

Feasibility and Potential Study of Yarlung Tsangpo River Power Generation Based on Optimization Model

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Abstract. The Yarlung Zangbo River is not only the longest plateau river in China, but also one of the highest rivers in the world. This paper studies ecology, geology, investment and benefits respectively. Based on the data of the elevation, drop and fish abundance of the Yarlung Zangbo River, combined with its geographical location, a multi-objective optimization model is established. To analyze the number of hydropower stations built on the Yarlung Zangbo River from the perspective of maximum energy utilization, this paper uses the dynamic programming method to find the maximum output energy of each hydropower station. The conclusion is that the total output of 16 hydropower stations is 51358600KW, which reaches a high level. It is estimated that the potential power generation capacity of the Yarlung Zangbo River is about 55 million KW.

Keywords: Water resources development, Hydropower station construction, Water diversion project.

1. Introduction

As the main carrier of surface runoff, river plays an indispensable role in the water cycle, which is the main water source for human life and ecosystem [1]. At the same time, river water resources significantly regulate regional climate, balance ecosystem and protect biodiversity. It is widely used in hydropower, irrigation, farming and other human-related activities [2]. The Yarlung Zangbo River, one of the highest plateau rivers in the world, originates from the northern foothills of the Himalayas. The riverbed drops more than 4000 meters from upstream to downstream, with a large drop in water level and abundant hydro energy reserves. The basin is rich in water and has an average annual runoff depth of more than 300mm, which makes it an important water resource and hydropower energy base in China [3]. It is necessary to make full use of the advantage of large water level difference in the main stream of the Yarlung Zangbo River to build a series of multi-step hydropower plants. Hydroelectric power generation is a renewable energy with small impact on the environment, high power generation efficiency and low power generation cost [4-5].

The input and income of hydropower station, geological and hydrological conditions, environmental costs and other factors are comprehensively considered. This paper selects a site on the main stream of the Yarlung Zangbo River and analyzes its feasibility, and then calculates the number of hydropower stations on the main stream of the Yarlung Zangbo River, estimates the potential total power generation capacity [6-7].

2. Feasibility Analysis

Due to the complexity of various factors to be considered in the construction of hydropower stations, we carry out a simplified analysis of the input and income, geological and hydrological conditions, and environmental costs. First of all, in terms of geology and hydrology, we consider the elevation and fall of the main stream of the Yarlung Zangbo River, for these two geographical factors are crucial to the operation efficiency of the hydropower station. The Yarlung Zangbo River, located south of the Tibet Autonomous Region, is the largest river on the Tibetan Plateau. Its water ecological environment gives rise to special fish fauna, and it is a treasure house of genetic resources of fish in China, and plays a vital role in maintaining the ecological security barrier in Southwest China [5]. Therefore, we select the abundance of fish in the Yarlung Zangbo River as the representative factor of environmental cost. Finally, in terms of economy, we assume that the hydropower station built at

the location with larger river drop can generate more benefits. The closer the hydropower station is to the upstream, the more capital will be invested in the construction of its power transmission equipment [8].

In addition, the valley in the upper reaches of the Yarlung Zangbo River is of plateau wide valley type, with a width of 1000~2000m. It is not suitable to build hydropower stations due to many branching streams, rivers, marshes and lakes, and its high altitude. Therefore, we only analyze the situation of some midstream and downstream in this model. We assume that x is the distance from the start of the midstream, increasing along the flow direction. By searching the data (from official sources), we obtain the relationship curve between altitude and distance x , and the relationship curve between fish abundance and altitude as shown figure 1 and figure 2.

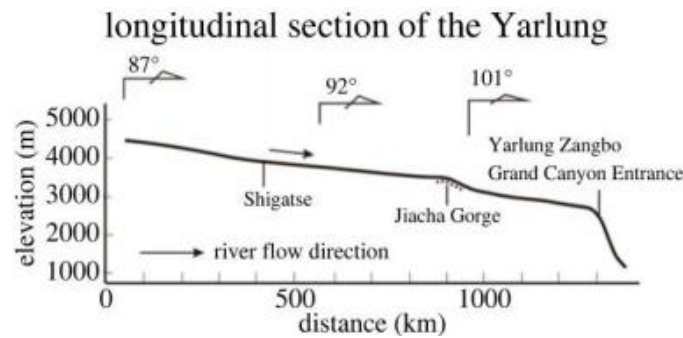


Figure 1. Relationship curve between altitude and distance

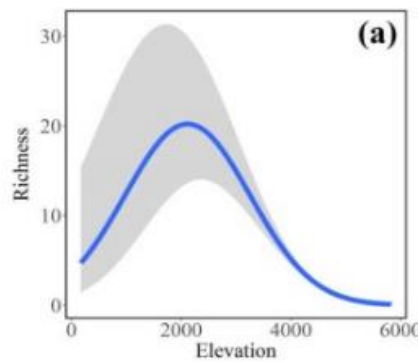


Figure 2. Relationship curve between fish abundance and altitude [5]

2.1. Data Processing and Analysis

Based on the above data, we use Matlab to derive the altitude from distance x , getting the relationship curve between riverbed slope and distance x . The greater the slope is, the greater the drop in a short distance is. The Relationship curve between riverbed slope and distance is shown in figure 3.

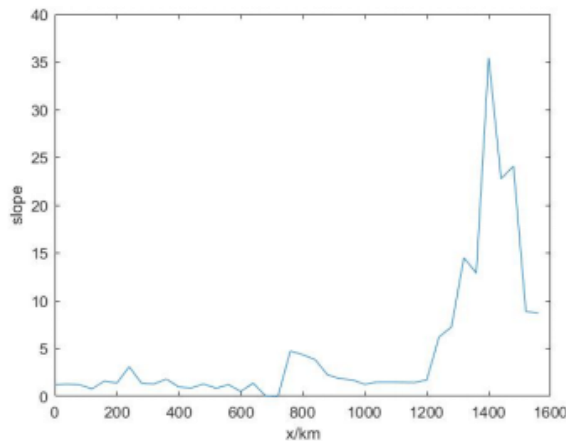


Figure 3. Relationship curve between riverbed slope and distance

Then we take some points from the relationship curve between fish abundance and altitude, in order to obtain the relationship curve between fish abundance and distance x through data processing, which is shown in figure 4.

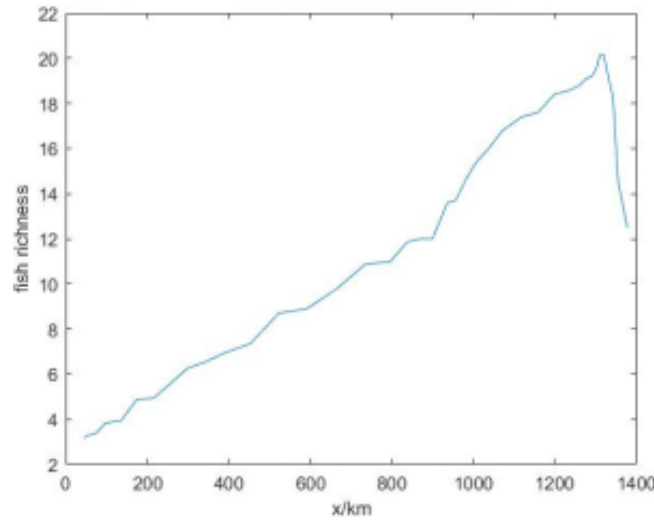


Figure 4. Relationship curve between fish abundance and distance

Based on the above data processing, we take altitude, slope and fish abundance as variables and use the multi-objective programming method. Let u be the construction factor of hydropower station. When u is larger, it is more beneficial to build a hydropower station [9]. Finally, we choose the location with large slope and low fish abundance. In addition, we also associate input and income with slope and distance x : the greater the slope is, the higher the income is; the greater the distance x value is, the lower the input is. Let $z = \frac{\text{income}}{\text{investment}}$, and select the position with larger z value.

2.2. Conclusion of this section

According to the above methods, we get the relationship curve between u and x , and the relationship curve between z and x is shown in figure 5 and figure 6.

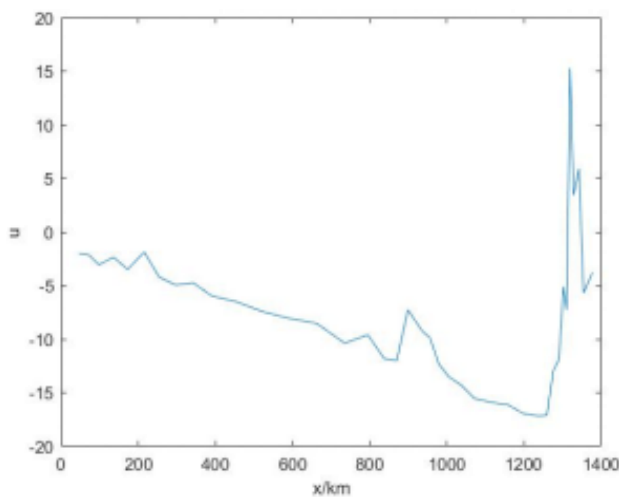


Figure 5. Relation curve of u and x

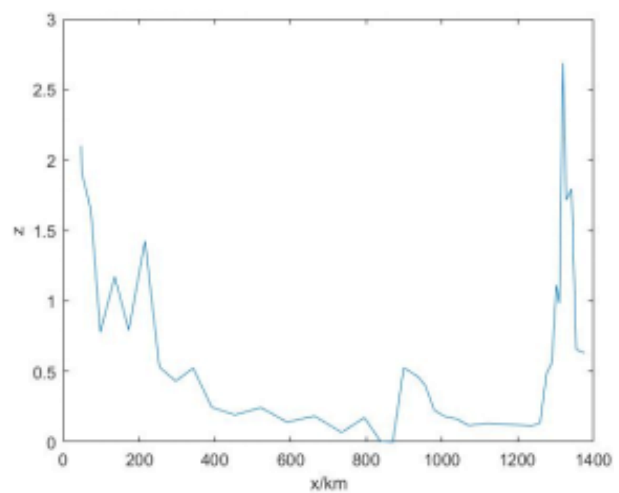


Figure 6. Relationship curve of z and x

It can be seen from the figures that when u is the largest, x is about 1319 km, meaning that the location is 1319 km from the beginning of the midstream [10]. At z maximum, x is about 1300 km. According to the map, the hydropower station should be built at the entrance of the Yarlung Zangbo Grand Canyon.

3. Mathematical Model of Multiple Hydropower Stations

We assume that the construction structure of multiple hydropower stations is as shown in the figure below, q_n^t (m^3/s) is the average inflow of the hydropower station n . S_n^t (m^3/s) is the allowable waste water of hydropower station n . Q_n^t (m^3/s) refers to the generation reference flow of hydropower station n . Structural model of several hydropower stations is shown in figure 7.

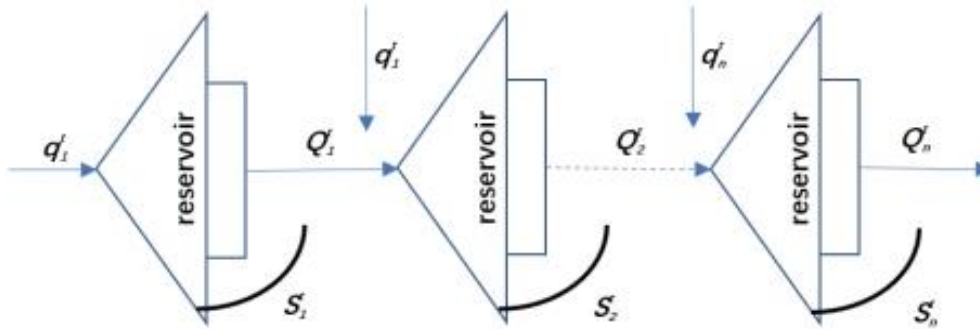


Figure 7. Structural model of several hydropower stations

In this paper, a mathematical model of multiple hydropower stations is adopted, which focuses on power generation and takes into account other integrated benefits. The physical meaning is: on the premise of meeting the safety output and various constraints of multiple hydropower stations, how to make full use of limited water resources, in order to maximize the total power generation of multiple hydropower stations. The objective function is:

$$E = \max \sum_{t=1}^{t=T} \sum_{i=1}^{i=N} A_i Q_i^t H_i^t \quad (1)$$

E (kW) is the sum of power generation of multiple hydropower stations. i is the variable of hydropower station number and N is the number of hydropower stations. A_i is the comprehensive output coefficient of hydropower station i . Q_i^t (m^3/s) is the average generation reference flow of hydropower station i . H_i^t (m) is the average net generating head of hydropower station i .

The comprehensive output constraint of hydropower station is:

$$\underline{P}_i^t \leq A_i Q_i^t H_i^t \leq \overline{P}_i^t \quad (2)$$

\underline{P}_i^t and \overline{P}_i^t (kW) are the maximum and minimum allowable output of hydropower station i .

The reservoir storage capacity is constrained as:

$$\underline{V}_i^t \leq V_i^t \leq \overline{V}_i^t \quad (3)$$

\overline{V}_i^t and \underline{V}_i^t (m^3) are the maximum and minimum values of the reservoir storage capacity that hydropower station i should guarantee.

The reservoir waste water volume is constrained as:

$$\underline{S}_i^t \leq S_i^t \leq \overline{S}_i^t \quad (4)$$

\overline{S}_i^t and \underline{S}_i^t (m^3/s) are the upper and lower limit values of the allowable waste water of hydropower station i .

The reservoir power generation flow is constrained as:

$$\underline{Q}_i^t \leq Q_i^t \leq \overline{Q}_i^t \quad (5)$$

\overline{Q}_i^t and \underline{Q}_i^t (m^3/s) are the upper and lower limit values of the quoted flow of hydropower station i .

The connection between multiple hydropower stations is relatively complex, so we simplify it as follows: when the upstream reservoir is impounded, the water from the upstream reservoir minus the amount of water stored in the reservoir, and plus the water from the interval between the upstream reservoir and the downstream reservoir, is the water from the downstream power station; When the upstream reservoir supplies water, the water from the upstream reservoir plus the water supply as well as the water from the interval between the upstream reservoir and the downstream reservoir, is the water from the downstream power station. Due to the complexity of the model, the time lag when the upstream reservoir flows to the downstream reservoir is not considered. The dynamic balance equation of reservoir water volume is as follows.

$$V_i^t = V_i^{t-1} + [q_i^t + K(S_{i-1}^{t-1} + Q_{i-1}^{t-1}) - S_i^t - Q_i^t]\Delta t \quad (6)$$

V_i^t is the initial and final reservoir storage capacity of hydropower station i , q_i^t is the average inflow of hydropower station i , and K is the weight factor.

3.1. Dynamic Programming Optimization Calculation

According to the data obtained from the search, we use the dynamic programming method to further calculate our model. The average runoff of the Yarlung Zangbo River is $4425m^3/s$. We assume that only medium-head hydropower stations and medium-sized reservoirs will be built, and the average head is set at $100m$. The upper limit of the quoted flow is $1000m^3/s$, and the upper limit of the reservoir storage capacity is 1 billion m^3 . Dynamic planning diagram is shown in figure 8.

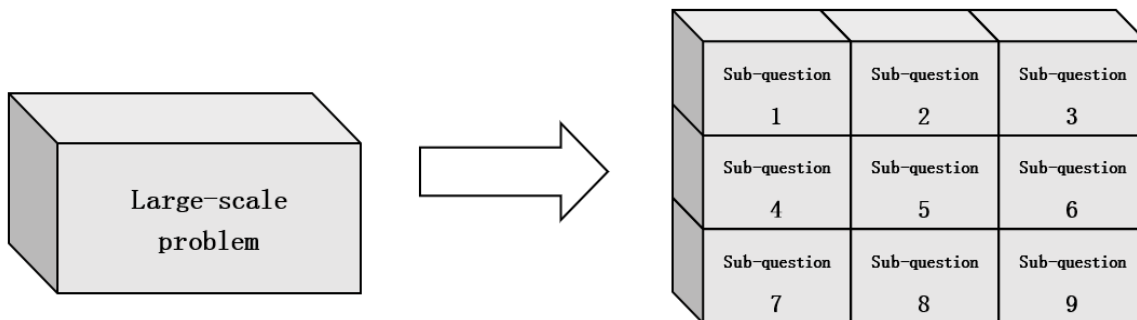


Figure 8. Dynamic planning diagram

We use dynamic programming algorithm to decompose the optimization of total power generation into several small problems. In order to maximize the power generation of each hydropower station, the optimization criteria are as follows: on the basis of meeting the constraints of hydropower stations and reservoirs, we select the water use strategy to optimize the power generation of multiple hydropower stations at the same time. According to the optimization criteria and dynamic planning principle, if two hydropower stations will be built, the objective function is as follows.

$$E_t[QF_1(t), V_2(t)] = \max_{QF_1, V_2} \{N_1[t, QF_1(t)]T(t) + N_2[t, V_2(t)]T(t) + E_{t-1}[QF_1(t-1), V_2(t-1)]\} \quad (7)$$

t represents unit time period. $N_1[t, QF_1(t)]$ represents the output when the generating capacity is $QF_1(t)$. Combined with the constraint conditions and solved by Matlab, we can get that the optimal total power generation of the two hydropower stations is $1162700kW$.

3.2. Conclusion of this section

By adding variables to the objective function to represent more hydropower stations through the above method, we can get the total power generation when the number of hydropower station is 3,4,5 ... and the relationship curve is as follows. Relationship between power generation and number of hydropower stations is shown in figure 9.

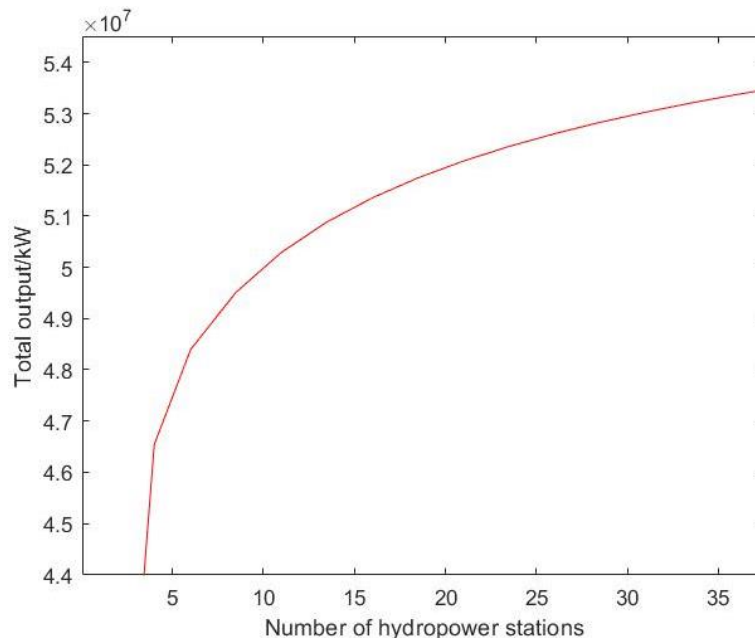


Figure 9. Relationship between power generation and number of hydropower stations

It can be concluded that the total output of 16 hydropower stations is 51358600kW, which has reached a high level. If hydropower stations continue to be built, the total power generation will grow slowly and the energy utilization efficiency of a single hydropower station will be low. To sum up, it can be inferred that the potential power generation capacity of the Yarlung Zangbo River is 55 million kW.

4. Conclusion

The Yarlung Zangbo River is not only the longest plateau river in China, but also one of the highest rivers in the world. Its development and utilization have always been a controversial issue. Based on the official data and other research data, this paper proposes an integrated development plan for the water resources of the Yarlung Zangbo River.

First of all, this paper studies ecology, geology, investment and benefits respectively. Based on the data of the elevation, drop and fish abundance of the Yarlung Zangbo River, combined with its geographical location, a multi-objective optimization model is established. It is concluded that the entrance of the Yarlung Zangbo Grand Canyon is the best place to build a hydropower station.

This paper analyzes the number of hydropower stations built on the Yarlung Zangbo River from the perspective of maximum energy utilization. Using the dynamic programming method, the problem of finding the maximum total output energy is transformed into some sub-problems, which aims to find the maximum output energy of each hydropower station. Based on the obtained data and some assumptions, we use Matlab to calculate, resulting that the total output of 16 hydropower stations is 51358600kW, which reaches a high level. It is estimated that the potential power generation capacity of the Yarlung Zangbo River is about 55 million kW.

References

- [1] Wohl E. Rivers in the Critical Zone. *Developments in Earth Surface Processes*. Amsterdam: Elsevier, 2015, 19: 267 - 293.
- [2] Xu Jiahui; Wang Shidong; Song Lijuan; Zhang Dapeng; Song Chunqiao. Remote sensing monitoring of the temporal and spatial variation of the river width in the main stream of the Yarlung Zangbo River and its response to hydrometeorology [J]. *Journal of Geography*, 2022, (11): 2862 - 2877.
- [3] Li Yan. Analysis of financial characteristics and construction and operation of hydropower projects [J]. *Finance and Accounting Study*, 2020, (35): 13 - 14+68.
- [4] Li, Kai & Shan, Wang & Wang, Xiaoi & Wang, Mengjun & He, Ruchuan & Wang, Mo. (2022). Distribution Pattern of Fish Richness in the Yarlung Zangbo River Basin. *Diversity*. 14. 10.3390/d14121142.
- [5] Wen X, Liu Fanqian, Tan Qiaofeng, Wang Hao. Study on short-term multi-level multi-objective optimal scheduling of terraced hydropower plants under complex hydraulic-power constraints [J/OL]. *Journal of Water Resources*: 1-13 [2023-02-25]. DOI: 10.13243/j.cnki.slx.20220852.
- [6] Yang L-L, Zhang F-Y. The first unit of the hydroelectric power station of Haixi Prefecture Cunjixia Water Conservancy Hub Project is officially put into operation and generates electricity [N]. *Qinghai Daily*, 2023-01-04(002). DOI: 10.28625/n.cnki.nqhrb.2023.000471.
- [7] Shaanxi Hanjinjiwei project Jinjinxia water conservancy hub dam full line pouring to the top [J]. *Water Pump Technology*, 2022 (06): 53.
- [8] Wang Z. Comprehensive study on water resources development of Biliuhe reservoir in Dalian [J]. *Heilongjiang Water Conservancy Science and Technology*, 2022, 50 (12): 109 - 111. DOI: 10.14122/j.cnki.hskj.2022.12.029.
- [9] Gadui hydropower station [J]. *China Energy*, 2021, 43 (05): 2.
- [10] Successful completion of the inflow cavern of Tibet Xianghe Water Conservancy Hub Project, which is under the operation and management of the Experimental Testing Center of the Yangtze River Academy of Sciences [J]. *Journal of the Yangtze River Academy of Sciences*, 2020, 37 (02): 152.