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SANAKHAM HYDROPOWER PROJECT

Reservoir Sedimentation and Backwater

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1 Overview of the Reservoir

Sanakham Hydropower Project is located on the main stream of the Mekong River, about 1.4km upstream of B.Pakheung Village, M.Kenthao County, P.Sayaburi in the People's Democratic of Laos. The reservoir area is wide and open, featuring massive mountains and dense vegetation on both banks, and U-shaped river channel. The natural stream gradient in the reservoir area is 0.29‰ in average. The reservoir storage at full supply level of 220m is 827 million m^3, and the reservoir storage-sediment ratio is about 15.

Don Men Village and Pak Lay Town are located at the reservoir area of Sanakham Hydropower Project. Pak Lay Town is the political, cultural and economic center of Pak Lay county and Pak Lay County Government is located there. Sanakham reservoir backwater connects with the tailwater of upstream cascade Pak Lay hydropower station, and Sanakham reservoir dam site is about 99.2 km away from tailwater of Pak Lay Hydropower Project.

2 Operation Mode of the Reservoir

In 2016, the structures in the feasibility study stage were adjusted according to the review comments in the *Feasibility Study Report of Sanakham Hydropower Project in Laos* (Approved Version) and the independent review comments on Sanakham Hydropower Project. The schemes for project layout after adjustment are as follows:

The main structures, from the left bank to the right bank, comprise the concrete auxiliary dam on the left bank, navigation lock, 13-opening sluice on the left bank for flood discharge, river retaining powerhouse in the middle (with 12 generating units), 5-opening sluice on the right bank for flood and sand discharge, and concrete auxiliary dam on the right bank. The dam crest length is 909.90m in total, the dam crest elevation is 229.50m, and the maximum dam height is 56.2m.

The powerhouse section with total length of 350.20m is divided into eight blocks from left to right, including the block with auxliary erection bay, the blocks with No.1 ~ No.12 units, and the block with main erection bay.

The 13-opening sluice for flood discharge is arranged on the terrace and flood plain on the left bank, with an opening size of 15m×22m (W×H) and a floor elevation of 198.0m; while the 5-opening sluice for flood and sand discharge is arranged on the right bank, with an opening size of 12.5m×16m (W×H) and a floor elevation of 192.0m for four openings, and an opening size of 12.5m×22m (W×H) and a floor elevation of 198.0m for the fifth. For the 5-opening sluice on the right bank connecting the powerhouse section and the fishway outlet, energy dissipation by hydraulic jump is applied. For the 13-opening sluice on the left bank, energy dissipation by hydraulic jump is used to the five sluice gates near the powerhouse, and energy dissipation by surface flow is used to the rest eight sluice gates.

The navigation lock of the project is desigend as per the single-stage single-line lock of Grade IV with capacity of 500t. The effective dimension of the lock chamber is 120m×12m×4m (L×W×D). The whole navigation lock is composed of upstream approach channel, upper lock head, lock chamber, lower lock head and downstream approach channel. The crest elevation is defined as 229.50m considering the requirement of navigable headroom.

The fishway on the right bank is designed with two inlets with floor elevation of 199m and 201.3m respectively, gate chamber of the fishway inlet is 5m. To protect fish running into reservoir from drifting to the river reach downstream of the dam, fishway outlet is arranged 170m away from dam axis. The minimum operating level of the reservoir is 219m, so the bottom plate of the fishway outlet is at EL.217m.

As a water retaining type power station, Sanakham plant will generate electricity with the inflow water, and its reservoir has no function of regulation and storage. According to the design scheme, operation mode of the reservoir is preliminarily proposed as below:

The hydrological station at Luang Prabang is adopted as the inflow flood control station (usually the flood water from Luang Prabang will take 1~2 days to reach Sanakham damsite), the operation mode of the reservoir with consideration of sand discharging is as blow:

In flood season, when the reservoir inflow is greater than the available discharge, surplus flood will be discharged firstly through the 5-opening sluice on the left bank and the rest sluice gates will be opened if necessary to maintain the reservoir level at the full supply level of 220m.

In case of a 3-year flood event occurring at Luang Prabang, flood release shall be started at Sanakham. The 5-opening sluice on the left bank with a stilling basin will be firstly opened and the rest sluice gates will be opened if necessary to limit the outflow discharge to not greater than the 3-year flood peak discharge, the reservoir level will be drawn down and the reservoir will operate in a manner of full opening and sand discharging. In case the inflow flood is greater than the 3-year flood, all the sluice gates will be fully opened for flood and sand discharge, and after the flood process, the reservoir will be refilled up to the full supply level for power generation. When the upstream reservoirs are discharging sand, all sluice gates of Sanakham reservoir shall be fully opened for sand discharge accordingly. Backwater of the reservoir shall be analyzed based on the sediment monitoring results. In case the backwater due to sedimentation in the reservoir area may affect Pak Lay Plant or the reservoir inundated area, or when the sedimentation level upstream of the dam is close to the elevation of the sand trap at the power intake, all the sluice gates shall be fully opened to draw down the reservoir level and discharge sand. The plant will operate normally in other periods.

During the reservoir operation, the operation mode of the reservoir with respect of sand discharge shall be optimized by in accordance with the results of sedimentation monitoring in the reservoir area.

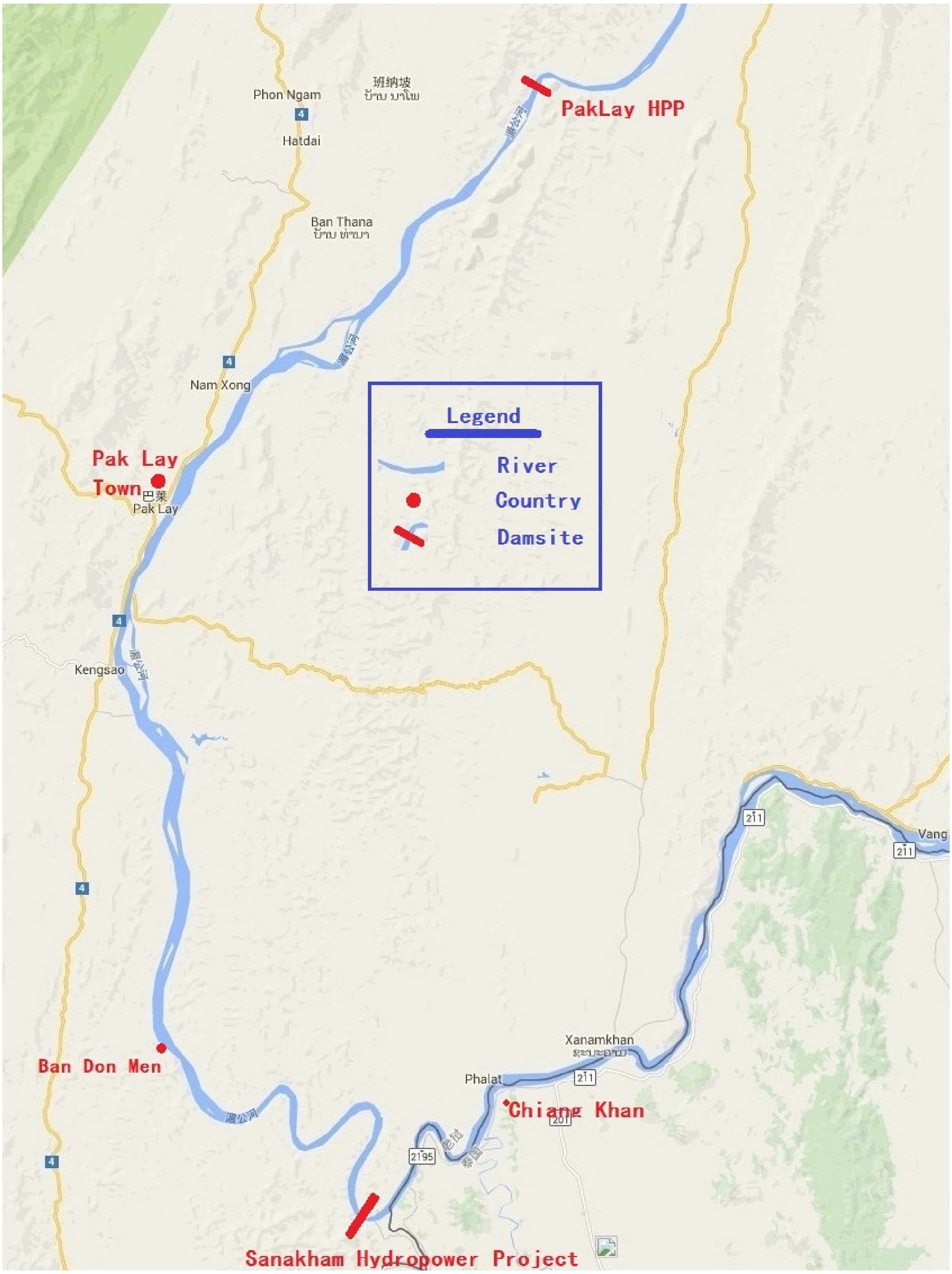

Figure 2-1 River Channel in Reservoir Area of Sanakham Hydropower Project

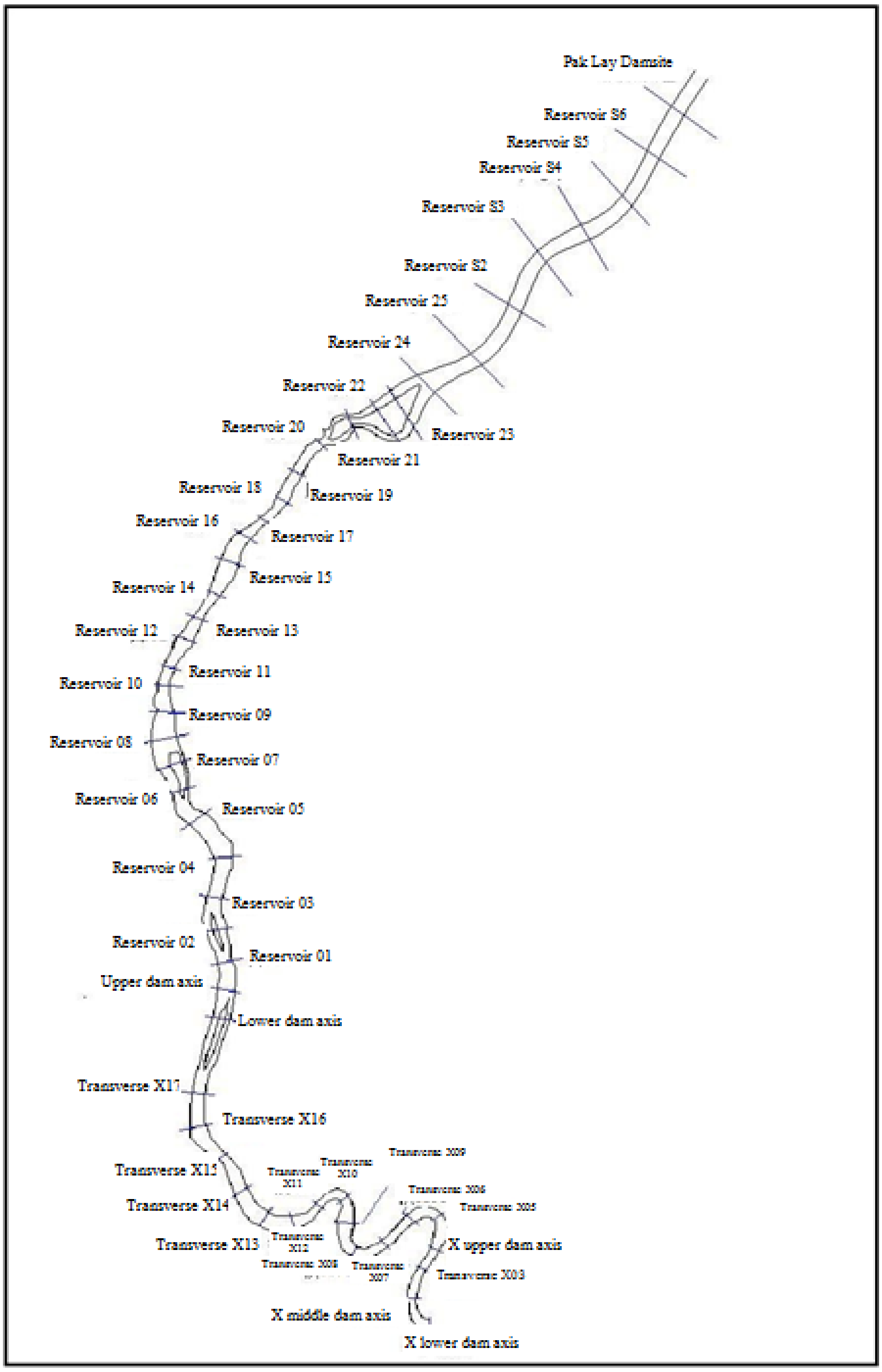

Figure 2-2 Cross Section of the River Channel in Reservoir Area of Sanakham Hydropower Project

3 Analysis and Calculation of Reservoir Sedimentation

3.1 Method and Principles of Calculation

Susbed-2, nonequilibrium sediment transport model with constant flow, developed by Wuhan

University is adopted for calculation of reservoir sedimentation. This model has been verified by prototype test data of large reservoirs and widely used in study and design of hydropower and water conservancy projects in China. Equations for sedimentation calculation are as below:

Continuity equation of flow:

$$\frac{\partial Q}{\partial x} = q_i \tag{1}$$

Equation of motion:

$$\frac{\partial}{\partial x}\left(\frac{Q^2}{A}\right) + gA\frac{\partial Z}{\partial x} + gJ_f = 0 \tag{2}$$

Continuity equation of sediment:

$$r'\frac{\partial A_s}{\partial t} + \frac{\partial (QS)}{\partial x} + \frac{\partial G}{\partial x} = 0 \tag{3}$$

Unbalance calculation mode of suspended load:

$$\frac{\partial (QS_k)}{\partial x} = -\alpha w_k B(S_k - S_{*k}) \tag{4}$$

Balance calculation mode of bed load: $G_k = G_{*k}$ (5)

Unbalance calculation mode of bed load:

$$\frac{\partial G_k}{\partial x} = -K_k (G_k - G_{*k}) \tag{6}$$

Bed load composition formula:

$$r'\frac{\partial (E_m P_k)}{\partial t} + \frac{\partial (QS_k)}{\partial x} + \frac{\partial G_k}{\partial x} + \varepsilon_1\left[\varepsilon_2 P_{0k} + (1-\varepsilon_2)P_k\right]\left(\frac{\partial Z_s}{\partial t} - \frac{\partial E_m}{\partial t}\right) = 0 \tag{7}$$

Resistance formula:

$$J_f = \frac{n^2 Q^2}{A^2 R^{4/3}} \tag{8}$$

Formula for sediment carrying capacity:

$$S_* = K\left(\frac{U^3}{gh\overline{\varpi}}\right)^m \tag{9}$$

Where, Q —— flow rate, m^3/s;

A —— flowing area, m^2;

A_s —— riverbed deformation area, m^2;

Z —— water level, m;

J_f —— energy gradient;

q_i —— inflow per transverse unit river length, m^2/s;

S_k —— grouping sediment content of suspended load, kg/m^3;

S_{*k} —— sediment carrying capacity, kg/m^3;

G_k —— grouping sediment discharge of bed load, kg/s;

G_{*k} —— effective sediment discharge, kg/s;

B —— river width, m;

w_k —— grouping sediment settling velocity, m/s;

α —— recovery saturation coefficient;

K_k ——recovery saturation coefficient of bed load;

P_k —— bed load composition of mixed layer;

P_{0k} —— bed load composition of natural riverbed;

E_m —— depth of mixed layer, m;

ε_1, ε_2 —— sign, in the calculation of pure sedimentation, $\varepsilon_1 = 0$; otherwise, $\varepsilon_1 = 1$. When the lower boundary of mixed layer involves the original riverbed, $\varepsilon_2 = 1$; otherwise, $\varepsilon_2 = 0$. k is non-uniform sediment group ordinal, in line with $S = \sum_k S_k$, $S_* = \sum_k S_{*k}$, $G = \sum_k G_k$, $G_* = \sum_k G_{*k}$.

The finite difference method is adopted in model equation for discretization.

Continuity equation of flow:

$$Q_{j+1} = Q_j + Q_l \tag{10}$$

Equation of motion:

$$Z_j = Z_{j+1} + \frac{n^2 \overline{Q}^2}{\overline{A}^2 R^{4/3}} + \frac{1}{2g}\left[\left(\frac{Q^2}{A^2}\right)_{j+1} - \left(\frac{Q^2}{A^2}\right)_j\right] \tag{11}$$

Where, “-” represents the average value.

Continuity equation of sediment:

$$r'\left[\psi\Delta A_{sj+1} + (1-\psi)\Delta A_{sj}\right]\Delta x = \left[(G_T)_j - (G_T)_{j+1}\right]\Delta t \tag{12}$$

Where: ΔA_{sj} and ΔA_{sj+1}—— deformation increment at j and j+1 sections;

ψ

——parameter for numerical calculation, taking $\psi > 0.5$ for stability.

Unbalance calculation mode of suspended load:

$$S_{kj+1} = S_{*kj+1} + (S_{kj} - S_{*kj})e^{-a\omega_k \Delta x / q} + (S_{*kj} - S_{*kj+1})\frac{\overline{q}}{a\omega_k \Delta x}(1 - e^{-a\omega_k \Delta x / q}) \tag{13}$$

Unbalance calculation mode of bed load:

$$G_{kj+1} = G_{*kj+1} + (G_{kj} - G_{*kj})e^{-K_k \Delta x} + (G_{*kj} - G_{*kj+1})\frac{1}{K_k \Delta x}(1 - e^{-K_k \Delta x}) \tag{14}$$

3.2 Calculation Scheme

The sedimentation and backwater of reservoir in three proposals that is with a normal pool level of 218m, 219 m and 220 m respectively are calculated for comparison.

3.3 Basic Data and Parameter for Calculating

3.3.1 Longitudinal and cross section data of reservoir area

The results measured in April 2008 and in January 2009 by NWH are adopted, which include one 99.2 km longitudinal section and 50 transverse sections in the reservoir area.

3.3.2 Analysis of Water and Sediment Characteristics

In design, the mean annual amount of the suspended sediment to flow into Sanakham reservoir is 69.0 million t. Sediment is very uneven in annual distribution. Inflow sediment mainly concentrates in the flood season. The sediment runoff from July to September during the flood season accounts for 77.9% of the annual sediment, while that from June to October accounts for 93% of the annual sediment. The mean annual inflow sediment is 0.496kg/m^3, the mean inflow sediment in the flood season (from July to September) is 0.686kg/m^3, and the mean sediment of the maximum month (August) is 0.734kg/m^3.

3.3.3 Representative Series of Water and Sediment

The interpolation water and sediment series of the Chiang Khan Station should be analyzed. The annual mean discharge from 1971 to 1980 is 4350m^3/s and the mean annual sediment is 93.80 million t, both values are similar to the long-time mean annual value (for long series, the annual mean discharge is 4430m^3/s and the mean annual sediment is 95.40 million t.). The long time includes rainy, normal and dry water and sediment years; therefore, the water and sediment series from 1971 to 1980 would be taken as the representative series for sedimentation calculation.

3.3.4 Sediment Gradation

The result of suspended sediment gradation provided in May 2015 by CNR is employed for suspended sediment gradation, as shown in Figure 3.1. Bed load sediment gradation utilizes the bed load gradation used in designing Pak Beng HPP by Kunming Institute, in which the median grain size is 16.9mm, the average grain size is 28.0mm, and the maximum gain size is 180mm.

Table 3.1 Result of Suspended Sediment Gradation Provided by CNR

Grain Size (mm)	0.0021	0.0056	0.0109	0.0152	0.0295	0.05	0.1	0.2	0.5	1	2
Weight of sed. less than d (%)	0.7	15.5	36.8	48.3	61.6	70	78.0	85.0	95.3	99.7	100

3.3.5 Sand Flushing Operation Mode of the Reservoir

According to the inflow water and sediment characteristics, considering that Sanakham has a low gated dam, the 18 flat-bottom flood sluices (5 outlets on right, 13 outlets on left) have been designed in the feasibility study, with their bottom elevations basically lower than the original riverbed elevation, which is favorable for flood discharge and sand flushing.

As a run-of-the-river proposal, Sanakham plant will generate electricity with the inflow water, and its reservoir has no regulating capability. In respect to this design proposal, the reservoir operation mode is preliminarily proposed below:

With the hydrological station at Luang Prabang as the inflow flood water control station (usually the flood water from Luang Prabang will take 1~2 days to reach Sanakham damsite), the sand flushing operation mode is blow:

In the flood season, when the reservoir inflow water is greater than the design discharge, surplus flood will be discharged firstly through the 5 bottom flood outlets with a stilling basin on the left bank and then other flood gates, to maintain the reservoir level at the normal poor level of 220.0 m.

In case of a 3-year flood event occurring at Luang Prabang, flood release shall be started at Sanakham. Firstly, the 5 bottom flood outlets with a stilling basin on the left bank and then other flood gates shall be opened, with the outflow less than the 3-year flood peak discharge, the pool level will be drawn down to the gate full opening for flood and sand discharge. When the inflow flood is bigger than the 3-year flood, the remaining flood gates will be fully opened for flood and sand discharge; and after the flood process, the reservoir will be refilled up to the normal pool level for power generation. When the upstream reservoirs are discharging sand, all gates of Sanakham reservoir shall be fully opened for sand discharge accordingly. Based on the sediment monitoring results, backwater at the reservoir shall be analyzed. When the backwater due to sedimentation in the reservoir area may affect the Pak Lay Plant or the reservoir inundated area, or when the sediment buildup approaches the sand barrier level in front of the intake, all flood gates shall be fully opened to draw down the pool level for sand flushing. In other periods, the plant will operate normally.

During the operation period, the sediment monitoring plan shall be well performed to accumulate more sediment data, so that the sand flushing mode can be optimized further.

3.3.6 Calculation Parameters

a) Sediment carrying capacity coefficient, K and m

The computational model of reservoir sedimentation adopts the sediment carrying capacity formula developed by Zhang Ruijng (a famous professor of Wuhan Water Conservancy and Electric Power College). The values of “K=0.2 and m=1.0” were used by Kunming Institute in the engineering design for Xiaowan Hydropower Project according to the analysis of the water/sediment data measured by Gajiu station. The analysis of the measured data by Shigu and Panzhihua stations on the Jinsha River indicated that K value ranges from 0.03 to 0.14; and m value ranges from 0.9 to 1.1.

Based on the above analogy analysis and the analog computation of natural river courses, 10-year water and sediment series data and the calculation on the original riverbed, the accumulative sedimentation of reservoir section after 10 years is only 0.59% of the inflow sediment, and the values of “K=0.2 and m=1.0” are applied in the sedimentation calculation for Sanakham reservoir.

As the results show,the river bed thalweg of river channel transverse section well correspond, and the erosional and depositional areas are small. In addition, the sediment discharge rate of suspended load accumulated for 10 years reaches 99.4%.

b) Saturation recovery coefficient

Saturation recovery coefficient α is a proportionality factor. The approach is to convert the river bottom sediment content and sand carrying capacity of river bottom flow into the average sand content and sand carrying capacity of water flow, α taking 1. Later on, many researchers introduced α and grant different physical meanings. Actually, α should be deemed as a comprehensive coefficient, and its value should be figured out with actual dada. Based on available research data, as for Sanakham, the coefficient takes 0.25 in the case of deposition, and 1.0 in the case of washout.

c) Roughness factor

The reservoir water surface profile used for roughness calculation is calibrated with the measured isotime water profile and the surveyed flood water surface profile, which were measured in two times of survey at 50 sections in total. Based on the water surface profile simulation, the roughness of the natural river channel 32km upstream of the dam ranges from 0.017 to 0.05, averaged in 0.03; the roughness of the natural river channel in the reservoir upstream section (32km~99km) is 0.016~0.052, averaged in 0.033. The simulated isotime water surface profile (discharge 2110m^3/s~1690m^3/s) is 0.16m higher than the measured value to the maximum, and 0.21m lower than the measured value to the minimum, averagely 0.0226m slightly higher than the measured value; the flood water surface profile (discharge 22200m^3/s~13100m^3/s) is 0.18m higher than the measured value to the maximum, and 0.25m lower than the measured value to the minimum, averagely 0.0155m slightly higher than the measured value. The resultant natural river channel water surface profile reflects well the water surface profile variations under different discharges.

d) Inflow sediment

Considering the role in sediment retention of cascade reservoirs which have been built or are under construction on the middle and lower reaches of the Lancang River, the inflow sediment of Sanakham reservoir is 69.0 million t in design, excluding the role in sediment retention of cascade reservoirs on the upper reach of Sanakham. The mean annual sediment runoff of 93.80 million t of representative series from 1971 to 1980 is selected, which is 24.80 million t more than the design inflow sediment. Therefore, the reduction of year-on-year sediment content would be achieved to make the sediment of representative series consist with the design inflow sediment. Representative series would be repeated to form different periods of inflow water and sediment series, so as to calculate the reservoir sedimentation.

3.4 Calculation Result of Sedimentation

According to the proposed sand flushing operation mode of the reservoir and calculation parameters of sedimentation, Susbed-2 model is adopted to calculate the reservoir sediment erosion and accumulation in different proposals. After 10 years of operation, the total inflow sediment would be 703.8 million t, of which the suspended load would account for 690 million t, the sedimentation in the reservoir area would account for 156 million t including 144 million t of suspended load, with an average sediment discharge ratio of 77.8%, which would cause a reservoir storage capacity loss of 15.3%, and the sediment would build up averagely to EL.191.5 m in front of the dam. After 50 years of operation, the total inflow sediment would be 3519 million t, of which the suspended load would account for 3450 million t, the sedimentation in the reservoir area would account for 334 million t including 287 million t of suspended load, with an average sediment discharge ratio of 90.5%, which would cause a reservoir storage capacity loss of 31.2%, and the sediment would build up averagely to EL.197.2 m in front of the dam. Sedimentation would mainly concentrate in the middle section (28.1 km - 58.4 km to the dam front) of the reservoir area where is relatively wide (averagely 1035 m wide at the surface level), less at the dam approaching section (dam front - 28.1 km) of the reservoir area where is relatively narrow (average 665 m wide at the surface level), and least at the reservoir tail section (58.4km away from the dam). After 10 years of operation, the sedimentations at the dam approaching section, middle section and reservoir tail section would account for 15.5%, 74.5% and 10% of the total sedimentation in the reservoir; after 50 years of operation, the sedimentations at the dam approaching section, middle section and reservoir tail section would account for 24.8%, 70% and 5.2% of the total sedimentation in the reservoir, which suggests that the sedimentation would move downward gradually.

Under the natural circumstances, the average flow velocity variation at the reservoir sections is shown in Figure 3-1. After 10 years of operation in the proposed operating mode, the average flow velocity variation at the reservoir sections is shown in Figure 3-2.

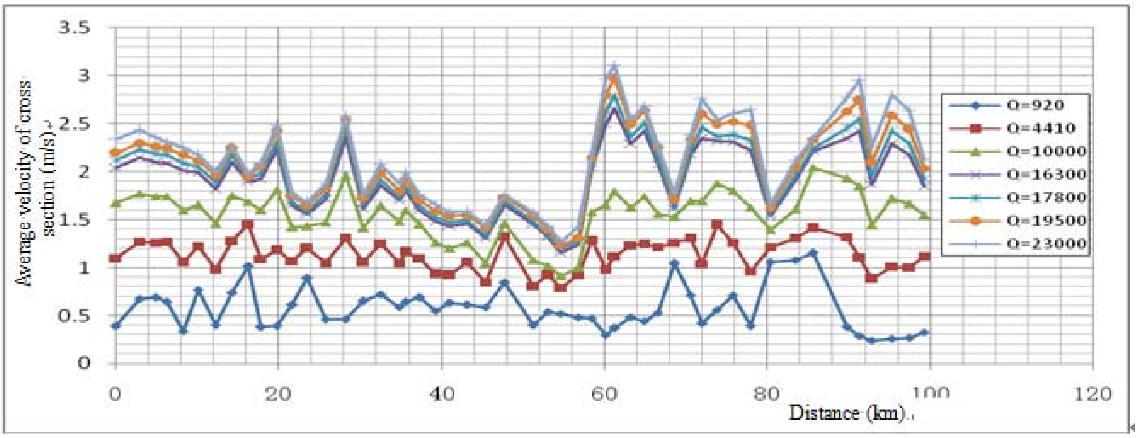

Figure 3-1 Average Flow Velocity Variation at Different Reservoir Sections under Natural Condition

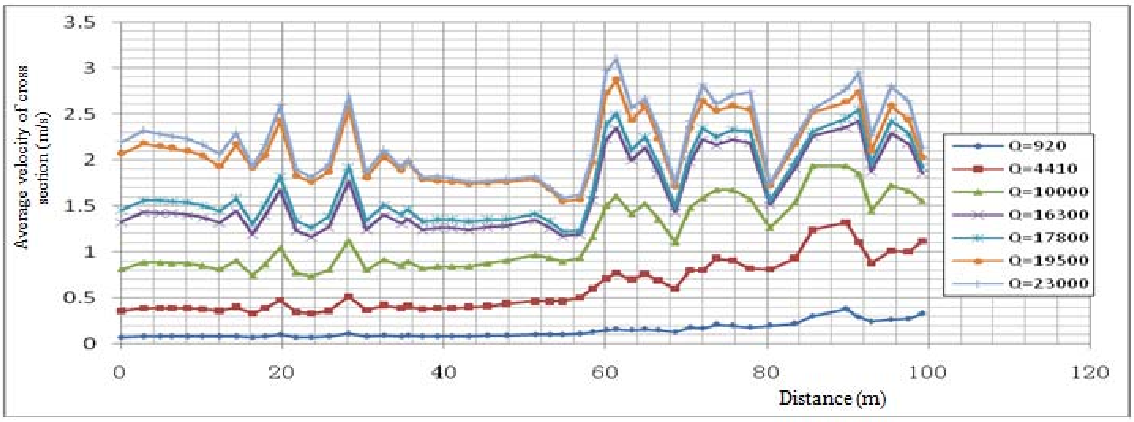

Figure 3-2 Average Flow Velocity Variation at Different Reservoir Sections after 10-year Operation

Average flow velocity statistics at different reservoir sections with characteristic discharges are summarized in Table 3.2.

Table 3.2 Flow Velocity Variation at Different Reservoir Sections

Condition	Discharge (m^3/s)	Average Flow Velocity Statistics at Different Reservoir Sections (m/s)			Remarks
		Dam approaching section	Middle section	Tail section	
Natural condition	4410	1.186	1.029	1.172	Annual mean discharge
	16300	1.974	1.54	2.117	2-year flood peak

					discharge
10-year sedimentation	4410	0.387	0.422	0.896	Annual mean discharge
	16300	1.386	1.291	2.067	2-year flood peak discharge

As analyzed above, in the reservoir tail section, the flow velocity variation between the natural condition and the after-operation condition would be relatively small. In the middle section and the dam approach section, the average flow velocity in case of small flow would drop greatly compared to that in the natural condition, because of the backwater effect when filling the reservoir in case of small flow; when the flow is greater, the two values have no big difference because of less backwater effect in case of big flow; the average flow velocity at the reservoir middle section would be smaller than that at the dam front. Given small flow velocity, sedimentation would build up, and the flow velocity variation in the reservoir area is consistent with the sedimentation varying trend.

According to the reservoir operation equation, with a simplified Buren Formula, the resultant reservoir's sand trapping rate is 22.9%, and the sand flushing ratio is 77.1%, which is quite close the 77.8% sand discharge ratio by the mathematical model series, and the result should be rational and credible.

See Table 3.3 and Figure 3-3 for calculation results of sedimentation in different normal pool level proposals after 10-year reservoir sedimentation.

Table 3.3 shows that in the selected 220 m normal pool level proposal, after 10-year operation of the reservoir, the sedimentation in the reservoir area is 127 million m^3, with an average sediment discharge ratio of 77.8%.

Table 3.3 10-year Sedimentation Result of Sanakham Reservoir in Different Normal Storage Level Proposals

Normal pool level (m)	218	219	220
Capacity under normal pool level (100 million m^3)	6.96	7.60	8.27
Total inflow sediment (100 million t)	7.038		
Total sedimentation (100 million m^3)	1.13	1.20	1.27
Average sediment discharge ratio (%)	80.1	78.9	77.8
Remained capacity (100 million m^3)	5.83	6.40	7.00
Capacity loss (%)	16.3	15.8	15.3

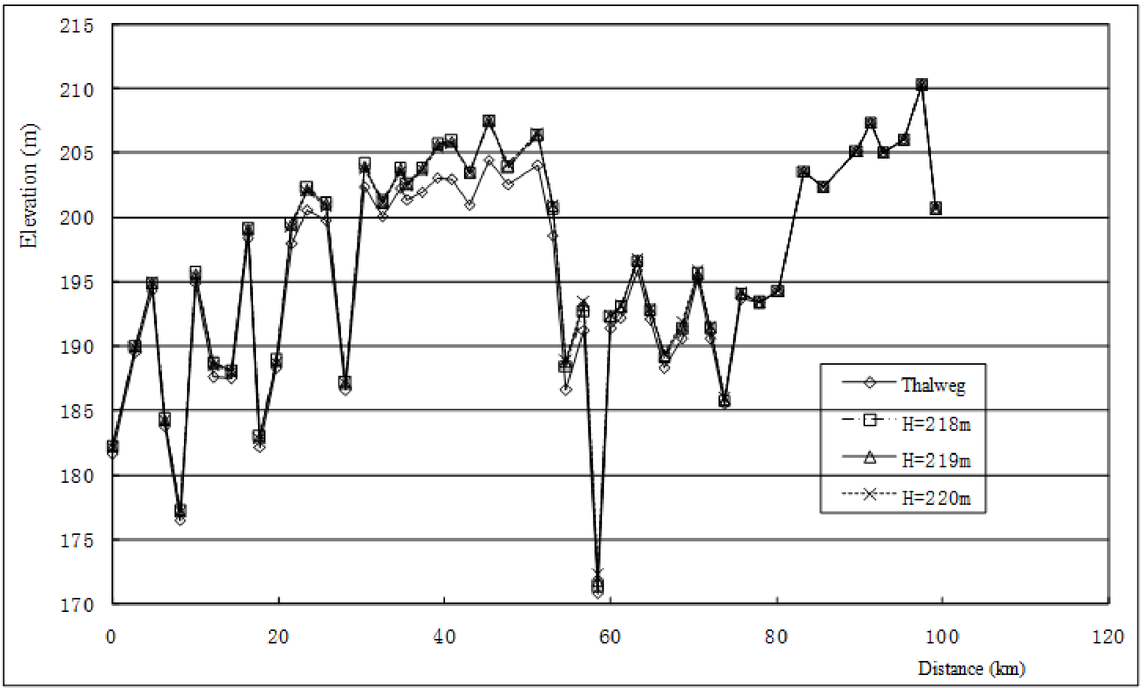

Figure 3-3 Longitudinal Section of Sanakham Reservoir Sedimentation in Different Normal Storage Level Proposals

After 10-year operation of the reservoir in the proposed mode, the sedimentation in the reservoir area would amount to 127 million m^3, with an average sediment discharge ratio of 77.8%, the average sediment content in the outflow water after sediment settling in the reservoir is 0.386kg/m^3, only about 22.2% lower than the natural scenario, which suggests that the reservoir have no much effect on the river water-sediment movement, especially in case of normal floods which play a bigger role in reforming the downstream riverbed, when the inflow water is greater than a 3-year flood, the reservoir will be released with all gates fully open, basically without altering the natural inflow water-sediment condition, and it would not exert noticeable effects on the downstream riverbed formation and stability; after 50-year operation, the average sedimentation at the dam front is about 3 m deep, averagely up to the elevation of 197.2 m, which would be 11 m lower than the elevation (208 m) of the sand barrier in front of the intake, and 13 m lower than the elevation (210 m) of the bottom of the upper approach channel, the sedimentation at the dam front should not bring about threats to the power plant and ship lock safety.

With a sediment barrier at the intake upstream, the top elevation of 208 m could prevent bed load from approach to the power intake, and sedimentation at the intake front would be mainly composed of suspended load. Considering that the intake bottom level is relatively lower, sand outlets are arranged underneath, whose inlet bottom elevation would be further lower than that of the intake. Ahead of each flood period, to prevent gates from being blocked up be sediment, sand outlet gates should be opened in the flood period for sand flushing. In the dry season, based on sediment monitoring data, sand outlet gates shall be opened irregularly for flushing sand. Proper operation of the sand outlets to prevent sediment silting in front of the sand outlets could spare sediment's adverse effects on the power plant's operation safety.

As analyzed above, after commissioning the reservoir, the sediment content in the outflow water would drop about 22%, so the water-sediment regime in the downstream river channel would not change much, besides some local washout in the dam downstream, there would cause no obvious erosion-deposition change in the downstream river channel. The downstream local washout can be solved through energy dissipater, anti-scoring design and/or taking physical measures.

The water flow in the dam approaching section is highly 3-dimensional, so a 1-D mathematical model can hardly reflect practical situation. It may be studied through a physical sediment model test.

4 Calculation of Reservoir Backwater

4.1 Basic Data

4.1.1 Calculation of Riverbed Surface

Reservoir backwater calculation is based on the 10-year sedimentation riverbed surface.

4.1.2 Roughness Factor

According to the water surface profile measured in April 2008 and the flood water surface profile investigated in 2007, it is calculated that the roughness of most of the natural river channels ranges from 0.02 – 0.049, and that of a few channels reaches to 0.07, with an average value of 0.033. In the calculation of reservoir backwater, 0.02 – 0.035 would be taken as the comprehensive roughness of Sanakham reservoir backwater based on the reservoir sedimentation.

4.1.3 Calculation of Discharge

According to the requirements of reservoir inundation design, 3-year flood standard is employed for Sanakham HPP. And this time, the flood frequency of 33.3% (17800m^3/s) in different proposals and the reservoir backwater with an annual mean discharge of 4410m^3/s are included in the design and calculation.

4.1.4 Calculation of Dam-front Water Level

The initial dam-front water level for calculation is the normal pool level.

4.2 Calculation Result of Reservoir Backwater

See Table 4.1 and Table 4.2 for calculation result of Sanakham reservoir sedimentation and backwater in different normal pool level proposals, and see Figure 4-1 for the longitudinal section of sedimentation and backwater in 220 m normal pool level proposal.

After a comprehensive analysis and comparison, the 220 m normal pool level proposal would be selected. The backwater level of annual mean discharge (4410m^3/s) in this selected proposal in Pak Lay Town (Reservoir 14# - Reservoir 16# reaches) is 220.42m - 220.48m, which is 4.27 - 3.78m higher than the natural water level; and the backwater level of 3-year flood (17800m^3/s) in Pak Lay Town is 223.99m － 224.4m, which is 0.30m - 0.19m higher than the natural water level.

4.3 Effect of Sanakham Reservoir Backwater on Tailwater of Pak Lay Plant

Because the Sanakham reservoir backwater connects with the tailwater of upstream Pak Lay Plant, it is required to calculate the water level-discharge relation curve of the effect of Sanakham reservoir backwater on tailwater section of Pak Lay Plant for calculation and comparison of cascade energy indexes. According to the normal pool level proposal, the effect of Sanakham reservoir backwater on tailwater of Pak Lay Plant is calculated on the 10-year sedimentation riverbed surface at this stage. See Table 4.3 and Figure 4-2 for the relation of backwater level and discharge in different normal pool level proposals at the tailwater section of Pak Lay Plant.

Table 4.3 Relation of Sanakham Reservoir Backwater Level and Discharge at the Tailwater Section of Pak Lay Plant

Discharge, m^3/s	Natural Water Level, *m*	Backed-up Water Level by Different Alternatives, *m*		
		H=218m	H=219m	H=220m
920	216.05	218.50	219.31	220.21
1,970	219.46	219.65	220.13	220.75
4,410	222.58	222.58	222.58	222.65
5,500	223.40			223.40

Table 4.3 shows that under the 220 m normal pool level proposal of Sanakham HPP, the rising value of backwater level with different flows at tailwater section of Pak Lay Plant ranges from 0.00 m to 4.16 m, and the rising value of backwater level is 0.07 m when the annual mean discharge is 4410m^3/s.

Table 4.1 Results of Backwater in Different Normal Pool Level Proposals of Sanakham Reservoir Q=4410m³/s (Mean Annual)

Section	Distance *km*	Thalweg *m*	Backed-up Water Level by Different Alternatives, *m*			Natural Water Level, *m*
			H=218m	H=219m	H=220m	
Dow. damsite	0	181.6	218	219	220	
Ups. damsite	2.81	189.5	218.01	219	220	
Cro. X03	4.8	194.4	218.01	219.01	220.01	
Cro. X04	6.25	183.7	218.02	219.01	220.01	
Cro. X05	8.19	176.5	218.02	219.01	220.01	
Cro. X06	10	194.9	218.02	219.02	220.02	
Cro. X07	12.2	187.6	218.02	219.02	220.02	
Cro. X08	14.3	187.5	218.03	219.02	220.02	
Cro. X09	16.3	198.4	218.04	219.03	220.03	
Cro. X10	17.8	182.2	218.04	219.03	220.03	
Cro. X11	19.7	188.3	218.04	219.04	220.04	
Cro. X12	21.6	198	218.06	219.05	220.05	
Cro. X13	23.5	200.6	218.07	219.06	220.05	
Cro. X14	25.7	199.8	218.08	219.07	220.05	208.29
Cro. X15	28.1	186.6	218.09	219.08	220.06	208.66
Cro. X16	30.4	202.4	218.11	219.1	220.08	209.14
Cro. X17	32.5	200.1	218.13	219.11	220.09	209.75
East gate 1	34.7	202.3	218.15	219.12	220.11	210.38
East gate 2	35.5	201.4	218.16	219.13	220.11	210.58
Res. 01	37.3	202	218.18	219.14	220.12	210.85
Res. 02	39.2	203.1	218.2	219.16	220.13	211.14
Res. 03	40.9	203	218.22	219.17	220.14	211.47
Res. 04	43	201	218.25	219.19	220.16	211.86
Res. 05	45.4	204.5	218.28	219.22	220.18	212.3
Res. 06	47.7	202.6	218.32	219.25	220.2	212.82
Res. 07	51.3	204.1	218.4	219.31	220.25	213.62
Res. 08	53.1	198.6	218.43	219.33	220.27	214.1
Res. 09	54.6	186.6	218.47	219.37	220.29	214.5
Res. 10	56.8	191.2	218.55	219.42	220.33	215.01
Res. 11	58.4	170.8	218.61	219.47	220.36	215.4
Res. 12	60.1	191.4	218.66	219.5	220.38	215.7
Res. 13	61.2	192.2	218.68	219.52	220.39	215.85
Res. 14	63.2	195.9	218.73	219.56	220.42	216.15
Res. 15	64.8	192.1	218.77	219.6	220.44	216.41
Res. 16	66.5	188.3	218.83	219.64	220.48	216.7
Res. 17	68.6	190.6	218.92	219.71	220.53	217
Res. 18	70.5	195.2	219.01	219.76	220.57	217.35
Res. 19	72	190.6	219.09	219.82	220.61	217.6
Res. 20	73.7	185.5	219.17	219.89	220.66	217.9
Res. 21	75.7	193.7	219.36	220.02	220.75	218.22

Table 4.1 Results of Backwater in Different Normal Pool Level Proposals of Sanakham Reservoir Q=4410m^3/s (Mean Annual) (Cont.)

Section	Distance *km*	Thalweg *m*	Backed-up Water Level by Different Alternatives, *m*			Natural Water Level, *m*
			H=218m	H=219m	H=220m	
Res. 22	77.8	193.4	219.48	220.12	220.82	218.69
Res. 23	80.3	194.3	219.66	220.25	220.92	219.16
Res. 24	83.3	203.6	219.97	220.48	221.08	219.82
Res. 25	85.6	202.4	220.32	220.65	221.25	220.32
Res. 26	89.7	205.2		221.25	221.68	221.05
Res. 27	91.3	207.4		221.5	221.8	221.39
Res. 28	92.8	205.1		221.65	221.95	221.65
Res. 29	95.3	206.1			222.21	222.02
Res. 30	97.4	210.4			222.45	222.34
Pak Lay damsite	99.2	200.66			222.65	222.58

Table 4.2 Results of Backwater in Different Normal Pool Level Proposals of Sanakham Reservoir Q=17800m^3/s (P=33.3%)

Section	Distance *km*	Thalweg *m*	Backed-up Water Level by Different Alternatives, *m*			Natural Water Level, *m*
			H=218m	H=219m	H=220m	
D/S damsite	0	181.6	218	219	220	213.41
U/S damsite	2.81	189.5	218.09	219.08	220.07	213.62
Cro. X03	4.8	194.4	218.16	219.14	220.13	213.71
Cro. X04	6.25	183.7	218.21	219.19	220.17	213.77
Cro. X05	8.19	176.5	218.28	219.24	220.22	213.92
Cro. X06	10	194.9	218.34	219.3	220.27	214.07
Cro. X07	12.2	187.6	218.42	219.37	220.32	214.18
Cro. X08	14.3	187.5	218.47	219.41	220.36	214.32
Cro. X09	16.3	198.4	218.61	219.54	220.47	214.45
Cro. X10	17.8	182.2	218.66	219.58	220.5	214.67
Cro. X11	19.7	188.3	218.71	219.62	220.54	214.97
Cro. X12	21.6	198	218.88	219.78	220.68	215.32
Cro. X13	23.5	200.6	218.98	219.87	220.76	215.67
Cro. X14	25.7	199.8	219.08	219.95	220.83	215.92
Cro. X15	28.1	186.6	219.22	220.09	220.97	216.35
Cro. X16	30.4	202.4	219.49	220.33	221.17	216.93
Cro. X17	32.5	200.1	219.63	220.46	221.29	217.41
East gate 1	34.7	202.3	219.85	220.65	221.46	218.04
East gate 2	35.5	201.4	219.91	220.71	221.51	218.29
Res. 01	37.3	202	220.11	220.87	221.64	218.65
Res. 02	39.2	203.1	220.27	221.01	221.76	218.89
Res. 03	40.9	203	220.41	221.14	221.87	219.26
Res. 04	43	201	220.59	221.29	222.01	219.68
Res. 05	45.4	204.5	220.88	221.48	222.17	220.17
Res. 06	47.7	202.6	221.22	221.79	222.43	220.64
Res. 07	51.3	204.1	221.75	222.27	222.83	221.36
Res. 08	53.1	198.6	222.08	222.5	223.01	221.72
Res. 09	54.6	186.6	222.35	222.68	223.15	222.12
Res. 10	56.8	191.2	222.76	222.99	223.35	222.56
Res. 11	58.4	170.8	223.07	223.24	223.56	222.89
Res. 12	60.1	191.4	223.28	223.44	223.7	223.14
Res. 13	61.2	192.2	223.45	223.6	223.83	223.35
Res. 14	63.2	195.9	223.69	223.85	223.99	223.69
Res. 15	64.8	192.1		224.05	224.18	223.97
Res. 16	66.5	188.3		224.21	224.4	224.21
Res. 17	68.6	190.6			224.65	224.56
Res. 18	70.5	195.2			224.87	224.87

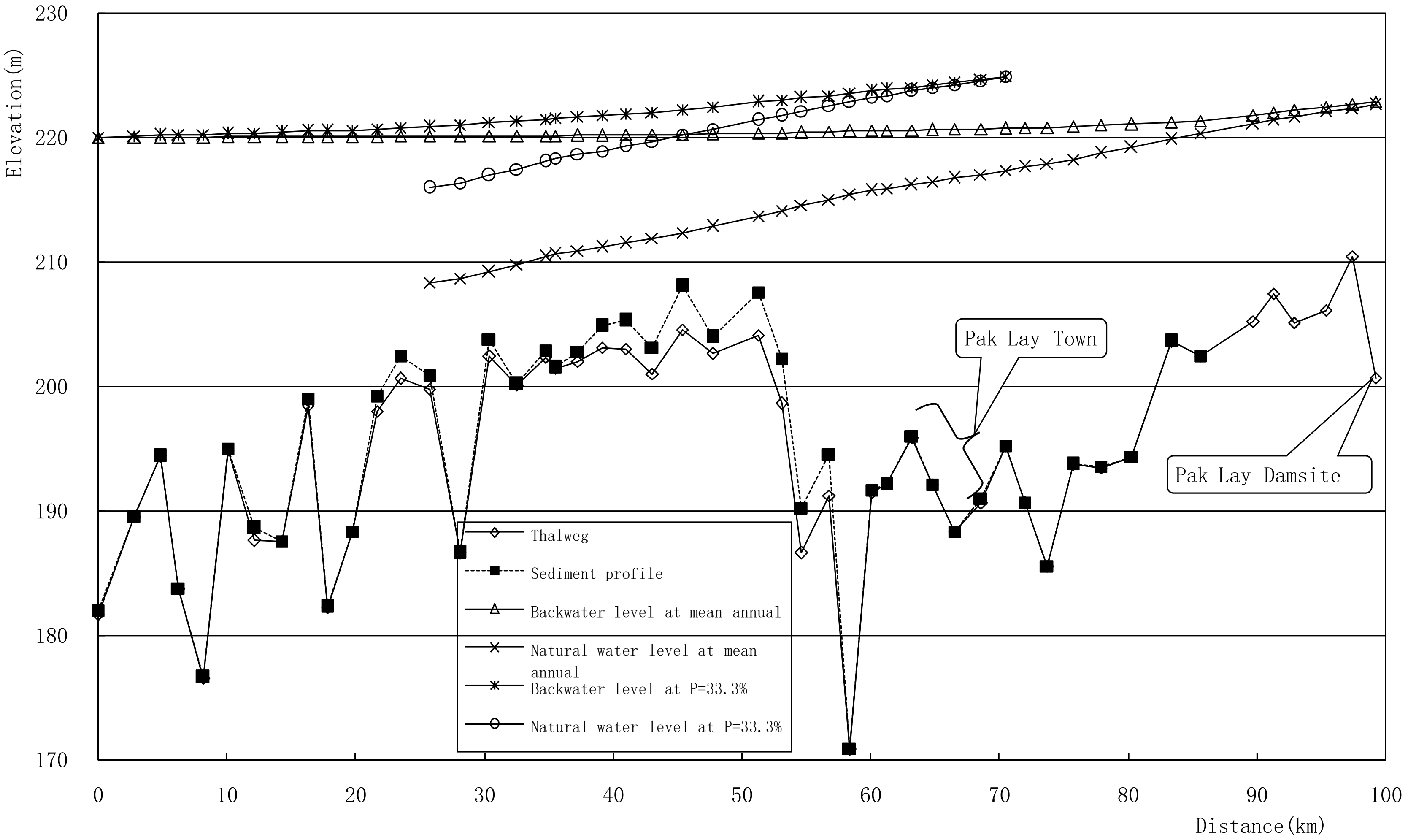

Figure 4-1 Longitudinal profiles of Sedimentation and Backwater under 220 m Normal Pool Level Proposal of Sanakham Reservoir

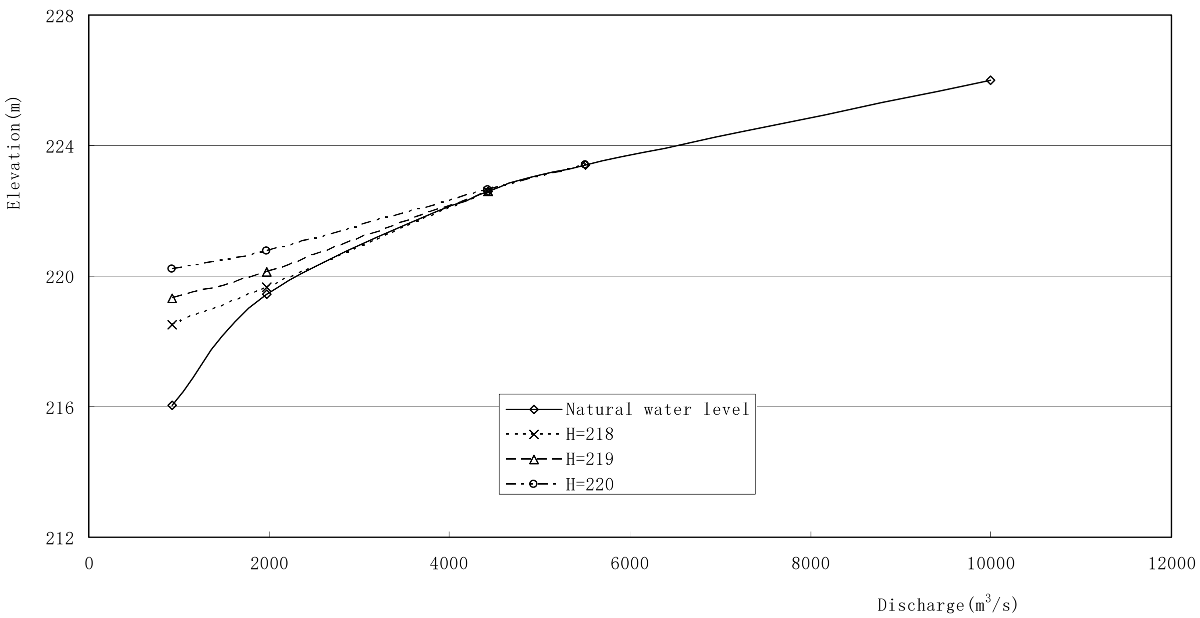

Figure 4-2 Relation of Backwater Level and Discharge in Different Normal Pool Level Proposals of Sanakham Reservoir at Tailwater Section of Pak Lay Plant