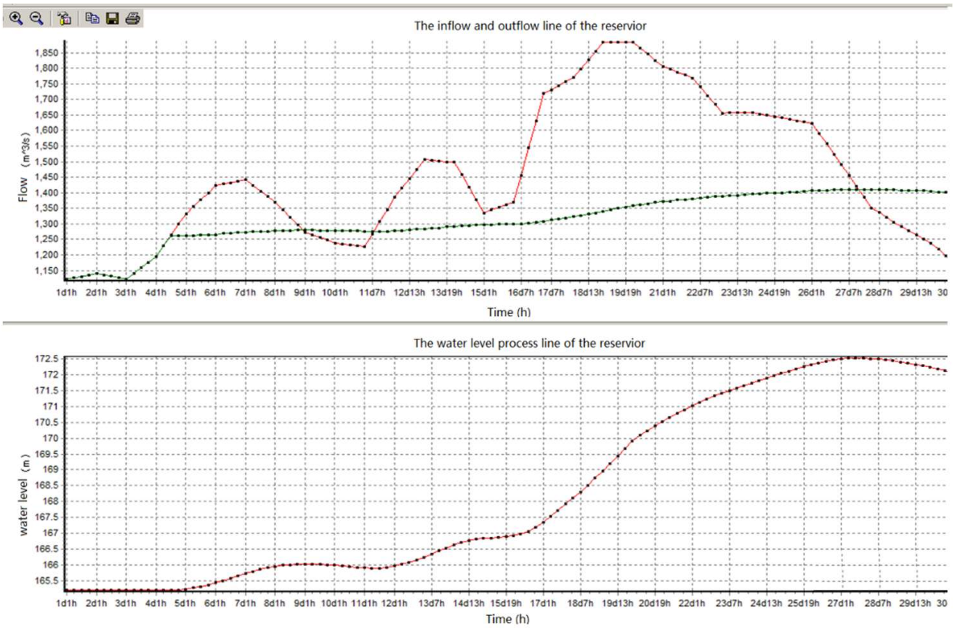


Chart 6. Inflow and outflow line of the reservoir with the water level process line.

4 Implementation Effect

Based on the calculation and analysis in section 3.1, the recommended time for the initial water storage is August 21, while the time approved by the owner is August 26-28. After the gate was closed, the initial gate storage level of 164.5 m as stipulated in the contract was reached on September 23, provided that the electricity output of K was guaranteed. After that, the water storage level was further increased and reached a maximum of 167.34m on October 28. The contracted water storage plan was completed ahead of schedule and exceeded, which was about 140 million m^3 more than the contract requires. During this period, the quality and the safety of the project were not affected.

Furthermore, the project proposes a new argument that in a certain year after 2019, after the end of September each year, with reference to the actual maximum flood peak that occurred in the year, the flood control standard for the middle and late periods of the flood season in this year can be formulated in real time. This work needs to be repeated by year because of the insufficient number of data samples which cannot provide accurate corresponding flood control data for once in 100 years, once in 200 years, and once in 500 years. When the data support will be sufficient, the flood control standards at the end of the flood season or even the complete flood season can be further promoted into a unified standard applicable to local runoff.

This is of great significance in later operation of hydropower stations to formulating a reasonable flood limit water level during the flood season, maximizing the flood retention, reducing overflow and discarding water from cascade power stations, raising the power generation water level during the dry periods, and greatly improving the comprehensive power generation efficiency. At the same time, this is also of great significance to mankind's understanding of the hydrology and water regime of the Kon River Basin and further water resources development.

5 Conclusions

The study on the initial water storage and joint dispatching management of the S has created conditions for ensuring the quality and safety of the project, advancing the construction progress, and achieving a solid foundation for early power generation. Through scientific dispatch, the goal of improving the economic efficiency of power generation of the power station and the downstream K power station has been achieved, and the power supply of the Guinea power grid has also been guaranteed. After more than a year of research and demonstration from 2019 to 2020, the research has achieved certain results in both social and economic benefits:

(1) In order to solve the serious shortage of original hydrological data in the basins of underdeveloped areas, this paper combines open source shared data such as modern meteorological satellite remote sensing technology, adopts suitable Rainfall-runoff Models, reproduces hydrological data, and systematically summarizes the hydrological laws of the basin in combination with local climate characteristics. These studies provide reliable data for the engineering construction, flood control, and power generation dispatching decisions of hydropower stations; at the same time, it also provides subsequent understanding of the hydrology and water regime of the Kon River Basin and further water resources development is very meaningful and enlightening.

(2) The calculation method of the discharge bottom hole characteristic curve in the relevant design specifications is characterized according to S, combined with the knowledge system support of basic disciplines such as hydraulics and fluid mechanics, data on the shape characteristics of the flow channel and the arc gate of the discharge bottom holes. Doing comprehensive analysis of inbound and outbound as well as water level, further refine the discharge coefficient and discharge data under different water levels and different arc gate openings. It makes the discharge curve more instructive in the process of joint dispatch and corrects the problem of negative inter-zone flow statistics among cascade hydropower stations. Under the guidance given by the accurate discharge curve, combined with the full application of the basin water regime measurement and reporting system and the arc gate online monitoring technology, the safe operation of the arc gate is ensured, and the safety of the project is guaranteed. The precise control of the discharge flow has enabled K's power generation to continuously set new historical records. The electricity supply in the dry season has been effectively improved. This has significantly improved the indirect industrial output value and social benefits of electric power.

(3) All of this permitted to promote project construction and efficient use of runoff resources in the rainy season, and to reach the contracted water storage level of 164.5m 38 days ahead of the main contract requirement. During the initial water storage period, the water used for power generation during the dry period of K has been increased by about 140 million m^3, the power generation has been increased by about 16.87 million kWh with a direct power revenue exceeds one million dollars..

The credible daily hydrological data prompted the design value from 3410m^3/s to 1870m^3/s. With the support of this key data, the progress of the main project has been vigorously promoted, which provides a compliance basis for the safety of the project with a solid foundation for early power generation. The early power generation benefit calculated based on the two units of this power station exceeds 20 million dollars..

(4) According to the research that has been achieved, it is necessary to further summarize and improve the data foundation and the joint operation mechanism of cascade reservoirs. How to combine system safety, power generation benefits and the maintenance of the local ecological environment is extremely important in the future operation of hydropower stations. In the future, a more authoritative, intelligent and efficient joint dispatch system needs to be formed.

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