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Hydropower and Sediment Siltation Evaluation Research
A Case Study of X Hydropower Station in Southwest China

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Abstract: With the acceleration of China's energy structure transition and the successful completion of the "14th Five-Year Plan" targets, hydropower's position as a backbone of clean energy has been continuously strengthened. Based on the latest 2025 hydropower data and energy policies, combined with modern sediment management methods, this paper conducts an optimized evaluation of the engineering tasks, installed capacity, and operation schemes of X Hydropower Station in Southwest China. In terms of sediment siltation assessment, the SUSBED-2 one-dimensional steady non-uniform flow sediment transport model was used to compare three operation schemes. The results show that the flood season restriction water level of 1,098 m can effectively control the reservoir capacity loss rate within 44%. The study indicates that an installed capacity of 120 MW for X Hydropower Station is the optimal solution balancing economic benefits and engineering feasibility.

1 Introduction

In recent years, China's hydropower installed capacity and electricity generation have continued to grow, becoming the cornerstone of clean energy supply. By 2025, the national conventional hydropower installed capacity is expected to reach 380 million kilowatts, ranking first in the world, demonstrating China's technological and resource advantages in the hydropower sector [1].

Yunnan Province, as one of the provinces with the richest hydropower resources in China, has a proportion of hydropower installed capacity that is extremely high nationwide, forming an energy structure dominated by hydropower and supported by clean energy [2]. Under this macro background, although large-scale cascade development has nearly reached saturation, medium and small hydropower projects still hold significant strategic value. However, with the increasing frequency of climate change and extreme weather, reservoir sediment siltation problems have become increasingly prominent, urgently requiring a reassessment of hydropower station design parameters through new technological means. This paper combines the latest hydropower development trends, policy guidance, and sediment management technology to conduct an in-depth analysis of the engineering tasks and installed capacity of X Hydropower Station in Southwest China.

2 Assessment of Project Tasks and Installed Capacity

2.1 Determination of Development Tasks

X Hydropower Station is located in a high mountain gorge area on the lower main stem of the Longjiang boundary river, and is a dam-toe diversion-type hydropower station. The powerhouse is approximately 19 km from Longling County; the drainage area above the dam site is 3773 km^2. The project serves a single purpose of hydropower generation. The layout adopts a concrete gravity dam with a maximum height of 68 m. The normal storage level is 1102.5 m, with a corresponding total storage capacity of 5.996 million m^3, a normal storage capacity of 5.490 million m^3, a dead water level of 1090 m, a dead storage capacity of 1.657 million m^3, and a regulating storage capacity of 3.970 million m^3, providing incomplete daily regulation capability. Its power supply range primarily serves the intra-provincial power grid dispatch, aligning with the main line of the national "West-to-East Electricity Transmission" strategy.

- Supply Range Determination. The supply range of X Hydropower Station remains primarily the Yunnan provincial grid, mainly serving the industrial electricity demand of X City and surrounding areas. According to the latest provincial grid dispatch data, the "West-to-East Electricity Transmission" strategy of Yunnan's grid remains the main line, and the electricity from X Hydropower Station will primarily participate in intra-provincial grid dispatch, meeting both local

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and inter-provincial transmission demands. It is noteworthy that Yunnan's grid bears the dual responsibilities of the national "West-to-East Electricity Transmission" strategy and meeting the country's growing electricity demand, facing significant power supply assurance pressure [3].

- Development Necessity. Data shows that despite the significant increase in hydropower installed capacity, per capita electricity consumption continues to rise, especially in regions combining mining and power, where industrial electricity demand is robust. The construction of medium and large hydropower stations remains a key infrastructure for addressing regional power gaps and supporting industrial development. As a medium-sized hydropower project, the construction of X Hydropower Station aligns with the national energy policy of "coordinating hydropower development and ecological protection" [4].

2.2 Installed Capacity Argumentation

During the pre-feasibility study phase, the recommended installed capacity for X Hydropower Station is 120 MW. Combining the latest data and technological developments, supplementary analysis is conducted from the following two aspects:

- Economic Benefit Analysis. According to the "law of diminishing marginal returns," when resource inputs (such as reservoir capacity and development intensity) increase, the marginal benefits (such as electricity generation and economic returns) per unit input will slow down [5]. Research indicates that the regulation capability of hydropower is crucial for enhancing new energy consumption, but the installed capacity must be controlled within the economically optimal range to avoid overall system cost increases due to diminishing marginal returns [6]. The National Energy Administration has explicitly stated that relying on the large hydropower base in Southwest China, fully considering the regulatory characteristics of hydropower, and optimizing new energy configurations is essential. In this context, an installed capacity of 120 MW can ensure the economic benefits of the station while forming a good complementary relationship with surrounding new energy projects.
- Technological Updates. The digital twin monitoring and control key technology for stable wide-load operation of large hydropower units has been successfully applied on-site at hydropower stations, significantly improving the real-time nature and control accuracy of stability monitoring. The latest digital twin technology indicates that through real-time monitoring and model simulation, the peak regulation capacity of the reservoir can be improved without increasing installed capacity [7]. This means that X Hydropower Station, while maintaining a 120 MW installed capacity, can enhance operational efficiency through technical means.To further validate the economic rationality of the installed capacity, this paper conducts an economic comparison of three capacity options: 90 MW, 120 MW, and 150 MW. Based on the latest hydropower engineering cost quotas and hydrological data of the longjiang boundary river, the main economic indicators for each scheme are shown in Table 1. The analysis uses a 25-year operational period and an 8% discount rate for benefit-cost analysis.

Table 1. Economic Indicator Comparison for Different Installed Capacity Schemes

Capacity Scheme (MW)	90	**120**	150
Annual Energy Output (GWh)	4.85	**6.07**	7.10
Total Investment (100M CNY)	6.95	**8.56**	11.50
Unit kW Investment (CNY/kW)	7722	**7133**	7667
Benefit-Cost Ratio (B/C)	1.15	**1.28**	1.12
Internal Rate of Return (%)	10.1	**12.6**	9.8

As shown in Table 1, the 120 MW scheme has the lowest unit kW investment (7133 CNY/kW), the highest benefit-cost ratio (1.28, and an internal rate of return of 12.6%, all superior to the 90 MW and 150 MW schemes. Although the 150 MW scheme increases annual energy output, it is constrained by river flow and head conditions; increasing installed capacity leads to a decline in unit utilization hours and diminishing marginal returns. The total static investment rises significantly, the benefit-cost ratio drops to 1.12, and the internal rate of return is only 9.8%, falling below the industry benchmark. The 90 MW scheme fails to fully utilize the hydropower resources. Therefore, an installed capacity of 120 MW represents the optimal solution balancing economic benefits and resource utilization.

3 Sediment Analysis of the Reservoir

The station is located in a mountainous river system, with an average natural riverbed slope of 7.0‰ in the reservoir area, and a steeper riverbed slope of 11‰ at 4 km from the dam site. At the normal storage level of 1102.5 m, the backwater length is about 7.4 km, and the water surface width ranges from 53 to 134 m, characteristic of a river-type reservoir. The natural state of the reservoir's riverbed consists of sand and cobbles.

X Hydropower Station has a relatively small reservoir capacity, with a reservoir-sand ratio of only 2.6, leading to a short sediment siltation equilibrium period. Additionally, the E Power Station, with a total installed capacity of 3200 kW, has already been built on a tributary 3.2 km within the reservoir area, restricting the water level selection for X Hydropower Station due to the platform elevation of the E Power Station. According to the requirements of the "Design Code for Hydropower and Water Conservancy Sediment Projects" [8] and in conjunction with the functions and engineering design requirements of X Hydropower Station, the main tasks for sediment siltation calculation are: analyzing the sediment siltation morphology under different operating water levels, studying the development process of reservoir sediment siltation and its impact on reservoir benefits; determining the siltation volume and sand discharge ratio for different operational years, providing a basis for anti-sand design; analyzing and calculating the backwater curves at different frequencies under natural and siltation equilibrium conditions, providing a basis for water level selection and inundation design.

3.1 Sediment Characteristics and Monitoring Technology

Recent years, sediment monitoring has transitioned from traditional sampling to real-time sensing. Traditional analysis mainly relied on an average suspended sediment concentration of 0.454 kg/m^3 , but the latest monitoring indicates that the particle size distribution of sediment is changing, especially during flood seasons, where the proportion of fine sand may be higher, accelerating the siltation rate of reservoirs [9]. The suspended sediment load exhibits uneven coarse-fine distribution, ranging from fine particles of 0.005 mm to coarse particles up to 0.5 mm, with a median particle size d50=0.04 mm and an average particle size d=0.09 mm. The water-sediment variation characteristics of the Jinsha River basin have been deeply studied, showing a significant impact of the sand interception effect on downstream sediment transport [10]. The latest digital twin technology has been widely applied in reservoir sediment monitoring, achieving three-dimensional topographic measurement and real-time perception of reservoir sediment siltation through thousands of sensors and unmanned devices, providing valuable experience for the sediment management of X Hydropower Station [11].Specifically, online suspended sediment monitoring stations and automatic cross-sectional topography measurement systems can be deployed at key reservoir cross-sections to acquire real-time data on incoming sediment concentration, particle size distribution, and cross-sectional siltation morphology. Through data assimilation techniques, the sediment-carrying capacity coefficient K (originally fixed at 0.03) and the saturation recovery coefficient α in the SUSBED-2 model can be dynamically calibrated. For example, during the 2025 flood season, if monitoring data indicate that the median particle size d50 of suspended sediment in three consecutive flood events is finer than the design value (e.g., decreasing from 0.04 mm to 0.02 mm), the sediment-carrying capacity coefficient K can be correspondingly increased to 0.035 – 0.04. The model would then predict an increase in the sand discharge ratio of approximately 3% – 5%, allowing the flood season restriction level to be marginally raised from 1098 m to 1099 m under the precondition of ensuring flood safety, thereby increasing annual energy output by approximately 0.8%. Conversely, if an increased proportion of coarse sand is detected, the operating level should be lowered in advance to enhance sediment flushing.

3.2 Sediment Siltation Prediction Results

3.2.1 Annual Distribution of Sediment Load

Based on the analysis of hydrological station data (as shown in Fig 1), the sediment load during the flood season (June to October) accounts for 91.2% of the annual sediment load, while the non-flood season accounts for only 8.8%. The annual sand distribution is lowest in January, with an average annual sediment load of only 0.98 million tons, accounting for 0.43% of the total; it peaks in July, with an average annual sediment load of 59.9 million tons, accounting for 26.4% of the total. Monthly sediment loads during the flood season generally account for 8.1% to 26.4% of the annual total, while non-flood season monthly loads each account for 0.43% to 3.5% of the annual total.

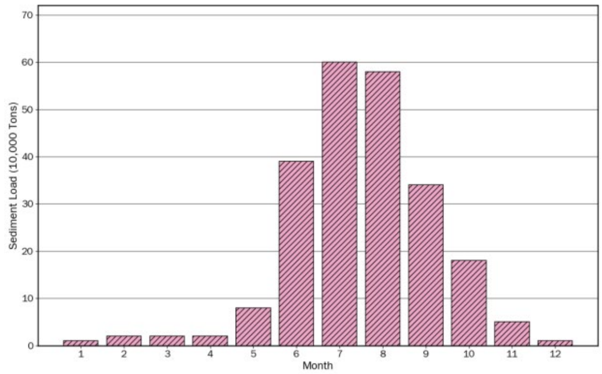

Fig 1. Monthly Sediment Load Distribution

3.2.2 Particle Size Distribution of Suspended and Bed Sediment

Fig 2 shows that the suspended sediment load has an uneven coarse-fine distribution, ranging from fine particles of 0.005 mm to coarse particles up to 0.5 mm. The median particle size is d50=0.04 mm, and the average particle size is d=0.09 mm. The bed material particles are fewer in fine particles and more in coarse particles, with a median particle size of d50=7.8 mm, an average particle size of d=25.4 mm, and a specific gravity of 2.70 t/m^3 .

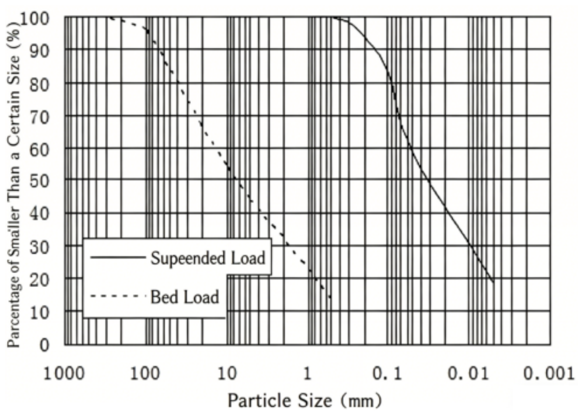

Fig 2. Sediment Particle Size Gradation Curve

3.2.3 Sediment Mathematical Model Computation

- Mathematical Model Overview. This sediment siltation analysis uses the SUSBED-2 one-dimensional steady non-uniform flow sediment transport model developed by Wuhan University of Hydraulic and Electric Engineering [12]. This model is based on river sediment dynamics theory, non-uniform suspended sediment imbalance transport, and research results on reservoir siltation and river channel erosion-deposition deformation. It provides a comprehensive solution and has been widely adopted in engineering designs such as the Gaoqiao Power Station, Yunlong Reservoir, Nuozu Power Station, Maliba Reservoir, and Manwan and Dachaoshan projects in Yunnan Province, achieving excellent results. This model is one of the recommended models in the "Design Code for Hydropower and Water Conservancy Sediment Projects."
- Computational Conditions. The backwater length of X Hydropower Station is approximately 7.6 km, with 14 cross-sections arranged based on annual measured 1:2000 topographic map profiles. The average spacing between cross-sections is 582 m, with a maximum spacing of 675 m and a minimum spacing of 327 m. The sediment siltation calculation period extends to siltation equilibrium, with a time step of one day. Due to the relatively small reservoir-sand ratio, the typical period of 1978-1981, which closely matches the multi-year average sediment load, is selected for calculation. The sediment siltation calculation considers three operating water level schemes: Scheme 1, normal storage level of 1102.5 m; Scheme 2, normal storage level of 1102.5 m with a flood season restriction level of 1098 m; Scheme 3, normal storage level of 1102.5 m with a flood season restriction level of 1095 m.
- Particle Size Grouping. Based on the composition of suspended and bed load sediment, the non-uniform sand is divided into 9 groups with endpoint particle sizes of $d0=0.001$, $d1=0.008$, $d2=0.02$, $d3=0.05$, $d4=0.1$, $d5=0.25$, $d6=1$, $d7=5$, $d8=100$, and $d9=300$ mm. The first 5 groups calculate suspended sediment, and the last 4 groups calculate bed load sediment.
- Parameters: The flow sand-carrying force coefficient $K=0.03$, $m=1.25$, the bed load sediment imbalance transport coefficient $K=0.002$, and the suspended sediment saturation recovery coefficient $\alpha=1.0$ during scouring and $\alpha=0.25$ during siltation.

3.3 Calculation Results

3.3.1 Sediment Siltation Volume

After the construction of X Hydropower Station, the annual cumulative siltation volume and inter-period sand discharge ratio for each scheme are shown in Tables 2 to 4. The tables indicate that as the reservoir operation years increase, the siltation volume gradually increases, and the sand discharge ratio also gradually rises.

- Scheme 1 (Table 2): After 5 years of operation, the cumulative siltation volume is 3.307 million m^3, with an average inter-period sand discharge ratio of 72%; after 10 years, the average inter-period sand discharge ratio reaches 93.5%, indicating that the reservoir has essentially reached a siltation equilibrium state, with a cumulative siltation volume of 4.424 million m^3.

Table 2. Scheme 1 Siltation Volume Changes (Normal Storage Level 1,102.5 m)

Project	3yr	5yr	8yr	10yr
Incoming Sand (10^4m^3)	639.7	1081.6	1744.3	2138.7
Outgoing Sand (10^4m^3)	432.7	750.9	1327.5	1696.3
Siltation Volume (10^4m^3)	207.0	330.7	416.8	442.4
Sand Discharge Ratio (%)	67.6	72.0	87.0	93.5

- Scheme 2 (Table 3): After 5 years, the cumulative siltation volume is 2.255 million m^3, with an average sand discharge ratio of 84%; after 7 years, the sand discharge ratio reaches 97.5%, indicating the reservoir has essentially reached a siltation equilibrium state, with a cumulative siltation volume of approximately 2.548 million m^3.

Table 3. Scheme 2 Siltation Volume Changes (Normal Storage Level 1,102.5 m, Flood Season Restriction Level 1,098 m)

Project	3yr	5yr	6yr	7yr
Incoming Sand (10^4m^3)	639.7	1081.6	1303.7	1500.2
Outgoing Sand (10^4m^3)	484.9	856.1	1053.7	1245.3
Siltation Volume (10^4m^3)	154.8	225.5	249.9	254.8
Sand Discharge Ratio (%)	75.8	84.0	89.0	97.5

- Scheme 3(Table 4): After 5 years, the cumulative siltation volume is 1.905 million m^3, with an average sand discharge ratio of 89%; the reservoir reaches siltation equilibrium in 6 years, with a sand discharge ratio of 90.5% and a cumulative siltation volume of 2.016 million m^3.

Table 4. Scheme 3 Siltation Volume Changes (Normal Storage Level 1,102.5 m, Flood Season Restriction Level 1,095 m)

Project	3yr	5yr	6yr
Incoming Sand (10^4m^3)	639.7	1,081.6	1,303.7
Outgoing Sand (10^4m^3)	506.6	891.1	1,102.1
Siltation Volume (10^4m^3)	133.1	190.5	201.6
Sand Discharge Ratio (%)	79.2	87.0	95.0

3.3.2 Siltation Morphology

The longitudinal siltation changes in the reservoir area for different years and schemes are shown in Figs 3 to 5. The figures clearly indicate that the sediment siltation morphology of X Hydropower Station is conical, primarily due to the small reservoir capacity, short backwater length, and relatively large incoming sediment.

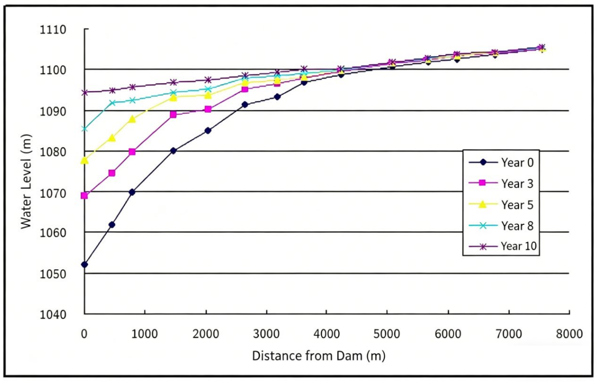

Fig 3. Scheme 1 Siltation Morphology for Different Operation Years

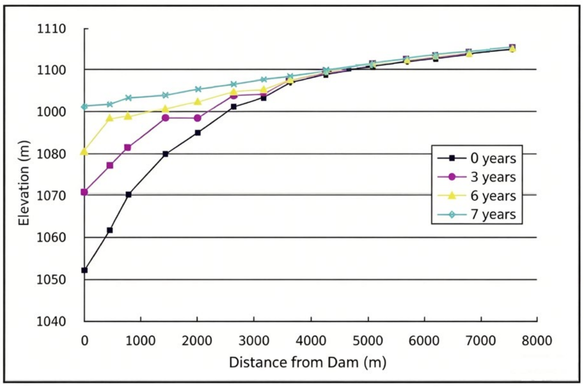

Fig 4. Scheme 2 Siltation Morphology for Different Operation Years

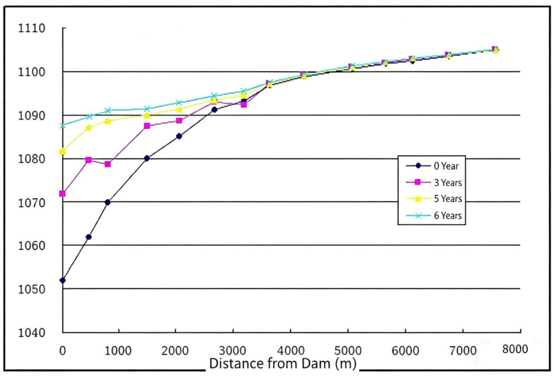

Fig 5. Scheme 3 Siltation Morphology for Different Operation Years

3.3.3 Reservoir Capacity Loss Analysis

The reservoir capacity changes for different operation years of X Hydropower Station are shown in Table 5.

- Scheme 1: After 10 years of operation, the reservoir essentially reaches siltation equilibrium. At this point, the total siltation volume in the reservoir area is 4.424 million m^3; the dead storage (dead water level 1090 m) is essentially full except for the pre-dam scour funnel; the normal storage has silted up by 4.24 million m^3, resulting in a capacity loss rate of 77% and a remaining volume of 1.244 million m^3.
- Scheme 2: After 7 years, the reservoir reaches siltation equilibrium. The total siltation volume is 2.548 million m^3; the dead storage (dead water level 1090 m) is also essentially full except for the pre-dam scour funnel; the normal storage has silted up by 2.403 million m^3, resulting in a capacity loss rate of 43.8% and a remaining volume of 3.087 million m^3.
- Scheme 3: After 6 years, the reservoir reaches siltation equilibrium. The total siltation volume is 2.016 million m3; the dead storage has silted up by 1.363 million m^3, resulting in a capacity loss rate of 89% and a remaining volume of 0.157 million m^3; the normal storage has silted up by 1.97 million m^3, with a capacity loss rate of 36% and a remaining volume of 3.52 million m^3.

Table 5. Normal Reservoir Capacity Changes for Different Operating Schemes (Under Siltation Equilibrium)

Project	**Scheme 1 (1102.5m)**	**Scheme 2 (1102.5-1098m)**	**Scheme 3 (1102.5–1095m)**
Siltation Equilibrium Years	10yr	7yr	6yr
Normal Storage Siltation Volume ($10^4 m^3$)	424.2	240.3	197.1
Normal Storage Remaining ($10^4 m^3$)	124.8	308.7	351.9
Normal Reservoir Capacity Loss Rate (%)	77.3	43.8	35.9

6 Backwater Analysis Calculations

According to relevant standards and submergence design requirements, the backwater calculations were performed under the condition of sedimentation equilibrium, considering backwater curves for P = 20%, P = 5%, and P = 3.33% in the reservoir area. Additionally, water surface line outcomes for the natural river channel at different frequencies were also calculated.

The boundary conditions for water surface line calculations are briefly described as follows:

- Backwater Calculation Basis: Calculated based on the constant non-uniform flow equation.
- Cross-sectional Data: The longitudinal and transverse cross-sectional data of the reservoir area under sedimentation equilibrium are derived from the results of sedimentation analysis calculations; natural condition cross-sectional data are obtained from the 1:2,000 topographic map profile.
- Channel Roughness: Based on field surveys, n=0.032-0.04.
- Peak Flow and Upstream Water Levels: Peak flow rates and upstream water levels at each frequency at

the dam site are determined based on flood regulation calculation results; the natural upstream water level is determined by the water level-flow relationship curve at the dam site.

When the reservoir reaches a sediment equilibrium state, a 20-year recurrence interval flood occurs. At Section 14 (7564 m from the dam), the backwater level is 0.3 m higher than the natural flood level. According to the Specification for Flooded Area Planning and Design of Hydropower Engineering Reservoirs, the backwater influence range is determined to be 7.6 km. The backwater calculation results for the X Hydropower Station reservoir area are shown in Tables 6-8, and the backwater curves are shown in Fig 6.

Table 6. Reservoir Area Backwater Calculation Results (P=3.33%)

No.	Distance from Dam(m)	30-Year Flood			Natural Water Surface Line (m)
		1102.5m	1098m	1095m	
1	0	1102.50	1098.00	1095.00	1061.79
2	470	1102.75	1098.55	1095.82	1068.80
3	797	1103.11	1099.06	1096.61	1075.43
4	1472	1103.91	1100.62	1098.28	1086.91
5	2044	1104.63	1101.74	1099.36	1091.06
6	2659	1105.17	1102.91	1100.92	1097.80
7	3180	1105.96	1104.19	1102.58	1102.20
8	3639	1107.01	1105.35	1104.00	1103.34
9	4245	1109.37	1108.09	1106.35	1105.70
10	5090	1109.79	1108.66	1108.12	1107.25
11	5674	1110.43	1109.38	1109.00	1108.52
12	6164	1110.92	1109.88	1109.57	1109.18
13	6786	1111.22	1110.68	1110.37	1110.02
14	7564	1112.93	1112.84	1112.70	1112.48
Note: Design flood peak flow for a 30-year event at the dam site is 2090 m³/s.					

Table 7. Reservoir Area Backwater Calculation Results (P=5%)

No.	Distance from Dam(m)	20-Year Flood			Natural Water Surface Line (m)
		1102.5m	1098m	1095m	
1	0	1102.50	1098.00	1095.00	1061.57
2	470	1102.72	1098.45	1095.75	1066.62
3	797	1103.03	1098.93	1096.48	1075.30
4	1472	1103.77	1100.43	1098.08	1086.61
5	2044	1104.45	1101.52	1099.13	1090.89
6	2659	1104.99	1102.73	1100.74	1097.64
7	3180	1105.75	1103.96	1102.33	1101.97
8	3639	1106.84	1105.19	1103.84	1103.07
9	4245	1109.05	1107.76	1106.11	1105.40
10	5090	1109.50	1108.38	1107.83	1107.03
11	5674	1110.15	1109.11	1108.73	1108.29
12	6164	1110.66	1109.62	1109.32	1108.95
13	6786	1110.97	1110.44	1110.12	1109.80
14	7564	1112.73	1112.60	1112.51	1112.30
Note: Design flood peak flow for a 20-year event at the dam site is 1940 m³/s.					

Table 8. Reservoir Area Backwater Calculation Results (P=20%)

No.	Distance from Dam(m)	5-Year Flood			Natural Water Surface Line (m)
		1102.5m	1098m	1095m	
1	0	1102.50	1098.00	1095.00	1060.75
2	470	1102.62	1098.12	1095.22	1066.13
3	797	1102.79	1098.46	1095.87	1074.75
4	1472	1103.28	1099.69	1097.27	1085.65
5	2044	1103.76	1100.69	1098.22	1090.18
6	2659	1104.27	1102.01	1100.05	1096.97
7	3180	1104.91	1103.04	1101.36	1101.00
8	3639	1106.17	1104.48	1103.18	1102.09
9	4245	1107.83	1106.48	1105.12	1104.20
10	5090	1108.41	1107.30	1106.78	1106.19
11	5674	1109.08	1108.07	1107.73	1107.41
12	6164	1109.67	1108.63	1108.37	1108.06
13	6786	1109.98	1109.49	1109.17	1108.89
14	7564	1111.92	1111.84	1111.74	1111.54
Note: Design flood peak flow for a 5-year event at the dam site is 1390 m³/s.					

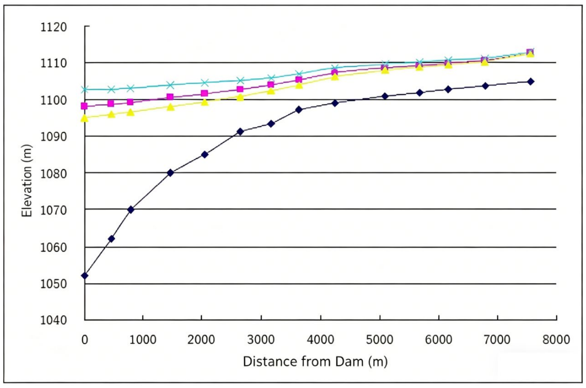

Fig 6. Backwater Curve Results for X Hydropower Station (P=5%)

5 Conclusions

- Installed Capacity Recommendation: Maintaining a 120 MW installed capacity remains the optimal choice.This scheme achieves an average annual energy output of 607 GWh, with a unit kW investment of 7,133 CNY/kW, a benefit-cost ratio of 1.28, and an internal rate of return of 12.6%, demonstrating significant economic benefits.By 2025, the national hydropower installed capacity has reached 448 million kW, showing a clear diminishing marginal benefit trend. Medium-sized hydropower projects should reasonably determine installed capacity while ensuring economic benefits. The integration of digital twin technology can further enhance operational efficiency and reduce the full lifecycle cost.
- Operational Scheme Recommendation: The flood season restriction water level at 1098 m (Scheme II) remains the optimal scheme under the current sediment characteristics and flood safety considerations. Under this scheme, the reservoir reaches sediment equilibrium in 7 years, with a Normal Reservoir Capacity Loss Rate of 43.8% and a remaining capacity of 3.087 million m^3, effectively balancing sediment flushing and power generation benefits. Although Scheme I does not require lowering water levels during the flood season, its capacity loss rate reaches 77.3%, which is detrimental to the reservoir's long-term operation. Scheme III has the lowest capacity loss rate (35.9%) but significantly impacts power generation during the flood season, requiring a comprehensive trade-off. Further comparison of the power generation benefits between Scheme 2 and Scheme 3: Under Scheme 2, the average operating head during the flood season (June – October) is approximately 2.1 m higher than that of Scheme 3, with an average annual energy output of approximately 607 GWh. Scheme 3, due to the lower flood season operating level of 1095 m, results in a reduced average head and an average annual energy output of approximately 573 GWh, which is about 5.6% lower than Scheme 2 (a difference of approximately 34 GWh). Scheme II is recommended, and it is suggested to further refine the operational water level by comprehensively considering sediment deposition, power station benefits, and other factors.

In summary, the construction and operation of the X Hydropower Station remain fully necessary and feasible, and it will play an important role in the future energy structure.

Acknowledgments

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