

SANAKHAM HYDROPOWER PROJECT



Overall Design Report of Sediment Monitoring System

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1 Outline

1.1 About the Project

Sanakham Hydropower Project is the 5th cascade project planned on the main stream of the Mekong River in Laos. The project site is located on the main stream of the Mekong River 1.4km upstream of Village Pakheung in District Kenthao, Province Sayaburi, Lao People's Democratic Republic. The Mekong River at the project site is on border of Province Sayaburi and Province Vientiane, District Kenthao of Province Sayaburi is located at the right bank, District Sanakham of Vientiane Province is located at the left river bank. The dam site is located about 1737km away from the Mekong estuary, about 155km away from the downstream Vientiane, 99km away from the upstream of the Pak Lay project, and about 25km to the Sanakham county seat. There is a simple access road linking to the dam site. The outbound condition is rather convenient. The river course at the dam site is broad and wide, and the area in vicinity of the project area is sparsely populated.

Sanakham Hydropower Project is developed mainly for power generation that will be of benefit to river navigation and fish pass, the major structures include powerhouse, sluice gate, 500t navigation lock, fish pass and etc. Normal water level is 220MSL, total installed capacity of the power station is 684MW, average annual energy output is 3.803 TW.h with annual utilization 5560h. A total of 12 bulb turbines with a discharge of 5801m³/s are intended.

1.2 Sediment Issues and Reservoir Desilting Operation Mode

(1) Sediment issues

Sanakham reservoir has the design normal water level of El. 220 m, which corresponds to a storage capacity of 827 million m³. As the ratio of reservoir volume to the oncoming sediment is 15, it should belong to a reservoir with serious sediment problem. But the sediment concentration of inflow is low (averagely, 0.496 kg/m³); it is a river-like reservoir; dammed water depth is small (about 16 m in the case of mean annual discharge, and about 11 m in the case of mean flood season discharge); and sediment delivery rate is larger when the reservoir is in operation (the yearly average sediment delivery ratio during initial operating stage exceeds 70%, and the average sediment delivery ratio during the first 50 years exceeds 90%). Reservoir sedimentation shall be so design as to keep it well controlled, reduce backwater inundation and inundation extent, and enable reservoir backwater in good connection with the tail water of upstream Pak Lay Hydropower Station. In order to study the influence of operating mode on the reservoir backwater extent under sedimentation, backwater calculation shall be carried out under different operating alternatives for the comparison of characteristic water levels. Since the dam has a longer water intake section, and the intakes are low in elevation, sediment flushing outlets should be furnished beneath the intakes to remove the sediments deposited before the intakes, ensuring the safe operation of the project.

(2) Reservoir desilting operation mode

According to the CNR independent review comments as well as the expert's review comments on the updated Feasibility Study Report in 2016, the general layout of the project structures has been adjusted as

follows:

The major structures are arranged in sequence from left bank to right bank as: left concrete auxiliary dam, ship lock dam section, left sluice dam section (13 sluices), riverbed powerhouse dam section (12 units), right sluice dam section (5 sluices), and right concrete auxiliary dam. The dam has the maximum height of 56.2m, and an overall length of 909.90m at the dam crest elevation of 229.50m.

The powerhouse dam section has an overall length of 350.20m, in 8 sub-sections, composed of the auxiliary erection bay dam section, the 1[#]~12[#] units powerhouse dam section, and the main erection bay dam section in order from left to right.

18 sluice outlets altogether (13 outlets in the opening size of 15m×22m (W×H) arranged at the left terrace and flood plain and 5 outlets in the opening size of 12.5m×16m (W×H) set at the right side), are divided as 11 dam sections, and have an overall length of 341.50m (left sluice 250m+ right sluice 91.50m). The left side of the right flood outlets neighbors the powerhouse dam section, the right side abuts on the fish pass outlet dam section, and the 5 outlets will adopt the hydraulic jump energy dissipation method. Among the 13 outlets at the left side, 5 of them against the powerhouse dam section will have the hydraulic jump energy dissipation method, and the remaining flood outlets will apply the surface flow energy dissipation way.

The navigation lock is designed as per the single-line capacity of 500 t of Grade IV. The effective dimension of lock chamber is 120×12×4m (length × width × sill depth). The whole navigation lock consists of the upstream approach channel, upper lock head, lock chamber, lower lock head and downstream approach channel. Considering the navigable clearance demand, the dam crest elevation is defined at EL.229.50m.

The fishway arranged on the right bank will have two inlets, respectively at EL. 199m and 201.3m, and the inlet gate chambers will have a width of 5m. To prevent migrated-upstream fish from being drifted to the dam downstream along the flood discharge, the outlet of the fishway is set at the upstream side 170m away from the dam axis, and considering the minimum reservoir level of EL.219m, the bottom elevation of the fishway outlet is set at EL.217m.

As a run-of-the-river scheme, Sanakham plant will generate electricity with the inflow water, and its reservoir has no regulating capability. Considering the project layout, the reservoir desilting 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 dams site), the desilting operation mode is blow:

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

In case of a 3-year-or-bigger flood event occurring at Luang Prabang, flood release shall be started at Sanakham. Firstly, the 5 flood gates on the left bank with a stilling basin, and then other flood outlets 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, 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 Pak Lay 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 plant 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.

1.3 Automatic System of Hydrological Data Acquisition and Transmission

Because some hydrological stations of sediment monitoring are combined with the automatic system of hydrological data acquisition and transmission, the following briefly describes the planned site layout of Sanakham automatic system of hydrological data acquisition and transmission.

During the Sanakham plant operation period, the automatic system is planned as follows: the telemetry station at Luang Prabang serves at the inflow flood forecast control station; a (rainfall) telemetry station is set at the upstream dam water region; an outflow station is set at the dam downstream; 20 telemetry stations are set in the in-between non-control area; and a new central station will be established in the Sanakham plant control center (plant dispatching building) for ease of managing the system. The station network arrangement of the automatic hydrologic data acquisition and transmission system of Sanakham HPP is shown in Table 1.1, and station network distribution map is shown in Figure 1.1.

Table 1.1 List of telemetry stations of ASHDCT of Sanakham HPP

No	Station	Country	Location	Item of hydrological data
1	Luang Prabang HS	Lao	Luang Prabang station	H,Q(Constructed newly)
2	Water Gauge A	Lao	at the entrance of the diversion tunnel	H (Constructed newly)
3	Water Gauge B	Lao	Upper cofferdams of Sanakham dam site	H ,P (Constructed newly)
4	Water Gauge C	Lao	Lower cofferdams of Sanakham dam site	H (Constructed newly)
5	Sanakham HS	Lao	at the exit of the diversion tunnel	H,Q(Constructed newly)

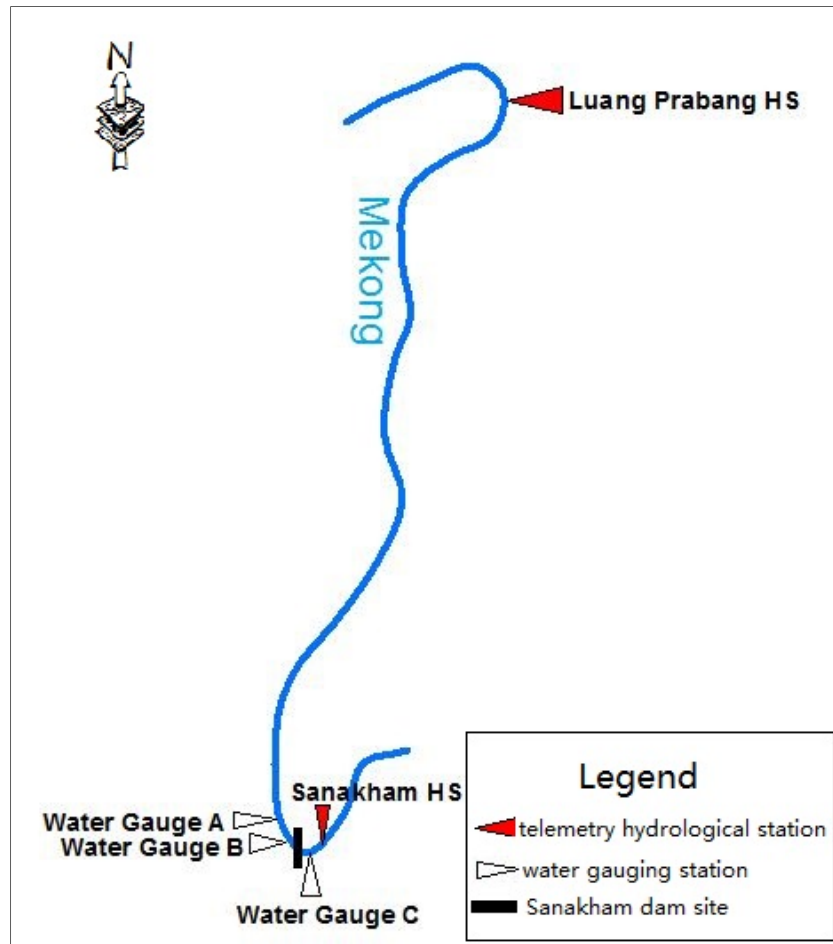


Figure 1.1 Hydrological (gauging) station network distribution map

2 Purposes and Contents of Sediment Monitoring Plan

2.1 System Purposes

Major sediment issues involve: the impact of the backwater (because of sedimentation in Sanakham reservoir) on the upstream Pak Lay tailwater, the impact of the backwater (due to sedimentation in the reservoir) and bank cave-in on the inundated area of the reservoir, the impact of the sedimentation on navigation, the scouring and sedimentation variation in upstream and downstream approach channels and their impacts, and the impact of the sedimentation in the reservoir on the downstream river channel scouring and sedimentation variation and stability. Therefore, it is necessary to conduct a sediment monitoring plan for the reservoir, in order to acquire the Sanakham reservoir inflow water and sediment volumes, scouring and sedimentation evolution, reservoir bank change, main navigation course variation and reservoir storage capacity change, provide accurate and reliable data for the plant operation and navigation dispatching management, and improve the plant managing level and economic efficiency.

2.2 Design Principles and Bases

Sediment monitoring design of Sanakham HPP complies with the following principles:

(1) The sediment monitoring network of Sanakham HPP is designed according to the principles of

advanced & reliable, economical & practical, and convenient for construction & maintenance management.

(2) The data of original hydrological stations should be fully used, and during layout of station network, the sites should be appropriately added and adjusted according to the requirements of sediment monitoring based on the existing station network.

(3) The social forces should be fully used to reduce personnel allocation as far as possible. Design basis of the sediment monitoring station network of Sanakham HPP:

Preliminary DG of LMB Mainstream dams (2009.8.31)

Code for reservoir hydrologic and sediment survey (SL339-2006)

River suspended sediment test specification (GB50159-92)

Specifications for the Waterway Survey (SL257-2000)

Survey Specification for Hydraulic and Hydro-Power Projects (Planning and design phase) (SL197-97)

2.3 Main Monitoring Contents

According to the major sediment problems associated to the reservoir, to monitor and analyze the sedimentation impacts, main sediment monitoring contents include:

- (1) Reservoir inflow and outflow water and sediment volumes;
- (2) Reservoir sedimentation variation;
- (3) Reservoir water surface profile;
- (4) Reservoir bank scouring/ sedimentation change and cave-in;
- (5) Dam downstream scouring monitoring during initial reservoir operation period;
- (6) Sedimentation in upstream and downstream approach channels.

3 Sediment Monitoring Programming

3.1 Sediment monitoring at inflow stations and outflow stations

The principle for establishing the sediment monitoring stations is to cover those hydrological and sediment elements change, and try best to utilize the existing hydrological stations and water regime forecasting system stations.

3.1.1 Arrangement of monitoring stations

(1) Inflow station (Luang Prabang station)

Proposal: An LISST-100X granulometer is put at the inflow station to monitor the real-time inflow sediment condition.

Site selection: The hydrological gauging station at Luang Prabang measures hydrological and sediment elements, with a catchment area of 268000km², which accounts for 91.8% of the catchment area till

Sanakham damsite, so the hydrological station can serve as the inflow sediment monitoring station for Sanakham reservoir. Sediment monitoring at the station is carried out in patrol inspection manner. To have better knowledge of Sanakham reservoir's inflow water and sediment, intense monitoring of level, flowrate, sediment concentration and grain gradation should be conducted at the hydrological station

Operation mode: A qualified professional agency should be employed to maneuver a survey boat to conduct patrol inspection. During carrying out normal testing, the instruments will be mounted in the inflow station, the LISST-100X field laser granulometer and data transmission equipment will undertake real-time water flow and sediment monitoring, and measured data will be transmitted to the central station through a transmitter or a satellite receiving terminal.

(2) Outflow station

The outflow station will rely on the water regime outflow station which is situated in the Sanakham dam downstream. The instruments and operation mode will be identical to those for the inflow station.

3.1.2 Equipment configuration and civil works

(1) Inflow station

For monitoring sediment, the inflow station must have the function of a hydrological station. The patrol survey mode of the inflow station may use ADCP to acquire and transmit hydrological data, define the stage-discharge relation, and an automatic device for water level gauging and real-time monitoring data reporting should be equipped for automatic hydrological data acquisition and transmission.

LISST-100X is a precise instrument. For acquiring continuous data and preventing from being affected by sediment during its installation, a simple station should be established and equipped with a water pump. The pump and LISST-100X granulometer will be controlled by a data transmission processor. Every 15 minutes, water will be pumped from the Mekong River and subjected to analysis by LISST-100X, and the analyzed data will be transmitted to the central station through the transmitter or the satellite receiving terminal.

Table 3.1 List of instruments and civil works for inflow station

Designation		Quantity	Unit	Remarks
Instruments & equipment	LISST-100X	1	piece	
	Pump type gauging station	1	set	
	Instrument box	1	piece	
	Data acquirer	1	piece	
	Beidou satellite terminal & antenna	1	set	

	Tranceiver	1	piece	
	Solar panel	1	piece	40W
	Battery cell	2	piece	100AH
	Keyboard	1	piece	
Civil works	Lightning grounding system	1	set	Soil resistance <10 ohm
	Instrument room	1	piece	2 rooms, in area of 8m ²
	Power supply	1	piece	
	Artificial water gauge	1	piece	Elevation system conversion for water gauge
	Pump station system	1	set	Installation of pump and pump station piping

LISST-100X can conduct field measurement of the particle distribution, optical transmission and scattered light quantity function. A red 670nm-long diode laser transmitter and siliceous detector will be used to scatter at a small angle suspended particles within the 32 angle range.

Post-processing by the instrument may produce the sediment size distribution, volume density, optical transmission and VSF. At the same time, it may also measure temperature and depth. The optional SeaBird MicroCat 37-SI CTD may be connected with the instrument, which enables the instrument to have more accurate electric conductivity, temperature and depth data.

LISST-100 technical indicators are as follows:

Technology: Small angle forward scattering;

Laser: Solid state diode (670 nm);

Optical path: 5.0cm (Standard), 2.5cm (Optional), 20.0cm (Optional)

Parameter: Particle size distribution

Light scattering function (VSF)

Light penetration

Water depth (0 to 300 m)

Water temperature (-5°C to 50 °C)

Implementation method: Underwater, laboratory, field, towing, anchorage, platform,

profile

Operating range: Concentration (Approximate range of the particles with an average size of 30 μ m):

5.0 cm light pool - 10 to 750 mg/l

2.5 cm light pool - 20 to 1500 mg/l

20 cm light pool - 2.5 to 175mg/l

(The range shows linear variation with the particle size)

Particle size range: 1.25 - 250 (Type B)

2.5 - 500 (Type C)

Light penetration: 0- 100%

Accuracy: Concentration: $\pm 20\%$ (Full range)

Light penetration: 0.1%

Resolution: Concentration: 0.5/l

Particle size distribution: 32 size grades, interval sampling

Measurement rate: Programmable, up to 4Hz (Measured 4 times per second)

Data programming acquisition unit: Internal memory and / or external data output,

RS-232C

Data capacity: 16MB

Interface: RS-232 C, WINDOWS 95/98/NT software

Energy: Internal power-Common alkaline battery

External power- REG +15 & -15 V @ 250 Ma max

Actual dimension: 32inch long 5 inch diameter (81 cm long 13 cm diameter)

Weight: 25 pounds (11.25KG) in the air; 8 pounds (3.6 KG) in the water

Rated working depth: 300m (For special requirements, depth can be upgraded)

In consideration of the characteristics of sediments in the Mekong River water, the application range of LISST-100 can serve as the instrument to measure sediments in the river.

(2) Outflow station

The instruments and civil works for the outflow station will be identical to those for the inflow station.

3.2 Dam-front and Reservoir Area Water Surface Profiles Monitoring

3.2.1 Layout of stations

The dam-front water level measurement will utilize the existing dam-front level gauging station

established for the water regime forecasting system. The reservoir tail level can use the tailwater level monitoring system for Pak Lay Plant, to spare new setting-up. It is preliminarily proposed to establish 2 automatic water level gauging stations at Don Men Village and Pak Lay Town.

3.2.2 Equipment installation and civil works

The list of level gauging instruments/equipment and civil works refers to Table 3.2.

Table 3.2 List of level gauging instruments/equipment and civil works

Designation		Quantity	Unit	Remarks
Instruments & equipment	Pump type gauging station	2	set	
	Instrument box	2	piece	
	Data acquirer	2	piece	
	Beidou satellite terminal & antenna	2	set	
	Maritime satellite terminal & antenna	2	set	
	Solar panel	2	piece	
	Battery cell	2	piece	100AH
	Keyboard	2	piece	
Civil works	Lightning grounding system	2	set	Soil resistance <10 ohm
	Instrument room	2		Floor area of 4m ²
	Artificial water gauge	2	set	Elevation system conversion for water gauge

3.3 Reservoir baseline survey

The reservoir baseline survey includes establishing a reservoir control network, erecting sectional stakes for reservoir area, and surveying works.

(1) Reservoir area control survey

Reservoir area control survey is the basis for hydrological and sediment monitoring in the reservoir area. Its task is to establish a plane and elevation system control networks for the whole reservoir area.

The reservoir area is about 99km long. Grade I lines in a total length of 120km are used as the first level control for the plane.

The reservoir area elevation control network is formulated in Grade III leveling lines, 200km in total length, and branch lines for different sections are in Grade IV, 150km in total length.

(2) Setting out of longitudinal and cross sections in reservoir area and survey works

Altogether 90 cross sections are arranged in the reservoir area, the sections along with the baseline have

a total length of 90km. One longitudinal profile for the reservoir area is laid out, about 100km in length. 90 pairs of sectional monitoring monuments are constructed in the reservoir area. The endpoints of different sections will be jointly surveyed, and cross and longitudinal sections will be surveyed accordingly.

(3) Topographic survey instruments

The underwater topography will be surveyed with a digital echo-sounding instrument, land topography by total survey station, positioned with GPS, and professional data acquisition software, computation software, image integration software will be used as well. The detailed list refers to Table 3.3. Since the reservoir area survey works would be vast in quantities, it is recommended that qualified agencies should be entrusted to carry out the survey with above-mentioned instruments.

Table 3.3 List of survey instruments and software

No.	Equipment name	Model	Manufacturer	Remarks
1	Trimble GPS	Trimble R7	Trimble Navigation, US	GPS RTK
2	Total survey station	TCR802	Leica	To acquire land topographic data
3	Multi-beam depth sounding system	R2SONIC2024	US R2SONIC	To acquire underwater data
4	Single-beam depth sounding system	Hi Target	Hi Target	To acquire underwater data
5	Vehicle, boat			Traffic means, to acquire underwater data
6	Computer			Data processing
7	Image software	Cass9.0	South Digital	Data processing
8	Data acquisition software	PDS2000		To acquire multi-beam data
9	Computation software	TBC2.8	Trimble Navigation, US	Calculation of GPS control net

(4) Reservoir shoreline monitoring

High precision satellite image of the Sanakham reservoir area will be acquired once a year. 3S technology can be used to generate the reservoir area topographic map, and then to analyze the interannual variations of the river course, shorelines and terraces. Each year before and after flood period, patrol survey should be conducted for the reservoir area, to the bank slopes in the reservoir area, especially those slopes possibly to deform.

3.4 Damsite Area Topography Monitoring (Power Intake & Approach Channel)

To follow up the sedimentation evolution in the damsite area and the approach channels, after the reservoir impoundment, the damsite area topography should be monitored every year, mainly to keep a

watchful eye on the locations such as the sand barrier, power intake, flood sluices, upstream and downstream approach channels. The topography survey method and instruments refer to Table 3.4. The underwater topography will be surveyed with a digital echo-sounding instrument, land topography by total survey station, positioned with GPS, and professional data acquisition software, computation software, image integration software will be used as well. The number of instruments will be determined according to the workload and the time schedule.

Topography survey requirements are narrated below:

- (1) Scope: 1km upstream of damsite~2km downstream of damsite;
- (2) The scale should not less than 1:500. The determined survey scope and scale should remain unchanged as far as possible;
- (3) Each year before and after flood period, overall survey should be conducted for these areas, and survey times at the approach channels should be more frequent than normal survey times.

3.5 Downstream River Course Topography Monitoring

High precision satellite image of the 30km-range downstream of Sanakham damsite will be acquired once a year. 3S technology can be used to generate the reservoir area topographic map, and then to analyze the interannual variations of the river course, shorelines and terraces. Each year before and after flood period, patrol survey should be conducted for the bank slopes in the downstream river course, especially those slopes possibly to deform.

3.6 Reservoir Area Landslide Deformation Body Monitoring

The two bank slopes near the dam area and in the reservoir area are relatively gentle, exposed groundwater elevation is higher than the normal pool level, and dense forest and vegetation are developed in large gullies. It is preliminarily judged that in the reservoir area there should not evoke large-scale slope stability problems, but for the reservoir shore slopes are composed of silt and silty clay soil, once the reservoir is impounded, the underground water level is raised, the soil will be soaked or wetted, which will cause soil softening and abrupt strength drop, plus wind wave actions, small-scale reservoir bank collapses could be triggered.

Before the reservoir impoundment, the topography of the two sides of the reservoir area should be observed, to identify the location, size and other parameters of possible landslide deformations, and monitoring instruments can be monitored according to the specific arrangement of the deformation bodies.

3.7 Monitoring Requirements

- (1) Inflow and outflow water and sediment monitoring

Inflow and outflow water and sediment monitoring will be conducted as per pertinent water and sediment measurement specifications.

- (2) Sectional survey

Before the reservoir is made ready for impounding, the reservoir baseline survey works shall be

finished, which will serve as the primary data for the reservoir's longitudinal and cross profiles.

After every 3~5 years of operation, the reservoir area shall be surveyed once again at the respective sections. If necessary, the flood water surface profile in the reservoir shall be surveyed as well.

(3) Bank slopes in the reservoir area shall be monitored regularly every year, as well as surveying the main fairway depth in the reservoir area.

(4) Regular or irregular monitoring of the upstream and downstream approach channels. Any accumulation maybe hindering smooth navigation shall be timely dredged.

(5) Regularly (2 times every month in the non-flood season, 4 times every month in the flood season, and another 3 times for a flood process, respectively before, on and after the flood peak) test sediments at the outflow section, and take typical sediment samples subject to grain size gradation analysis.

3.8 Main Monitoring Results

Monitoring data shall be summarized and sorted out as per related specifications and the PDG of MRC. The main results include:

- (1) Water and sediment data and variation trend at inflow gauging station;
- (2) Sediment volume, sediment content, sediment gradation, mineral composition at outflow gauging station;
- (3) Water surface profile of reservoir area under different discharges;
- (4) Reservoir's sediment accumulation distribution;
- (5) Reservoir's storage capacity variation, rectified storage capacity curve;
- (6) Damsite area (scope from damsite upstream 1km to downstream 2km) topography monitoring, mainly including the sedimentation distribution, accumulation thickness and development trend at the sand barrier, power intake and in the upstream and downstream approach channels;
- (7) Downstream river course topography monitoring results;
- (8) Bank cave-in positions and volumes in the reservoir area.

4 Staffing

Considering cost-effectiveness, no dedicated survey personnel will be assigned for the power plant. Qualified professional agencies could be entrusted to conduct the survey jobs at the damsite and in the reservoir area.

5 Cost Estimate

The cost for the reservoir sediment monitoring program is estimated to be 3,145,000CNY, including 1,000,000 CNY for the equipment and installation cost, 1,602,000CNY for the reservoir baseline survey, 318,000CNY for the civil works, and 225,000CNY for other items, as detailed in Table 5.1.

According to the monitored inflow and outflow water and sediment data, reservoir sedimentation,

sediment accumulation in approach channels, the impact of sedimentation on the plant and navigation safety and normal operation should be analyzed, as well as the outflow water and sediment variation and reservoir area sedimentation laws after the reservoir is commissioned, and if necessary, the reservoir operation mode should be optimized as appropriate.

Table 5.1 Cost estimate for sediment monitoring program at Sanakham reservoir (CNY)

Unit: 10⁴ CNY

No.	Works or cost designation	Unit	Quantity	Unit price	Sub-total	Remarks
Part I: Civil Works					31.8	
1	Dam-front reservoir level gauging station (new)		1			Cost covered by water regime forecasting budget
2	Reservoir area level gauging station		2	6	12	
3	Central station		1			Cost covered by water regime forecasting budget
4	Concrete survey monuments	number	180	0.1	18	Including precast, installation, embedding costs, the construction cost after the impoundment
	Management fee	%	10		1.8	
Part II: Equipment and Installation Works					100	
5	Sediment monitoring, analysis instruments\ equipment and their installations	set	2	40	80	
6	Waterborne traffic equipment cost (boat)		1	20	20	
Part III Survey					160.2	

6	Benchmark traverse network	km	100	0.5	50	
7	Reservoir area sectional survey	times	1	40	40	Survey once the entire reservoir area after its impoundment
8	Damsite area survey	times	1	20	20	
9	Technical job cost	%	22		24.2	
10	Cost for procuring and analyzing images	km ²	130	0.2	26	
Part IV: Other cost					22.5	
11	Reserve fee	%	6		17.5	
12	Charges of Chiang Khan Station data				5	Estimated only
Sum of Part I, II, III and IV					314.5	