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SANAKHAM HYDROPOWER PROJECT

Design Report of Fish Passage Facilities

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Preface

Lantsang-Mekong River is the 9th largest river in the world and the 5th largest river in Asia, and is also an international river which passes six countries including China, Laos, Myanmar, Thailand, Cambodia and Viet Nam. This river originates from north side of Tanggula Mountains on Qinghai-Tibet Plateau in China, and the length of the portion in China is 2161km; after flowing out of China, Lantsang River is called as Mekong River, and finally flows into South China Sea in Mekong Delta near Ho Chi Minh City in Viet Nam. Generally, this river flows from northwest to southeast. The total length of Lantsang-Mekong River is about 4881km, and the drainage area is about 81km^2.

At the marine outfall of Lantsang-Mekong River, the multi-year average flow rate is 15,060m^3/s, and the annual average runoff rate about is 475 billion m^3; at the place where Lantsang River flows out of China, the multi-year average flow rate is 2,410m^3/s, and the annual average runoff rate is 76 billion m^3 (16% of that at marine outfall).

With the length and drainage area being 2,720km and 621 thousand km^2 respectively, Mekong River is ranked No. 1 among all rivers in Southeast Asia. According to the relevant data, the theoretical hydroenergy reserve of Mekong River is about 58,000MW, and the recoverable hydroenergy resource is about 37,000MW. The multi-year average power generation is 180 billion kW·h, among which 51% is attributable to Laos and 33% is attributable to Cambodia. At present, the hydroenergy resources developed in Mekong River only account for 1% of total hydro energy resources.

As the 5th cascade of power plant on mainstream of Mekong River in Laos, Mekong Sanakham Hydroelectric Power Project is located on upper river, about 1.4km away from B. Pakheung, M. Kenthao, P. Sayaburi, Lao People's Democratic Republic. The section of Mekong River within the dam site is the boundary river between P. Sayaburi and P. Vientiane in Laos, the right bank is within the territory of M. Kenthao and P. Layin P. Sayaburi, and the left bank is within the territory of M. Sanakham in P. Vientiane. Along the river course, the dam site is about 1737km away from marine outfall of Mekong River, is about 155km away from the capital city Vientiane, and is 81km away from Pak Lay Power Project at upper reach. The dam site is about 250km away from Sanakham County on left bank, and on the left bank, there is simple highway connected with dam site, and the external traffic is very convenient. The river section within the dam site is in an open place with few signs of human habitation.

Mekong Sanakham Hydroelectric Power Project will be a hydropower project which is mainly developed for power generation and also for navigation and fish passage. This project will be composed of plant building, flood gate, single-stage single-line 500t navigation lock and fishway. The normal water level of the reservoir will be 220MSL, max. dam high will be 56.2m, the total installed capacity of power project will be 684MW, the average annual power generation will be 3.803 billion kW·h, and the annual utilization hours will be 5560h. 12 bulb tubular units will be installed, with the flow rate used reaching 5,801m^3/s. The total reservoir capacity (The verified flood level is less than 223.30m) will be 1073 million m^3. The total construction period of this project will be 85 months, and construction period for the first two units will be 70 months.

The Mekong River is abundant in fish resources, and there are more than 1,300 kinds of fishes (among which 233 kinds have been verified by the fishery authorities), which are the important protein source for residents on both banks, accounting for about 50%~80% of food protein. According to the guiding rules for design of fish way on Mekong River, hydroelectric power project constructed on Mekong River shall be equipped with fish passage facilities as a part of the dam. Therefore, fish way shall be designed for the Sanakham Hydroelectric Power project.

The NWH has attached great importance to the design of Sanakham fishway. Centering around the implementation of a set of effective fish passage measures, this Corporation has carried out the field survey, expert consulting and other works. In June 2011, the project Department made arrangement for several professional teams to survey the site, surveying the topography of left and right banks of dam site, and now the route of fishway has been preliminarily determined. In May 2012, the design of the fishway was reviewed and discussed and the first draft of the design report of fish passage facilities for hydroelectric power project on Mekong river was completed in July 2013 by the Corporation. Yangtze River Fisheries Research Institute of Chinese Academy of Fishery Sciences provided the consultant service in July 2014.

Sanakham Hydroelectric Power Plant is designed as a run-of-river plant with low water head. The right bank is relatively wide, suitable for arrangement of fishway. Mekong River is abundant in fish resources, to ensure the effectiveness of fish passing, imitative-ecological fishway providing imitated natural interior structure and various flow patterns and environments is designed on the right bank for upstream moving. While for downstream moving, eco-friendly turbine and sluice gate are used in combination

with fishway.

On the basis of the works mentioned above, in light of the actual situations of Sanakham Hydroelectric Power Plant, and through the cooperation among disciplines including hydrotechnics, hydrology, metal structure, construction and environmental protection, the *Design Report of Fish Passage Facilities for Sanakham Hydroelectric Power Plant* has been prepared.

Since gratitude is hereby extended to Yangtze River Fisheries Research Institute of Chinese Academy of Fishery Sciences, Changzhou Hydraulic Complex, Yangtang Hydroelectric Power Plant and Institute of Hydroecology under Ministry of Water Resources and China Academy of Sciences for the guidance and help given by them for the design of fish passage measures for Sanakham Hydroelectric Power Plant!

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1 INTRODUCTION

1.1 Background

The Mekong River is abundant in fish resources, and there are more than 1,300 kinds of fishes (among which 233 kinds have been verified by the fishery authorities), which are the important protein source for residents on both banks, accounting for about 50%-80% of food protein. According to the requirements of guiding rules for fishway design formulated by Mekong River Committee (MRC), every hydroelectric power plant constructed on Mekong River shall be equipped with the upstream/downstream fish passage measures for fishes. Therefore, while design the main body of this Project, the fish passage measures shall also be designed as a part of this Project.

1.2 Design reference

1.2.1 Laws and Regulation

(1) The Lao Environmental Protection Law (1999)

(2) The Decree on Environmental Assessment No. 112/PM (2010)

(3) The Lao Amended Forestry Law (No. 06/NA-Dec.2007)

(4) The Lao Wildlife and Aquatics Law (No. 07/NA-Dec.2007)

(5) The Lao Water Law (1996)

(6) The Lao Amended Land Law (No. 04/NA-Oct.2003)

(7) Regulation on Environment Assessment (No. 1770/WREA/2000)

1.2.2 Technical standards and specifications

(1) *Preliminary Design Guidance for Proposed Mainstream Dams in the Lower Mekong Basin*, Mekong River Commission, 2009;

(2) *Specifications for Design of Fish Passage Facilities for Hydropower Projects* (draft for review), industrial standard issued by Ministry of Electricity of the People's Republic of China;

(3) *Design Guidelines for Fish Passage Facilities of Hydropower Projects* (draft for review), industrial standard issued by Ministry of Water Resources of the People's Republic of China.

2 OVERVIEW OF THE PROJECT

2.1 Overview of the river basin

2.1.1 General description of river basin

The Lancang- Mekong River is an international river, and it is originated from the end of glacier at the southern foot of Mt. Lasaigongma (El. 5,160m) in southern part of Qinghai Province, China. Geerji River and Emuchu River, tributaries in the upstream, flow from Qinghai into Tibet, merge at Changdu and are referred to as Lancang River thereafter. It flows from Tibet into Yunnan, and leaves China at the estuary of Nanla River in Mengla County, Xishuangbanna Prefecture, southwest Yunnan, and it is not referred to as The Mekong River until after leaving the Chinese territory. The Mekong River successively flows across Myanmar, Laos, Thailand, Cambodia and Vietnam, and joins South China Sea at Saigon (Ho Chi Minh City), Vietnam. Mekong River is successively the Sino-Myanmar, Lao-Myanmar and Lao-Thai border river. Based on relevant information, the mainstream length of Lancang River in the Chinese territory is 2,130km, the Sino-Myanmar border river 31km, the Lao-Myanmar border river 234km, the Lao-Thai border river 976km, the section in the Lao territory 789km, the section in Cambodia 490km, and the section in Vietnam 230km. The full length is about 4,880km, and the basin area is about 0.795 million km^2. The characteristic values of basins in the countries that the Mekong River flows across may be referred to Table 2.1-1.

Table 2.1-1 Characteristic Values in Mekong River Countries

Items	China	Myanmar	Laos	Thailand	Cambodia	Vietnam	Total
Basin Area (km^2)	165,000	24,000	202,000	184,000	155,000	65,000	795,000
Percentage of Basin Area (%)	21	3	25	23	20	8	100
Percentage of Water Volume (%)	16	2	35	18	18	11	100

Note: The source of information is *Overview of the Hydrology of the Mekong Basin* published by The MRC in 2005.

The shape of the Lancang – Mekong Basin is approximately a ribbon, which is narrow on the upper part and wide on the lower part. It spans 25 degrees of latitude, with great differences in natural geographic conditions in the basin. According to the classification of the MRC, The Mekong River could be classified as the Upper Mekong River and the

Lower Mekong River. The Upper Mekong River refers to Lancang River in the Chinese territory and the section of the Mekong River in Myanmar, while the Lower Mekong River refers to the section of the Mekong River in the territories of Laos, Thailand, Cambodia and Vietnam. The Upper Mekong River and the Lower Mekong River are approximately divided by Chiang Saen Hydrological Station. For the convenience of description, the Lower Mekong River is called The Mekong River hereinafter if not specific reference.

The Mekong Basin may be topographically classified into five areas: Northern Plateau, Annamite Mountain Range, Southern Highland, Korat Plateau and the Mekong River Plain. The Northern Plateau includes North Laos and the hilly areas of Loei and Chiang Rai Province in Thailand. The elevation is as high as 1,500m~2,800m, with a few upland plains and valley terraces only; The Annamite Mountain Range extends over 800km from northwest to southeast, the northern and central slopes are relatively steep, and the southern part are hilly land; The Southern Highland includes Kravanh Mountains in Cambodia, the eastern part are mountains stretching long and unbroken, while the southwest part are hilly land; Korat Plateau includes the northeastern part of Thailand and part of Laos, and it is a butterfly-shaped intermontane basin about 500km long and wide, Mun River and Chi River, the tributaries, flows across here. The Mekong River Plain is large area of lowland, including the delta area.

2.1.2 River planning

In 1957, under the auspices of Economic Commission for Asia and Far East (ECAFE for short and re-named as ESCAP in 1987), Study and Coordination Commission for Mekong Catchment (MRC - Mekong Commission for short) participated by Vietnam, Laos, Cambodia and Thailand was established. As from 1963, MRC has conducted substantial project planning and feasibility study. In 1970, MRC worked out the *1970 Guiding Plan for the Catchment,* in which seven cascade water conservancy and hydropower projects were planned in the 2,400km-long mainstream from the estuary to Chiang Sean of Thailand. The storage capacity of the seven cascade reservoirs amounted to $258,900\times10^6m^3$, and effective storage was $136,000\times10^6m^3$ while the total installed capacity reached 23,300MW. Pamong Project was a high-dam reservoir, and more than 300,000 people were resettled. In 1989, a revised scheme came out, including

a comparison scheme of seven cascades and eight cascades. In order to solve the problem of large inundation loss of cascade reservoirs, with the assistance of UN Development Programme and French Government, a 9-cascade development scheme was put forward in 1994 after study of more than two years. All hydropower projects in this scheme are run-of-river type, which shall help greatly cut down inundation losses, and the population to be resettled is 60,000. However, 10,000MW of installed capacity is reduced.

According to the latest research result of cascade development scheme of the Mekong River, the main stream of the Mekong River is developed in ten cascades which are (from upstream to downstream) Pak Beng, Luang Prabang, Sayabouly, Pak Lay, Sanakham, Pa Mong, Ban Koum, Don Sahong, Stung Treng and Sambor.

Pak Beng, Luang Prabang, Sayaburi, Pak Lay, Sanakham are planned in Laos, Pa Mong, Ban Koum are planned on the reach of the Mekong River bordering Laos and Thailand, Don Sahong is planned on the reach bordering Laos and Cambodia, Stung Treng, Sambor are planned in Cambodia.

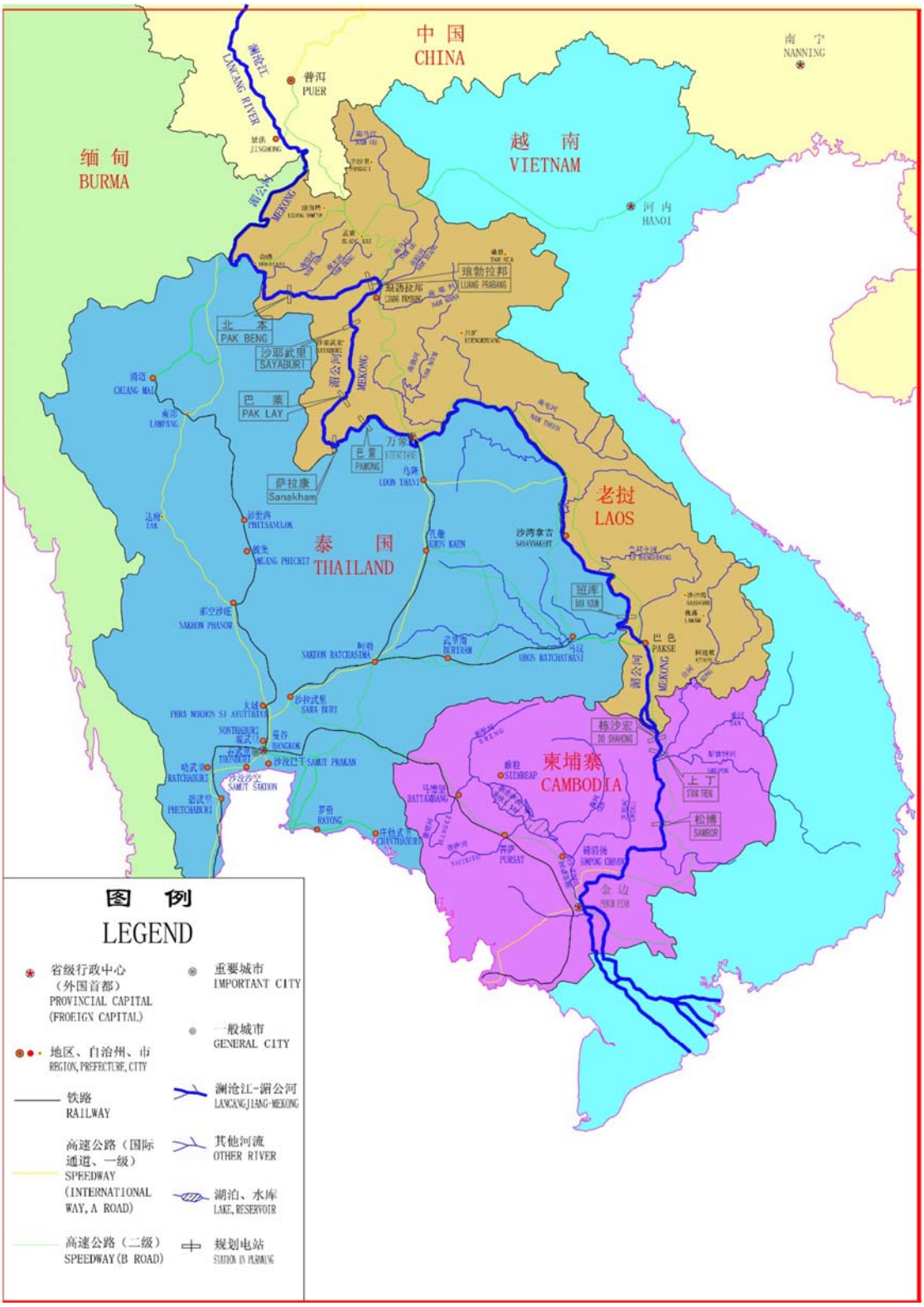

Figure 2.1-1 Sketch of Cascade Hydropower Projects on Mainstream of Mekong River.

2.2 Geographical Location

As the 5th cascade of power plant on mainstream of Mekong River in Laos, Mekong Sanakham Hydroelectric Power Plant is a run-of-the-river power plant. The power plant

is located on upper river, about 1.4km away from B. Pakheung, M. Kenthao, P. Sayaburi, Lao People's Democratic Republic. The section of Mekong River within the dam site is the boundary river between P. Sayaburi and P. Vientiane in Laos, the right bank of reservoir site is within the territory of M. Kenthao in P. Sayaburi, and the left bank is within the territory of M. Sanakham in P. Vientiane. Along the river course, the dam site is about 1737km away from the marine outfall of Mekong River, and is about 155km away from the capital city Vientiane(lower reach of dam site). The dam site is about 25km away from Sanakham Countyon left side. The lower reach which is 2km away from the dam site serves as the boundary river between Thailand and Laos. On the left bank of Mekong River, there is simple highway connected with the dam site, so that the external traffic is convenient (See Attached Figure 1 for geographical location of this Project).

2.3 Geomorphology

2.3.1 Dam site

The dam of the Sanakham HPP is located 1.65 km upstream of the confluence where the Nam Heuang River joints the Mekong River. The dam axis strikes SW180°, and the left bank where the dam axis is arranged has flat terrain, with an average slope ratio of about 3°~ 6°, and 15°~ 25° at the right bank. The river valley is in "U" shape, with an average width of the river surface of about 300m during mean flow season, and the width of the upstream river valley is about 738m at normal water level of 220m.

The right bank dam abutment is of a solitary ridge, with bedrock exposed at the front edge at EL. 230m; the abutment is oblique to the rock formation orientation and the river orientation; and the right bank slopes are fundamentally stable.

The left bank terrace has a width of 350m ~ 500m, with an overburden thickness of 8m ~ 12m; the left bank has an 80m ~ 120m wide flood plain consisting of fine sand, with thickness of 12m ~ 15m and underlying bedrock consisting of gray slate intercalated with sandstone.

The mainstream deviates to the right bank, and the riverbed overburden is shallow at the right side and deep at the left side. It is suggested that the riverbed overburden thickness is 5m ~ 21m based upon geophysical test.

2.3.2 Reservoir area

The reservoir area enjoys topography of low mountains and hills with small undulation, without low adjacent valleys. The valley is relatively open, with low slopes and a few islands.

At normal water level, the reservoir backwater is about 81km upriver from the dam site to Pak Lay dam site.

There are 12 tributaries along the two river banks (7 tributaries at the right bank, 5 tributaries at the left bank), the largest tributary runs across Pak Lay; the slope ratio is generally 20° ~ 35° and the slope surface is mainly overburden consisting loose Quaternary gravelly soil with dense vegetation.

2.4 Hydro-Geology

The project area enjoys dry wet monsoon climate in Southeast Asia tropical ~ subtropical inland. Rainy season starts from June to October, the period from November to next May is dry season, with an average annual precipitation of about 1900 mm, a maximum temperature of 38 ℃, a lowest temperature of 3 ℃ and an annual average temperature of 27 ℃.

No groundwater containing heavy metal elements is found according to data (from the year 1950 to 2000) collected by Lao National Weather Station. The Mekong River is datum level set as the lowest runoff level of industrial waste materials. The backwater will not be very high after reservoir impoundment, which will less likely cause any change as how runoff replenishes the groundwater. The underground water mainly consists of porous phreatic water in loose Quaternary deposit and bedrock fissure water. Bedrock fissure water is mainly found in fractured bedrock, especially, moderately ~ weakly weathered rock. It is largely replenished by rainfall, and flows into the Mekong River and adjacent gullies in form of spring and phreatic flow.

Porous phreatic water mainly found in the riverbed, floodplain and the loose layers along the river banks, it is mainly replenished by water river, rainfall and irrigation water; it is relatively abundant and flows into the Mekong River.

2.5 Weather Conditions

The Mekong River Basin is located in the center of the Asian monsoon region and its climate is affected by the monsoon, with two distinct seasons, i.e. dry season and wet

season. From May to mid-October, the humid and rainy climate is affected by the southwest monsoon from the sea; from November to the next April, the dry season is affected by the continental northeast monsoon.

Because the Lancang - Mekong River has a wide latitude, the rainfall varies greatly in the basin; the annual average rainfall in the lower reach of the Lancang River is 914.5mm ~ 1596.2mm; normal annual rainfall in the Mekong River basin increases from 1000mm below in Thailand's northeastern region up to 4000mm in southern Laos, Cambodia and Vietnam mountainous regions.

According to statistical meteorological element data collected at Vientiane station from the year 1980 to 2004, the annual average temperature, extreme maximum temperature, extreme minimum temperature are 26.5 ℃, 40.2 ℃ and 8.5 ℃, respectively; annual average relative humidity is 73.3%, average annual rainfall, annual average evaporation are 1703.1mm and 1670.3mm; the annual average wind speed, the maximum wind speed and the maximum annual average wind speed are 1.3m/s, 35m/s, 22m/s, respectively.

2.6 Hydrology

2.6.1 Runoff

The average annual runoff of the Sanakham dam is 4400 m^3/s, and the annual runoff is 138.76billion m^3, and the monthly average runoff is shown in Table 2.6−1. The minimum daily runoff and the maximum daily runoff (the year 1923 to 2012) are 592 m^3/s and 24500 m^3/s, respectively.

Table 2.6-1 Design annual runoff at Sanakham HPP dam site Unit: m^3/s

Month	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May
Average runoff	3390	6860	11600	10900	6600	3840	2360	1680	1340	1150	1160	1670

Sanakham HPP monthly average runoff at the dam site taken the impact of storage regulation of the upstream cascade reservoirs into consideration is shown in Table 2.6-2. Annual daily runoff at the Sanakham dam site is adjusted considering the impact of storage regulation of the upstream cascade reservoirs. The minimum and the maximum daily runoff in a long series are 842 m^3/s and 20335 m^3/s, respectively.

Table 2.6-2 Monthly average runoff considering impact of storage regulation of upstream cascade reservoirs Unit: m^3/s

Item	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May
Average runoff	3330	5530	9520	9960	6390	3680	2880	2440	2140	1930	1800	2050

2.6.2 Flood

Laos enjoys tropical climate, flood season typically starts from May to November, big flood usually occurs from mid-August to mid-September in Chiang Khan ~ Vientiane region. Most of big floods of the Mekong River are of single-peak type, rising and falling slowly, and one flood can even last for a few months. Floods typically occur in August and September. Design flood data at the Sanakham dam are shown in Table 2.6-3.

Table 2.6-3 Design flood data at the Sanakham dam Unit: m^3/s

Item	Average		Design frequency $X_{p(\%)}$						
			0.01	0.02	0.05	0.1	0.2	0.333	0.5
Q_m	16600		37300	36100	34400	33100	31700	30800	29900
Item	Average	Design frequency $X_{p(\%)}$							
		1	2	3.33	5	10	20	33.33	50
Qm	16600	28400	25000	23900	22900	21300	19400	17800	16300

Design staged flood data of Sanakham HPP site are shown in Table 2.6-4.

Table 2.6-4 Design staged flood data of Sanakham HPP site Unit: m^3/s

Stage	Service period	Design frequency $X_{p(\%)}$			
		3.33	5	10	20
Jan.	Jan. 1 ~Jan. 31	3350	2880	2600	2370
Feb.~Apr.	Feb. 1 ~Apr. 30	2110	2050	1970	1820
May	May 1 ~May 31	5640	5230	4180	3340
Jun.	Jun. 1 ~Jun. 25	9420	9150	8200	6740
Jul.~Sep.	Jun. 26 ~Oct. 5	23900	22900	21300	19400
Oct.	Oct. 6 ~Nov. 5	15400	15000	13400	12100
Nov.	Nov. 6 ~Nov. 30	10200	9700	8370	6800
Dec.	Dec. 1 ~Dec. 31	5160	5080	4620	3850

2.6.3 Sediment

Suspended load: the analysis shows that average annual suspended load inflow of Sanakham reservoir is 69 million t. Annual distribution of inflow suspended load measured at Sanakham reservoir is referenced and variation of water and sediment inflow is shown in Table 2.6-5.

Table 2.6-5 Annual distribution of water and sediment inflow of Sanakham reservoir

Item	Jan.~Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.~Dec.	Annual
Sediment (10, 000t)	107	47.0	214	993	2319	2063	825	332	6900
Percent (%)	1.55	0.68	3.10	14.40	33.61	29.89	11.95	4.81	100
Runoff(m^3/s)	1336	1650	3420	6920	11800	10900	6570	3083	4400
Sediment concentration (kg/m^3)	0.077	0.106	0.241	0.536	0.734	0.730	0.469	0.204	0.496

Table 2.6-5 shows that annual distribution of water and sediment inflow of Sanakham reservoir is uneven, the sediment in flood season from July to September accounts for 77.9% of the annual amount, with average sediment concentration of 0.686 kg/m^3 and annual average sediment concentration of 0.496kg/m^3.

Bed load: bed load at the dam site is estimated in the feasibility stage using ratio of suspended load to bed load (0.2), i.e., annual average bedload transport quantity at the dam site is 1.31 million t.

Suspended load particle size gradation: a total eight copies of suspended particle size gradation data in July, August 1961 are available at Vientiane Station on the Mekong River, in which, the maximum suspended sediment particle size is 0.09mm, accounting for 87.2 percent of total suspended load and the sediment particle size greater than 0.09mm is modified with reference to suspended load grain size gradation plotted at Jiuzhou station on the Lancang River. Wherein the moderate particle size is 0.018mm, the average particle size is 0.046mm and the maximum particle size is 1mm (see Table 2.6-6).

Table 2.6-6 Suspended load particle size gradation (Vientiane station on the Mekong)

Particle size d(mm)	0.005	0.009	0.02	0.04	0.1	0.25	0.5	1.0

Weight of sediment with size smaller than d (%)	21.8	32.0	53.0	73.2	89.2	97.75	99.6	100

2.7 Project Layout

Sanakham Hydroelectric Power Plant is a hydropower project which is mainly used for power generation and is also used for navigation and fish passage. The main structures will include plant buildings, flood gate, single-stage single-line 500t navigation lock and fishway. The normal water level will be 220MSL, the total installed capacity of power plant will be 684MW, the average annual power generation will be 3.803 billion kW·h, and the annual utilization hours will be 5560h. It is preliminarily planned to adopt 12 bulb tubular units, with the flow rate used reaching 5,801m^3/s.

In the feasibility study stage, the layout of hydraulic complex from left bank to right bank is recommended as follows: auxiliary concrete dam on left bank, dam section for navigation lock, dam section on left bank for 13 flood gates, riverbed-type dam section for plant buildings (12 units), dam section on right bank for 5 flood & sediment discharging gates, and auxiliary concrete dam on right bank. The total length of dam top will be 909.9m, the elevation of dam top will be 229.5m, and the maximum height of concrete dam will be 56.2m. (See Attached Figure 2 for the layout of hydraulic complex)

2.8 Characteristics of Project

The main characteristic indexes of this Project are detailed in Table 2.8-1.

Table 2.8-1 Characteristics of Mekong Sanakham Hydroelectric Power Project

No.	Description	Unit	Quantity	Remarks
I	Hydrology			
1	Area of drainage basin			
	Total drainage area of Lantsang-Mekong River	km^2	795000	
	Drainage area upstream of the dam site	km^2	290103	
3	Multi-year average annual runoff rate	100 million m^3	1387.6	
4	Representative flow rate			
	Multi-year average flow rate	m^3/s	4400	
	Actually-measured maximum flow rate	m^3/s	22600	Chiang Khan Station (1971)
	Actually-measured minimum flow rate	m^3/s	540	Chiang Khan Station (2004)
	Design flood standard and flow rate	m^3/s	34700	P=0.05%

No.	Description	Unit	Quantity	Remarks
	Check flood standard and flow rate	m^3/s	38800	P=0.01%
5	Sediment			
	Multi-year average suspended sediment discharge	10 thousand t	6900	
	Multi-year average sediment discharge	kg/m^3	0.496	
	Actually-measured maximum suspended sediment discharge during flood season	kg/m^3	0.686	September
	Multi-year average bedload discharge	10,000t	138	
II	reservoir			
1	reservoir water level			
	Check flood level	m	223.30	
	Design flood level	m	221.70	
	Normal pool level	m	220	
	Dead water level	m	219	
2	Reservoir area at normal pool level	km^2	131.64	
3	Backwater length at normal pool level	km	81	
4	Reservoir capacity			
	Total storage (natural)	100 million m^3	10.73	At check flood level of 223.30m
	Regulating storage	100 million m^3	0.668	
	Dead storage	100 million m^3	7.602	At dead water level of 219m
	Storage coefficient	%	0.048	
	Regulating property			
III	Discharging rate and corresponding water level at lower reach			
	Maximum discharging rate at design flood level	m^3/s	34700	
	Corresponding water level at lower reach	m	219.57	
	Maximum discharging rate at check flood level	m^3/s	38800	
	Corresponding water level at lower reach	m	220.93	
	Minimum flow rate	m^3/s	540	
	Corresponding water level at lower reach	m	199.62	
	Flow rate with all generator units in operation	m^3/s	5801	
	Corresponding water level at lower reach	m	205.32	
IV	Benefits indexes of this Project			
	Power-generation benefits			
	Total installed capacity	MW	684	
	Firm capacity (P=90%)	MW	257.3	The cascade regulation at upper reach is considered

No.	Description	Unit	Quantity	Remarks
	Multi-year average power generation	100 million kW·h	38.03	The cascade regulation at upper reach is considered
	Annual utilization hours	h	5560	The cascade regulation at upper reach is considered
V	Inundation loss and permanent land occupation by the project			
	Migrant population	person	2935	621 households
VI	Main structures and equipment			
1	Dam			
	Dam type		Concrete gate dam	
	Foundation rock		Slate with sandstone	
	Basic seismic intensity / seismic fortification intensity	Grade	6/6	
	Dam crest elevation	m	229.50	
	Maximum dam height (powerhouse)	m	56.2	
	Crest length	m	909.90	
2	Flood-discharge building			
2.1	Number of Flood gate section		18	
3	Powerhouse			
3.1	Type		Powerhouse in river channel	
3.2	Dimension of power house (length × width × height)	m×m×m	262.2×80.7×58.4	
3.3	Water diversion			
	Designed water-diversion flow rate	m^3/s	5801	
	Rated water head	m	13.3	
3.4	Dimension of auxiliary building (length × width × height)	m×m×m	313.5×36×24	
4	Navigation lock			
4.1	Stages of navigation lock		Single stage	
4.2	Lines of navigation lock		Single line	
4.3	Scale of navigation lock		Class IV (500t)	
4.4	Design level of navigation lock			
	Highest navigable stage at upper reach	m	220	
	Lowest navigable stage at upper reach	m	219	Dead water level at upper reach
	Highest navigable stage at lower reach	m	212.55	Downstream level at to 3-year-flood
	Lowest navigable stage at lower reach	m	199.62	Downstream level corresponding to assurance rate of 95%
4.5	Main dimensions of navigation lock			
	Effective dimensions of the lock	m	120×12×4	
	Max. lift length	m	20	
	Length of improved channel	km	81	
	Length of head bay that coincide with dam axis	m	36	
4.6	Lock capacity			
	Designed fleet of ships	t	2×500	

No.	Description	Unit	Quantity	Remarks
	Designed carrying capacity	10 thousand ton /year	217	
	Daily average water consumption of the lock	m^3/s	5.62	
5	Main E&M equipment			
5.1	Turbine			
	Number	set	12	
	Model number		GZ（814）-WP-745	
	Rated output	MW	58.16	
	Rated head	m	13.3	
	Rated flow	m^3/s	483.4	
5.2	Generator			
	Number	set	12	
	Model number		SFW57-70/	
	Unit capacity	MW	57	

2.9 Operation Mode

Sanakham Hydroelectric Power Plant is mainly used for power generation and is also used for navigation. With the normal water level being 220m, it is a run-of-the-river hydroelectric power plant. In order to improve the flexibility of operation, the dead water level of Sanakham Hydroelectric Power Plant will be set at 219m, and the regulating capacity will be 66.81 million m^3. In consideration of the factors including power generation, flood control, sediment discharging and navigation, the operation mode of power plant is determined as follows:

(1) Operation Mode for Power Generation

Since Sanakham Hydroelectric Power Plant will focus on electricity sold, the peak regulation is of less importance. In addition, the peak regulation may impose some adverse impacts on safety of navigation and lower reach. Therefore, no peak regulation is considered for this power plant, the power generation will be carried out on the basis of natural flow rate, and the water level in reservoir water is maintained at 220m. When the inflow rate is higher than the flow rate introduced for generator unit (5801m^3/s), the flood & sediment discharging gates on right bank will be opened for discharge water.

(2) Operation Mode for Flood Control and Sediment Discharging during Flood Season

The flood may occur during the flood season (June - November). When Luang Prabang Hydrological Station on upper stream is encountered with the once-in-3-year flood (before the construction of Pak Beng Hydroelectric Power Plant) or Pek Beng Hydroelectric Power Plant on upper stream is encountered with the once-in-3-year

flood and begins to discharge the flood, Sanakham Hydroelectric Power Plant will carry out the preliminary discharging, and the preliminary discharging rate will be controlled at 17,800m^3/s, and the water level in reservoir will begin to reduce. The time spent for the flood from upper reach (Luang Prabang Hydrological Station or Pak Beng Hydroelectric Power Plant) to arrive at Sanakham Hydroelectric Power Plant is about one to two days. Therefore, the preliminary discharging time is also one to two days. As the water level in reservoir reduces, more flood gates will be opened gradually, so as to maintain the discharging rate at 17,800m^3/s; when the water head is less than 4m, the power plant will be shut down; when the water level in reservoir further reduces to 213.85m, all the lock gates will be opened for discharging flood and sediment.

The fold regulating mode of Sanakham Hydroelectric Power Plant during flood season may be adjusted and optimized on the basis of the effect of flood regulation and sediment discharging in future.

(3) Operation Mode for Navigation

When the inflow rate is higher than the once-in-3-year flood rate (17,800m^3/s), the incoming water will exceed the navigation standard for navigation lock, then the navigation lock will be out of service.

3 FISHES INVESTIGATION

3.1 Methodology of the field survey

3.1.1 Investigation methods

(1) Secondary data from literature and related documents was reviewed.

(2) Wet and dry season field surveys as well as the collection of aquatic organisms was performed at the six 6 sampling stations.

(3) Samples were collected of the following aquatics: fish, plankton, benthic invertebrate and aquatic plants. All samples were collected, particularly fish, and were identified, weighed and counted. As for plankton and the benthic invertebrate, density as cells/m^3 and number of animals/m^2 are evaluated.

(4) Fishery activities were observed and recorded.

1) Freshwater Plankton Sampling

Thirty liters of water were collected from the depth of between 0 to 30 cm using a plankton net. The sampled water was passed through plankton net of 59 microns mesh size in order to separate the aquatic life from the water. The sample of aquatic life was then preserved with 5% formalin solution for further laboratory analysis.

The data of freshwater planktonic organisms at each sampling station can be easily compared by computing "Species Diversity Index (SDI)" by employing the following equations:

$$\text{Species Diversity Index} = \sum_{i=1}^{N}\left[\left(\ln\frac{Ni}{N}\right)\times\left(\frac{Ni}{N}\right)\right]$$

Where: Ni = Population density of each species

N = Total population density of all species

The evaluation criteria for Species Diversity Index (SDI) are as follows (Table 3.1-1):

Table 3.1-1 Evaluation criteria for species diversity Index

SDI Range	SDI Interpretation
0 –1	Slight Diversity

1 – 2	Moderate Diversity
2 – 3	High Diversity
3 – 4	Heavy Diversity

The collected and preserved freshwater plankton samples were further analyzed in the laboratory for identification of plankton organisms and for determining their abundance.

2) Freshwater Benthos Sampling

The sediment at the bed was collected with the help of Ekman dredge sampler. The collected samples (prepared by 5 composite grab samples) were then sorted out through a series of sieves to separate benthic macro-invertebrate organisms. Retained organisms were preserved with 7% formalin solution for further laboratory analysis.

3) Freshwater Fish Sampling and Survey

- Secondary data from literature and related documents was reviewed.
- All samples were collected, identified, weighed and counted.
- Fishery activities were observed and recorded.
- The freshwater fish sampling was carried out at same station as the water sampling by using suitable gears such as beach seine, gill net or cast net depend on the characteristics of study areas. The nets for beach seine were of about 1-3 cm mesh size and 30-100 m long to cover the water surface area and then the samples will be collected.
- Data on fishery activities, available markets, the amount of harvested fish and processing procedures was collected through interviews with local people.
- Indirect sampling was performed by making observations at a fish market on the kinds and quantities of fishery products.
- Fishermen interviewed on type and quantity of fishery products they harvest.

4) Aspects of Concern

- Type and abundance of plankton, benthos and fish.
- Fish species, abundance and diversity in the concerned water bodies.
- Impacts of changing water levels and flow regime on fish habitats including floodplains, flood scrub-land, rapid and rock pools.

- Deterioration of water quality may lead to serious impacts on aquatic ecological system during construction and operation.
- Blockage of fish mitigation due to dam construction.
- Inadequate minimum flow downstream from reservoirs will lead to serious impact on aquatic ecological system.

5) Data analysis

- Identified, described and mapped the various aquatic habitats found in the upstream tail water area.
- Assess potential impacts of the project development in construction phase and operation phase on fishery resources.
- Identify fish and other aquatic animals according to family, genus and species, type, density, and diversity of fish in the concerned waterways.
- Separate fish into migratory and non migratory fish. Description of all fish species, identified with regard to migration requirements, food and breeding requirement.
- Fishery and other aquatic animal's production - assess the value of the resource.
- Fishing methods and importance of fishery activities in the nutrition and livelihood requirements of affected communities.

6) Impact Assessment and Recommendation

- Ecological impact due to deteriorated water quality.
- Potential impact on fish migration.
- Impact on distribution of fish species along upstream and downstream area of Mekong Sanakham HPP.
- Evaluate the fish production, migration, fisheries and fishery enhancement.
- Evaluate the likely impact on rare and endangered fish species.
- Effects of impoundments on the aquatic conditions of the project, evaluate likely change of fish production and populations and other aquatic animals.
- Effects of flow regulation on aquatic ecology.
- Review the practicality of a fish pass as a method of addressing fish migration requirements.
- Fishery production and management program.
- Propose possible mitigation measures and monitoring program methods on fishery and cost

possible to Project.

3.1.2 Sampling time and location

In order to get accurate data, sampling was performed in both the dry and rainy reasons, November 2010 and July 2011 respectively.

There were six sampling stations:

- Station 1: upstream area at Houay Ting
- Station 2: upstream area at Keng Mai
- Station 3: upstream area at Ban Houay Thon
- Station 4: dam site area
- Station 5: downstream area before Nam Heuang confluence
- Station 6: downstream area at Houay Mee confluence

3.2 Result of Fishery Study

3.2.1 Overview

A total of 43 fish species were found in the wet season and dry season surveys. Cyprinidae accounts for about 40% in the catch; Bagridae accounts for about 10% in the catch; Siluridae accounts for about 10% in the catch; Salmonidae accounts for about 10% in the catch.

Matrixes 1 and 2 below provide further details. Much of the catch of large species comprised juveniles. There is a general trend within many species for smaller fish to be caught in the river confluences, which are important nursery areas for these fish and also for some large species. Many of the fish species have a similar spawning behavior of migration from river to flooded areas during the onset of the rainy season and a return to river habitats at the end of that period; so they tend to spend the rainy season in seasonally inundated areas and the dry season in deep pools in the Mekong mainstream or its tributaries. For most fish of the Family Cyprinidae, spawning occurs in the pelagic zone of the Mekong River and its eggs and larvae are pelagic, drifting larvae being taken to their nursery habitats by the water flows. The spawning ground for

many Mekong fish species are in the tributaries.

In the Mekong River at the Sanakham area, it is known to fishermen that the schools of Jullien's Barb or Pa Earn Thong (Probarbus jullieni) can be found during the early rainy season or the early high water level at the rapids area at Ban Keng Mai, 15 km upstream of Sanakham town. Typically, high catches are made at the beginning of wet season (June-July) when many fish are migrating to breeding grounds and also at the end of the wet season (November-December) when fish are migrating off flooded areas and swimming towards dry season refuges.

The presence of ripe eggs in the ovaries of Probarbus jullieni at the rapids area at Ban Keng Mai during early November was found for a week. For many years, there has been cooperation between Thai-Lao fishery biologists; Thai biologists have come to collect the Probarbus jullieni spawning for the artificial propagation and nursing at the Fishery research Station of Loei province at Chiangkhan town, Thailand . Probarbus juvinillieni fingerlings from the hatchery were released into the Mekong river during 2007-2009 but there was no monitoring recorded on this activities.

Matrix 1 – Results of dry season sampling

Fish species composition and their quantity at six sampling stations in the Mekong River and the Mekong Sanakham HPP area November 28-30, 2010 (Dry Season) (sampling area = 200 sq.m)						
Station 1 Houay Ting (upstream area)						
	Family	**Scientific name**	**Local name**	**number**	**size range (cm)**	**weight (g)**
1	Cyprinidae	*Hypsibarbus vernayi* (Norman, 1925)	Tapaag, Pla Pak	1	8.6	14.8
2	Cyprinidae	*Mystacoleucus marginatus* (Valenciennes, 1842)	Pla kekoe, keeyorg,narm larng	17	1.2-7.8	20.4
3	Cyprinidae	*Paralaubuca typus* Bleeker, 1864	Pla Taeb, Pla Paeb kwai	1	8.9	5.9
4	Siluridae	*Micronema hexapterus* (Bleeker, 1851)	Pla Daeng, Narng	1	25.7	34.6
5	Cichlidae	*Oreochromis niloticus* (Linnaeus, 1758)	Pla nil	1	2.2	0.1
6	Soleidae	*Brachirus harmandi*(Sauvage, 1878)	Pla Pe, Pla Baimai	1	5.6	4.9
7	Tetraodontidae	*Tetraodon cambodgiensis* Chabanaud, 1923	Pla Pugpao tadaeng,Pla Pao	1	8.4	13.2
	Total 5 families	7 genera 7 species		23		93.9
		Shannon-wienner diversity index = 1.041				
Station 2 Keng mai(upstream area)						
	Family	**Scientific name**	**Local name**	**number**	**size range(cm)**	**weight (g)**
1	Cyprinidae	*Barbonymus gonionotus* (Bleeker, 1850)	Pla pak, Tapian khao	1	20.0	124.0
2	Cyprinidae	*Mystacoleucus chilopterus* Fowler, 1935	Pla kekoe, keeyorg,narm	5	7.3-9.4	19.4

			larng			
3	Cyprinidae	*Mystacoleucus marginatus* (Valenciennes, 1842)	Pla kekoe, keeyorg,narm larng	12	1.2-8.4	15.6
4	Cyprinidae	*Opsarius koratensis* (Smith, 1931)	Tapian khao	1	4.1	0.4
5	Cyprinidae	*Paralaubuca barroni* (Fowler, 1934)	Pla Taeb, Pla Paeb	3	8.1-8.9	9.2
6	Bagridae	*Hemibagrus nemurus* (Valenciennes, 1840)	Pla kot,kot lueng	1	14.6	16.5
7	Sisoridae	*Bagarius yarrelli* (Sykes, 1839)	Pla khae kwuai, khae kwai	1	15.1	20.3
8	Mastacembelidae	*Macrognathus siamensis* (Günther, 1861)	pla lod, lod jud	1	17.2	15.4
9	Mastacembelidae	*Mastacembelus favus* Hora, 1924	Pla lard,Kating lai	1	20.9	26.5
10	Channidae	*Channa gachua* (Hamilton, 1822)	Pla kor, kor gung	1	12.8	12.2
11		*Channa striata* (Bloch, 1793)	Pla kor, Chon	1	11.2	15.8
	Total 5 families	9 genera 11 species		28		275.3
		Shannon-wienner diversity index = 1.862				
Station 3 Houay Thon		(upstream area)				
	Family	Scientific name	Local name	number	size range (cm)	weight (g)
1	Cyprinidae	*Rasbora paviana* Tirant, 1885	Pla gasiew,Siew kwai Sumatra	1	4.1	1.4
2	Cyprinidae	*Hypsibarbus vernayi*(Norman, 1925)	Tapaag, Pla Pak	1	11.7	20.5
3	Cyprinidae	*Mystacoleucus marginatus* (Valenciennes, 1842)	Pla kekoe, keeyorg,narm larng	4	6.3-6.5	13.8
4	Cyprinidae	*Paralaubuca harmandi* Sauvage, 1883	Pla Taeb, Pla Paeb kwai	2	8.6-8.9	8.4
5	Bagridae	*Hemibagrus filamentus* (Fang & Chaux, 1949)	Pla kot,kot lueng	1	15.7	20.1
6	Bagridae	*Pseudomystus siamensis* (Regan, 1913)	Pla kheehia,Pla kayaeng hin	2	7.9-12.5	15.9

7	Cichlidae	*Oreochromis niloticus* (Linnaeus, 1758)	Pla nil	1	14.0	38.7
8	Tetraodontidae	*Auriglobus nefastus* (Roberts, 1982)	Pla Pao khiew, Pugpao khiew	1	5.2	4.1
	Total 4 families	8 genera 8 species		13		122.9
		Shannon-wienner diversity index = 1.925				
Station 4 Dam site area						
	Family	Scientific name	Local name	number	size range (cm)	weight (g)
1	Cyprinidae	*Hypsibarbus wetmorei* (Smith, 1931)	Tapaag, Pla Pak kum	5	6.9-11.4	35.8
2	Cyprinidae	*Mystacoleucus marginatus* (Valenciennes, 1842)	Pla kekoe, keeyorg,narm larng	10	1.7-6.9	15.8
3	Cyprinidae	*Opsarius koratensis* (Smith, 1931)	Nam Muk Korat	4	4.1-6.2	15.9
4	Cyprinidae	*Paralaubuca harmandi* Sauvage, 1883	Pla Taeb, Pla Paeb kwai	2	8.3-10.4	9.8
5	Cyprinidae	*Puntioplites proctozystron* (Bleeker, 1865)	Pla Gamarng	1	5.9	3.9
6	Cyprinidae	*Raiamas guttatus* (Day, 1870)	Pla aow, pla mak Hao	1	12.1	12.4
7	Bagridae	*Hemibagrus nemurus* (Valenciennes, 1840)	Pla kot,kot lueng	1	13.1	13.8
8	Hemiramphidae	*Dermogenys pusilla* Kuhl & van Hasselt, 1823	Pla Kem	2	3.4-6.5	0.5
9	Mastacembelidae	*Mastacembelus favus* Hora, 1924	Pla Lard, Kating lai	1	15.6	16.8
10	Soleidae	*Brachirus harmandi*(Sauvage, 1878)	Pla Pe, Pla Baimai	2	5.7-5.8	10.1
	Total 5 families	10 genera 10 species		29		134.8
		Shannon-wienner diversity index = 1.961				
Station 5 downstream area (500 m before Nam Heung confluence)						
	Family	Scientific name	Local name	number	size range (cm)	weight (g)
1	Cyprinidae	*Barbichthys laevis* (Valenciennes, 1842)	Pla harng buang	1	3.1	0.2

2		*Mystacoleucus lepturus* Huang, 1979	Pla Narn Larng Ta suy	2	3.2-3.9	0.5
3		*Paralaubuca harmandi* Sauvage, 1883	Pla Taeb, Pla Paeb kwai	4	8.1-8.9	12.6
4	Hemiramphidae	*Dermogenys pusilla* Kuhl & van Hasselt, 1823	Pla Kem	3	4.3-6.4	0.6
5	Gobiidae	*Gobiopterus chuno* (Hamilton, 1822)	Pla boo noi, Pla Boo suy	1	2.3	0.2
6		*Papuligobius ocellatus* (Fowler, 1937)	Pla Boo	1	3.7	0.4
7	Soleidae	*Brachirus harmandi*(Sauvage, 1878)	Pla Pe, Pla Baimai	2	3.9-6.7	9.1
8	Tetraodontidae	*Tetraodon suvattii* Sontirat, 1989	Pla Pak Pao	2	7.1-11.1	31.6
	Total 5 families	8 genera 8 species		16		55.2
		Shannon-wienner diversity index = 1.960				
Station 6 downstream area (Houay Mee confluence)						
	Family	Scientific name	Local name	number	size range (cm)	weight (g)
1	Notopteridae	*Chitala ornata* (Gray, 1831)	Pla tongklai, Pla Krai	1	19.2	45.8
2		*Notopterus notopterus* (Pallas, 1769)	Pla Tong, Pla Slaad	2	12.7	25.4
3	Clupeidae	*Clupeichthys aesarnensis* Wongratana, 1983	Pla Siew gaew	1	3.4	0.2
4	Cyprinidae	*Barbonymus altus*(Günther, 1868)	Pla liane fai, Pla vian fai	1	5.5	1.9
5		*Barbonymus gonionotus* (Bleeker, 1850)	Pla pak, Tapian khao	1	9.7	11.8
6		*Cyclocheilichthys furcatus* Sontirat, 1989	Pla Jok mai,	1	4.4	1.2
7		*Osteochilus lini* Fowler, 1935	Pla na mohng, Soy na mohng	5	6.2-9.4	62.5
8		*Osteochilus vittatus* (Valenciennes, 1842)	Pla Nokkhao	3	5.6-7.3	24.9
9		*Puntius brevis* (Bleeker, 1850)	Pla khao na, Tapian bung	1	4.7	1.9
10		*Sikukia gudgeri* (Smith, 1934)	Pla Makmung, Nam Fai	9	2.0-2.6	10.2
11	Nandidae	*Pristolepis fasciata* (Bleeker, 1851)	Pla kaa, Pla Mor Chang yiab	5	5.3-8.4	30.9
12	Osphronemidae	*Trichogaster microlepis* (Günther, 1861)	Pla Gadued, Gradee narng	2	8.3-8.6	12.6

13		*Trichogaster trichopterus* (Pallas, 1770)	Gadee kwai, gradee mor	8	6.0-8.7	59.4
	Total 5 families	10 genera 13 species		40		288.7
		Shannon-wienner diversity index = 2.225				

Matrix 2 – Results of wet season sampling

Fish species composition and their quantity at six sampling stations in the Mekong River and the Mekong Sanakham HPP area
July ,19-22,2011 (Wet Season)
(sampling area = 200 sq.m)

Station 1 Houay Ting(upstream area)

	Family	Scientific name	Local name	number	size range (cm)	weight (g)
1	Cyprinidae	Cyclocheilicthys armatus (Cuv. & Val., 1842)	Pla Saitan	2	3.2-4.3	2.1
2		Cyclocheilicthys apogon (Cuv. & Val., 1842)	Pla Saitan tadaeng	2	3.5-4.0	1.1
3		*Hypsibarbus vernayi*(Norman, 1925)	Tapaag, Pla Pak	3	6.7-12.9	32
4		*Mystacoleucus marginatus* (Valenciennes, 1842)	Pla kekoe, keeyorg,narm larng	8	3.0-5.7	7.1
5		*Osteochilus hasselti* (Cuv.&Val.,1842)	Pa Eethai, Sroi nokkhao,keekhom	14	6.0-8.5	50
6		*Oxygaster pointoni* (Fowler, 1934)	Pa Taeb, Pla Paeb	1	3.5	2.6
7		*Paralaubuca typus* Bleeker, 1864	Pla Taeb, Pla Paeb kwai	2	5.6-6.3	4.5
8		*Raiamus guttatus* (Day,1869)	Pa Ao, Nang Ao	1	5.9	10.4
9		*Rasbora argyrotaenia (Bleeker, 1850)*	Siew Kwai	3	2.3-5.7	10.5
10		*Rasbora paviei* (Tirant, 1885)	Pa Gasiew, Siew thaeb	19	2.5-4.0	5.6
11		*Rasbora aurotaenia* Tirant,1885	Pa Gasiew, Siew thaeb	2	2.2-3.2	0.9
12	Cichlidae	*Oreochromis niloticus* (Linnaeus, 1758)	Pla nil	1	13.5	5.7
13	Gobiidae	*Gobiopterus chuno* (Hamilton, 1822)	Pla boo noi, Pla Boo suy	3	0.2-0.3	0.2
	Total 3 families	10 genera 13 species		58		132.7
		Shannon-wienner diversity index = 2.062				

Station 2 Keng mai(upstream area)

	Family	Scientific name	Local name	number	size range (cm)	weight (g)
1	Cyprinidae	*Barbonymus gonionotus* (Bleeker, 1850)	Pla pak, Tapian khao	1	16.0	140.0
2		*Mystacoleucus chilopterus* Fowler, 1935	Pla kekoe, keeyorg,narm larng	5	6.5-8.7	9.9
3		*Mystacoleucus marginatus* (Valenciennes, 1842)	Pla kekoe, keeyorg,narm larng	6	2.3-5.6	14.6
4		*Osteochilus hasselti* (Cuv.&Val.,1842)	Pa Eethai, Sroi nokkhao,keekhom	6	6.2-7.1	14
	Total families	3 genera 4 species		18		178.5
		Shannon-wienner diversity index = 1.248				
Station 3 Houay Thon		(upstream area)				
	Family	Scientific name	Local name	number	size range (cm)	weight (g)
1	Cyprinidae	*Rasbora paviei (*Tirant, 1885)	Pla gasiew,Siew kwai sumatra	1	4.1	1.4
2		*Mystacoleucus marginatus* (Valenciennes, 1842)	Pla kekoe, keeyorg,narm larng	3	5.5-6.0	5.8
3		*Paralaubuca harmandi* Sauvage, 1883	Pla Taeb, Pla Paeb kwai	1	8.8	11.5
4		*Cyclocheilicthys enoplos* Bleeker, 1850	Pa Jok	1	5.8	1
5	Ambassidae	*Parambassis siamensis* (Fowler,1937)	Pa karbkong, pankaew	1	2.5	0.3
6	Sisoridae	*Bagarius yarrelli* (Sykes, 1839)	Pla khae kwuai, khae kwai	1	6	1.6
	Total 3 families	6 genera 6 species		8		21.6
		Shannon-wienner diversity index = 1.667				
Station 4 Dam site area						
	Family	Scientific name	Local name	number	size range (cm)	weight (g)
1	Cyprinidae	*Raiamas guttatus* (Day, 1870)	Pla aow, pla mak Hao	1	9.5	5.5

2		*Osteochilus hasselti* (Cuv.&Val.,1842)	Pa Eethai, Sroi nokkhao,keekhom	6	4.0-5.5	3.6
3		*Henicorhynchus siamensis* (Sauvage,1881)	Pa soi khao	8	2.3-3.1	3.6
4	Pangasiidae	*Pteropangasius pleurotaenia (Sauvage,1878)*	Pa Yorn peek,Sangawad thong kom	2	9.6-10.5	7.7
5	Siluridae	*Krytopterus cryptopterus* (Bleeker,1851)	Pa ka kai	1	11.2	6.5
	Total 3 families	5 genera 5 species		18		26.9
		Shannon-wienner diversity index = 1.291				
Station 5 downstream area (Nam Heung confluence)						
	Family	Scientific name	Local name	number	size range (cm)	weight (g)
1	Cyprinidae	*Amblyrhynchichthys truncatus* (Bleeker,1851)	Pa Ta min	1	3.1	0.2
2		*Sikukia gudgeri* (Smith 1934)	Nam Fai	1	6.1	3.5
3		*Puntioplites proctozysron* (Bleeker, 1865)	Ka mang,	2	3.2-3.9	0.5
4		*Paralaubuca harmandi* Sauvage, 1883	Pla Taeb, Pla Paeb kwai	4	8.1-8.9	12.6
5	Soleidae	*Brachirus harmandi*(Sauvage, 1878)	Pla Pe, Pla Baimai	2	3.9-6.7	9.1
6	Pangasiidae	*Pteropangasius pleurotaenia* (Sauvage,1878)	Pa Yorn peek,Sangawad thong kom	2	9.6-10.5	7.7
7		*Pteropangasius micronema* Bleeker, 1851	Yorn	3	8.5-10.6	11.5
	Total 3 families	6 genera 7 species		15		45.1
		Shannon-wienner diversity index = 1.841				
Station 6 downstream area (Houay Mee confluence)						
	Family	Scientific name	Local name	number	size range (cm)	weight (g)
1	Clupeidae	*Clupeichthys aesarnensis* Wongratana, 1983	Pla Siew gaew	3	3.1-3.3	0.4
2	Cyprinidae	*Barbonymus altus*(Günther, 1868)	Pla liane fai, Pla vian fai	1	6.1	3.9

3		*Barbonymus gonionotus* (Bleeker, 1850)	Pla pak, Tapian khao	1	12.9	21.2
4		Cyclocheilicthys armatus (Cuv. & Val., 1842)	Pla Saitan	3	3.1-4.3	3.5
5		Cyclocheilicthys apogon (Cuv. & Val., 1842)	Pla Saitan tadaeng	1	3.6	1.2
6		*Labiobarbus lineatus* (Sauvage, 1878)	Kee larm, Sroi	5	1.5-3.6	6
7		*Osteochilus hasselti* (Cuv.&Val.,1842)	Pa Eethai, Sroi nokkhao,keekhom	5	5.5-6.2	18
8		*Puntius brevis* (Bleeker, 1850)	Pla khao na, Tapian bung	2	5.1-5.5	2.3
9		*Sikukia gudgeri* (Smith, 1934)	Pla Makmung, Nam Fai	1	2.2	0.8
10		*Thynnichthys thynnoides* (Bleeker,1852)	Pa Goom, Sroi kledthee	1	8	4.2
	Total 2 families	8 genera 10 species		23		61.5
		Shannon-wienner diversity index = 2.088				

3.2.2 Present use of the resources

During the present study, there were very few fishermen found along the Mekong River at Sanakham. Fishing is only a part time activity. Three main fishing areas were noted: Keng Mai at the rapids area; the mouth of NamHoung River; the river confluence with the Nam Mee.

At the mouth of the NamMee River, fishing gear being used including bamboo scoop and submerged traps. Fish shelters are created by placing branches and shrubs in the near shore and the fish are removed at the evening.

In general, fishery activity from Sanakham to the upstream at Ban Houay Ting is less prevalent, the main reason being the strong currents in the Mekong. At Sanakham town, only a few people fish in the Mekong River, while the majority fish in smaller tributaries such as Nam Heung and Houay Mee (tributaries downstream of proposed Mekong Sanakham HPP main-dam site) where fish are easier to catch. Villagers in this area fish for subsistence and a small amount are sold in local markets.

Subsistence fisheries are a much more important activity than commercial fisheries in the Mekong Sanakham HPP area. Near rivers and other water bodies subsistence fishing usually focuses on the smaller species; occasionally large fish are caught and they are usually not consumed locally but sold to restaurants at Sanakham town or sent to Chiang Khan in Thailand. Wild fish generally command a higher price than cultured fish in the market.

3.2.3 Current management and protection programs

Most fishermen use nets (for Cyprinids) and hooks (for catfishes), but the illegal use of electrocution (using 12 Volt batteries) was also found. Various techniques are used for collecting the fish such as setting up a shelter and after a week placing a net in the shelter to harvest the fish. At downstream areas of the Mekong River at the Houay Mee confluence , short gillnets (3-5 m long) near shores are used extensively, particularly on the right bank of Mekong River.

There are currently no management and protection programs for fishery resources in

this area.

3.2.4 Commercially or socially important species and habitat

Various stream flow types (riffles, rapids and runs) are characteristic of Mekong River. River morphology, such as narrow, mid-stream rocks and islands, constitute important habitats and contribute to the fish diversity of the Mekong. Fish typically migrate upstream to spawning grounds when the water levels start to increase, spawning while the water level is still increasing to ensure that the current brings eggs and larvae into nursery areas on the flood plain further downstream.

Micronema apogon, M. bleekeri, and M. hexapterus are three species of the genus Micronema and are found mainly in large rivers with turbid water and adjacent streams; also they are found in lakes and impoundments. These fish are believed to spawn using flood plain lateral migration from the Mekong River. These three species are important, high value fish in all the fisheries throughout their range. Fish samples were observed in the upstream area, Houay Thon up to Houay Ting of the study area.

3.2.5 Rare, endangered or protected species and habitats

Probarbus jullieni (Jullien's Golden Carp) is included in the IUCN List of Endangered Animals. This is one of the most esteemed species of the Mekong. Several specific spawning grounds have been identified in Mekong River in Northern Lao PDR and Loei (Thailand) at a site named Bung Ghang, Amphoe Sang Khom, Nong Khai province. Large mature adults migrate upstream to their spawning ground, where they spawn from December-January. Eggs, larvae and small juveniles drift downstream to their nursery habitats, which are shallow, sandy reaches of the river. These fish are found in the project area at the Keng mai rapids in the project area, with a size of up to 165 cm. This fish is sold to restaurants at a high price when caught.

Below is a list of the 30 migratory species which could exist in the project area (Table 3.2-1).

Table 3.2-1 Length-size of the 30 Mekong Fish Species of Environmental Migration Cues

Scientific Name	**Family**	**Common name**	**Maximum length** *(cm)*	**Length at maturity** *(cm)*

Pangasius polyuranodon	Pangasiidae	Shark catfishes	80	44
Paralaubuca typus		Minnows or carps	18	11.8
Cyclocheilichthys enoplos Cyprinidae	Cyprinidae	Minnows or carps	74	41.1
Tenulosa thibaudeaui	Cyprinidae	Herrings,shads, sardines	30	18.5
Bangana behri	Cyprinidae	Minnows or carps	60	34.1
Barbonymus gonionotus	Cyprinidae	Minnows or carps	40.5	24.1
Hemisilurus mekongensis	Siluridae	Sheatfishes	80	44
Labeo chrysophekadion	Cyprinidae	Minnows or carps	90	48.8
Mekongina erythrospila	Cyprinidae	Minnows or carps	45	26.5
Micronema bleekeri	Siluridae	Sheatfishes	60	34.1
Pangasianodon gigas	Pangasiidae	Shark catfishes	300	141.4
Pangasius macronema	Pangasiidae	Shark catfishes	30	18.5
Botia modesta	Cobitidae	loaches	25	15.7
Chitala blanchi	Notopteridae	Featherbacks or knifefishes	120	62.9
Cyprinus carpio carpio	Cyprinidae	Minnows or carps	120	75.2
Hemibagrus filamentus	Bagridae	Bagrid catfishes	50	29
Lycothrissa crocodilus	Engraulidae	Anchovies	30	18.5
Macrochirichthys macrochirus	Cyprinidae	Minnows or carps	100	53.5
Osphronemus exodon	Osphronemidae	Gouramies	60	34.1
Pangasius bocourti	Pangasiidae	Shark catfishes	120	62.9
Pangasius conchophilus	Pangasiidae	Shark catfishes	120	62.9
Pangasianodon hypophthalmus	Pangasiidae	Shark catfishes	130	67.5
Pangasius krempfi	Pangasiidae	Shark catfishes	120	62.9
Pangasius kunyit	Pangasiidae	Shark catfishes	70.2	39.2
Pangasius larnaudii	Pangasiidae	Shark catfishes	130	67.5
Pangasius pleurotaenia	Pangasiidae	Shark catfishes	35	21.2

Pangasius sanitwongsei	Pangasiidae	Shark catfishes	300	141.4
Parachela oxygastroides	Cyprinidae	Minnows or carps	20	12.9
Pristolepis fasciata	Nandidae	Asian leaffishes	20	12.9
Wallago leerii	Siluridae	Sheatfishes	180	90

Source: MRC Technical Paper No. 14. 2006

3.2.7 Fish Migration of the Lower Mekong River Basin

(1) fish groups to their ecology and migration patterns

In Mekong River, the fishes may be divided into three categories on the basis of their living habits and characteristics:

a) "Black fish": The fishes in this category like the habitats with slow flow (such as swamp and lake),but can also get adapted to relatively poor environment (such as low dissolved oxygen). The construction hydroelectric power plant will impose less impact on these fishes, and they can also reproduce in large quantities in reservoir environment.

b) "White fish": The fishes in this category have relatively strong migratory characteristic, and most of the time in their life cycle is spent for migration. These fishes carry out long-distance migration (up to several thousands of kilometers), and are very sensitive to change in environmental conditions. If the flow state inhabitant is changed from flowing state to static state, these fishes will be affected to a relatively great extent. The construction of dam in mainstream or tributary will block up their migratory path.

c) "Grey fish": The fishes in this category have a part of characteristics of the fishes in both categories mentioned above(For example, some fishes migrate, and some fishes live in static water).The construction of hydroelectric power plant will impose certain impact on these fishes.

There are 150 kinds of "white fishes" and long-distance migratory fishes, among which 37 kinds are listed by LMB as important fishes, and 34 kinds are recorded as living in the upper LMB where Sanakham section is located. According to the survey on catch, the main proportion is as follows:

Cyprinidae accounts for about 40% in the catch; Bagridae accounts for about 10% in the catch; Siluridae accounts for about 10% in the catch; Salmonidae accounts for about 10% in the catch.

In the course of survey, some fishes such as Botia and Pangasius have been verified. The body weight of Pangasius caught is up to 40kg. At present, maybe it is the largest

fish under Silurus genus. It was ever caught ten years ago, but has not been caught recently. One of its affinis, namely Siluriformes, can be occasionally caught.

In Sanakham section, the exotic species mainly include Cyprinidae, and the fishes in Crenicichla family (mainly including common carp, tilapia, tilapia nilotica and Indian carp). The common carp and tilapia account for 20%; the weight of common carp can reach up to about 5kg, and the tilapia is smaller. Except for the above-mentioned exotic species, no other exotic species has been found.

(2) Fish Migration

The migration carried out by the fishes in Mekong River mainly includes spawning migration and feeding migration. The fishes migrate to upper river for spawning, and then the fish eggs and juvenile fishes drift along the river to flood plain, where they seek for food and grow. When the rainy season begins, the fishes start the feeding migration to fertile flood plain.As for most of fishes, the feeding migration and spawning migration are carried out simultaneously. The upstream spawning migration is mainly carried out by adult fishes, and the downstream feeding migration is mainly carried out by juvenile fishes and those adult fishes returning from upstream spawning migration.

The seasonal migration is necessary for maintaining the health of fish population in Mekong River. Not all fishes need migration. In order to obtain the important habitat, the migratory fishes will seasonally migrate for certain distance, so as to complete the life cycle. In the Mekong basin, the migratory distance of some kinds of fishes is relatively short (no more than 100m), but some kinds of fishes have to migrate for 1,000km or longer distance so as to complete their life cycle.

The lower Mekong basin has been defined as 3 main migration systems, namely:

1) Lower Mekong migration system from estuary to Khone Falls in southern portion of Laos.

2) Middle Mekong migration system from Khone Falls to Vientiane. The characteristic of this system is large tributary and wetland.

3) Upper Mekong migration system from Vientiane to China. It is the least abundant among these three systems.

Figure 3.2-1 Main Fish Migratory Systems in Lower Mekong Basin

It is likely that not all types of migration are included, but most are included. (Protection on migration of wild animals as defined in international convention, namely CMS Convention) Without the migration ability, many animals, including the fishes of which the population quantity reduces, will gradually disappear biologically or geographically, or gradually become extinct.

The migration of fishes in Mekong basin is carried out in light of change of season in every year. The upstream migration of fishes in Sanakham area occurs in April and May when the rainy season comes. The migration down the stream occurs at the end of rainy season, and the fishes migrate to deep-water shelter and wait for new start there. Every migration is very necessary for maintaining the health of fish population.

Most of the migratory fishes in Mekong River migrate to the specific river section in

Mekong basin and then spawn. Many fishes in Mekong River spawn near the water surface, and the fish eggs immediately combine with the semen from male fishes. The fertilized eggs drift down the stream, and under the external environmental conditions (such as water temperature), the hatch spends about 72 to 96 hours. The flood plain is not in Sanakham area, and there are many tributaries and brooks which can provide the important habitats for the fishes to spawn. The figure below shows that, Sanakham is located in upper Mekong migration system, and the Pak Lay-Luang Prabang section is an important water area for spawning of fishes.

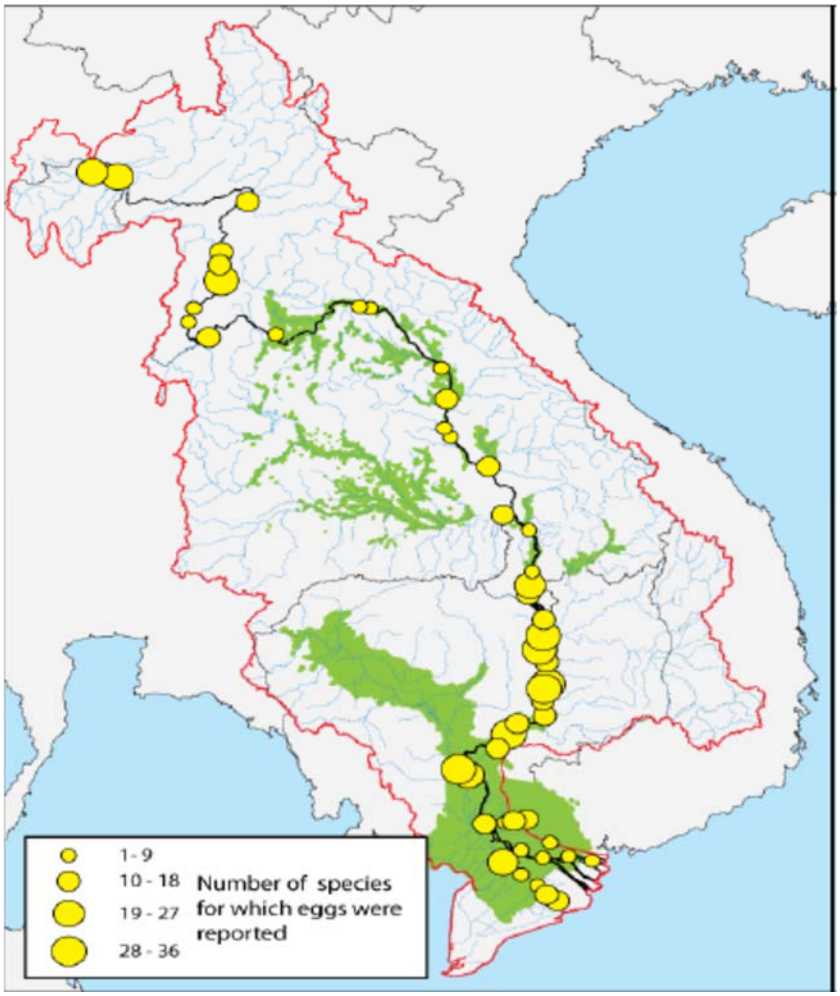

Figure 3.2-2 Spawning Grounds in Mainstream of Mekong River

Most of the adult fishes in Mekong River spawn in this special area until the eggs hatch out, and the seedlings are close to the nursery areas (flood plain or deep-water habitats in the river section from Sanakham to Vientiane) with rich food.

In such places, the seedlings grow and develop. After the spawning period in rainy season, many seedlings return to the mainstream, and on the basis of different kinds and environment conditions, they start the periodic migration. The reproduction of some

fishes in Mekong River is complicated, and involves many forms.

3.3 Impact on Fish Ecology

With respect to the impact by construction of dam on fishes in Mekong River, in the EIA report for Pak Beng Hydroelectric Power Plants in upper Mekong River, the impact is evaluated as follows:

About 5%-10% of species is in imminent danger, about 15%-25% of economically endangered speciesis close to extinction, about 30%-40% of economically endangered speciesis dying out, and 1%-3% of rare species may gradually become extinct owing to the construction of the first dam in upper Mekong River.

The construction of Sanakham Hydroelectric Power Project will cause certain impacts on the aquatic ecological system, and one of the main impacts is the impact on fishes. On the basis of the previous evaluation on fishery in Mekong River, it is determined that the dam will cause impact on fish resources in Mekong River, but the extent of such impact has to be further assessed.

The impacts imposed by construction of dam and reservoir on fishery main include: the impact on spawning grounds, feeding grounds and shelter by reservoir-caused submergence; the impact by fluctuation of water level; the impact by change inflow rate; the impact by change in water quality; the impact on fish migration by dam-caused blockage.

In light of the results of previous assessment of environmental impacts caused by construction of run-of-the-river power plant on Mekong River, the impacts by Sanakham (Sanakham) Hydroelectric Power Project on fish resources are analyzed as follows:

3.3.1 Impact on Fishes by Dam-caused Blockage

After this Project is constructed, the dam will divide the river course into two sections, namely upper reach of dam and lower reach of dam, which means that the habitats for fishes will be broken and the gene exchange between upper reach of dam and lower reach of dam will be prevented. In the long term, this will reduce the genetic diversity

of fishes, affect the viability of fishes, and finally reduce the quantity of fish population.

Impact by dam-caused blockage on migratory fishes: Many fishes in Mekong River will, as reminded by the subtle environmental information such as water temperature, water depth and water turbidity, migrate on the basis of the change in season. The migration includes the migration from one mainstream to another mainstream, the migration from mainstream in dry season to tributary and wetland in rainy season, and the migration from one tributary to another tributary. The construction of dam will prevent the migratory fishes from arriving at their spawning grounds, so that the fish resources will reduce.

According to the introduction of present status of fish ecology, Sanakham is located in the upper migratory system of Mekong River, and the construction of dam there will block up the migratory path of migratory fishes. Therefore, it is necessary to take reasonable remedial measures, such as the construction of fishway.

3.3.2 Impact of Sanakham HPP on long distance migratory fishes

According to survey data available, there are around 150 species of "white fish" and long distance migratory fishes, of which, 37 species of fish are classified as precious ones by lower Mekong basin and 34 species of fish are recorded by upper Mekong basin. As indicated by fish catching investigation, family Cyprinidae accounts for 40%, family Siluridae 30%, family Bagridae 15%, family Salmonidae 10% and others 5% of the total catch.

In the Sanakham river reaches, there are the Pangasius gigas which migrate for long distance and Pangasianodon hypophthalmus, Pangasius bocourti, Pangasius conchophilus, Pangasius larnaudii, Pangasius sanitwongsei and Bagarius yarrelli Sykes, which migrate for short distance.

The construction and operation of the project will not only obstruct migration of long distance migratory fishes but affect their upbound spawning, downstream movement and gene exchange between upstream and downstream fishes. In the long run, the genetic diversity of fishes would be decreased. In the further works, radio telemetry and marked recapture will be applied to accurately determine species and route of long

distance migratory fishes and provide concrete help for fish migration.

In accordance with sampling survey of fish eggs and planktons during environmental impact evaluation, the spawning period and breeding period of fishes in the Mekong River occur mainly in rainy season, i.e. from April to October every year.

Sampling for fish eggs and planktons

3.3.3 Damage to fish habitats after dam construction

Sanakham HPP is of low-dam run-of-river power station with low head. Its operation has an insignificant impact either on the hydrological conditions of the Mekong River or on the ecological conditions of the downstream reaches. The short distance of reservoir backwater and small area of reservoir inundation scarcely affect the habitats in the reservoir area. On the contrary, the increased water area would create new habitats. In conclusion, the project is a low-dam run-of-river hydropower station based on upstream inflow and no regulation is required for runoff in this case, so neither ecological environment of the upstream and downstream reaches nor habitats of the reservoir area will be affected by the operation of the power station, besides, new areas of spawning will be created for fishes.

3.3.4 Impact by Reservoir Submergence

Mekong River has rich fish resources, but the water accumulation in reservoir will submerge certain spawning grounds, feeding ground sand shelters. The submergence by reservoir and the change in water level will great affect the spawning grounds (especially the areas connected with island, the spawning grounds near flat shore, and

the nursery areas near main river course) and the shelters where the seedling and adult fishes may evade natural enemy (wetland).

The submergence will also disturb the original river course -The natural law for generation of nutritive substances in flood plain will reduce the productivity of aquatic ecological system. Mekong River is a river with relatively great hydrological change in dry season and wet season. The river in flood plain relies to a great extent on the nutritive substances released by plant rotten in flood plain, so as to maintain the agricultural production and food chain in aquatic ecological system.

3.3.5 Impact by Reservoir Operation

The physiological activities of many fishes are relatively sensitive to environmental change, some important fishes with economic value are relatively sensitive to the change in water depth, water temperature, turbidity and flow velocity, and it is likely that the change in some environmental factors are the inducement for migration. In the reservoir and lower reach, such factors will change owing to the construction of hydroelectric power plant.

The maximum height of dam in Sanakham Hydroelectric Power Plant will be 56.2m, the runoff operation mode will be adopted, and the normal water level will be 220m. These changes may affect some environmentally-sensitive fishes, and their quantity and distribution will change.

During the operation period of reservoir, the sediment accumulation at the upper reach of dam and the sediment entrainment at lower reach of dam, the reduction of broken wood chips, and the change in hydrochemical conditions and flow state will also reduce the habitats in the river.

The direct and indirect actions of water turbine will also increase the mortality of fishes.

3.3.6 Impact on Fish Population

After the power plant is constructed, the flow velocity in reservoir will reduce, the fishes which are adapted to living in river will gradually migrate to upper river section and tributary water area, and the water area in reservoir will be occupied by the fishes

which are adapted to living in static water. Therefore, the construction of reservoir will impose relatively obvious impact on the fishes which are fond of impetuous torrent.

Since the flow velocity in reservoir is reduced, some juvenile fishes will have to pass the slowly-flowing backwater area, so that the time spent for reaching lower reach will increase (because the juvenile fishes can't swim and have to drift along the water flow), which will be unfavorable for growth of juvenile fishes and will increase the mortality of juvenile fishes.

Since the migratory fishes are blocked, the structure of fish population will change. Generally, the construction of power plant will reduce the activity space for migratory fishes, some space will be vacated, the such small habitats vacated by migratory fishes will be occupied by some small fishes, non-migratory fishes and predatory fishes, so that the structure and distribution of fishes will change.

The KhoneFalls and Tonle SapLakein the lower Mekong River are the river section where the spawning grounds and migratory paths are concentrated, and its sensitivity is relatively high. In comparison, in the upper Mekong River, the kinds and quantity of migratory fishes are less, so that the sensitivity is relatively low.

3.3.7 Impact on Rare Aquatic Animals

Mekong River is abundant in aquatic organisms, there are some rare and endangered species, and the construction of power plant will impose great impact on habitats of such species. If no effective protective measures are taken, these fishes will become more endangered. In addition, owing to the change in aquatic environmental conditions, the likelihood that the rare and endangered species appear will also reduce accordingly.

3.3.8 Impact on Fishery

The fish resource is the important protein source for residents on both banks of Mekong River, accounting for about 50%-80% of food protein. After the power plant is constructed, the hydrographic conditions in reservoir will change, the flow velocity will reduce, the composition of fishes in reservoir will change, and it is expected that the residents on both banks of Mekong River and the aquaculture at lower reach will be

affected to a certain extent.

3.4 Fish Protection Measures

The impact by the construction of Sanakham Hydroelectric Power Plant on fish resources is one of the issues to which the Laos government pays much attention. Several hydroelectric power plants have been planned for Mekong River, and 5 cascades have been planned within the territory of Laos. In order to maintain the diversity of aquatic organisms and the resources in Mekong River, it is necessary to comprehensively and systematically study the fish passage facilities. In the main works of Sanakham Hydroelectric Power Plant, it is necessary to research into the upstream measures and downstream measures for fishes. The upstream measures and downstream measures of fishes mainly include the following measures.

3.4.1 Upstream Measures of Fishes

(1) Fishway

The fishway can resume the connectivity of river course, and provide the path for fishes to migrate. At home and abroad, most of the fishways are constructed in power plants where the water head is low and the amplitude of change in water level is relatively low. Through the fishways, the fishes can continuously pass the dam by themselves without disturbance or injury, a few individuals can also pass the dam downstream, and few human factors are involved. Fishways have been widely applied in power plants with low water head.

(2) Fish Lock

The operating principle and operating mode of fish lock are similar to those of navigation lock. In the fish lock, the fishes pass the dam as the water level rises. The fish lock is also called as hydraulic fish hoister, and is equipped with fish blocking, fish luring and fish guiding facilities if necessary. The fish lock can’t achieve the continuous fish passage, so that it is only suitable for the hydropower projects where the quantity of dam-passing fishes is not high. Electrical and mechanical equipment is required, and the repair expenses are high.

(3) Fish Hoister

A fish hoister is mainly composed of fish collecting slot, fish box and elevator. The fish box serves as conveyor, and is equipped with a door which can be closed. When it is at the lower position, the fish box will be immersed to the bottom, and the fishes will be attracted into the fish collecting slot by using water flow. In the fish collecting slot, the door which can be moved, opened and closed will push the fishes into the fish collecting box, the lower door of the elevator will be closed, and the fishes in fish collecting box will be "caught", be transported to the top of dam with pulley (track), and then be transported to the reservoir through a channel.

(4) Fish Collecting &Transporting System

The fish collecting & transporting system is mainly composed of fish collecting facility and transporting facility. The fishes will be collected in migratory path at lower reach of the dam by using the specially-designed fish collecting facility, be placed in the fish collecting box, and then be transported to the fish transporting boat; thereafter, the fish transporting boat will transport the fishes to the upper reach of dam, so as to complete the upstream migration of fishes.

3.4.2 Downstream Measures of Fishes

(1) Fishway

The fishway can resume the connectivity of river, connect the upper reach and lower reach, and provide the migratory path for fishes. In addition, the fishway can also help the fishes to move downstream, and some fishes can arrive at lower water area through fishway.

(2) Water Turbine Unit

The water turbine unit in Sanakham Hydroelectric Power Plant will be the bulb-type water turbine, of which the blades are relatively large. Sanakham Power Plant will be a run-of-the-river power plant. With the low water head and the low water turbine speed in the course of power generation, the water turbine unit will be an ecologically-friendly unit, so that the fishes can move downstream from water intake and enter the downstream river via the water turbine unit.

(3) Flood Gate

According to the layout of Sanakham Hydroelectric Power Plant, there will be 14 flood gates on left bank and 5 flood &sediment discharging gates on right bank. During the flood-discharging period in rainy season and the flood &sediment discharging period of power plant, the difference of water level between upper reach and lower reach will not be large, and the downstream fishes can achieve the downstream passage through floods gate and sediment discharging gates.

3.5 Proposing the target of passing fish

3.5.1 Determine the target fish

The *Fish Migrations in the Mekong River Basin* issued by MRC (MRC) reveals that: there are more than 1,300 kinds of fishes in Mekong basin, among which 233 kinds under 55 families are commonly found in mainstream, flood plain and estuary.

It is pointed out in the NCG's Final EIA Report that the migratory path for fishes in Mekong River may be divided into three sections: the lower section is from marine outfall to KhoneFalls; the midstream section is from KhoneFalls to Vientiane; the upper section is from Vientiane to China. This route involves the least diversity of species. The Sanakham river section belongs to upper migratory path, and the species diversity is not as high as that in middle and lower Mekong River. Among all kinds of fishes in Mekong River, 37 kinds are listed as major species, and 34 kinds appear in Sanakham river section. The main and important fish families in Sanakham are as follows: *Cyprinidae* (accounting for about 40% in the catch), *Bagridae (*accounting for about 10% of catch), *Siluridae (*accounting for about 10% of catch) and *Pangasidae (*accounting for about 10% of catch).

The *Fish Migrations in the Mekong River Basin survey* issued by MRC in 2003 reveals that, in the Sanakham river section, there are the *Pangasius gigas* which migrate for long distance migration, and the *Pangasianodon hypophthalmus*, *Pangasius bocourti*, *Pangasius conchophilus*, *Pangasius larnaudii*, *Pangasius sanitwongsei* and *Bagarius yarrelli Sykes* which migrate for short distance. The short-distance migratory fishes

belong to *Siluriformes*, and most of such fishes migrate upwards before the beginning of rainy season. The fishes in upper Mekong River migrate upwards from the boundary river section at the lower reach of Vientiane and between Thailand and Laos to the mainstream of Mekong River at the boundary of Laos, Myanmar and Thailand, and spawn during the period from May to August; the fish eggs hatch out after drifting down the river for several hundreds of kilometers. Generally, these fishes can grow to about 1.5m, and their main food is plant fruit, zooplankton and algae. In the EIA Report (NCG 2014), it is pointed out that, there is the IUCN endangered fish *Probarbus jullien* in Sanakham river section.

Therefore, the main fish passage objects of Sanakham Hydroelectric Power Plant are: *Pangasius gigas*, *Cirrhinus microlepsis*, *Wallago attu*, *Pangasianodon hypophthalmus*, *Pangasius bocourti*, *Pangasius conchophilus*, *Pangasius larnaudii*, *Pangasius sanitwongsei*, *Bagarius yarrelli Sykes*, and *Probarbus jullien*. The fish passage objects mainly include the long-distance migratory fishes and short-distance migratory fishes. With respect to quantity, on the basis of actual situation of resources, it shall be ensured that most of fishes can pass the dam.

3.5.2 Passing fish size

According to the investigation on fish implemented during dry season of 2010 and rainy season of 2011 indicated in ESIA report for Sanahkam HPP, the longest fish among the catch was *micronema hexapterus*, with the body length of 25.7 cm. On the other hand, according to the data recorded by Mekong River Commission (MRC), *Pangasius gigas* and *Pangasius sanitwongsei* are the longest among the main fishes passing the structures of Sanahkam HPP. The longest body length is about 300 cm with the average body length in mature stage of 140 cm. It may have relationship with the sampling time and methods. It is abundant in the downstream of Mekong river from the survey data, which is possible that some fish may swim upstream to the damsite in flood season. So it is necessary to consider the big individuals passing the fishway.

There are 15 kinds of fish, whose length are larger than 50 cm, in which 8 kinds belong to Siluriformes, 4 kinds are Cypriniformes, the left three are Synbranchiformes,

Osteoglossiformes and Perciformes respectively. The longest species are *Pangasius gigas* and *Pangasius sanitwongsei,* which the biggest one is longer than 300cm according to the Research by MRC. It is not suitable to let it pass, but the fishway can make sure the most part of mature ones can pass so as to solve the breeding problem. It has been sexual mature when its length is nearly 50cm, even to the *Pangasius gigas* and *Pangasius sanitwongsei* which are the biggest fish in freshwater on the basis of the historical data. So it is suitable to determine the passing fish size as 50cm- 60cm in the process of fishway design.

3.5.3 Quantity of passing fish per year

It is big difference between the flood and dry season on the fish size and quantity because of the big difference in flood and dry season climate in Mekong River. The passing activities of fish main happen in the breeding season. Although it is different months for fishes, it is relative concentrated. So it is considered the amount in peak time as the quantity of target fish.

The passing rate of passing fish will be more that 95% of target fishes, considering 7 kinds of target fish species at least, which the average one is nearly 500g-1000g, and 1000 fishes per species according to the catches in the survey. And the same time, other kinds of fish can pass the fishway more or less. So it can be calculated that the quantity of passing target fishes per year is more than 3.5 tons.

3.5.4 Season of passing fish

The upstream migration by the fishes in Sanakham section of Mekong River occurs when the rainy season comes. In other words, in April or May every year, the fishes start the migration, and it ends in September or October. Therefore, the main fish passage season for fishway in Sanakham Hydroelectric Power Plant is from April to October every year.

4 BRIEF INTRODUCTION TO THE FISH PASSAGE FACILITIES

4.1 Origin and history of fish passage facilities

By using the rheotropism of fishes, the so-called fish passage facilities generate at the fish inlet a water flow of which the velocity is higher than surrounding flow, so as to attract the fish. Whether the fishes can react to the flow velocity in fish inlet and whether the fishes can overcome the flow velocity in fish inlet decide the effect of fish passage facilities.

The early fish passage facility was the pool-type skewed slot excavated in rock and the migratory fishes could move upwards step by step, so that it is called as fish ladder, and maybe it is the embryonic form of fishway. Afterwards, the wooden fish ladder prevailed, which was equipped with internal division plate so as to reduce the flow velocity. Most of the fish passage facilities constructed over recent years are of reinforced concrete structure.

In Europe, the fishway was firstly constructed about more than 300 years ago. In 1662, Bearn, a province in southwestern portion of France, has every promulgated the regulations, requiring the construction of upstream & downstream passage for fishes on dams and weirs. Some simple fishways had been constructed at that time. During the period from the end of 19th century to the beginning of 20th century, Landmark, a Norwegian, and Denil, a Belgian, carried out long-term study on substances used to increase the roughness of skewed slot, and the Denilfish ladder has been applied till now. In 1938, the first large-scale modernized fish ladder with fish collecting system in the world was constructed on Bonneville Dam in USA. Thereafter, the fish passage facilities including fish hoister, fish lock and fish collecting boat emerged in various countries successively. According to incomplete statistics, by the beginning of 1960s, more than 200 fish passage facilities has been constructed in USA and Canada, more than 100 in Western Europe, and more than 18 in former Soviet Union. There were 67 fish passage facilities Japan in 1933. At the end of last century, the number of fishways

was increased obviously, and there were near 400 fishways in North America and more than 1,400 in Japan. The highest fishway and the longest fishway were Beicha fishway (hoisting height: 60m)and Pardon fishway (total length: 4,800m) in USA.

4.2 Types And Characteristics of Fish Passage Facilities

The fish passage facilities constructed on dams fall into the following types, namely fishway, bypass watercourse with natural features, fish lock, fish hoister, fish collecting &transporting boat, and special fishway. ON the basis of structural type, the fishways fall into pool-type fishway and Daniel fishway. The selection of appropriate fishway depends on kinds of fishes, hydraulic conditions, water head, expenses and other factors. The key factors for success of fishway not only include the requirement that the type and designed parameters of selected fishway must be suitable for site and task, but also include the location and water consumption. The fish passage facilities are briefly introduced as follows:

(1) Pool-type Fishway

The pool-type fishway is the most common type of fishway, of which the operating principle is as follows: The height which is to be overcome is divided into several small drops, so as to form a series of pools; there is a division plate between adjacent pools, and on the division plate there are weirs, notch, vertical joint or submerged orifice, all of which are used to control the water level of every pool and the flow velocity in fishway. The pool has two functions: On one hand, the energy will be dissipated through confrontation between water flows, so as to improve the flow state and reduce the flow velocity in fish passage hole; on the other hand, the pools will also serve as the rest place for fishes. The water level difference between two adjacent pools is decided by the kinds of fishes. The gradient of pool-type fishway varies from 10% to 15%. On the basis of orifice and division plate, the fishways also fall into overflow weir type, immersed orifice type, vertical joint type and combined type.

Figure 4.2-1 Ice Harbor Fishway of Vernon Dam (Viewed from upper reach) Ice Harbor Fishway of Vernon Dam (Viewed from lower reach)

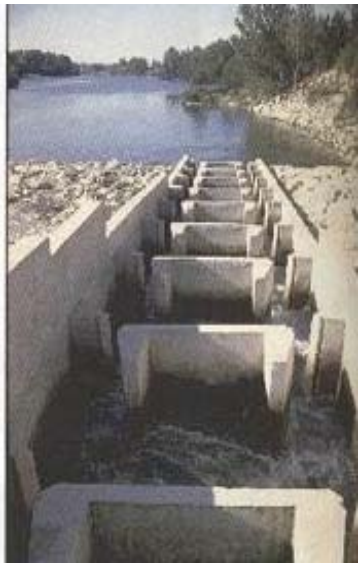

Figure 4.2-2 Single-side Vertical Joint Type Fishway for Small Flow Gauging Weir of Mauzac Power Plant on Dordogne River (left) Double-side Vertical Joint Type Fishway on Gardon River(right)

(2) Daniel Fishway

The Daniel fishway was created by the Belgian engineer Daniel, and its operating principle is as follows: the baffle plates and sills at small distance are set up on baseboard or wall of relatively-steep rectangular water slot, so as to reduce the average flow velocity and dissipate the energy. In the Daniel fishway, the water flow has the characteristics such as high flow velocity, high turbidity and high aeration degree. This type of fishway is relatively selective, and is applicable to the stronger fishes and the

places without large water level difference.

Figure 4.2-3 Daniel Fishway Model Upstream Migration of Trout in Daniel Fishway Model

(3) Bypass Watercourse with Natural Characteristics (Imitated Natural Passage)

The bypass watercourse with natural characteristics is a watercourse which is designed for fishes to bypass specific barrier and is very similar to the natural tributary of river. As indicated by Parasiewitz et al. (1998), the function of bypass watercourse with natural characteristics is somewhat resumptive, because it substitutes some aquatic habitats which have got lost owing to water accumulation. The characteristic of these watercourses is that their gradient is very low (1%~5%), and is even lower in low-land rivers. Different from pool-type fishway, there is no obvious and systematically-distributed drop in bypass watercourse, and the energy is dissipated by regularly-distributed impetuous torrent or water cascades (Gebler, 1998). The main disadvantage of this solution is that, it needs a quite large space near the barrier, and if no special device (lock gate, and water gate) is installed, it can’t get adapted to the remarkable change in water level at upper reach.

Figure 4.2-4 Imitated Natural Bypass Channel

(4) Fish Lock

The operating principle of fish lock is very similar to that of navigation lock. The fishes are attracted into the closed temporary holding pool at the lower reach, and then the temporary holding pool is filled into the tilting axis. At the upper reach, the fish go out of the temporary holding pool through the opened door. The water flow at lower reach is generated by the bypass of temporary holding pool at lower reach, so as to drive the fishes to leave the fish lock. As compared with the traditional fishways, the main disadvantage of fish lock is the limited volume, which is attributable to the discontinuous operation of fish lock and the limited volume of temporary holding pool at lower reach.

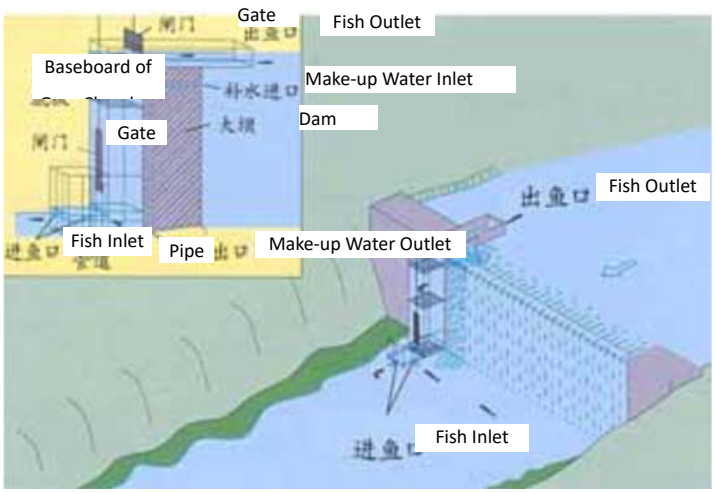

Figure 4.2-5 Schematic Diagram for Fish Lock

(5) Fish Hoister

The operating principle of fish hoister is to use a trap to directly catch the fishes. When the trap is lifted, the fishes and some water in lower portion of the trap are also lifted until the trap reaches the top of dam. Thereafter, the lower portion of the trap will turn

forwards, so as to pour the contents into the reservoir. As compared with other types of fish passage facilities, the main advantage of fish hoister is the low costs, the low volume and the low sensitivity to change in water level at upper reach.

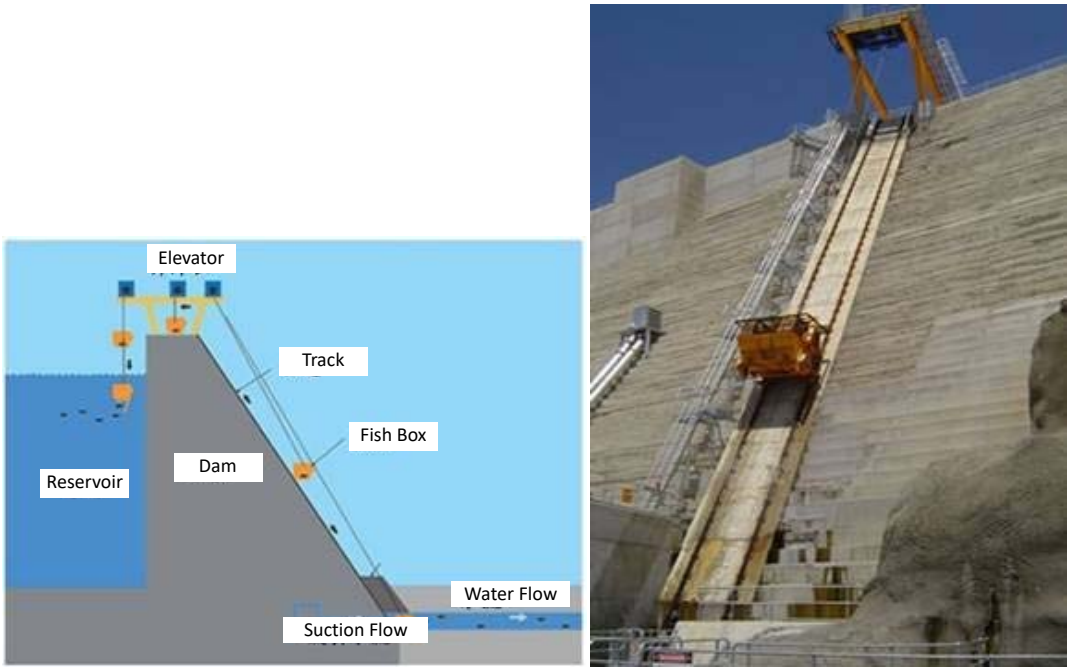

Figure 4.2-6 Schematic Diagram for Appearance of Fish Hoister

(6) Fish Collecting & Transporting Boat

The fish collecting & transporting boat, namely "floating fishway", is movable, can get adapted to the change in flow state at lower reach, and can be moved to the place where the fishes gather for luring and collecting fishes. It is composed of two parts, namely fish collecting boat and fish transporting boat. In other words, it is a "fishway" composed of two flat boats. The fish collecting boat will move to the fish gathering area, its two ends will be opened so as to let the water flow through the boat, and the water make-up unit will be used to make the flow velocity at inlet 0.2m/s~0.3m/s higher than that in river, so as to pure the fishes into the boat. Thereafter, the fish driving device will drive the fishes into the fish transporting boat following it, and the fish transporting boat will pass the dam through the navigation lock and release the fishes into the upper reach. The fish collecting & transporting boat is mainly composed of fish collecting boat, fish transporting boat, fish driving device, fish counter, fish receiving grid and net.

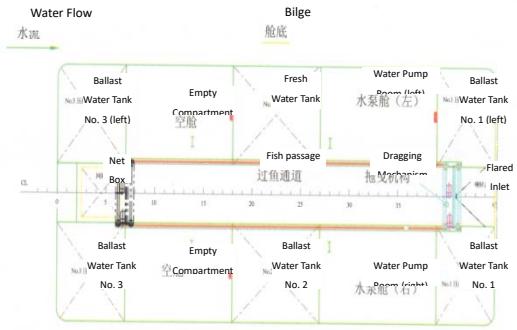

Figure 4.2-7 Fish Collecting & Transporting Boat

(7) Special Fishway

The special fishway is set up for special objects, such as ayu fishway and eel fishway. The ayu fishway is the fish ladder for juvenile ayu, which may also be used to catch the juvenile ayu. The eel fishway is a special device, which may be the eel cavity constructed with stone on side wall of fish ladder, or the fish ladder for eel in special structure.

Figure 4.2-8 Eel Fishway for Radial Water Gate Figure 4.2-9 Fish Passage Facility on Arzal Dam for Eel

4.3 Demonstration and Analysis on Upstream/Downstream Fish Passage Facilities

In light of the dam passage requirement of Sanakham Hydroelectric Power Plant, it is necessary to not only consider the upstream passage of fishes, but also consider the downstream passage of fishes. The upstream fish passage facilities main include

fishway, imitated natural passage, fish hoister, fish lock and fish collecting & transporting facility; the downstream fish passage facilities main include bypass system with blocking grid, fish collecting & transporting facility and flood spillway with water turbine. The main purpose of fish passage facilities of Sanakham Hydroelectric Power Plant is to achieve the spawning migration of migratory fishes and the gene exchange between fish populations at upper and lower reaches of dam, and maintain the normal growth and reproduction of fishes in Mekong River. Therefore, both the upstream fish passage and downstream fish passage shall be considered.

4.3.1 Upstream Fish Passage Option

On the basis of the characteristics of Sanakham Hydroelectric Power Project, the geomorphological and geological conditions of surrounding areas as well as the kinds and living characteristics of fishes in the river section, the comprehensive comparison and selection have been carried out for upstream options such as imitated natural passage, fishway, fish lock, fish hoister and fish collecting & transporting system, and the upstream fish passage options available for this Project have been preliminarily determined. The operating principle, application scope, advantages, disadvantages and fish passage effect of various fish passage facilities as well as the arrangement feasibility analysis for Sanakham Hydroelectric Power Plant are detailed in Table 4.3-1.

Table 4.3-1 Operating Principle, Application Scope, Advantages, Disadvantages and Fish Passage Effect of Upbound Fish Passage Facilities as well as Feasibility Analysis for Sanakham Hydroelectric Power Plant

No.	Fish Passage Measure	Operating Principle	Application Scope	Advantages	Disadvantages	Fish Passage Effect	Feasibility for this Project
1	Imitative-ecological bypass fishway	The fishway passes the dam and has the imitated natural appearance.	It can help many kinds of fishes to pass the dam, can achieve the continuous fish passage, and can achieve the upbound/downbound passage of dam	Large application scope	Large land will be occupied, and there shall be sufficient space on both sides of hydraulic complex and at upper reach	All aquatic organisms can pass the dam, and it is the only method to bypass the dam	The terrace on right bank of hydraulic complex is open, so that the space conditions for construction of imitated natural fishway are satisfied.
2	Pool-type fishway	The concrete passage is adopted, there are division plates in the passage, so as to divide the passage into a series of interconnected or ladder-type pools.	There are several types available, and they are all applicable to the dams with medium and low water head.	It can achieve the continuous fish passage and can maintain the connectivity of water system to a certain extent. A few individuals can downwards pass the dam; the fishes can pass the dam by themselves.	The fishway is selective for target of passing fish; the effect depends on fish luring system to a relatively great extent, and after the fishway is constructed, it is difficult to make renovation or adjustment	The fishway falls into three types: the narrow slot type can form the relatively good suction flow; the pool type requires relatively low flow rate; the Daniel type needs relatively high flow rate	In light of its characteristics, Sanakham Hydroelectric Power Plant Project has the conditions for setup of technical-type fishway.
3	Fish lock	This is a concave passage, there is controllable lock gate on both upper and lower ends,	It is applicable to high water head, or the area	The water consumption is relatively low, and it is	The requirements on design and construction technology are relatively	It is mainly applicable to large fishes (such as sturgeon) and the fishes	Most of the fishes are small fishes, the dam is relatively high, and

No.	Fish Passage Measure	Operating Principle	Application Scope	Advantages	Disadvantages	Fish Passage Effect	Feasibility for this Project
		and the suction flow is formed by opening/closing the lock gate or filling water into passage.	where the space and flow rate are limited.	applicable to large fishes (such as sturgeon)	high, and the frequent maintenance and operation will lead to high expenses	with relatively low swimming ability.	the river course is of valley type, so that it is not advised to adopt the fish lock.
4	Fish hoister	It is an elevator equipped with water transporting slot and mechanical device. The fishes are lifted up from the lower reach by elevator, and then be sent to the upper reach by channel.	It is applicable to high water head, or the area where the space and flow rate are limited.	It is applicable to the fish passage for high dam, and can be adapted to relatively large change in water level in reservoir; as compared with fishway for the same water head, the construction costs are relatively low, the land occupied is less, and it can be constructed conveniently in hydraulic complex.	Mechanical facilities are of complicated structure, the possibility of failure is relatively high, the frequent maintenance and operation are required, the continuous fish passage can't be achieved, and the fish-passage quantity is limited.	It has relatively good effect for salmon and trout as well as the fishes with relatively low swimming ability effect	Since the dam of Sanakham Hydroelectric Power Plant is not high, it is not advised to adopt the fish hoister.
5	Fish collecting & transporting system	The fishes are collected by the fish collecting facilities at lower reach or upper reach of dam, and then be transported to reservoir or lower reach of dam by fish transporting system for release, so as to achieve the reproduction and	This system is applicable to high water head, or the area where the space and flow rate are limited	The fish-collecting point may be adjusted flexibly, the fish-luring flow velocity can be adjusted in a relatively large range, the fish collecting effect is relatively good, the fishes can be transported to the appropriate water area for	The management and operation expenses are high.	The fish collecting & fish transporting system is designed in light of the biological characteristics of fishes, and the fish passage effect is good.	The lower reach of dam in Sanakham Hydroelectric Power Plant has the conditions for construction of fish collecting & transporting facilities.

No.	Fish Passage Measure	Operating Principle	Application Scope	Advantages	Disadvantages	Fish Passage Effect	Feasibility for this Project
		exchange between fishes at lower reach and upper reach of dam.		release, the two-way fish passage can be achieved, and the layout of hydraulic complex will not be affected.			
Conclusion of Comprehensive Comparison and Selection		Sanakham Hydroelectric Power Plant will be developed based on dam, the height of dam will be up to 56m, and the difference of water level between upper and lower reaches will be 20m. The terrace on both banks of river course is open, and the conditions for construction of imitative-ecological fishway and technical-type fishway are satisfied. Mekong River is available for navigation, so that it is advised to construct the fish collecting & transporting system; since the imitative-ecological fishway is suitable for dam passage by many kinds of fishes, can achieve the continuous fish passage, and can achieve the upstream/downstream passage of dam, the design may be carried out in combination with one tributary at lower reach of dam. As a result, the imitative-ecological fishway is taken as the feasible fish passage option.					

4.3.2 Downstream Fish Passage Option

The common fish downstream options include bypass system in combination with blocking grid, fishway, fish collecting & transporting facilities , and flood spillway with water turbine. Since there are many kinds of fishes in Mekong River and the individuals are large, the combination of several methods is more suitable for downstream passage of fishes. Therefore, it is advised to adopt the imitative-ecological fishway, fish collecting & transporting facility, flood spillway and water turbine, so as to achieve the downstream fish passage.

4.3.3 Comparison and selection of fish-pass scheme

The fishway is a fish passage means which is relatively suitable for the power plant with the water head less than 20m-25m, and can achieve the continuous fish passage. The fishway has the following advantages. For example, the fishes can pass the dam by themselves without disturbance or injury, the connectivity of river course can be resumed to a certain extent, a few individuals can achieve the downbound passage of dam, and there are less human factors involved. As a result, the fishway has been widely applied in power plants with low water head. The water head of Sanakham Hydroelectric Power Plant is relatively low (20m), and the geomorphological conditions of both banks are suitable for construction of fishway. Since the river section where this Project is located is in the upper Mekong migration system, there are migratory fishes in the river. Therefore, the construction of fishway is favorable for migration of “white fishes”.

Through the comparison and analysis on advantages, disadvantages and applicability of each option and in light of the actual situations of Sanakham Hydroelectric Power Plant, it is firstly advised to adopt fishway as the major fish passage means for Sanakham Hydroelectric Power Plant, so as to resume the connectivity of river. According to the comparison and analysis on options for fishway on left and right banks, the terrace on the right bank is relatively open, there are hills on the left bank, and the navigation lock which may affect the operation of fishway will be set up on left bank.

Therefore, it is advised to adopt the option whereby the imitative-ecological bypass fishway will be constructed on right bank.

5 UPSTREAM/ DOWNSTREAM FISH PASSAGE

5.1 Application of Fishway

The first fishway was constructed in the 17th century. Since the beginning of the 20th century, owing to the rapid development of economy in western countries, the demands on hydropower energy as well as flood prevention, irrigation and urban water supply have increased continuously, so that the water conservancy & hydropower projects have been developed greatly. In addition, the impact by these projects on fish resources has also become increasingly outstanding. As a result, the research and construction of fishway has also developed.

The fishway is an engineering measure used to protect the aquatic species resources. In order to study and construct the fishway, it is necessary to determine the object of protection firstly. In foreign countries, the fishway is mainly constructed for passage of migratory fishes which have relatively high economic value (such as salmon and trout). Normally, they live in the areas at high latitude (such as the sea-bound rivers in North America, North Europe, Russia, North Japan as well as Heilongjiang and Jilin in Northeast China). They grow in sea water but spawn in fresh water, and their eggs also hatch in fresh water. These fishes are relatively large in size, have very strong ability to overcome flow velocity, and have relatively high adaptability for complicated flow state. The statistical data reveals that, the longest fishway and the fishway with the highest water head in the world are Nonh Fork Fishway (hoisting height: 59.7m; total length: 2,700m) and Pardon Fishway (hoisting height: 57.5m; total length: 4,800m) constructed by USA in 1950s. According to incomplete statistics, more than 200 fish passage structures have been constructed in USA and Canada, about 100 in Europe, about 35 in Japan, and about 15 in the former Soviet Union. The relatively famous fishways include the fishway for Bonneville Dam in USA, the fishway for Devil Gorge in Canada, the

fishway for Dangrande Dam in British and the Itaipu fishway in Brazil.

As for the fishway for Beicha Dam in USA, the main fish-passage objects are salmon and trout. In 2004, 13,549 fishes passed the dam, including 6,599 Salmo Linnaeus, 5,176 Oncorhynchus tshawytscha, and 1,774 Oncorhynchus keta; in 2005, 6,302 fished passed the dam, including 2,198 Oncorhynchus tshawytscha, 2,882 Oncorhynchus keta, and 1,222 Oncorhynchus keta. Fish passage system for Itaipu Dam in Brazil- "The Canal da Piracema" (imitated natural fishway and fishway), constructed in December 2002, is the longest bypass fishway in the world, with the hoisting water head reaching 118.4m. It is indicated through research that, there are 19 kinds of long-distance migratory fishes in Parana basin, among which 17 kinds can be attracted into fishway. However, as affected by the factors including substrate and flow velocity, only 2 kinds can reach the fishway outlet. Only 0.5% of fish individuals can smoothly pass the fishway and enter into Itaipu Reservoir (S. MAKRAKIS, 2010), and the time spent for passing the fishway is about one week.

The fishways in China are mainly set up for rare fishes, *Cyprinidae*, shrimp and crab. In 1958, the fishway was constructed in Qililong Power Plant on Fuchunjiang River in Zhejiang, China for the first time, with the maximum water head being about 18m; in 1960s, more than 30 fishways were constructed in Heilongjiang and Jiangsu, such as Liyugang, Doulonggang and Taipingzha fishways. According to incomplete statistics, more than 40 fishways have been constructed in water conservancy projects in China. Most of the constructed fishways are located on the gate dams with low water head in plain regions near sea or along river, so that the bottom slope is relatively gentle, and the hoisting height is not large (about 10m). As for Yangtang Fishway in China, the hoisting head is 4.5m, the annual average fish passage quantity is about 580,000 fishes, and more than 10 kinds of fishes are involved. As for Changzhou Fishway in China, the hoisting head is 15.29m, the test is being carried out for monitoring the effect, and the fish passage effect is relatively high in the present.

5.2 Requirements on Design of Fishway

5.2.1 Requirements on Design of Inlet

Whether the fishes can quickly find and smoothly enter into the inlet of fishway is the key for success of a fishway; if the inlet is improperly designed, even though there are good fish passage conditions in fishway.

The migratory path and gathering area of migratory fish follow certain laws:

(1) The fishes always migrate upwards in the river, and will not change their direction. When encountering any impetuous torrent, steep sill or dam, the fishes will move to the water area which matches with their swimming ability and seek for passage. In the course of upward migration, if they can't move against the impetuous torrent, the fishes will also move to nearby area where the flow state is relatively gentle. Therefore, they will always migrate upwards in the areas at both sides of river course where the flow velocity is appropriate, or along the land line;

(2) In the course of migration, the fishes will evade the water flow which is unfavorable for their balance and movement, such as violent turbulent motion, hydraulic jump and swirl;

(3) The fresh and fertile water area rather than contaminated area will be selected;

(4) Generally, the juvenile fishes will select the area exposed to sunshine and free from wind, and will move along the river bank.

On the basis of the above-mentioned laws and the technical standards for fish passage facilities , the requirements on design of inlet are showing blew:

(a) The inlet of fishway shall be located at the area near any side of main flow where there is downward water flow;

(b) The inlet of fishway shall be located at the uppermost location at lower reach of dam where the fishes can arrive (barrier of flow velocity or boundary of upper reach), and the corners on both sides of such location; As for power plant projects, the tailwater of power plant is the water flow frequently encountered at lower reach of dam, and the fishes often, as attracted by the tailwater, gather at front edge and both sides of tailwater of plant buildings.

(c) The inlet of fishway shall be located at the fresh and fertile water area where the water flow is stable and straight;

(d) The flow velocity at the inlet shall fit all the passing fish objects and shall not exceed the burst swimming speed of the fish with the weakest swimming performance among the fishes passing by. According to the results of indoor test on burst swimming speed of some fishes in a glass tank conducted in China, the burst swimming speed of Cyprinidae and Siluridae species does not exceed 1.1 m/s. According to hydrological characteristics of the dam site, natural flow velocity of the river channel is slow; therefore, it is recommended that the designed flow velocity at the inlet not exceed 1.1 m/s.

(e) The operating water level downstream of the fishway is 201.10~208.12m, with large variation range. The water depth at the fishway inlet shall not be less than 2.0 m, and more than 1 inlet is necessary.

(f) Electric screen(s) for blocking fish shall be arranged at the inlet for fish luring.

(g) Water replenishment facilities shall be arranged at the inlet, such as water replenishment pipe, to increase flow and flow velocity at the fishway inlet, so as to improve the fish luring efficiency.

5.2.2 Requirements on Design of Outlet

The fishes will come out from the outlet of fishway and then enter into the upper reach, so that the design of outlet shall meet the following requirements:

(1) The outlet shall be able to get adapted to the change in water level in reservoir. In the fish passage season, when the water level in reservoir changes, the fishway outlet shall have sufficient water depth and shall be properly linked with the water level in reservoir water level, and there shall be neither exposed sand beach nor blockage of watercourse outside of the outlet;

(2) The outlet shall be away from flood spillway and water inlet for plant buildings, so as to prevent the fishes which have entered into reservoir from being brought to lower reach by such water flow;

(3) The outlet shall be near the river bank, the water flow outside of the outlet shall be calm and smooth, the flow direction shall be well-defined, and there shall be free from swirl, so that the fishes can smoothly move upwards along the water flow and water front;

(4) The outlet shall be away from contaminated area, dock and navigation lock;

(5) The outlet shall also consider the requirements of return of fishes. The outlet shall face up to the flow direction in the reservoir, so that the downbound juvenile fishes and parent fishes can smoothly enter into the fishway.

(6) The operating water level upstream of the fishway of Sanahkam HPP is 219 m~220 m. A certain water depth which should be controlled within 2.0 m~3.0 m shall be maintained at the outlet, with facilities for water level regulation arranged.

(7) Fish blocking facilities may be arranged at the outlet, to prevent fishes returning to the downstream.

5.2.3 Requirements on Design of Main Body

The design requirements of main body of imitative-ecological bypass fishway shall follow the following principles:

(1) The main body shall be located at the same side with the inlet and outlet of fishway, so as to avoid the crossing of dam and facilitate the management;

(2) The main body shall be far away from mechanical vibration, sewage and noisy area, and shall be located in a quiet environment;

(3) Normally, the slot shall be open and be exposed to natural light, and may not be enclosed.

(4) The bottom width of the fishway shall be determined according to the body length of the fishes passing by and the scale of fish passing, and it should be 3~5 times body length of the longest fish and should not be less than 0.8 m. According to the average body length of *Pangasius gigas* which is the largest among the fishes passing by recorded in the data of the river channel, the bottom width of the fishway of Sanakham HPP shall not be less than 5 m.

(5) The fishway shall be as gentle as possible and the gradient should not be greater than 1:20. Since natural gradient of river channel in the dam site area of the HPP is very small, it is recommended that the gradient in the fishway not be greater than 2%. Rubble may be embedded for the excessively steep slope.

(6) Imitative-river channel is adopted for the fishway with the top width not less than 6 m. Bottom slope and bank slope shall be kept stable with adoption of ecological bank protection structure and reinforcement at the extension point of the steep slope.

(7) Water depth in the fishway shall be determined according to the body size and ecological habits of the fishes passing by. According to the body length of the fishes passing by recorded in the data of the river channel, it is recommended that water depth in the fishway of Sanahkam HPP not be less than 1 m.

(8) According to the fish species passing by and characteristics of natural river channel of Sanahkam HPP, it is recommended that the average flow velocity be taken as 0.4 m/s ~ 0.6 m/s and the maximum flow velocity as 1.5 m/s.

5.3 Basic Parameters for Design of Fishway

5.3.1 Selection of operation water level

The migratory season for fishes in Mekong Sanakham area is from March to October every year. Therefore, the main fish passage season of Sanakham fishway is determined as April - October in every year. The multi-year average minimum water level during April – October is 201.16m (The regulating capacity of reservoir at upper reach is considered).

Water level at upper reach of fishway:

Maximum water level: 220.00m; minimum water level: 219.00m.

Designed water level at lower reach:

Table 5.3-1 Characteristic Water level at Lower Reach of Sanakham Hydroelectric Power Plant

	Water Level (m)	Corresponding Flow Rate (m^3/s)

Multi-year average minimum water level during April-October	201.16	1795
Multi-year average water level	204.20	4400
Tailwater level with 12 units in operation	205.32	5801
Multi-year average maximum water level during April-October	208.12	9995
Once-in-50-year flood level at lower reach	215.83	25000
Once-in-2000-year flood level at lower reach	219.57	34700

The operating water level of fishway at lower reach will be: 201.16m~208.12m, and the change in water level will be 6.96m. The elevation of platform top of gate in inlet will be controlled in accordance with the once-in-50-year flood.

5.3.2 Designed Flow Rate of Fishway

According to the results of feasibility study stage, the flow rate of fishway is set as 6.6m^3/s for calculation of runoff regulation. Therefore, when the natural flow rate is less than 5,801m^3/s, the flow rate of fishway shall be limited to 6.6m^3/s. In the flood season, the flow rate in fishway will be increased in light of the actual situation of fish passage. The cross section of fishway shall be selected in light of the factors such as the kinds of fishes in Mekong River and the living habits of such fishes, and the economic benefits of power plant shall also be considered. While the fishes' needs on spawning migration are satisfied, the sectional size shall be properly controlled.

5.3.3 Basic Parameters for Design of Fishway

According to the specification related to the design of fish passage facilities and combing the construction conditions, operation parameters and main passing fish objects of Sanakham HPP, the fishway design requirements and main parameters are as follows at this stage.

Table 5.3-2 Fishway Design Parameters in Recommended Proposal

Categor	Items	Index	Unit

y			
Fishway form	Fishway form	Imitative-ecological bypass fishway on the right bank	
Inlet requirements	Downstream operating water level	201.16~208.12	m
	Water depth at inlet	≥2	m
	Flow velocity at inlet	≤1.1	m/s
	Bottom substrate requirements	Connecting with the riverbed and bank substrate (metasandstone and alluvial silty-fine sand overburden), to provide access for demersal fishes	
	Fish blocking and luring	Arrangement of electric screen for fish blocking and water replenishment pipe	
Outlet requirements	Upstream operating water level	219~220	m
	Water depth at outlet	2~3	m
	Control mode at the outlet	Sluice may be used for operation control	
Requirements on main body	Average flow velocity	0.4~0.6	m/s
	Maximum flow velocity	1.5	m/s
	Design discharge	≥6.6	m^3/s
	Bottom width	≥5	m
	Top width	≥6	m
	Minimum water depth	≥1	m
	Design water depth	1.5~2.5	m
	Gradient	≤2	%
	Fishway form	Piling up ecological gabion and paving cobblestone and vegetation for its bottom and two sides	
	Observation room	Arranging an observation room at both fishway inlet and outlet sections	

5.4 Design of Imitative-ecological fishway

5.4.1 Selection of Location of Fishway

According to the layout of hydraulic complex recommended in the feasibility study

stage for Sanakham Hydroelectric Power Plant, from the left bank to right bank, there will be: auxiliary concrete dam on left bank, dam section for navigation lock, dam section on left bank for 13 flood gates, riverbed-type dam section for plant buildings (12 units), dam section on right bank for 5 flood & sediment discharging gates, and auxiliary concrete dam on right bank. From the viewpoint of fish passage effect and fish protection, the fishway shall be located near the right side of generator set; secondly, the land on right side of dam site is gentle, and the gradient is relatively low, so that it is relatively suitable for construction of imitated natural fish passage facility; thirdly, the estuary where Namhong River (a tributary of Mekong River) is merged into the mainstream is located on right side of dam site, about 165km away from the same site at lower reach, a fishway inlet may also be set up in such tributary. In consideration of the above factors, it is planned that the imitated natural fish passage facility will be located on the right side of dam site. An electric fish-blocking screen will be set up in the tailwater of plant building, so as to lure the fishes to the fishway inlet at lower reach of dam.

5.4.2 Determination of Elevation of Baseboard of Fishway Inlet and Outlet

The operating water level in fishway at upper reach will be 219m~220m, and according to the guiding rules for design of fishway, the water depth at fishway outlet shall be controlled at 2.0m-3.0m, and the elevation of baseboard at fishway outlet shall be 217.0m.

At the lower reach, the operating water level in fishway will be 201.16~208.12m, and the operating water level will change greatly. The water depth at fishway inlet may not be less than 2.0m. Two fish inlets will be designed, so as to get adapted to the change in water level at lower reach. The elevation of lower inlet floor is EL. 199m and that of higher inlet floor is EL. 206m.

5.4.3 Layout of Main Portions of Fishway

(1) Layout of Fishway Inlet

In light of the geomorphological conditions of Sanakham and the layout of hydraulic

complex, the imitated natural fishway will be located on terrace on right bank, and the elevation of terrace will be about 216.0m. An imitated natural fishway will be excavated on the terrace. The imitated natural fishway will be composed of fish inlet section, imitated natural section and fish outlet section.

A total of two fishway inlets will be set up. One fishway inlet will be set up near the estuary of Namhong River (a tributary of Mekong River), and it is preliminarily planned that the elevation of inlet baseboard will be 206m; another fishway inlet will be set up in the mainstream of Mekong River and at the upper reach of estuary of Namhong River, and the elevation of inlet baseboard will be 199m. Each fishway inlet will be equipped with a lock chamber, in the lock chamber there will be a service gate. Excavated open channel is applied to fishway inlet, in a "splayed" shape. The channel bottom narrows from 10m to 5m within the range of 20m, to connect with the fishway. Luring facilities such as lighting and electric screen for fish blocking will be set at the inside and outside of the inlet respectively based on the response to light, color and sound given by fish.

(2) Layout of Fishway Body

Imitative-ecological section is connected to the rear of inlet. Slope is excavated to the slope foot of mountain along the right bank sluice. Imitative-ecological line is arranged on the left bank of Namhong River and naturally extends and bends along the terrain. The full length of imitated natural channel is 2.48km, with a comprehensive gradient of 0.075%.

The imitative-ecological section is with a trapezoidal cross-section, with the bottom width of 5m and the water depth of more than 1.5m. The excavation slope on both sides below the bedrock surface is 1:0.5m, and above the bedrock surface is 1:1.5. Within the range affected by fishway operating water level, pebble bed will be paved at the bottom and slopes on both sides to satisfy the fish passing. Grass planting for slope fixation and landscaping will be applied to the place above the range affected by fishway operating water level. On fishway, several pools will be provided as the rest pools for fishes. In addition, an observation room equipped with such equipment as observation

window and fish passing counter will be set at the inlet section and outlet section of fishway respectively. The observation window will be set at side of upstream face of imitated natural fishway, flushing with the trench wall. The window bottom and the fishway bottom share the same elevation; while the window top flushes with the fishway water surface.

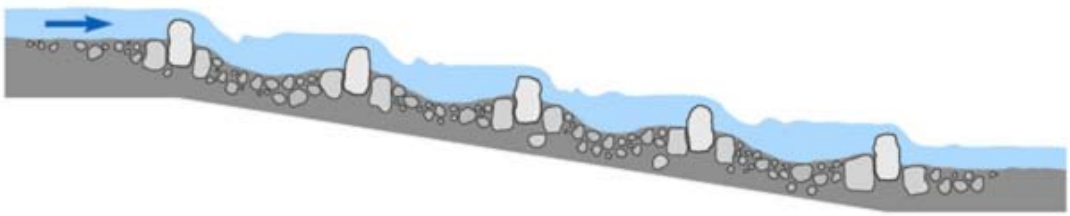

Figure 5.1 Schematic Diagram for Cross-section of Imitative-ecological fishway

(3) Layout of Fishway Outlet

Fishway is provided with one outlet, which is located in the reservoir, with the bottom elevation of EL. 217m and bottom width of 5. Fishway outlet located at 250m upstream of dam axis is a trapezoidal open channel. The excavation slope on both sides below the bedrock surface is 1:0.5, and above the bedrock surface is 1:1.5. The fishway outlet control section is located on the right bank auxiliary dam, where 2 gates, 1 bulkhead gate, 1 service gate are provided. The discharge capacity can be adjusted by controlling the service gate opening, so that the water entering fish passing facilities can satisfy fish migration at any water level. Meanwhile, in the event of a flood, gates can be closed to protect the fishway against flood scouring.

(4) Structural Type of Fishway

The inlet and outlet sections of fishway will be of concrete structure at the early stage. At the late stage, by laying the cobble and vegetation on bottom and both sides, the concrete channel will be converted into the primitive passage suitable for fishes, so as to form the imitated natural fish passage facility.

In the area where the fish inlet is located, some artificial fish reefs will be set up appropriately and linked with the fish inlet, so as to form the ecological environment for gathering of fishes at lower reach of dam. The jet flow will be set up in fish inlet for

attracting the fishes into fishway, and the micro-ecological environment which is similar to the natural brooks and trenches and suitable for living of fishes may be set up in the imitated natural passage, so as to meet the requirements of upbound migration of fishes. On the revetment at upper and lower reaches of imitated natural fishway, some evergreen vine will be planted about 1m~2m above the highest water surface line, and some evergreen trees with underdeveloped root will be planted about 5m~6m above the water surface line, so as to imitate the natural environment.

On the basis of the experience at home and abroad and in light of the characteristic that the water level at lower reach of Sanakham Power Plant changes greatly, for the purpose of facilitate the fishes to find the fish inlets and reducing the number of fish inlets, it is advised to set up 5~6 water make-up points for each fish inlet and send water to such water make-up point from the reservoir, so as to increase the fish luring effect by jet flow. In addition, the fish blocking, fish driving, audio and lighting means may also be adopted near the inlets.

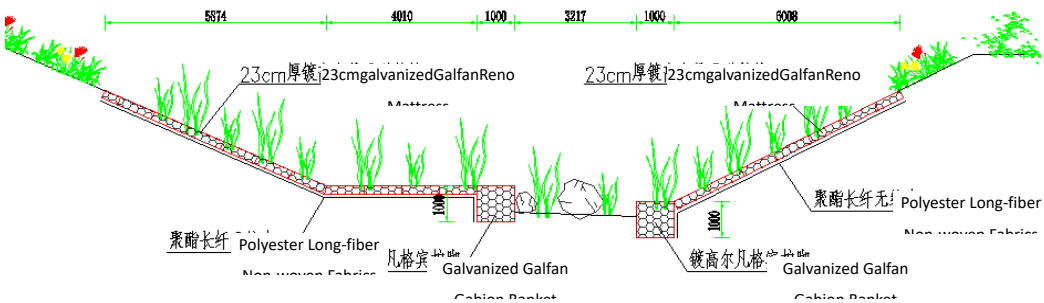

Figure 5.2 Sectional View of Imitative-ecological fishway

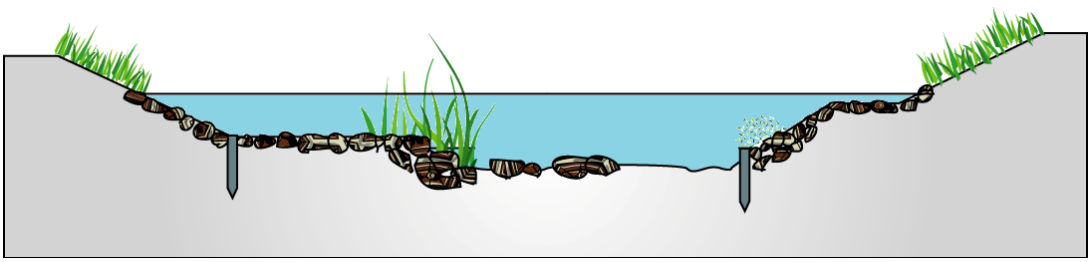

Figure 5.3 Schematic Diagram for Cross-section of Imitative-ecological fishway

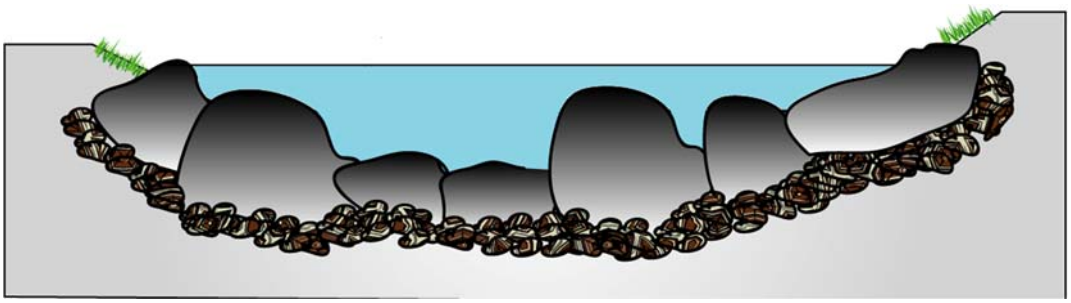

Figure 5.4 Schematic Diagram for Cross Section of Imitative-ecological fishway

(5) Arrangement of Electric Fish Blocking Screen

In order to better guide the fishes into the fishway inlet, the electric fish screen shall be set up in lower reach of Sanakham power plant. One end of the electric screen will be located on right bank and about 10m at reach upper of imitated natural fishway inlet, and the other end is fixed on the training wall at lower reach of dam. The electric screen will extend to the lower reach of the dam, and will be ∠-shaped. The total length will be about 150 m. The angle between bevel edge of ∠ shape and main stream will be about 60°, the length of bevel edge will be about 100m, and the length of edge in parallel of the main stream will be about 50 m (The specific design parameters shall be calculated on the basis of the actual situations of project site). The single-row dismountable electrode-type electric screen will be adopted as electric fish screen, the electric screen will be divided into four "design unit" in light of the location and length of electric screen, and four sets of plus generators and auxiliary equipment will be provided. The in-series sectionalized electrodes of which the diameter is 8.85cm will be adopted for electric screen, and will be hung up by suspended cable to the river bottom.

(6) Layout of fishway observation room

Observation facility is an important part of fishway. The purposes of observation facility setup include: making statistics of species, specification and quantity of upstream fishes passing through fishway; observing the fish adaptability to the fishway, swimming mode and upstream path; mastering the upstream rate and physical consumption of all kinds of fishes in fishway; analyzing the quantity of fishes passing through and the relation with various environments, including day and night, season,

weather, hydrology, water temperature, operating condition of the fishway etc.; strengthening the understanding on fish activity habits and rules and guiding the operating practice of fishway; developing science popularization education activity; and improving the aquatic ecological protection consciousness.

For fishway observation at home and abroad, observation room is mainly adopted for daily observation and statistics now.

1) Location selection

To assess the partition flow pattern and fish passing effect of fishway, observation room is adopted. The main observation part is generally set at the fishway outlet, where each fish recorded has gone through the whole fishway and will enter upstream. The state of fishes passing through the observation room may largely reflect the fish adaptability to the flow condition and physical consumption, which can be used as the basis for estimating the fishway flow and fish passing conditions.

In Sanakham HPP, the fishway inlet and outlet sections are provided with 1 observation room respectively, to help the observers observe and master upstream migration variation of fishes at different parts above and below the dam.

2) Indoor design

The building area of observation room is 3.0m×5.0m, which is a two-layer structure. On the ground floor, it is the fishway observation room, which is mainly used to place equipment such as camera and electronic counter. Abat-jour is not provided for the ground floor where green or blue waterproof lamp is used for lightning. 2 glass observation windows are set on fishway side wall to observe the fish upstream migration. Electric counter is used to record the species and quantity of upstream migration fishes; while camera is used to record the actual situation of fishes passing through the fishway. Recording and counting are applied to the statistics and rule research of upstream migration of fishes, providing the science popularization materials for the relevant people and the basis for the future research on upstream migration rules and living habits of fishes and the fishway construction.

The upper floor of structure is a showroom where people can watch the real-time fish migration in fishway by monitoring terminal. Introductions of main migration fishes can be displayed on the surrounding walls.

3) Observation window

Top of the observation window flushes with the water surface of fishway, so the observation window is taken as 2.0 m in height. Width of observation window depends on the requirements of visual level and fish observation, not less than 1m generally. For better observation effect, the width of 4.5m is adopted here.

Reinforced columns and beams are set in the middle observation window, and every side is provided with three 1.5m×1.5m windows. The glass is made of organic glass, which is clear and transparent and is characterized by wear resistance and pressure resistance, with the thickness of not less than 2cm.

Because moss and sediment are easily adhered to the external glass of observation window, especially around water surface profile, frequent cleaning work is required to maintain observation effect, where artificial periodic cleaning may be adopted.

4) Observation facilities

Observation modes include direct observation and indirect observation. Direct observation means observing at observation window by naked eyes and making statistics.

Indirect observation means adopting observation instruments to observe, which mainly include underwater camera, network camera, sonar fish finder, television monitor and counter. Refer to Table 5.4-1 for details.

Computer system software may be adopted for automatic photographing, videoing, recording and archiving, so as to distinguish the fish type and size based on the stored pictures.

Table 5.4-1 Observation Facilities

S/N	Equipment	Quantity	Unit Price (RMB)	Total (RMB 10,000)
1	Underwater camera	4	10000.00	4.00

2	Web camera	8	10000.00	8.00
3	Ethernet switch	1	35000.00	3.50
4	Sonar fish finder	2	13000.00	2.60
5	Counter	2	1500.00	3.00
6	Network attached storage	2	100000.00	20.00
7	Image analysis system	2	50000.00	10.00
8	Monitoring terminal (including software)	2	30000.00	6.00
	Total			57.1

5) Lighting facilities

In general, the fishway water visibility is 30 cm ~ 70 cm. In case of no artificial lighting facility, it is hard to perform observation and statistics at night or on cloudy days. Meanwhile, muddy water may exist after flood period. To observe fishway well, auxiliary light source needs to be set. Therefore, artificial lighting facility shall be set in pool outside of the observation window for counting and observing all the fishes passing through the fishway.

Energy-saving lamps with moisture resistance performance are employed for lighting. Lamps have stainless steel housings and are characterized by adjustable light intensity, soft lightness and good waterproof and sealing performance. 2 rows of lamps are set opposite each observation window, with 1 row on each side and 2 lamps in each row.

6) Others

Observation room shall be provided with ventilation, lighting, dehumidifying and temperature control facilities. In this project, every observation room is provided with exhaust fan, air conditioner, dehumidifier, hygrometer, thermometer, etc. The possibility of introducing and installing advanced observation instruments are taken into account in space setup at the same time.

6 OPERATION MANAGEMENT AND MONITORING EVALUATION

The main contents include operation management, operation monitoring, safety monitoring, survey evaluation and continuous improvement. In the maximum actual working scope, the fishway shall meet the biological and hydrographical requirements, and shall be able to operate under the minimum seasonal flow rate and once-in-20-year flood level.

The provisions on fishway monitoring facilities will be integrated with the design and operation stage for environmental management & monitoring plan. This includes the ability to safely obtain the fish sample from fishway, and also includes the ability to monitor the movement of fishes and the quality of water.

It is necessary to establish the monitoring plan which can quantify the efficiency of fishway. The efficiency of fishway can be determined by sampling at upper reach of dam and lower reach of dam, and the quantity and proportion of fishes smoothly passing the fishway can be determined by using the data above.

6.1 Trial Operation

Before the facilities and equipment are put into formal operation, it is necessary to test the fishway and relevant equipment, so as to identify the problems which may occur in actual use, and bring forth the advices on correction and improvement, and raise the working efficiency of this Project during formal operation.

During the trial operation period, it is necessary to carefully monitor the operation of main structures and relevant equipment of this Project, so as to ensure the normal operation of various facilities. In addition, during the trial operation period, it is necessary to measure the hydrodynamical conditions in the fishway and at the inlet, and monitor whether the important indexes such as flow velocity and water depth in fishway as well as flow velocity at inlet can meet the design standard. On the other hand, it is necessary to observe the temporal and spatial distribution of fish school at the lower

reach of dame, and observe the kinds and quantity of fishes which actual enter into the fishway, identify the situations unfavorable for fish passage before the fishway is put into formal operation, and immediately make correction, so as to create the optimal conditions for fish passage.

(1) It is necessary to study the motion laws of fishes near fishway inlet, actually measure the fishway inlet flow velocity, and observe the fish luring effect of inlet.

(2) It is necessary to actually measure the flow velocity in narrowed section of the fishway, observe the water flow, flow state and fish passage effect in fishway, identify the problems existing in operation of fishway, and bring forth the improvement measures.

(3) It is necessary to survey the change in fish resources at upper and lower reaches of dam, and evaluate the benefits of fishway.

(4) It is necessary to formulate the rules and regulations for management, operation and observation, maintain the normal operation of fishway, and bring the benefits of fishway into full play.

(5) It is necessary to accumulate the data about operation of fishway, so as to provide reference for subsequent design of fish passage facilities.

6.2 Formal Operation

Mekong Sanakhamarea fish upstream migration time with the arrival of the rainy season occur simultaneously, that annual April to May migratory fish start to end September to October, therefore, the main fish passage season of Sanakham fishway is from April to October each year, the annual April to October fishway be run.

According to the results of feasibility study stage, the flow rate of fishway is set as 6.6m^3/s for calculation of runoff regulation. Therefore, when the natural flow rate is less than 5,801m^3/s, the flow rate of fishway shall be limited to 6.6m^3/s. In the flood season, the flow rate in fishway will be increased in light of the actual situation of fish passage.

Fishway Run Reservoir highest level 220.00m, the lowest level 219.00m, set up an outlet, Bottom elevation 217m, fishway operation period, to run into the water and the water level fishway is controlled by gates, So that the flow rate and flow pattern in the channel remain stable and meet the requirements of the fish traced. The depth of the fishway is ensured 2m to 3m, fishway downstream set two inlets to facilitate fish migration. by opening or closing the lock gate of inlet at lower reach, the water level in the area where the inlet of imitated natural passage is located will be controlled, so as to avoid relatively large height drop or excessively high water level, which may hinder the swimming of fishes.

It is necessary to inspect, maintain and repair the fish passage facilities and auxiliary equipment on a regular basis, and carry out full inspection and repair before the coming of fish passage season, so as to ensure that the functions of fish passage facilities will be brought into full play.

6.3 Fishway Monitoring and Evaluation

To monitoring and evaluation of fishway, imitative-ecological fishway program design, set up an observation room in the middle of the fishway, set up an observation window and over the fish counter, fish finder ultrasonic, radio telemetry, underwater cameras and other equipment inside fishway monitoring assessment program bionic fishway design, set in the middle of a fishway observation room. The observation window will be located at the upstream face of imitated natural fish passage facility, aligned with the slot wall. Its bottom will be at the same elevation as the bottom of fishway, and its top will be aligned with the water surface in fishway. To ensure the normal operation of the observation room, at the same time set up emergency modification costs, the observation room for timely modification.

In addition, it is necessary to observe the fish passage effect of fishway on a regular basis, analyze the fish passage effect, accumulate the basic data, establish the monitoring & evaluation database, and achieve the data sharing. The observation will

be conducted by fish research & survey agency in the later stage as it is a long-term task of great significance.

The optimized fish migration measures will be further proposed based on statistical data and observation of fish species that migrate downstream through fishway, including fish species quantity.

Observation of fish species of the Mekong River mainly includes such aspect as fish spawning, fish species and resources, fish downstream migration, which will provide basis for the programs made for station operation and monitoring as well as fish species protection. Observation facilities shall be provided for fish behavior observation.

6.4 Management and Maintenance

After the fishway is put into operation, the maintenance and repair shall be strengthened. Many fish passage facilities were finally discarded owing to improper management or insufficient maintenance.

The management, supervision and subsequent monitoring of fish passage facilities shall be undertaken by the environmental authorities or specialized institutions. A special department shall be set up in the management body for this Project, professional management personnel shall be allocated to such department, and the supervision and management from the environmental authorities and specialized institutions shall be accepted. As for specific fish passage facilities, it is necessary to formulate the operating procedures, management specifications, maintenance specifications and monitoring specifications for fish passage facilities.

(1) It is prohibited to catch fishes or pour waste/sewage in the fishway;

(2) It is prohibited to berth boat or pour waste/sewage at the outlet of fishway;

(3) It is necessary to inspect the start and stop of gate opening/closing machine, so as to ensure that such machines can be started up and stopped at any time;

(4) It is required to clear away the floating matters in fishway from time to time, so as

to prevent blockage;

(5) It is necessary to clear away the sediment or shell of mollusc in fishway on a regular basis, so as to ensure that the passage is clear;

(6) It is required to clean the observation window in observation chamber from time to time, so as to ensure the certain transparence;

(7) All observation instruments and equipment shall be protected against moisture, so as to ensure that they are always in usable conditions.

6.5 Ecological Hydraulics and Aquatic Biology Laboratory

Fish passage observation station is proposed in the *Report on Fish Passage Facilities for Sanakham Hydropower Project* for monitoring the performance of the fish passages and the observation station can also be used to conduct ecological hydraulics and aquatic organism experiments.

The Mekong River boasts a multitude of fish species with diversified ecological habits. However, fundamental research on fish biology and fish conservation has been premature. Given that fish study is a systematic and professional work, one single Owner is incapable of solely performing scientific research on fish species. Therefore, it is recommended that the research be conducted by experts from a professional organization appointed by GOL to provide technical support for fish species protection.

7 PRELIMINARY CONSTRUCTION PLANNING

7.1 Plan of Material Sources

The concrete aggregate is provided by the aggregate processing system arranged on the left bank downstream, and the concrete is supplied by the concrete mixing system arranged on the right bank.

7.2 Construction method

(1) Earth-rock excavation

The fishway is arranged in the dam abutment on the right bank, located inside the project scope of Sanakham HPP, so fishway excavation shall be synchronically constructed with the hub of the main engineering; and earthwork excavation is conducted with 1~2 m^3 backhoe, cooperated with 10~20t dumpers for mucking.

(2) Pouring concrete

The concrete is supplied by the concrete system on the right bank of Sanakham HPP, conveyed to each working surface with the chutes arranged utilizing dam crest highway and fishway highway on the right bank; 3~6 m^3 concrete tank trucks are used to transport concrete, placing with chute and vibrating with insert type vibrator.

7.3 General construction layout

(1) Road layout and material flow direction

Foreign materials are transported into the project area through existing external traffic highway of the complex project, transported to designated locations to store by way of on-site roads.

The on-site traffic relies on mainly the dam crest road on the right bank, spoil road at the downstream of the right bank and the fishway road, leading to each raw material supplying place and spoil field. The spoil is transported to the stacking site and spoil site from the working surface by way of the dam crest road on the right bank, the spoil road at downstream; The concrete is proposed to be supplied by the concrete system,

of which the concrete product supply route is from the concrete system to reach working surface by way of the dam crest road and fishway road.

(2) The layout of construction site

The construction site of this project is mainly the material stocking area. Because the fishway scale is not large, gentle slopes on both sides of the dam crest road on the right bank can be utilized as the construction site.

7.4 General construction progress

Although the fishway project has not large quantities, it is located within the project area, of which its construction is greatly impacted by the complex project, the fishway construction is conducted simultaneously with the major project on the right bank. The specific duration is scheduled as follows:

(1) Earth-rock excavation

The earth-rock excavation of the fishway located in the dam abutment is conducted synchronically with the dam abutment excavation construction; the excavation of dam abutment of right bank of Sanakham HPP is scheduled to complete from April ~ July of the 5th year, and the fishway is scheduled mainly to conduct from April ~ July of the 5th year, a total of 4 months.

(2) Pouring concrete

According to the schedule of construction diversion planning and general construction progress of the complex project, the concrete pouring of the fishway is proposed preliminarily to arrange from August of the 5th year to September of the 6th year, with the duration of 14 months.

8 CONCLUSION AND ADVICES

8.1 CONCLUSION

Through the basis of the analysis and discussion on fish passage options, imitative-ecological bypass fishway is applied to the upbound fish passage and imitative-ecological fishway&navigation lock in combination with spillway and turbine is applied to the downbound fish passage for Sanakham Hydroelectric Power Plant. In light of the geomorphological conditions on left/right bank and the layout of hydraulic complex, it is advised to locate the fishway on right bank. The fishway will be provided with two inlets, one is set near the estuary of Namhong River, and the other is set on the bank of the mainstream of Mekong River. The imitative-ecological section following the inlets is 2.39km in total length, excavated on the right bank terrace, with a trapezoidal cross section with bottom width of 5m and top width of 6m. The bottom slope of the fishway is about 0.075%. Several pools will be set along the fishway and serve as the rest pools for fish. The fish outlet will be set in an open area 165m away from the dam. Since the water head of Sanakham Hydroelectric Power Plant is 20m, it is appropriate to adopt the fishway as fish passage means. By constructing the fishway, the connectivity of river can be resumed, the impact by construction of dam can be reduced, and the continuous fish passage can be achieved.

8.2 Advises

Imitative-ecological bypass fishway design is difficult with uncertainties as there has not yet ripe and widely applied technology that is available in aspect of fish pass design and operation in addition to diversified biological characteristics of fish species. It is necessary to conduct further investigation, testing and research to improve the performance and effectiveness of the fish passage facilities.

In the next stage, more detailed activities will be carried out in the aspects such as investigation of fish resources, fish species, necessary hydraulic model tests and numerical model calculations for fishway as well as program for fish passage facilities

supervision in order to meet the objectives and requirements as stated in MRC's Preliminary Design Guidance.

8.2.1 Survey of fish ecology

(1) Scope of work and target fish study

Fish resources survey and EIA review will be made to identify fish species distribution, resources within the upstream and downstream of the project area.

Ecological habits survey will be conducted within the upstream and downstream of the project area to identify fish habitats, breeding grounds, migratory/breeding habits and migratory periods.

Target fish study: On the basis of the above-mentioned survey of fish resources, and further study of the target fish, study the physiological characteristics of the target fish, life cycle, migratory behavior, type, and so on swimming performance.

(2) Program

This activity will be jointly performed by the special fish survey agency and Powerchina Northwest Engineering Corporation Limited.

8.2.2 Experimental study of fish swimming ability

(1) Scope of work

Test and research will be conducted on the swimming capability (including the capability of adapting to flow velocity, critical swimming speed, burst swimming speed, sustained swimming ability) of the fish that will pass the fishway facilities. The test will be conducted to get a deep insight into how do fish species of varied length, weight behave in flow of varied velocity and their swimming stamina. The test results will be used as basis in calculation by using mathematical models for resistance of fish in varied sizes against flow velocity and their swimming stamina. Analysis shall be performed for swimming capabilities of hardly-caught fish species with large sizes, long migratory distance.

The flow velocity at critical locations such as fishway channel, inlet, outlet as well as upstream and downstream operating levels will be determined according to fish

swimming ability, operation mode of the power plant and the sluice gate, etc.

(2) Program

This activity will be jointly conducted by the special fish survey agency and Powerchina Northwest Engineering Corporation Limited.

8.2.3 Fishway layout scheme

(1) Scope of work

Fishway layout scheme, including structure type, dimensions, layout of fishway inlet/outlet, scheme of ancillary facilities (i.e. fish luring and catching facilities) layout, will be further optimized according to the project complex layout and research finding regarding fish habits.

Study on fish migratory measures shall be further performed to fish passage facilities according to the project complex layout and research finding regarding fish habits.

(2) Program

This activity will be jointly conducted by the special fish survey agency and Powerchina Northwest Engineering Corporation Limited.

8.2.4 Hydraulic model test

(1) Scope of work

Hydraulic model tests, including integral and local structure models, will be conducted. Integral structure model test is used to simulate overall fishway structure, inlet layout and regime of river flow that lures fish. The test will provide basic data for the operation model test and analysis of proper layout scheme for the fishway and inlet location, outline, dimension, elevation, flow regime of the area adjacent to the outlet and connectivity with downstream river flow based on layout of water intake, layout and discharge capacity of water release structures.

Local structure model test is used for carrying out study and optimization of fishway structure, river flow, flow velocity, water depth, flow regime, etc. The proper fishway structure and dimensions, flow regime that are favorable to migratory fish swimming upriver, including the layout and dimensions of rest pool, will be proposed according

to test results.

(2) Program

This activity will be jointly conducted by the special fish survey agency and Powerchina Northwest Engineering Corporation Limited.

8.2.5 Fishway operation management and prototype observation program

The dispatching of the plant operation shall be in coordination with dispatching mode of fishway operation on ecology-basis to make sure that hydraulics conditions of the upstream and downstream river course during migration period are satisfactory for fish migration. In addition, measures shall be taken to prevent fishway deposition or avoid drifting materials from entering into the fishway. Management plan shall be promulgated to prevent man-made sabotage.

On the basis of model test findings, combined with the operating conditions hydropower, fish migration feature, river hydraulics hydrological cycle, proposed prototype observation content, layout scheme observation conditions and specific instruments and equipment.

Prototype observation items, conditions and arrangement of instruments shall be proposed based on the model test results, operation conditions of the plant, fish migration features and hydraulics of the river course. Prototype observation items include hydraulics observation and performance of fish passage facilities during fishway operation period. Hydraulics observation items include fishway flow capacity, internal flow pattern, flow velocity, water depth, connectivity of upstream and downstream river flow, etc. The performance of fishway observation includes the upriver path, fish flocking area at the fishway inlet, water flow effect, fish moving in the fishway, species, quantity of fish moving upriver and migration time, etc.

In addition, observation for fish species, resources within the upstream and downstream scope of the river reach shall be conducted during the plant operation to provide basic data for assessment the impact of the plant operation on the fish resources of the Mekong River on long-term basis.