5. HYDROLOGICAL STUDY

5.1 GENERAL

5.1.1 OBJECTIVES

The main objectives of the hydrological studies for the Nam Ngiep-I Hydroelectric Power Project were to:

- review and update the basic relevant hydrological data,
- review and estimate the long-term sequence of daily inflow to the reservoir,
- estimate flood levels for various probabilities of occurrence,
- estimate the probable maximum flood inflow into the reservoir,
- review and estimate net evaporation losses from the reservoir, and
- review and estimate sediment inflow into the reservoir.

5.1.2 STUDY AREA

(1) Basin Topography

The Nam Ngiep River is a left bank tributary of the Mekong River, with the confluence about 7 km upstream of the town of Pakxan (Paksane). The source of the Nam Ngiep is near the town of Xieng Khouang (Phonsavan). As shown in Figure 5.1.1, the Nam Ngiep River flows from north to south though a dense forest area between its origin on the Tra Ninh plateau at EL.1,200 m and the Mekong plain at EL.160 m. The western and northern edges of the basin form a gorge as a result of erosion. The maximum altitude of the ridge, which is located west of the basin, is 2,819 m. Its total length is 160 km, and it drops a total of 1,300 m along its course. At its confluence with the Mekong, the Nam Ngiep has a total catchment area of 4,510 km^2.

Figure 5.1.1 Map of Nam Ngiep-I

The proposed Nam Ngiep-I dam site is located at 18°39'N and 103°30'E. The catchment area at the proposed dam site is 3,700 km^2.

(2) Climate Conditions

The project site is located in a tropical area, which is characterized by a well-defined dry season in the winter and a rainy southwestern monsoon in the summer months. The meteorology of the project area is influenced by the southwestern monsoon, with the wet season from April to October and the dry season from November to March as shown in Figure 5.1.2.

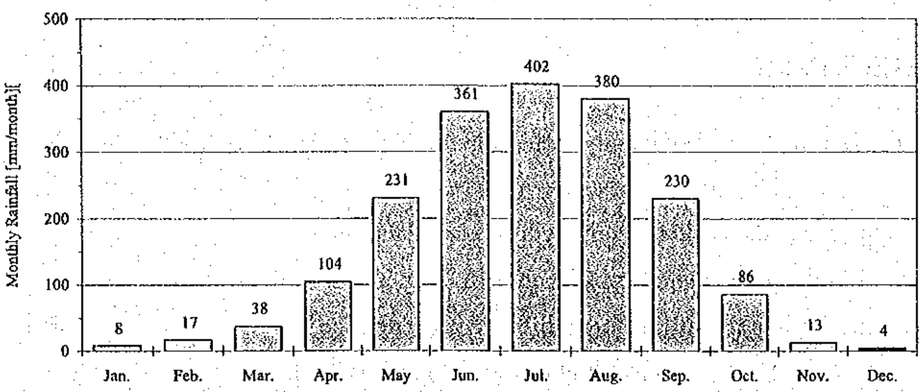


Figure 5.1.2 Basin Mean Monthly Rainfall for Nam Ngiep-I Dam Site (Average 30 years; 1971 - 2000)

According to the pre-feasibility study (*Sogreah*, 1991), cyclones arrive from the China Sea and run up the Mekong valley mostly on the left bank but sometimes on the right bank. When they reach the Nam Ngiep basin, the high ridges in the western and northern areas inhibit them from running further to the north and cause them to stagnate until the atmospheric depression disappears. The rainfalls are concentrated during the short summer period and thus the runoff is particularly high despite the dense vegetation in the basin.

5.2 REVIEW OF PREVIOUS HYDROLOGICAL STUDIES

5.2.1 REVIEW OF PREVIOUS HYDROLOGICAL STUDIES

The main previous hydrological studies related to the Nam Ngiep-I Hydroelectric Power Project are as follows.

(i) *"Pre-F/S on Hydropower Layout of Nam Ngiep-I", Sogreah and HEC, January 1991* (both in English and in French).

(ii) *"Hydropower Development of Nam Ngiep-I, updating of revised prefeasibility study", Sogreah, November 1995.*

(iii) "Inventory Studies on Lower Mekong Water Resources", Lahmeyer and HP(Hydrotecnica Portuguesa), February 1997.

(iv) *"Interim Report on Hydropower Development Plan for the Lao PDR", Lahmeyer and HP(Hydrotecnica Portuguesa), February 1997.*

(v) *"Nam Theun 2 Study of Alternatives", Lahmeyer and Worley, March 1998.*

(vi) *"A Power System Planning within the Lao PDR", Knight Piesold Ltd., 1996.*

(vii) *"Feasibility Study on The Nam Ngiep-I Hydroelectric Power Project in the Lao PDR", (Phase-I Report), JICA, February 2000.*

Results of previous studies are summarized in Table 5.2.1:

Table 5.2.1 Summary of Results on Previous Study for Nam Ngiep-I HEPP

No.	Source (Study by)	Study Year	C.A. [km^2]	Mean Annual Rainfall [mm/year]	Mean Annual Runoff [m^3/s]	Runoff Coeff.	PMP [mm] Duration (hours)			PMF (24 hr) Peak Q [m^3/s]	Specific Sediment Yield [$t/km^2/year$]	Annual Sediment Inflow Vol. [MCM/Yr]
							24 hr	48 hr	72 hr			
1	Sogreah & HEC (Pre-F/S)	1991	3,700	2,960	281.0	0.81	840	1,109	-	15,900	< 2,400	< 6.80
2	Sogreah (Updateing Pre-F/S)	1995	3,700	2,960	210.8	0.61	-	-	-	15,900	< 1,800	< 5.10
3	Lahmeyer (Inventory Studies)	1997	3,730	-	152.0	-	-	-	-	-	-	-
4	Lahmeyer, et.al, (Hydropower Dev.Plan)	1997	(4,367) at M.Mai	(2,409) at M.Mai	(184.5) at M.Mai	0.55	-	-	-	-	-	-
5	Lahmeyer & Worley (NT2 Alternative)	1998	3,700	-	162.0	-	-	-	-	15,900	-	-

Source:

(1) "Pre-F/S on Hydropower Layout of Nam Ngiep 1", Sogreah and HEC, January 1991 (both in English and in French).

(2) "Hydropower Development of Nam Ngiep 1, updating of revised prefeasibility study", Sogreah, November 1995.

(3) "Inventory Studies on Lower Mekong Water Resources", Lahmeyer and HP(Hydrotecnica Portuguesa), February 1997

(4) "Interim Report on Hydropower Development Plan for the Lao PDR", Lahmeyer and HP(Hydrotecnica Portuguesa), February 1997

(5) "Nam Theun 2 Study of Alternatives", Lahmeyer and Worley, March 1998

In the Phase-I Study, these existing studies were reviewed and summarized as follows:

(1) Pre-F/S on Hydropower Layout on Nam Ngiep-I

The Pre-F/S on hydropower layout of Nam Ngiep-I was carried out by *Sogreah* and *HEC* and completed in January 1991. The Pre-F/S was later revised and updated in November 1995. The Study Team has gathered the following reports regarding hydrological study.

1) *Pre-F/S on Hydropower Layout of Nam Ngiep 1, Sogreah and HEC, January 1991* (both in English and in French).

2) *Hydropower Development of Nam Ngiep 1, updating of revised prefeasibility study, Sogreah, November 1995.*

The Pre-F/S had carried out the following hydro-meteorological analyses:

1) Calculation of catchment area at Nam Ngiep-I dam site (= 3,700km^2)

2) Estimation of mean annual basin precipitation at Nam Ngiep-I dam site carried out by means of regional rainfall analysis
   - Mean Annual Precipitation (MAP) = 2,960mm

3) Estimation of mean annual runoff at Nam Ngiep-I dam site carried out by a probabilistic theory
   - Mean Annual Runoff (MAR) = 1,798 mm (or 210.8m^3/s)
   - Runoff ratio = 0.61

4) Estimation of monthly discharge data series at Nam Ngiep-I dam site obtained by generation model, using monthly distribution of the annual total. The correlation coefficients between monthly and annual discharges and the variation coefficients of the square roots of the monthly discharges, derived from those observed at B.Nanay (the Nam Xedon River) and at Nam Ngum dam.

- Two 20-year series of predicted monthly discharges at Nam Ngiep-I dam site

(2) Hydropower Development Plan for the Lao PDR

The Hydropower Development Plan for the Lao PDR was initiated in June 1994 and the Interim Report containing the results of the hydropower inventory study was completed in February 1997 by *Lahmeyer International* and *HP (Hydrotecnica Portuguesa)*. The Hydropower Development Plan reviewed the following items:

1) Previously identified hydropower projects
2) Availability of hydro-meteorological data
3) Characteristics of previously identified projects (location and hydrology)

The Nam Ngiep-I HEPP was excluded from the Hydropower Development Plan due to the existence of Memorandum of Understanding on the development by IPP. However, hydro-meteorological study presented in the Hydropower Development Plan provides the Study Team useful information on the estimate of reliable long-term monthly discharge series at the Nam Ngiep dam site.

The Hydropower Development Plan presents the following hydro-meteorological analysis covering the entire Lao PDR:

1) Examination of the periods of availability of precipitation and discharge data up to the year 1991 obtained from the *Mekong River Commission*,
2) Estimation of the mean annual precipitation and mean discharge over the standard period (30 years from 1962 to 1991),
3) Isohyet maps of mean annual precipitation over the standard period in the Lao PDR,
4) Establishment of a simple discrete river basin model for each of the Mekong tributary river basins, and
5) Derivation of monthly discharge series at the project sites over the standard period, using hydrological characteristics obtained from the river basin models.

The estimated mean annual precipitation and runoff at Muang Mai station (1962-1991) are tabulated below:

Table 5.2.2 Estimated Mean Annual Precipitation and Runoff at Muang Mai (1962-1991)

Area (km^2)	MAP (mm)	MAR (mm)	MAR (m^3/s)	Runoff Ratio
4,367	2,409	1,332	184.5	0.55

(3) Inventory Studies on Lower Mekong Water Resources

According to the *Interim Report on Hydropower Development Plan for the Lao PDR, Lahmeyer and HP, February 1997*, Nam Ngiep-I Project was listed among the previously identified hydroelectric schemes in the Lao PDR by the following inventory studies on lower Mekong water resources.

1) Inventory of Promising Tributary Projects in the Lower Mekong Basin, Mekong Secretariat, December 1970.
2) Lower Mekong Water Resources Inventory, Summary of Project Possibilities, prepared by *WATCO* for the *Mekong Secretariat*, September 1984.

The following brief hydrological data are referred to in the *Hydropower Development Plan for the Lao PDR, Lahmeyer and HP, February 1997.*

Table 5.2.3 Hydrological Data of Nam Ngiep-I Dam Site

Drainage Area of Nam Ngiep Dam Site (km^2)	Mean Annual Runoff (m^3/s)
3,730	152

The mean annual runoff was supposedly estimated by regional hydro-meteorological analysis using mean annual basin rainfall for the dam site and regional runoff ratio. No further details were obtained by the Study Team.

(4) Nam Theun-2 Study of Alternatives

Nam Theun-2 Study of Alternatives was carried out by *Lahmeyer and Worley* and the Final Report was presented in March 1998. The study reviewed the hydrology of non-Nam Theun-2 IPP, including the following analyses:

1) Review on previous hydrological studies
2) Flow estimation at IPP sites

The estimated annual discharge at Nam Ngiep-I is tabulated below. The same procedures were adopted for this analysis as for the Hydropower Development Plan.

Table 5.2.4 Estimated Mean Annual Runoff at Nam Ngiep-I Dam Site (1966-1995)

Catchment Area (km^2)	Mean Annual Runoff (mm)	Mean Annual Runoff (m^3/s)
3,700	1,383	162

This study also generated a 30-year monthly runoff series from 1966 to 1995 at the Nam Ngiep dam site. The same procedure was adapted with Hydropower Development plan. The estimated mean annual precipitation at the Nam Ngiep dam site is not described in the report.

(5) Power System Planning in the Ministry of Industry and Handicraft

The report on "Power System Planning within the Lao PDR" was carried out by *Knight Piesold Ltd.* in 1996 to assist in developing the appropriate skill mix within the Ministry of Industry and Handicraft (MIH). The study, which excludes the Nam Ngiep-I HEPP, was completed and the Final Report presented in January 1998.

The study reviewed the previous studies and basically adapted the estimate of annual mean precipitation and runoff at stream gauging stations and project sites presented by the Hydropower Development Plan for the Lao PRD. Therefore no new hydro-meteorological estimates were carried out by the study.

5.2.2 REVIEW OF THE CATCHMENT AREA

The catchment areas at the Nam Ngiep-I proposed dam site and Muang Mai stream gauging station estimated by previous studies are shown in Table 5.2.5.

Table 5.2.5 Comparison of Catchment Area at Nam Ngiep-I Dam Site and Muang Mai Station

Study (or Organization)	C/A at Dam Site (km^2)	C/A at Muang Mai (km^2)
1. Mekong River Commission (*)	-	4,270 (98.8%)
2. DMH (1997) (**)	-	4,305 (99.7%)
3. Inventory Study by MRC (1970)	3,670 (99.2%)	-
4. Pre-feasibility Study (1991)	3,700 (100%)	**4,320 (100%)**
5. Hydropower Development Plan (1997)	-	4,367 (101.1%)
6. Nam Theun 2, Study of Alternatives (1998)	3,700 (100%)	-
7. JICA Study (1998)	3,700 (100%)	**4,320 (100%)**

Note : (*) Lower Mekong Hydrologic Yearbook (1988-1993)
(**)Hydrological Data Book on the Mekong River Basin in Lao PDR (An Interim Report)

In the Phase-I Study, the JICA Study Team (1998) calculated the catchment areas at Nam Ngiep-I dam site and Muang Mai gauging station using a 1:100,000 map, with the same result as the Pre-feasibility Study by *Sogreah* (1991).

The deviation of seven different estimates of catchment area at Muang Mai and Nam Ngiep-I dam site lies within +/- 1% of the latest estimate by the Study Team. Therefore, the following estimates of catchment at Muang Mai stream gauging station and the Nam Ngiep-I dam site by the Pre-feasibility Study (1991) are adopted for further study since the same estimates were recalculated by the Study Team.

In the Phase-I Study, using a topographical map of a scale 1:100,000, the catchment areas at several major sites in the Nam Ngiep River basin were measured by planimeter. The result is as shown in Table 5.2.6.

Table 5.2.6 Adapted Catchment Areas at Major Sites in the Nam Ngiep River Basin

No.	Site/Station	Catchment Area (km^2)
1.	Proposed Nam Ngiep-I Dam site	3,700
2.	B. Hatkham W.L. gauging station (Nam Ngiep)	3,744.3
3.	Total C.A. of Nam Xao River Basin	313
4.	B. Thahua W.L. gauging station (Nam Xao)	304.2
5.	Muang Mai W.L. gauging station	4,320
6.	Total Nam Ngiep basin (confluence with Mekong River)	4,533

5.3 AVAILABLE HYDRO- METEOROLOGICAL DATA

The available long-term hydro-meteorological data in and around the project area are quite limited as shown in below.

Table 5.3.1 Collected Hydro- Meteorological Data

Data		Observation Station	Altitude	Start	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	2000	Agency
Climate (Monthly)	1	Paksan (Paksane)	155m	1929																				●	●	●	●	●	●	●	●	●	●	●	Hydromet
	2	Xiengkhouang(M.Pek)	1,050m	1981	x	x	x	x	x	x	x	x	x	x	x	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	DMH
	3	Vangvieng	215m	1929			●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	DMH
	4	Phonsavang			●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	DMH
	5	Vientiane	170m	1907				●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	Hydromet
Rainfall (Daily)	R1	Bolikhamxay	159m	1984																				●	●	●	●	●	●	●	●	●	●	●	DMH
	R2	Paksan	155m	1929	●	●	●	●	●	●	●	●	●	●		○	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	Hydromet
	R3	B.Muang Mai	158m	1978								●	●						●			●	●	●	●	●	●	●	●	●	●	●			Hydromet
	R4	Muang Kao (M.Borikhan)	158m	1986								○											●	●	●	●	●	●	●	●	●	●	●	●	DMH
	R5	M.Khoun(B.Thoum)	1,110m	1994																										●	●	●	●	●	DMH
	R6	Xiengkhouang(M.Pek)	1,050m	1929												●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	DMH
	R7	M.Phaxay(B.Houei)	1,100m	1996																										●	●	●	●	●	DMH
	R8	Nalong	460m																		●	●	●	●	●	●	●	●	●	●	●	●	●	●	DMH
	R9	Bounyeuk(Tadieth)	230m																										●	●	●	●	●	●	DMH
	R10	Thabok	160m	1986																			●	●	●	●	●	●	●						Hydromet
	R11	Vientiane	170m	1907	●	●	●	●	●	●	●	◎	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	Hydromet
	R12	Vang Vieng	215m	1929		●	●	●	●	●	◎	◎	●	●	●	●	◎	●	◎		●	●	●	●	●	●	●	●	◎	●	●	●	●	●	Hydromet
	R13	Muong Mork	900m																											●	●	●	●	●	DMH
	-	Long cheng	1,000m																																DMH
	-	Phonsavang (M.Longxan)	290m																																DMH
Water Level (Daily)	1	B.Muang-Mai (Nam Ngiep)	152.51m	1978	x	x	x	x	x	x	x	●	●	●		●	●		●	×	●	●	●	●	●	●	●	●	●	●	●	●	●	●	DMH
	2	B.Phonyeng (Nam Ngiep)																												●	●	●			DMH
	3	B.Hatkham (Nam Ngiep)		1998	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	●	●	●	JICA
	4	B.Thahua (Nam Xao)		1998	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	●	●	●	JICA
	5	Paksane (M.Xang)		1976	x	x	x	x	x							●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●			DMH
Daily Q	1	B.Muang-Mai (Nam Ngiep)	152.51m	1987	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x		●	●	●	●	●	●	●	●	●	●	●	●	●	MRC
Discharge Obs. Data	1	B.Muang-Mai (Nam Ngiep)	152.51m	1987	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	●	●	●	●	●	●	●	●		●	●	●	●	●	DMH
	2	B.Hatkham (Nam Ngiep)		1998	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	●	●	x	x	x	x	x	x	x	●	●	●	JICA
	3	B.Thahua (Nam Xao)		1998	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	●	●	●	JICA
	4	B.Phonyeng (Nam Ngiep)																															●		DMH

Note) "●": Collected, "-": Not available to collect, "x": No measured, "◎": only monthly data collected, "○": only annual data available, "Δ": some months are not available.

No suspended-load data or bed-load data are available for the Nam Ngiep River. Meteorological data such as air temperature, relative humidity, barometric pressure, solar radiation, sunshine hours, evaporation and wind velocity were also not measured in the Nam Ngiep River basin.

5.4 FIELD SURVEY

5.4.1 INSTALLATION OF RAINFALL GAUGE STATIONS

There are four existing rainfall gauge stations in the Nam Ngiep River basin. Two by DMH (Department of Meteorology and Hydrology, Ministry of Agriculture and Forestry) stations at Mt. Phaxay and Mt. Khoum in the upper reach of the basin, one MRC (Mekong River Commission) station at Muang Mai, and one JICA station at B. Dong in the Thaviang Sub-District installed during the Phase I Study.

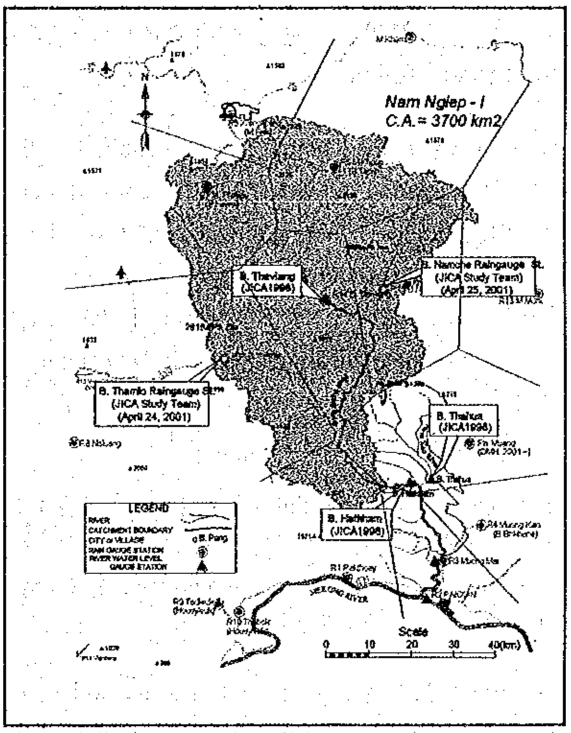
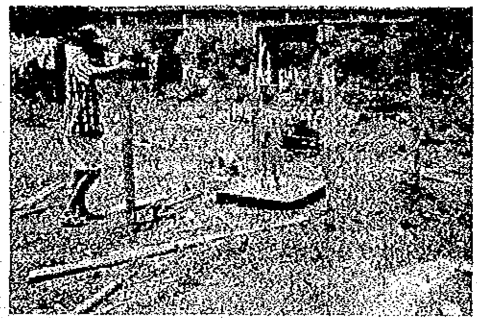


Figure 5.4.1 Existing and Installed Hydrological Observation Stations in the Nam Ngiep River Basin

In the Nam Ngiep River basin, there are several large mountains of more than 2,000 m elevation, Mt. Phaxay, Mt. Khe, Mt. Xao, and Mt. Bia, and the basin run-off may be largely subject to the hydrological characteristics of these mountains. Therefore, the accuracy of this development study will be increased considerably by getting good data on precipitation in these mountains.

As suggested in the Phase I Study, the existing rainfall-gauge stations are not sufficient to adequately capture the basin average rainfalls on the Nam Ngiep River. Therefore, the JICA Study Team and MIH staff installed two additional rain gauges in the basin on April 24 to 25, 2001.


Installation of Rainfall Gauge at B. Namche

B. Namche and B. Thamlo near Mt. Bia shown in the map above were selected for the new rain gauge stations because of their representative location in the basin, easy access and maintenance, surrounding topography, availability of administrative staff, site drainage condition, local security, etc.

Table 5.4.1 Installed Rain Gauge Stations in April, 2001 (JICA Study Team)

No.	St. Name	Installed Date	Longitude	Latitude	El.m	Province	District
1.	B. Thamlo	24 Apr. 2001	18° 55' N	103° 10' E	920 m	K. Syasonboun	Saysonboun
2.	B. Namche	25 Apr. 2001	19° 02' N	103° 30' E	400 m	K. Syasonboun	Saysonboun

The Team will also continue collection and analysis of data from those gauging stations and up-date the hydro-meteorological data of the Nam Ngiep River basin.

5.4.2 WATER LEVEL AND DISCHARGE OBSERVATIONS

An existing water level gauge station installed in the Nam Ngiep River basin is located at Muang Mai (catchment area = 4,320 km^2) near the confluence with Mekong River. It has been periodically maintained by the Department of Meteorology and Hydrology since 1978. To estimate the long-term discharge at the proposed dam site, two-(2) additional water level gauge stations were installed during the Phase-I Study (1st September, 1998) by the JICA Study Team.


Staff Gauge at B. Hatkham (JICA Study Team)

1) B. Hatkham W.L. Station (Nam Ngiep River), 8.5 km down-stream from proposed dam site (C.A. = 3,744.3 km^2)
2) B. Thahua W.L. Station (Nam Xao River), 3 km upstream from confluence with Nam Ngiep River (C.A. = 304.2 km^2)

The observed daily gauge height records and discharge measurement data at these water level stations were reviewed in this stage. The updated stage-flow (H-Q) rating curve at the B. Hatkham (Nam Ngiep) and B. Thahua (Nam Xao) water level stations are shown below (Figures 5.4.2 and 5.4.3).

River Name	Station	No.	Obs. Date (Y/M/D)	Time	Weather	Q Obs. Discharge (m^3/s)	Gauge Hight (m)	Q Obs. Method
Nam Ngiep	B. Hatkham	A-1	1998/9/2	13:10	fine	535.33	12.22	Current meter
		A-2	1998/12/8	15:30	cloudy	39.68	9.68	
		A-3	1999/1/9	12:52	cloudy	23.44	9.83	
		A-4	1999/5/19	11:15	cloudy	170.13	10.68	
		A-5	1999/6/25	14:20	cloudy	359.56	11.57	
		A-6	1999/8/3	9:25	cloudy	229.45	11.19	
		A-7	1999/9/5	11:15	cloudy	250.15	11.14	
		A-8	1999/10/9	9:57	cloudy	184.96	10.77	
		A-9	1999/11/28	13:00	fine	68.53	10.15	
		A-10	2000/1/27	15:20	fine	60.75	9.60	
		A-11	2000/6/4	9:33	cloudy	196.18	10.30	
		A-12	2000/7/30	9:59	cloudy	320.77	11.35	
		A-13	2000/10/1	9:15	cloudy	229.41	10.89	
		A-14	2000/12/17	9:37	cloudy	74.18	10.10	
		A-15	2001/2/17	13:17	cloudy	32.12	9.92	
		A-16	2001/7/4	10:49	rainy	359.29	11.59	
		A-17	2001/9/29	17:28	fine	196.52	10.84	
		A-18	2002/1/9	11:35	fine	56.87	10.05	
		A-19	2002/3/27	9:45	fine	27.35	9.86	

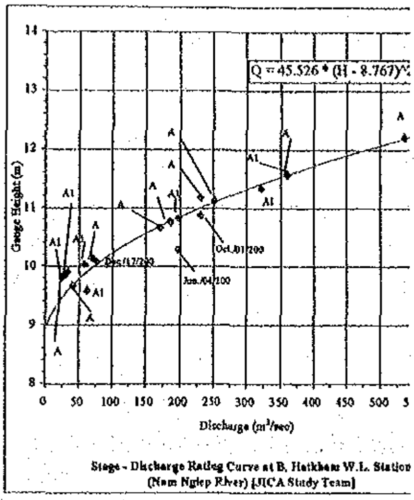


Figure 5.4.2 Observed Discharge and Stage-Flow (H-Q) Rating Curve at B.Hatkham (Nam Ngiep)

River Name	Station	No.	Obs. Date (Y/M/D)	Time	Weather	Q Obs. Discharge (m^3/s)	Gauge Hight (m)	Q Obs. Method
Nam Xao	B. Thahua	B-1	1998/9/2	18:25	fine	57.20	11.61	Current meter
		B-2	1998/12/9	11:53	cloudy	1.17	9.58	
		B-3	1999/2/10	10:50	fine	0.52	9.44	
		B-4	1999/5/29	14:06	cloudy	7.91	10.17	
		B-5	1999/6/26	16:40	cloudy	22.84	10.85	
		B-6	1999/8/3	11:50	cloudy	48.22	11.37	
		B-7	1999/9/5	12:37	cloudy	21.08	10.74	
		B-8	1999/10/9	12:17	cloudy	9.74	10.32	
		B-9	1999/11/29	14:35	fine	2.88	9.70	
		B-10	2000/1/27	18:15	fine	1.92	9.48	
		B-11	2000/6/4	9:33	cloudy	54.63	10.81	
		B-12	2000/7/30	11:26	cloudy	7.89	10.79	
		B-13	2000/10/1	11:12		38.11	10.60	
		B-14	2000/12/17	11:35	cloudy	2.10	9.65	
		B-15	2001/2/18	9:02	cloudy	0.44	9.47	
		B-16	2001/7/4	13:05	cloudy	46.95	11.52	
		B-17	2001/9/20	8:40	fine	11.96	10.33	
		B-18	2002/1/10	8:40	fine	1.54	9.54	
		B-19	2002/3/2	14:35	fine	2.88	9.70	

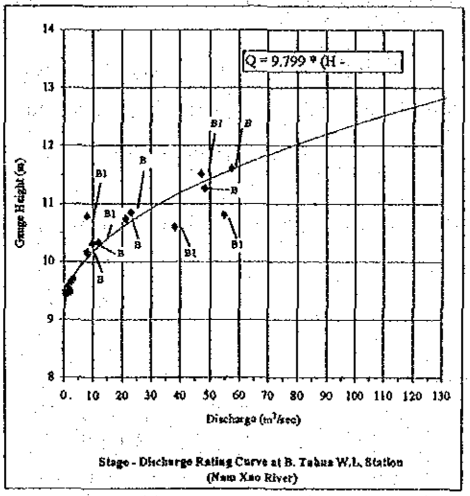


Figure 5.4.3 Observed Discharge and Stage-Flow (H-Q) Rating Curve at B. Thahua (Nam Xao)

The above stage-flow rating curve at B. Tahua station indicate that the water levels are effected by backwater of the Nam Ngiep River. Hence, the water level and discharge data at B. Thahua station are not used directly for the hydrological analysis but are used for the reference.

5.5 LOW FLOW ANALYSIS

5.5.1 GENERAL APPROACH

To evaluate the optimum development scale of projects through computation of power output, continuous long-term runoff data for a time period of more than 20 years at the proposed dam site is normally needed. Further, the runoff data should be of high accuracy, because estimation of the economic viability of the project is highly sensitive to the runoff records. However, it is often the case that long-term runoff records are not available. It is therefore important to extend the available records using a rainfall-runoff model from available rainfall records.

records using a rainfall-runoff model from available rainfall records.

As described above, the runoff records at Ban Hatkham water level gauging station near the proposed dam site in Nam Ngiep River are only available for 3 years between 1998 to 2001. This data observation period does not seem to be sufficient for reliable planning of the project. The daily water level records at Muang Mai gauging station are available 20 years (1978-80, 82-83, 85, 87-2000). The daily runoff records at Muang Mai gauging station are available from 1987 onwards.

However, considering that the rainfall records are available at several stations in and around the Nam Ngiep River basin in the period from 1971 to 2000 (30 years), it should be possible to estimate the discharge data for the period of 1971 to 2000 by using a rainfall-runoff model.

Along this line, the Tank model (*Sugawara*, 1956) method is applied in this study as a rainfall-runoff model, the parameters of which are calibrated by using rainfall and available runoff records.

Firstly, the available runoff records at the Muang Mai and Ban Hatkham water level gauging stations are evaluated by means of a runoff coefficient. Then low-flow analysis by the Tank model is carried out to expand the available runoff data.

The outline of low flow analysis is described in the flowchart below.

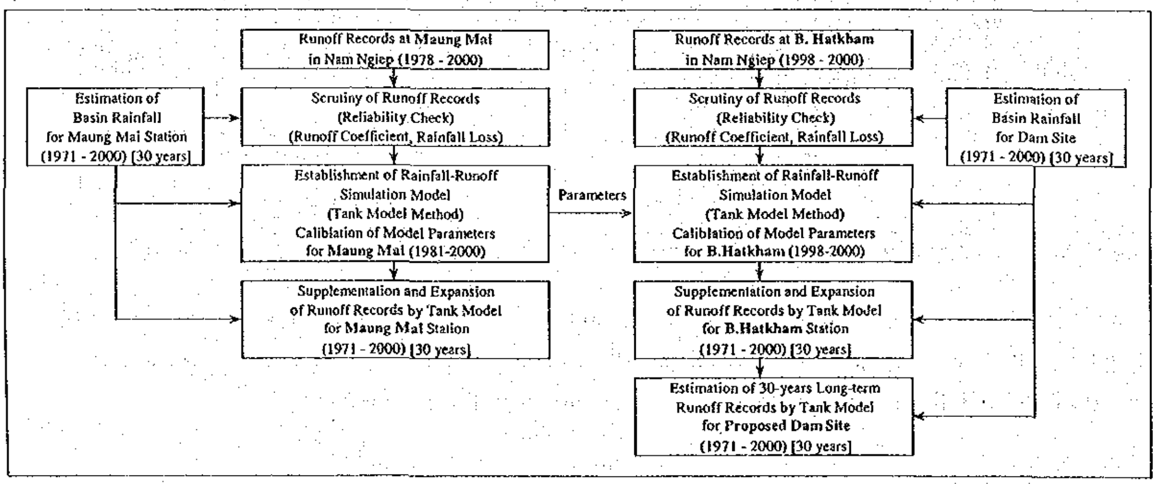


Figure 5.5.1 Overall Workflow of Low Flow Analysis

5.5.2 BASIN MEAN RAINFALL

The basin mean rainfall for the catchment of the proposed Nam Ngiep-I dam site, B. Hatkham gauging station and Muang Mai gauging station are prepared for the period from 1971 to 2000 (30 years) by *Thiessen* method. The estimated basin mean rainfall at the proposed dam site and the Muang Mai gauging station are summarized in Table 5.5.1.

Table 5.5.1 Estimated Basin Mean Rainfall (1971 - 2000 average)

Unit: mm

Catchment	C.A. [km^2]	Averaged Year	1 Jan.	2 Feb.	3 Mar.	4 Apr.	5 May	6 Jun.	7 Jul.	8 Aug.	9 Sep.	10 Oct.	11 Nov.	12 Dec.	Annual
Dam Site	3,700	1971-2000	8.0	16.8	37.6	104.4	231.2	360.6	402.3	379.7	230.0	85.9	12.9	3.9	1,873.4
Muang Mai	4,320	1971-2000	7.9	18.0	40.0	107.8	242.0	385.9	425.2	397.6	243.1	87.6	12.8	4.0	1,971.9

The estimated mean annual basin rainfall (MAR) averaged over 30 years (1971-2001) for the catchment of the proposed dam site and the Muang Mai gauging station are 1,873 mm and 1,972 mm respectively. Theses values are less than from previous studies: 2,900 mm/annum for the dam site by pre-F/S (Sogreah, 1991); 2,409 mm/annum for the Muang Mai gauging station by Lahmeyer (1997). However, the previous studies used only a few rainfall stations near the project area, and the periods of records were short. The observed annual rainfall records of the upper basin near the town of Xeing Khouang are usually smaller than those of the lower basin (near Muang Mai). This result is based on observed daily rainfall data from 14 stations in and around the project basin. Therefore, the above results are adopted for this feasibility study.

5.5.3 RUNOFF MODEL

(1) Concept of the Tank Model

The basic concept of the Tank model (*Sugawara*, 1956) is a simple tank with holes to let out water. The outflow from each hole is proportionate to the height between the hole and water surface. Provided that a tank is accommodated with one bottom hole and two side holes, the rule for outflow computation is as follows;

$$y_n = 0 \qquad (X_n \leqq h_1)$$

$$y_n = \alpha_1(X_n - h_1) \qquad (h_1 < X_n \leqq h_2)$$

$$y_n = \alpha_2(X_n - h_2) + \alpha_1(X_n - h_1) \qquad (h_2 < X_n),$$

$$z_n = \beta X_n,$$

$$X_{n'} = X_n - y_n - z_n,$$

$$Z_n+1 = X_{n'} + x_n + 1 \qquad \text{------------------} (1)$$

where, X_n : water depth of stage n,

y_n : outflow from side holes of stage n,

z_n : outflow from bottom hole of stage n,

x_n : inflow of stage n,

α_1, α_2 : coefficient of side holes, and

β : coefficient of bottom hole.

Normally, a tank model combining several tanks in a series makes a better simulation result. In Japan, the tank model consisting of four tanks in a series successfully analyzes a number of river basins. In such models, each tank interacts in the manner described in the above equation (1). The top tank receives the rainfall as inflow to the tank, while the tanks below get the supply from the bottom holes of the tank directory above. The last or the bottom tank only has a side hole. The aggregated outflow from all the side holes of the tanks constitutes the inflow into the river course. Trial-and-error is needed to determine the tank parameters that minimize the difference between the observed and estimated runoff.

(2) Calibration of the Tank Model Parameters

The calibrated model parameters for the Muang Mai and the B.Hatkham gauging stations are shown in Figure 5.5.2.

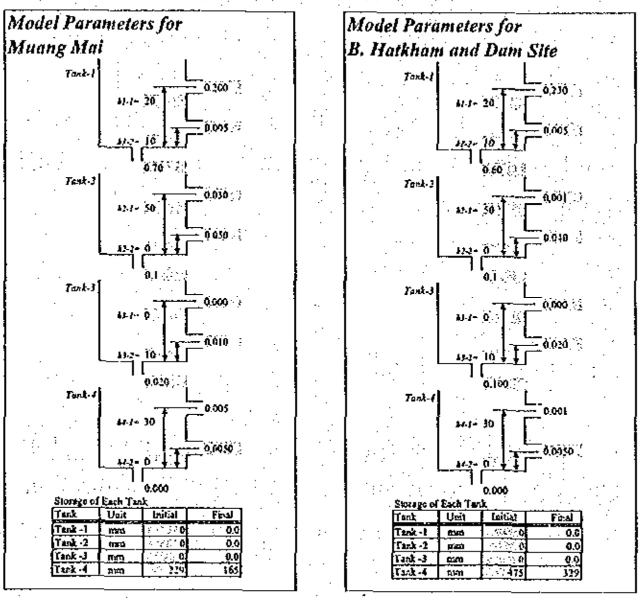


Figure 5.5.2 Calibrated Tank Model Parameters for Muang Mai and B. Hatkham/Dam Site

The model parameter values are calibrated based on the observed discharge at the Muang Mai and the Ban Hatkham gauging stations. The calculation was conducted by daily time step. Results of calibration of the model parameters for the catchment of the Muang Mai are shown below.

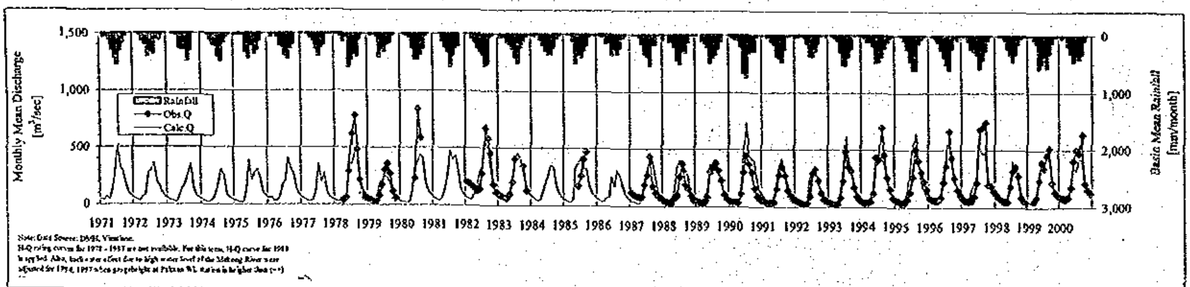


Figure 5.5.3 Comparison between Observed and Estimated Monthly Discharge by Tank Model at Muang Mai (Nam Ngiep) [C.A. = 4,320 km²]

After the calibration, the parameters of the Tank Model for the Muang Mai, the calibrated parameters were applied to estimate discharge at the dam site. Only some model parameters were changed based on the based on the observed daily discharge data at the B. Hatkham gauging station from September 1998 to 2000 (around 2.5 years). The results of the Tank Model for the B. Hatkham are shown below:

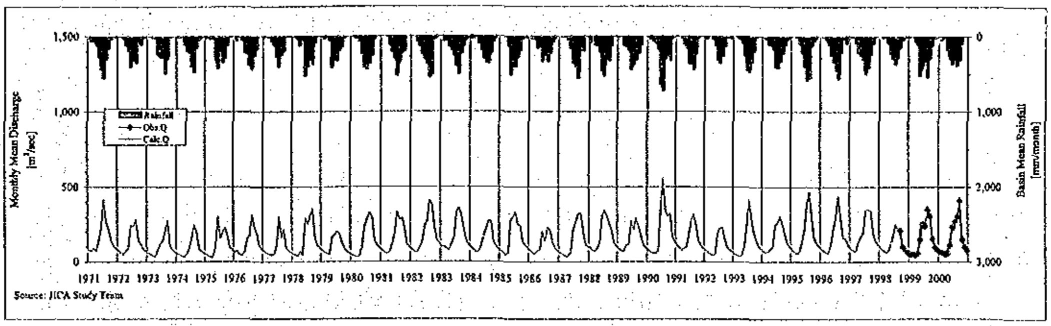


Figure 5.5.4 Comparison between Observed and Estimated Monthly Discharge by Tank Model at B. Hatkham (Nam Ngiep) [C.A. = 3,774 km2]

5.5.4 LONG-TERM SEQUENCE OF RUNOFF

Using the model for the B. Hatkham, the daily stream flow sequences at the proposed Nam Ngiep-I Dam site for the period 1971-2000 (30 years) are estimated. Mean monthly discharge for 30 years (1971-2000) at the proposed dam site is shown in Table 5.5.2.

Table 5.5.2 Estimated Monthly Discharge at Proposed Nam Ngiep-I Dam Site

Site: Proposed Dam Site Unit: m^3/sec

Year	Month	1 Jan.	2 Feb.	3 Mar.	4 Apr.	5 May	6 Jun.	7 Jul.	8 Aug.	9 Sep.	10 Oct.	11 Nov.	12 Dec.	Annual Mean
1	1971	81.7	70.8	93.7	73.4	131.6	233.3	412.3	263.0	214.3	133.0	107.1	88.3	158.5
2	1972	74.0	60.8	53.3	73.1	91.1	242.0	231.6	279.5	143.0	118.0	86.8	71.6	127.1
3	1973	59.1	50.9	40.3	34.4	80.3	120.5	139.7	208.2	272.0	103.8	80.4	65.4	104.6
4	1974	55.5	46.9	37.2	36.5	55.7	92.9	159.6	243.1	197.8	84.8	70.4	58.6	94.9
5	1975	49.9	39.7	33.7	32.2	107.1	299.8	157.6	192.4	226.0	168.6	95.3	80.2	123.5
6	1976	65.0	72.4	48.4	44.4	68.6	150.8	175.2	316.1	230.3	184.8	106.4	86.0	129.0
7	1977	71.7	59.6	51.9	46.1	51.8	108.6	298.5	163.6	215.0	91.9	77.0	63.0	108.2
8	1978	53.7	43.9	39.0	67.9	40.8	288.6	250.6	302.2	349.5	161.1	110.8	92.1	150.0
9	1979	77.4	63.9	55.4	50.3	169.8	172.3	202.0	189.8	130.5	85.0	68.7	57.3	110.2
10	1980	48.2	38.5	35.3	34.3	100.0	233.2	276.1	325.9	296.6	136.6	110.6	91.9	143.9
11	1981	77.0	63.0	54.3	66.8	114.3	186.8	332.4	273.7	293.5	210.5	115.7	96.4	157.0
12	1982	80.6	66.0	63.2	93.9	130.3	234.9	266.8	403.5	382.6	237.7	145.7	120.3	185.5
13	1983	99.9	103.5	86.6	83.9	122.6	164.8	329.2	354.7	308.2	209.1	142.5	111.6	176.4
14	1984	96.0	81.4	64.7	69.1	114.6	178.4	219.9	276.9	262.7	131.7	105.3	86.4	140.6
15	1985	71.6	59.6	51.7	57.9	275.0	296.2	327.1	250.5	241.3	139.2	111.9	95.2	164.8
16	1986	78.8	64.7	55.8	77.1	78.7	201.3	139.2	231.8	202.8	131.3	88.8	73.9	118.7
17	1987	60.5	52.5	41.7	36.3	64.5	211.1	264.3	317.9	320.4	200.3	116.4	96.4	148.5
18	1988	98.1	76.0	70.2	90.4	128.7	301.7	338.4	307.2	255.0	206.9	126.4	105.6	175.4
19	1989	86.7	73.1	70.3	110.6	114.2	268.7	214.7	288.1	233.9	164.2	109.6	91.2	152.1
20	1990	76.6	63.2	60.2	58.0	75.7	346.8	547.0	340.5	300.5	321.0	163.9	133.7	207.3
21	1991	110.5	92.5	78.9	92.1	98.1	190.4	278.1	311.3	245.5	145.4	108.7	89.7	153.4
22	1992	81.0	64.2	56.1	47.5	52.3	186.4	223.7	224.6	155.0	101.3	81.4	74.1	112.3
23	1993	57.3	48.6	38.8	46.5	97.9	232.2	414.1	294.3	198.6	149.7	108.5	89.7	148.0
24	1994	75.8	66.6	69.4	84.3	102.5	247.5	258.3	300.9	249.2	179.7	124.9	100.7	155.0
25	1995	83.4	69.5	58.4	64.4	128.5	210.8	381.5	464.4	306.8	159.6	128.7	107.1	180.3
26	1996	88.0	74.4	63.6	63.2	118.6	220.8	295.1	435.6	288.2	158.0	157.3	110.0	172.7
27	1997	91.4	77.3	67.8	131.3	167.2	190.8	342.6	347.1	337.7	182.0	136.3	112.9	182.0
28	*1998*	*93.8*	*79.6*	*65.0*	*66.2*	*107.6*	*167.9*	247.1	214.9	*185.9*	*104.4*	*85.2*	*71.2*	*124.1*
29	1999	59.0	50.8	43.2	43.8	227.7	251.8	237.4	331.0	292.6	158.0	117.8	98.2	159.3
30	2000	81.9	70.1	58.4	89.7	152.8	229.5	209.4	295.8	305.0	151.2	110.8	91.9	153.9
Average		76.1	64.8	56.9	65.5	112.3	215.4	272.3	291.6	254.7	157.0	110.0	90.4	147.2

Source: JICA Study Team (2002)

The mean annual discharge at the proposed dam site (catchment area of 3,700 km^2) is 147.2 m^3/sec (1,259 mm/annum), with the runoff coefficient of 0.67 (= MAR/MAP = 1,259/1,873 = 0.67) as shown below:

Table 5.5.3 Estimated Runoff Coefficient of Catchment of Dam Site (Average 1971-2000)

C.A.(km2) 3,700

		Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Annual
Basin Mean Rainfall	mm	8.0	16.8	37.6	104.4	231.2	360.6	402.3	379.7	230.0	85.9	12.9	3.9	1,873.4
Avearge Runoff	m^3/sec	76.1	64.8	56.9	65.5	112.3	215.4	272.3	291.6	254.7	157.0	110.0	90.4	147.2
Avearge Runoff	mm	55.1	42.4	41.2	45.9	81.3	150.9	197.1	211.1	178.4	113.6	77.0	65.4	1,259.4
Runooff Coefficient (Annual Avearge)														0.67

This estimated mean annual runoff (MAR) of 147.2 m^3/sec (= specific yield of 4.38 $m^3/sec/100\ km^2$) for the Nam Ngiep-I dam site is also less than previous study results. (i.e. 281 m^3/sec of pre-F/S by *Sogreah*, 210.8 m^3/sec of updated pre-F/S by *Sogreah*, 152 m^3/sec by *Lahmeyer* and 162 m^3/sec by Lahmeyer & Worly). However, the specific yields of MAR for various hydropower projects in Lao PDR are between 1.34 to 7.59 $m^3/sec/100\ km^2$ (average is 4.28 $m^3/sec/100\ km^2$) as shown in the table below.

Hence, the MAR specific yield of 4.38 $m^3/sec/100\ km^2$ for the Nam Ngiep-I dam site is almost the same as the average of the central (Nam Theum, etc.) or north-west zone near the project site (Nam Ngum, etc.) and well within reasonable range of MAR in this region.

Table 5.5.4 Comparison of MAP, MAR and Runoff Coefficient for Major Hydropower Projects in Lao

No.	Project Name	Zone (Area) of Laos	Distance from N.Ngiep [km]	Source (Study by)	Study Year	C.A. [km^2]	MAP [mm/year]	MAR Discharge [m^3/s]	MAR Specific Yield [mm/year]	MAR Specific Yield [$m^3/s/100\ km^2$]	Runoff Coeff.
1	Xe Kaman -1/2	SE	580 km	HEC	1995	3,800	2,100	133.0	1,104	3.50	0.53
2	Se Kaman	SE	580 km	Lahmeyer & Worley (NT2 Alternative Study)	1998	3,800		124.0	1,029	3.26	
3	Xa San (Xe Kong Basin)	SE	550 km	JICA	1993	3,224	2,238	124.0	1,213	3.85	0.54
4	Sekong 4	SE	550 km	Lahmeyer & Worley (NT2 Alternative Study)	1998	5,279		181.0	1,081	3.43	
5	Sekong 5	SE	550 km	Lahmeyer & Worley (NT2 Alternative Study)	1998	2,615		86.0	1,037	3.29	
6	Houay Ho	SE	510 km	Lahmeyer & Worley (NT2 Alternative Study)	1998	192		10.8	1,774	5.63	
7	Xe Katam-1&2	SE	500 km	JICA	1991	290	2,100	9.8	1,061	3.37	0.51
8	Xe Katam-1&2	SE	500 km	HEC Enterprises Corp.	1995	297	2,600	15.3	1,625	5.15	0.62
9	Xe Katam-1	SE	500 km	Lahmeyer & Worley (NT2 Alternative Study)	1998	297		15.0	1,593	5.05	
10	Xe Katam-2	SE	500 km	Lahmeyer & Worley (NT2 Alternative Study)	1998	258		13.0	1,559	5.04	
11	Xe Set -1	SE	470 km	Norconsult	1995	325	3,140	14.6	1,417	4.49	0.45
12	Xe Set -2	SE	480 km	Norconsult	1999	268.5	2,468	11.2	1,315	4.17	0.53
13	Xe Set -3	SE	480 km	Norconsult	1999	187.5	2,587	8.2	1,379	4.37	0.53
14	Xe Don (Sedon) 2	SE	450 km	Nippon Koei & Sogreah	1991	4,090	1,920	129.4	998	3.16	0.52
15	Nam Theum 1	Mid.	70 km	SWECO & HEC	1992	13,800		585.0	1,337	4.24	
16	Nam Theum 1	Mid.	70 km	Lahmeyer & Worley (NT2 Alternative Study)	1998	14,070		687.0	1,540	4.88	
17	Nam Theum 1/2	Mid.	130 km	Norpower	1993	8,937		461.0	1,627	5.16	
18	Nam Theum 2	Mid.	170 km	SMEC	1991	4,013	2,600	241.0	1,894	6.01	0.73
19	Nam Theum 2	Mid.	170 km	Lahmeyer & Worley (NT2 Alternative Study)	1998	4,013		243.0	1,910	6.06	
20	Nam Theum 3	Mid.	170 km	Lahmeyer & Worley (NT2 Alternative Study)	1998	2,282		111.0	1,534	4.86	
21	Theum Hinboun	Mid.	170 km	Lahmeyer & Worley (NT2 Alternative Study)	1998	8,985		471.0	1,653	5.24	
22	B. Hin Heup	Mid.	110 km			5,115	2,414	258.0	1,591	5.04	0.66
23	Xe Bang Hieng (Ban Keng Done)	Mid.	110 km	Hården & Sandborg	1992						
24	Nam Ngiep-1 (Pre-F/S)	NW	0 km	Sogreah & HEC	1991	3,700	3,960	281.0	2,395	7.59	0.81
25	Nam Ngiep-1 (Updateing Pre-F/S)	NW	0 km	Sogreah	1995	3,700	2,960	210.8	1,797	5.70	0.61
26	Nam Ngiep-1	NW	0 km	Lahmeyer & Worley (NT2 Alternative Study)	1998	3,700		162.0	1,381	4.38	
27	Nam Ngum -1	NW	120 km	Beca Worley & Lahmeyer	1993	8,460	2,100	297.0	1,107	3.51	0.53
28	Nam Ngum -1 (Extension)	NW	120 km	Lahmeyer & Worley	1995	8,460	2,100	296.0	1,103	3.50	0.53
29	Nam Ngum -2	NW	90 km	Lahmeyer & Worley	1995	5,750	2,100	163.0	894	2.83	0.43
30	Nam Ngum -2	NW	90 km	Lahmeyer & Worley (NT2 Alternative Study)	1998	5,812		190.0	1,031	3.27	
31	Nam Ngum -3 (Upper damsite)	NW	110 km	SMEC	1995	3,888	1,800	92.0	746	2.37	0.41
32	Nam Ngum -3	NW	110 km	Lahmeyer & Worley (NT2 Alternative Study)	1998	3,899		107.0	865	2.74	
33	Nam Ngum -3 (Lower damsite)	NW	110 km	SMEC	1995	4,335	1,800	108.0	786	2.49	0.44
34	Nam Ngum -5	NW	140 km	Lahmeyer International	1997	483	2,300	22.8	1,489	4.72	0.60
35	Nam Mang -3	NW	50 km	Beca Worley & Lahmeyer	1993	116	2,227	4.1	1,104	3.50	0.50
36	Nam Leuk	NW	70 km	Beca Worley & Lahmeyer	1993	274	2,227	9.6	1,105	3.50	0.50
37	Nam Leuk	NW	70 km	Lahmeyer & Worley (NT2 Alternative Study)	1998	274		15.7	1,807	5.73	
38	Nam Song	NW	130 km	Beca Worley & Lahmeyer	1993	1,303	2,642	80.6	1,951	6.19	0.74
39	Nam Lik	NW	190 km	Hainan SIT Enterprise, Beijing Hydro.IDI	1996	1,993	2,129	88.6	1,402	4.45	0.66
40	Nam Lik	NW	190 km	Lahmeyer & Worley (NT2 Alternative Study)	1998	2,059		100.0	1,532	4.86	
41	Nam Ou	NW	240 km	Lahmeyer & Worley (NT2 Alternative Study)	1998	11,760		303.0	813	2.58	
42	Nam Tha -1	NW	370 km	Acres, RSW, Hydro Quebec	1997	7,630	1,760	168.0	694	2.20	0.39
43	Nam Tha	NW	370 km	Lahmeyer & Worley (NT2 Alternative Study)	1998	7,630		191.0	302	2.54	
44	Nam Xong					1,303	2,642	80.6	1,951	6.19	0.74
45	Se Namnoy			Lahmeyer & Worley (NT2 Alternative Study)	1998	533		28.3	1,674	5.31	
46	Se Pian			Lahmeyer & Worley (NT2 Alternative Study)	1998	293		15.1	1,625	5.15	
47	Houay Makchan			Lahmeyer & Worley (NT2 Alternative Study)	1998	83		4.3	1,634	5.18	
48	Hong Sa			Lahmeyer & Worley (NT2 Alternative Study)	1998	439		5.9	424	1.34	
Average							2,338	-	1,349	4.28	0.56

Notes:

C.A.: Catchment Area MAP: Mean Annual Precipitation (Rainfall) MAR: Mean Annual Runoff

5.6 FLOOD ANALYSIS

5.6.1 GENERAL APPROACH

Flood analysis was carried out to estimate floods of different occurrence probability, as well as the probable maximum flood (PMF), at the proposed Nam Ngiep-I dam site. These flood estimates are required for the design of spillways and diversion facilities, and for determination of the dam height.

To estimate the floods of different occurrence probability, statistical analysis was applied to the observed daily discharge records of the Muang Mai gauging station located 43.6 km downstream of the proposed dam site on the Nam Ngiep River. To estimate the probable maximum flood (PMF), hydrograph analysis was applied. The hydrograph method synthesizes the probable maximum flood (PMF) runoff hydrographs from the probable maximum mean basin precipitation (PMP) from the unit hydrograph, which shows the relationship between a single unit of the basin mean rainfall and runoff. It is generally agreed that the Unit Hydrograph method (Sherman, 1932) is applicable for catchment areas less than 5,000 km^2 (*Linsley et.al, Hydrology for Engineering, Mc.GRATH HILL*).

In this study, the unit hydrograph by *Soil Conservation Service* (SCS), which was empirically developed in USA and has been applied for various water resources development projects, was employed because no long term hourly flood hydrographs are available at the Muang Mai and Ban Hatkham gauging stations for constructing the unit hydrograph. The outline of flood analysis is described in the chart below.

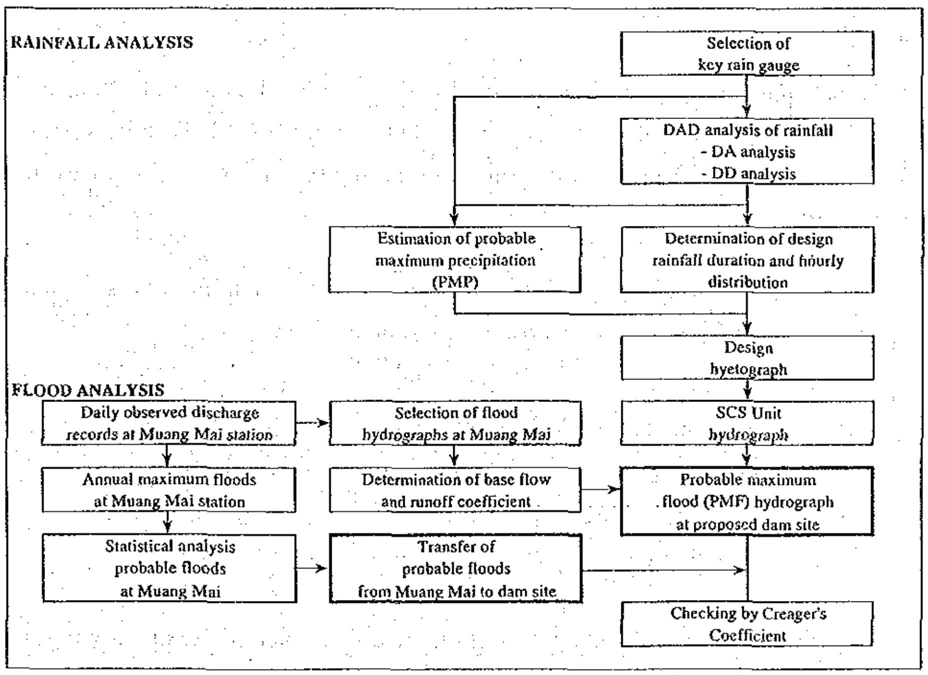


Figure 5.6.1 Overall Work Flow of Flood Analysis

5.6.2 RAINFALL ANALYSIS

(1) Daily Rainfall

Daily rainfall has been recorded at a total of 14 rain gauge stations in/around the Nam Ngiep River basin. The collected daily rainfall records are from the period 1971 to 2000 (30 years). These daily rainfall records will be used in the Depth-Area analysis to estimate the area reduction factor for rainfall for the succeeding flood analysis.

(2) Hourly Rainfall

Hourly rainfall has been recorded at Pakxan, Xieng Khuang, Muang Mai, Vientiane (DMH) and Ban Thaviang (JICA) gauge stations in/around Nam Ngiep River basin. However, in this study, only one (Thaviang) station's hourly rainfall record is collected to estimate the rainfall pattern in the basin for succeeding flood analysis. The Ban Thaviang automatic rainfall gauging station, which is located in the center of the project basin was established by the JICA Study Team in September, 1998 (Phase-I study period).

(3) Depth-Area-Duration (DAD) Analysis

DAD analysis is carried out to examine the following relationships.

i) Relationship between rainfall depth and area (DA analysis), and

ii) Relationship between rainfall depth and duration (DD analysis)

<u>Depth-Area (DA) Analysis</u>

Heavy rainfall occurs intensively for a short duration and in a limited area in the Nam Ngiep River basin. Therefore the average depth of rainstorm (basin mean rainfall) is likely to be smaller than the depth of point rainstorm. Depth-Area analysis aims at obtaining the area reduction factor to estimate the basin mean rainfall.

In general, the relationship between point rainfall depth and average rainfall area is expressed by an exponential equation, known as *Horton*'s equation as presented below.

$$P_b = P_o * exp\,[-kA^n]$$

Where, P_b : Average rainfall depth over an area A [mm]

P_o : Maximum point rainfall depth at the storm center [mm]

A : Area in question [km^2]

k, n : Constant for a given area

To estimate the basin mean rainfall from point rainfall, the area reduction factor showing the ratio of basin mean rainfall is introduced as expressed below.

$$P_b = f_a * P_o$$

Where, P_b : Basin mean rainfall depth [mm]

P_o : Point rainfall depth [mm]

f_a : Area reduction factor

If *Horton*'s equation is applied, the area reduction factor under the given rainfall duration is given by the following equation.

$$f_a = exp\ [-kA^n]$$

Firstly, the area reduction factor is estimated at 0.46 for the catchment area of 3,700 km^2 for the proposed Nam Ngiep-I dam site by applying *Horton*'s equation assuming that constant k and n are 0.1 and 0.25, respectively. These constants have been widely and empirically applied for 24 hours rainfall in tropical forest rain areas.

Secondly, the relationship between daily point rainfall and daily basin mean rainfall at the proposed Nam Ngiep-I dam site is analyzed to estimate the area reduction factor of the river basin. The selected rainfall stations for this analysis were Pakthouay, Pakxan, Muang Mai, Munag Kao, Naluang, Tadleuk, Thabok and Vang Vieng (eight stations) in/around the Nam Ngiep River basin. These stations have heavy rainfall records every year. The basin mean rainfall is determined by averaging the annual maximum daily point rainfall at a certain rain gauge station and the corresponding basin mean rainfall on the same date by *Thiessen*'s polygon method. The point rainfall is plotted against the area reduction factor as shown in Figure 5.6.2.

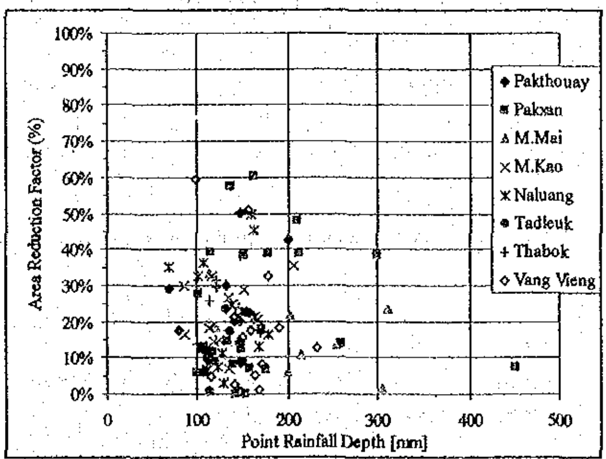
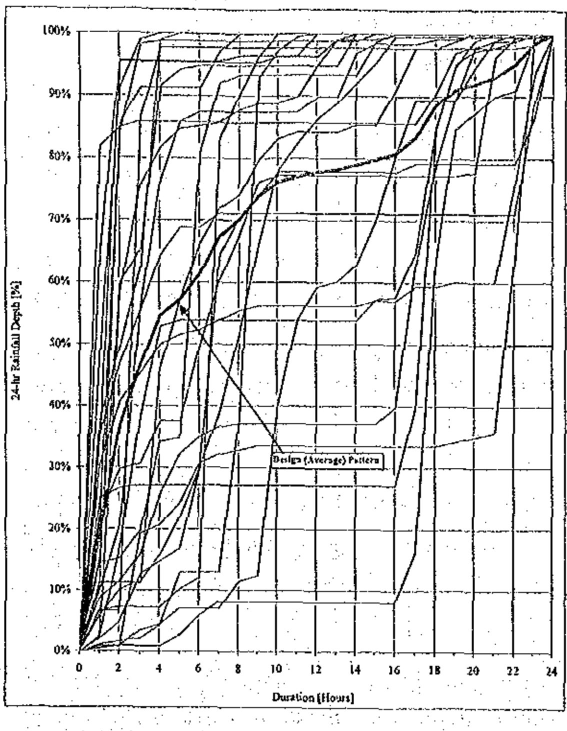


Figure 5.6.2 Area Reduction Factor of Point Rainfall to the Basin Mean Rainfall at the Proposed Nam Ngiep-I Dam Site Catchment (24 hour rainfall)

The area reduction factor showing the ratio of area rainfall to the maximum point rainfall varies from 0.01 to 0.60 for the area rainfall. In due consideration of the above, the design area reduction factor was conservatively determined to be 0.60, which is an envelope for the area reduction factor.

Depth-Duration (DD) Analysis

Observed hourly rainfall records at the Ban Thaviang rainfall gauge station exceeding 45 mm within 24 hours were selected to estimate the hourly rainfall hyetograph of heavy storm rainfall. Figure 5.6.3 shows the accumulated hourly rainfall curves of selected rain storms around the project basin.



Average Rainfall Pattern (24-hr)

Time	Depth
0	0%
1	19%
2	37%
3	47%
4	55%
5	57%
6	61%
7	67%
8	70%
9	74%
10	76%
11	77%
12	78%
13	78%
14	79%
15	80%
16	81%
17	84%
18	89%
19	91%
20	92%
21	93%
22	95%
23	99%
24	100%

Figure 5.6.3 Accumulated Hourly Rainfall Pattern (24-hr Rainfall) at B.Thaviang Station

Based on the above, the rainfall hyetograph duration of 24 hours was adopted as the design rainfall hyetograph for estimating the probable maximum flood (PMF).

(4) Probable Maximum Rainfall (PMP)

There are broadly four approaches for estimating the probable maximum precipitation (PMP) as follows.

i) Meteorological (theoretical) approach in consideration of the upper physical limit of moisture source;

ii) A statistical approach that was empirically developed by *Hershfield* based on rainfall records in the USA. The method was explained in the "Manual for estimation of probable maximum precipitation, operational hydrology report No.1", *World Meteorological Organization (WMO)* -No.332;

iii) Historical approach by examining the historical maximum rainfall ever occurred in the area of interest; and

iv) *U.S. Weather Bureau* method for the Mekong River Basin.

Due to the limited meteorological date in/around the Nam Ngiep River basin, methods ii) and iv) were applied to estimate the probable maximum precipitation (PMP) in this study.

a) *Hershfield* Method (WMO, 332)

Result of the estimation of PMP by the *Hershfield* (WMO, 332) method is shown below.

Table 5.6.1 Estimated PMP for Nam Ngiep-I Dam Catchment By Using *Hershfield*'s Method

	24 hr PMP	48 hr PMP	72 hr PMP
PMP for Nam Ngiep Dam Catchment (3,700 km^2)	590	690	730

b) U.S. Weather Bureau Method

To estimate of the Probable Maximum Rainfall (PMP), the *U.S. Weather Bureau* (1970) method was used due to limited rainfall and meteorological data such as dew point, humidity, wind velocity in the project area. Generalized PMP estimates for the Lower Mekong River basin were carried out by the *Hydrometeorological Branch Office of Hydrology, US Weather Bureau* in 1970. In this study a detailed description was given of the meteorological regimes prevailing in this region, synoptic situations associated with large storms and the application of the procedures of the *World Meteorological Organization (WMO, 1986) manual.*

The result of the estimated PMP for the Nam Ngiep-I catchment is shown in Table 5.6.2.

Table 5.6.2 Estimated PMP for Nam Ngiep-I Dam Catchment By Using USWB Method

	6 hr	12 hr	24 hr	36 hr	48 hr	72 hr
PMP at Vietnam Coast for 3700 km^2 *1)	383	590	786	860	897	937
Total Adjustment Factor *1)	80%	80%	80%	80%	80%	80%
PMP for Nam Ngiep Dam Catchment (3,700 km^2)	310	480	630	690	720	750

Source: *1): US Weather Bureau (1970), "Probable Maximum Precipitation, Mekong River Basin" Hydrometeorological Report No.46
Note: Estimated values are rounded up near 10 values.

5.6.3 HYDROGRAPH ANALYSIS

(1) Unit Hydrograph

As explained above, the unit hydrograph developed by the *Soil Conservation Service* (SCS) synthetic unit hydrograph method is shown below.

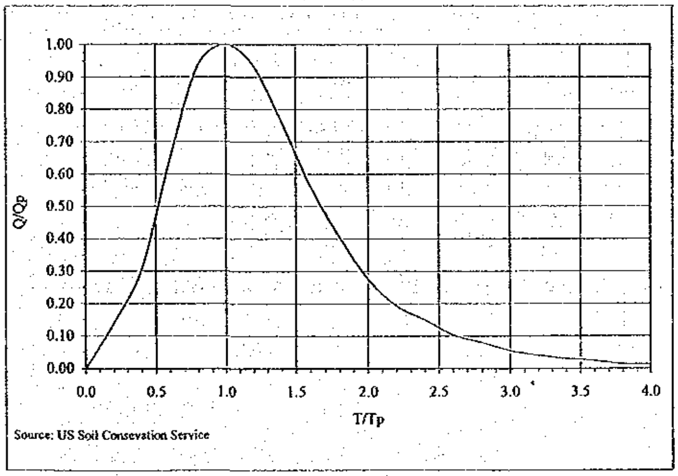


Figure 5.6.4 Standard Dimensionless Hydrograph by Soil Conservation Service (SCS)

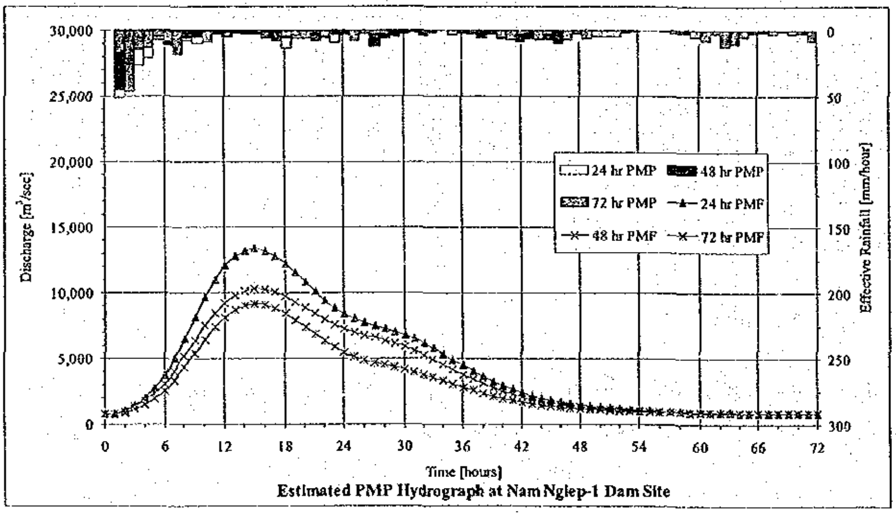
(2) Probable Maximum Flood (PMF)

Since hourly rainfall records in the project catchment were insufficient, the unit hydrograph at the Nam Ngiep-I dam site was developed by means of the *Soil Conservation Service* (SCS) synthetic unit hydrograph method.

The SCS method was developed by analyzing a large number of basins from various geographic locations. Unit hydrographs were evaluated for a large number of actual watersheds and then made dimensionless by dividing all discharge ordinates by the peak discharge and the time ordinates by the time to peak. The average of these dimensionless unit hydrographs was computed.

The SCS unit hydrograph is derived from the flood concentration time and unit basin mean rainfall. The unit hydrograph is constructed for a unit rainfall of 1 mm.

The PMF hydrographs and estimated peak discharge calculated using the SCS unit hydrograph and PMP calculated firstly by *Hershfield*'s method, and secondly by the *U.S. Weather Bureau* method, are shown and summarized in Figures 5.6.5 and 5.6.6 respectively.

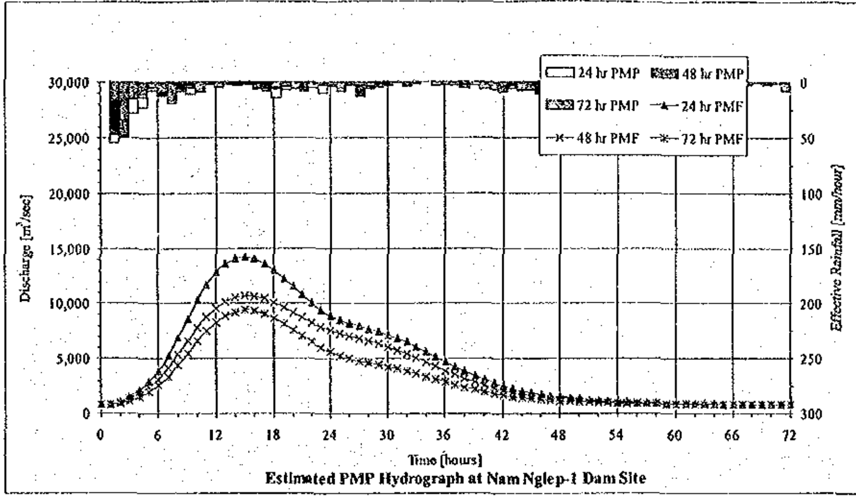


C.A.[km2] = 3,700

Duration of PMP [hours]	PMP [mm]	PMF Peak Discharge [m3/sec]	Specific yeald [m3/sec/100km2]
24 hr	590	13,370	361
48 hr	690	10,320	279
72 hr	730	9,180	248

Assumed Base flow [m3/s]	800
Direct Runoff Coefficient	0.45

Figure 5.6.5 PMF Hydrograph at Proposed Nam Ngiep-I Dam Site (PMP by *Hershfield*'s Method)



C.A.[km2] = 3,700

Duration of PMP [hours]	PMP [mm]	PMF Peak Discharge [m3/sec]	Specific yeald [m3/sec/100km2]
24 hr	630	14,220	384
48 hr	720	10,740	290
72 hr	750	9,410	254

Assumed Base flow [m3/s]	800
Direct Runoff Coefficient	0.45

Figure 5.6.6 PMF Hydrograph at Proposed Nam Ngiep-I Dam Site (PMP by USWB Method)

In these results, the peak discharge of the 24-hr PMF is the most critical value; 13,370 m^3/sec by *Hershfield*'s method and 14,220 m^3/sec by *U.S. Weather Bureau* method. These values are slightly lower than the results of previous study, i.e. 15,900 m^3/sec.

For reference, the final report of the study for *"Power System Planning in the Ministry of Industry and Handicraft", (Knight Piésold 1998)* summarized PMF envelope curve formulas for various hydropower studies as below:

For the Se Kong River basin, (JICA 1995), *Creager's* formula was used to set up an envelope curve based on floods in Lao, Thailand, Vietnam and Cambodia. The Probable Maximum Flood (PMF) is given by

$$Q_{PMF} = 61 * A^{A^{(-0.05)}}$$

Where; A is catchment area [km^2].

In a study of floods for the Nam Ngum-3 project (SMEC 1996), the resulting values were then compared to PMF estimates for other major dam projects in tropical areas, and found to lie close to the best fit relationship, given by:

$$Q_{PMF} = 206.4 * A^{0.5271}$$

Table 5.6.3 Comparison of PMF and Design Flood for Major Hydropower Projects in Laos

No.	Project Name	Zone (Area) of Laos	Distance from N Ngiep (km)	Source (Study by)	Study Year	C.A. (km²)	PMF (n-days) Peak Q (m³/s)	Specific Yield (m³/s/100 km²)	Vol. (MCM)	Duration
1	Xe Kaman-1/2	SE	580 km	HEC	1995	3,800	13,000	342		1 days
2	Se Kaman	SE	580 km	Lahmeyer & Worley (NT2 Alternative Stud	1998	3,800	13,000	342		
3	Xa San (Xe Kong Basin)	SE	550 km	JICA	1993	3,224				
4	Sekong 4	SE	550 km	Lahmeyer & Worley (NT2 Alternative Stud	1998	5,279				
5	Sekong 5	SE	550 km	Lahmeyer & Worley (NT2 Alternative Stud	1998	2,615				
6	Houay Ho	SE	510 km	Lahmeyer & Worley (NT2 Alternative Stud	1998	192	1,220	635		
7	Xe Katam-1&2	SE	500 km	JICA	1991	290				
8	Xe Katam-1&2	SE	500 km	HEC Enterprises Corp.	1995	297				
9	Xe Katam-1	SE	500 km	Lahmeyer & Worley (NT2 Alternative Stud	1998	297				
10	Xe Katam-2	SE	500 km	Lahmeyer & Worley (NT2 Alternative Stud	1998	258				
11	Xe Set -1	SE	470 km	Norconsult	1985	323				
12	Xe Set -2	SE	480 km	Norconsult	1999	268.5				
13	Xe Set -3	SE	480 km	Norconsult	1999	187.5				
14	Xe Don (Sedon) 2	SE	450 km	Nippon Koei & Sogreah	1991	4,090	14,600	357	7,750	13 days
15	Nam Theun 1	Mid.	70 km	SWECO & HEC	1992	13,800	32,000	232		15 days
16	Nam Theun 1	Mid.	70 km	Lahmeyer & Worley (NT2 Alternative Stud	1998	14,070	34,100	242		
17	Nam Theun 1/2	Mid.	130 km	Norpower	1993	8,937	19,700	220		
18	Nam Theun 2	Mid.	170 km	SMEC	1991	4,013	13,515	337	9,615	15 days
19	Nam Theun 2	Mid.	170 km	Lahmeyer & Worley (NT2 Alternative Stud	1998	4,013	13,515	337		
20	Nam Theun 3	Mid.	170 km	Lahmeyer & Worley (NT2 Alternative Stud	1998	2,282				
21	Theum Hinboun	Mid.	170 km	Lahmeyer & Worley (NT2 Alternative Stud	1998	8,985				
22	B. Hin Heup	Mid.	110 km			5,115				
23	Xe Bang Hieng (Ban Keng Done)	Mid.	110 km	Harden & Sandborg	1992					
24	Nam Ngiep-1 (Pre-F/S)	NW	0 km	Sogreah & HEC	1991	3,700	15,900	430		
25	Nam Ngiep-1 (Updateing Pre-F/S)	NW	0 km	Sogreah	1995	3,700	15,900	430		
26	Nam Ngiep-1	NW	0 km	Lahmeyer & Worley (NT2 Alternative St	1998	3,700	15,900	430		
27	Nam Ngum -1	NW	120 km	Beca Worley & Lahmeyer	1993	8,460				
28	Nam Ngum -1 (Extension)	NW	120 km	Lahmeyer & Worley	1995	8,460	8,800	104		1 days
29	Nam Ngum -2	NW	90 km	Lahmeyer & Worley	1995	5,750				
30	Nam Ngum -2	NW	90 km	Lahmeyer & Worley (NT2 Alternative Stud	1998	5,812	10,890	187		
31	Nam Ngum -3 (Upper damsite)	NW	110 km	SMEC	1995	3,888	12,150	313		3 days
32	Nam Ngum -3	NW	110 km	Lahmeyer & Worley (NT2 Alternative Stud	1998	3,899	12,156	312		
33	Nam Ngum -3 (Lower damsite)	NW	110 km	SMEC	1995	4,335	15,260	352		3 days
34	Nam Ngum -5	NW	140 km	Lahmeyer International	1997	483				
35	Nam Mang -3	NW	50 km	Beca Worley & Lahmeyer	1993	136				
36	Nam Leuk	NW	70 km	Beca Worley & Lahmeyer	1993	274				
37	Nam Leuk	NW	70 km	Lahmeyer & Worley (NT2 Alternative Stud	1998	274				
38	Nam Song	NW	130 km	Beca Worley & Lahmeyer	1993	1,303				
39	Nam Lik	NW	190 km	Hainan SIT Enterprise, Beijing Hydro IDI	1996	1,993	-	-		-
40	Nam Lik	NW	190 km	Lahmeyer & Worley (NT2 Alternative Stud	1998	2,059	-	-		-
41	Nam Ou	NW	240 km	Lahmeyer & Worley (NT2 Alternative Stud	1998	11,760				
42	Nam Tha -1	NW	370 km	Acres, RSW, Hydro Quebec	1997	7,630	15,000	197		
43	Nam Tha	NW	370 km	Lahmeyer & Worley (NT2 Alternative Stud	1998	7,630	15,000	197		
44	Se Namnoy			Lahmeyer & Worley (NT2 Alternative Stud	1998	533	3,860	724		
45	Se Pian			Lahmeyer & Worley (NT2 Alternative Stud	1998	293	1,980	676		
46	Houay Makchan			Lahmeyer & Worley (NT2 Alternative Stud	1998	83	900	1,084		
47	Hong Sa			Lahmeyer & Worley (NT2 Alternative Stud	1998	459				
48	Khao Laem (Thailand)	Thailand		SMEC, NT2 HEPP (1991)	1976	3,720	7,100	191		
49	Nam Noi (Thailand)	Thailand		SMEC, NT2 HEPP (1991)	1986	4,220	8,350	198		
50	Prek Thnot (Cambodia)	Cambodia		SMEC, NT2 HEPP (1991)	1990	3,630	41,000	1,129		
51	Ahning (Malaysia)	Malaysia		SMEC, NT2 HEPP (1991)	1984	120	2,580	2,150		
52	Klang Gates (Malaysia)	Malaysia		SMEC, NT2 HEPP (1991)	1984	77	1,610	2,091		
53	Batu (Malaysia)	Malaysia		SMEC, NT2 HEPP (1991)	1984	50	915	1,830		
54	Batang Ai (Malaysia)	Malaysia		SMEC, NT2 HEPP (1991)	1974	1,200	6,122	510		
55	Kenyir (Malaysia)	Malaysia		SMEC, NT2 HEPP (1991)	1976	2,600	15,470	595		
56	Kedung Ombo (Indonesia)	Indonesia		SMEC, NT2 HEPP (1991)	1982	614	8,000	1,303		
57	Jatigede (Indonesia)	Indonesia		SMEC, NT2 HEPP (1991)	1977	1,460	10,500	719		
58	Yonki (Papua New Guinea)	PNG		SMEC, NT2 HEPP (1991)	1985	851	14,230	1,672		
59	Ok Menga (Papua New Guinea)	PNG		SMEC, NT2 HEPP (1991)	1982	231	8,000	3,463		
60	Copperlode Falls (Australia)	Australia		SMEC, NT2 HEPP (1991)	1976	44	1,360	3,091		
61	Moochalabra (Australia)	Australia		SMEC, NT2 HEPP (1991)	1971	57	1,800	3,158		
62	Warragamba (Australia)	Australia		SMEC, NT2 HEPP (1991)	1960	47,100	56,600	120		
Average							-	830		-

Using the above two formulas, the PMF for the Nam Ngiep-I dam site is estimated at 14,173 m³/sec and .15,686 m³/sec, respectively.

Hence, the estimated PMF value of 14,220 m³/sec for the Nam Ngiep-I dam site in this study is well within the reasonable range of values in the region.

(3) Probable Floods

Probable flood discharges for various return periods are estimated based on the observed daily discharge records at the Muang Mai water level gauging station for the period of 1978 to 2000.

The frequency curve at the Muang Mai water level gauging station is shown in Figure 5.6.7.

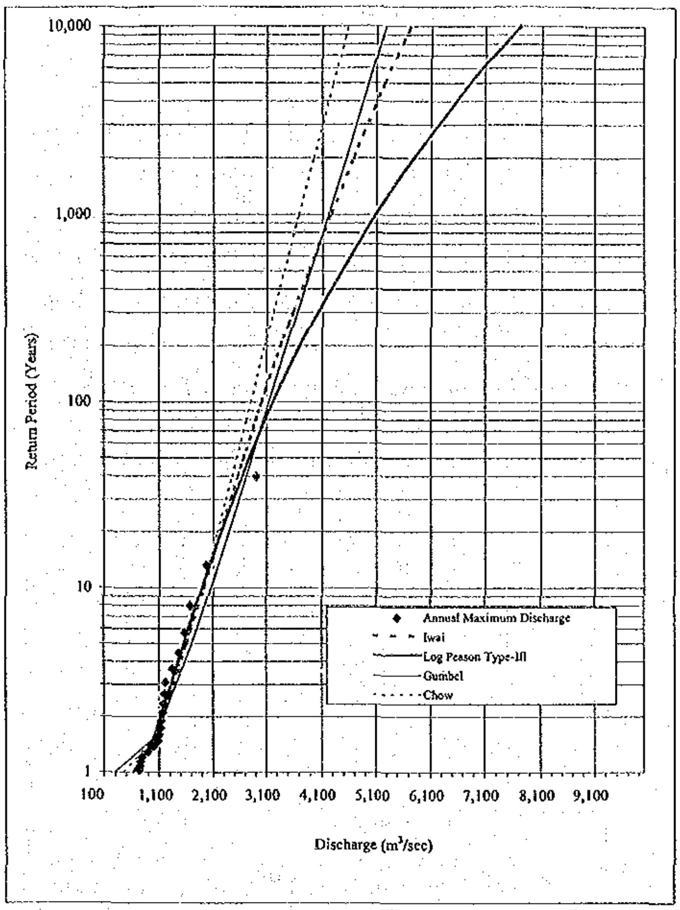


Figure 5.6.7 Frequency Curve for Annual Maximum Daily Mean Discharge at Muangmai WL Station [C.A.=4,320 km^2]

For the applied frequency curves in Figure 5.6.7, the "*Log Pearson Type-III*" method provides the most fit. The estimated probable flood peak discharges at the proposed Nam Ngiep-I dam site for a series of return periods are enumerated in Table 5.6.4.

Table 5.6.4 Probable Flood Peak Discharge at Proposed Nam Ngiep-I Dam Site

Return Period (Year)	Excess Probability	Flood Peak Discharge (m^3/sec)
1.01	0.9901	680
1.50	0.6667	1,000
2	0.5000	1,150
5	0.2000	1,590
10	0.1000	1,930
20	0.0500	2,300
30	0.0333	2,530
40	0.0250	2,700
50	0.0200	2,840
80	0.0125	3,140
100	0.0100	3,290
200	0.0050	3,800
300	0.0033	4,130
500	0.0020	4,560
1,000	0.0010	5,210
2,000	0.0005	5,930
5,000	0.0002	7,000
10,000	0.0001	7,920

Note: (Peak Discharge at Muang Mai) = (Daily Mean Maximum Discharge at Muang Mai) x 1.2

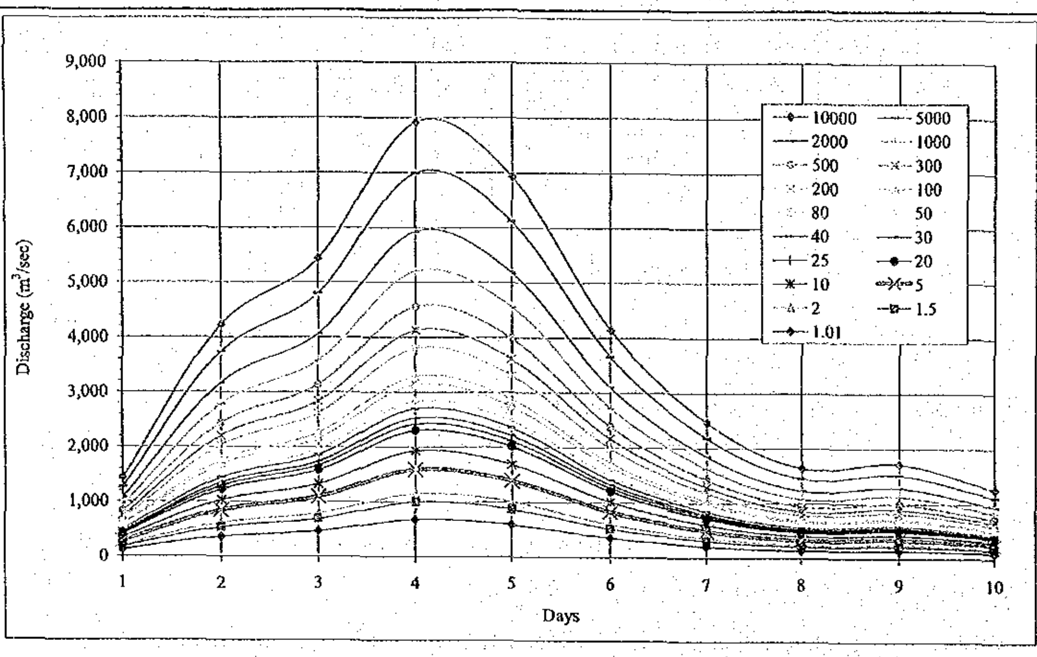
(Dam Site Flow) = (Muang Mai Flow) x 3,700 / 4,320

Frequency curve was applied "Log Peason Type-III"

(4) Hydrographs of Probable Floods

Hydrographs of probable floods at the proposed Nam Ngiep-I dam site were prepared by using a flood hydrograph recorded at the Muang Mai gauging station and scaling the results by the ratio of peak discharges. The July 1993 flood was selected as a representative flood hydrograph pattern as it represents the maximum observed flood during the period of 1988~2000, which is the period when stage-flow (H-Q) rating curves are available for the Muang Mai gauging station. Incidentally, the observed maximum water level (H = 10.98 m) at the Muang Mai gauging station was recorded on the 25th of July 1980.Discharge measurements were not available before 1997.

Estimated flood hydrographs of various flood probabilities at the proposed Nam Ngiep-I dam site are shown in the Figure 5.6.8 below.



Day	Obs.Q at M.Mai (m³/s)	Estimated Flood Discharge at Dam Site (m³/sec)																		
		Return Period (Year)																		
		1.01	1.5	2	5	10	20	25	30	40	50	80	100	200	300	500	1000	2000	5000	10000
1	284	123	181	208	288	349	416	438	458	488	514	568	595	687	747	825	942	1,073	1,266	1,433
2	838	363	534	614	849	1,030	1,228	1,292	1,350	1,441	1,516	1,676	1,756	2,028	2,204	2,434	2,781	3,165	3,736	4,227
3	1,077	466	686	789	1,091	1,324	1,578	1,660	1,736	1,852	1,948	2,154	2,257	2,607	2,833	3,128	3,574	4,068	4,802	5,433
4	1,570	680	1,000	1,150	1,590	1,930	2,300	2,420	2,530	2,700	2,840	3,140	3,290	3,800	4,130	4,560	5,210	5,930	7,000	7,920
5	1,373	595	875	1,006	1,390	1,688	2,011	2,116	2,213	2,361	2,484	2,746	2,877	3,323	3,612	3,988	4,556	5,186	6,122	6,926
6	821	356	523	601	831	1,009	1,203	1,265	1,323	1,412	1,485	1,642	1,720	1,987	2,160	2,385	2,724	3,101	3,661	4,142
7	490	212	312	359	496	602	718	755	790	843	886	980	1,027	1,186	1,289	1,423	1,626	1,851	2,185	2,472
8	325	141	207	238	329	400	476	501	524	559	588	650	681	787	855	944	1,079	1,228	1,449	1,639
9	341	148	217	250	345	419	500	526	550	586	617	682	715	825	897	990	1,132	1,288	1,520	1,720
10	251	109	160	184	254	309	368	387	404	432	454	502	526	608	660	729	833	948	1,119	1,266

Note) Obs.Q at M.Mai : observed flood discharge at Muang Mai WL Station during 14 to 21 July, 1993.

Figure 5.6.8 Probable Flood Hydrographs at Proposed Nam Ngiep-I Dam Site

(5) Dry-Season's Probable Floods

Probable flood data (peak discharge) during the dry-season from November to March are necessary when considering the design of temporary facilities. The observed discharge at the Muang Mai gauging station from 1978 to 2000was used with a "*Log Peason Type-III*" frequency curve to estimate probable flood peak discharges at the proposed Nam Ngiep-I dam site for respective return periods, as shown in the table below.

Table 5.6.5 Probable Flood Peak Discharge during Dry-Season (November - March)at Dam Site

Return Period (Year)	Excess Probability	Dry-Season's Flood Peak Discharge (m^3/sec)
2	0.5000	156.6
5	0.2000	215.6
10	0.1000	255.4
20	0.0500	294.2
25	0.0400	306.6
30	0.0333	316.8
40	0.0250	332.8
50	0.0200	345.4

(6) *Creager*'s Coefficient for PMF and Other Floods at the Nam Ngiep-I Dam Site

Creager's coefficient for flood calculation is computed by the following equations.

$$Q_p = (46 * 0.02832) * C * (0.3861 * A)^a$$

$$a = 0.894 * (0.3861 * A)^{-0.048}$$

Where, Q_p : Peak discharge [m^3/sec]

C : *Creager*'s coefficient

A : Catchment area [km^2]

Figure 5.6.9 shows the relationship between flood peak discharge and catchment area for floods with return periods of 1,000 and 10,000 years and also for the PMF for the Nam Ngiep-I HEPP and other water resources development projects in Lao PDR. The estimated floods at the Nam Ngiep-I dam site are well within the reasonable range of comparative design floods in the region.

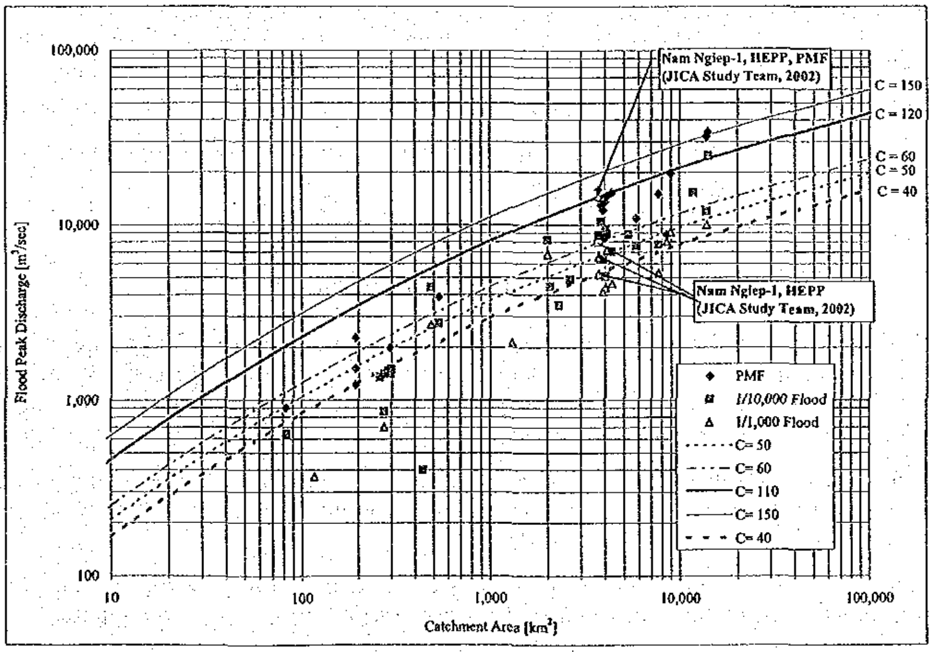


Figure 5.6.9 Probable Floods, PMF for the various Hydropower Projects in Lao

5.7 RESERVOIR NET EVAPORATION

The net evaporation rate from the reservoir surface water (lake evaporation losses) was estimated based on monthly pan-evaporation records at Vangvieng, Vientiane, Xiengkhouang and Pakxan meteorological stations and basin mean rainfall. Actual evaporation from the reservoir surface is known to be less than that from a pan because of the large thermal inertia of the lake and susceptibility of the pan to heat gains from radiation.

Values of pan coefficients generally lie in the range 0.7 to 0.8 although much higher coefficients are considered to be appropriate for humid coastal regions and a factor of 0.85 has been recommended. In this study, the pan coefficient is assumed as 0.8. The estimated monthly evaporation is shown below:

Table 5.7.1 Estimated Net Evaporation from Reservoir Surface for Nam Ngiep-I HEPP

Unit: mm

Month	1 Jan.	2 Feb.	3 Mar.	4 Apr.	5 May	6 Jun.	7 Jul.	8 Aug.	9 Sep.	10 Oct.	11 Nov.	12 Dec.	Annual Total
Open Water Evaporation	131.4	113.1	133.9	115.2	75.6	75.6	95.5	95.5	98.4	114.1	108.0	111.6	1,268.0
Rainfall In Res.W. Surface	8.0	16.8	37.6	104.4	231.2	360.6	402.3	379.7	230.0	85.9	12.9	3.9	1,873.4
Net Evaporation form Res. W.Surface	123.5	96.3	96.3	10.8	0.0	0.0	0.0	0.0	0.0	28.2	95.1	107.7	557.8

5.8 RESERVOIR SEDIMENTATION

Since no measurement data related to sediments in the Nam Ngiep River are available, the following approach was taken to estimate of reservoir sedimentation for this study.

(1) Mean Annual Sediment Yield (Specific Sediment Discharge) for Nam Ngiep-I (C.A. = 3,700 km^2) proposed dam site is estimated from the following formula.

$$S = 488 * A^{-0.01}$$

(Source: *Lahmeyer International (1997), "Hydropower Development Plan for the Lao PDR" Hydropower Inventory"*)

where S: average annual specific sediment discharge [tonnes/km^2/year],

A: drainage area [km^2]

Therefore, S = 488 * 3,700 ^ (-0.01) = 450

= around 500 [tonnes/km^2/year] was assumed.

(2) Sediment density for the Nam Ngiep-I dam site is assumed as 1,300 kg/m^3 as sediment samples from the bed of reservoirs have densities varying from 500-1,800 kg/m^3 (*Murthy*, 1977). (Source: *Murthy, B. N., 1977. "Reservoir sedimentation, life and remedial measures", Symposium on Silting Reservoirs. India, Cent. Board Irrig. Power, Publ. No. 126; Vol.1, pp.123 -134*)

(3) The capacity-inflow ratio for Nam Ngiep-I dam project will be 0.5 depended on the ratio of gross storage volume / annual mean inflow volume (= 2,279 MCM / 4,541 MCM = 0.502)

According to the *Brune* curves (*U.S. Bureau of Reclamation, 1974*), the trap efficiency will be 95% using the value of capacity-inflow ratio (0.5).

Estimated reservoir sedimentation is shown blow:

Table 5.8.1 Sediment Yield of Major Hydropower Projects in Laos

No.	Project Name or Name of River	Zone (Area) of Laos	Distance from N.Ngiep [km]	Source (Study by)	Study Year	C.A. [km²]	(Rate of Erosion) Specific Sediment Yield [t/km²/year]	Deposition Rate [t/year]	Suspended Sediment Concentration [kg/m³]	Sediment Bulk Density [kg/m³]	Trap Efficiency [%]	Annual Sediment Inflow Vol. [MCM/year]	Rate of Denudation [mm/year]
1	Xe Kaman -1/2	SE	580 km	HECEC Australia	1995	3,800	410	1,558,000		1,000	100%	1.56	0.41
2	Xa San (Xe Kong Basin)	SE	550 km	JICA	1993	3,224							
3	Houay Ho	SE	510 km	Hydroconsul	1993	223	404	0					
4	Xe Katam-1&2	SE	500 km	JICA	1992	290	300	0					
5	Xe Katam-1&2	SE	500 km	HEC Enterprises Corp.	1995	297							
6	Xe Set -1	SE	470 km	Norconsult	1985	325	431	0					
7	Xe Set -2	SE	480 km	Norconsult	1999	268.5							
8	Xe Set -3	SE	480 km	Norconsult	1999	187.5							
9	Xe Don (Sedon) 2	SE	450 km	Nippon Koei & Sogreah	1991	4,090	193	790,000			100%	6.00	
10	Nam Theun 1	Mid.	70 km	SWECO & HEC	1992	13,800							
11	Nam Theun 1/2	Mid.	130 km	Norpower	1993	8,937	73	650,000					
12	Nam Theun 2	Mid.	170 km	SMEC	1991	4,013	73	0					0.05
13	Nam Theun 2 (Alternative Study)	Mid.	170 km	Lahmeyer & Worley	1997	4,013	300	1,203,900					
14	Nam Theum	Mid.	170 km	Mekong Secretariat	1986	14,700	488	7,173,600					
15	B. Hin Heup	Mid.	110 km			5,115	212	0					
16	Xe Bang Hieng (Ban Keng Done)	Mid.	110 km	Hården & Sundborg	1992	19,400	345	0					
17	Nam Ngiep-1 (Pre-F/S)	NW	0 km	Sogreah & HEC	1991	3,700	< 2,400	< 8,880,000		1,300	100%	< 6.80	< 1.85
18	Nam Ngiep-1 (Updateing Pre-F/S)	NW	0 km	Sogreah	1995	3,700	< 1,800	< 6,660,000		1,300	100%	< 5.10	< 1.38
19	Nam Ngiep-1 (This Study)	NW	0 km	JICA	2002	3,700	*1) 500	1,850,000		*2) 1,300	*3) 95%	1.35	0.38
20	Nam Ngum -1	NW	120 km	Beca Worley & Lahmeyer	1993	8,460		2,350,000					
21	Nam Ngum -1 (Extension)	NW	120 km	Lahmeyer & Worley	1995	8,460							
22	Nam Ngum -2	NW	90 km	Lahmeyer & Worley	1995	5,750							
23	*Nam Ngum -3 (Upper dam, Present)*	NW	110 km	SMEC	1995	3,888	85	328,700	0.085	(460 *4)	93-99%	0.72	0.18
24	Nam Ngum -3 (Lower dam, Present)	NW	110 km	SMEC	1995	4,335	85	366,490	0.085	(460 *4)	90-98%	0.72	0.18
25	Nam Ngum -3 (Upper damsite, Plan)	NW	110 km	SMEC	1995	3,888	423	1,643,500	0.085	(459 *4)	93-99%	3.57	0.90
26	Nam Ngum -3 (Lower damsite, Plan)	NW	110 km	SMEC	1995	4,335	423	1,832,450	0.085	(460 *4)	90-98%	3.98	9.90
27	Nam Ngum -5	NW	140 km	Lahmeyer International	1997	483	459	221,578		1,160	100%	0.22	0.40
28	Nam Mang -3	NW	50 km	Beca Worley & Lahmeyer	1993	116		40,000					
29	Nam Leuk	NW	70 km	Beca Worley & Lahmeyer	1993	274	347	95,000					
30	Nam Song	NW	130 km	Beca Worley & Lahmeyer	1993	1,303	277	415,000					
31	Nam Lik	NW	190 km	Hainan SIT Enterprise, Beijing Hy	1996	1,993	40	79,300	0.028				
32	Nam Tha -1	NW	370 km	Acres, RSW, Hydro Quebec	1997	7,630	137	1,048,000					
33	Houay Namsai -1						429						
34	Houay Namsai -2						417						

Note
*4) This value is dry bulk densiy for the Nam Ngum from: Uppsala University study.

According to the Updated Pre-F/S Report (No.19) in 1995, the specific sediment yield was estimated between 1,800t/km²/year in the report and 347t/km²/year in the Nam Leuk HEPP (No.29).

5.9 RECOMMENDATIONS OF SUPPLEMENT STUDY

For the implementation of the Project, more reliable hydrological data will be required. The following additional/continual studies and installation of additional facilities are proposed.

Rainfall Gauging Stations

(1) Continuation of rainfall observations at three-(3) rainfall gauging stations (i.e. Ban Thaviang, Ban Namche and Ban Thamlo).

(2) Re-examination of the location of the above three rainfall gauging stations considering O&M requirements.

(3) Improvement of the above three-(3) rain gauge stations (addition of the data logger system)

(4) Study of telemetry systems for rainfall and water level measurement in the basin (future).

Meteorological Stations (New)

(5) Installation of new automatic meteorological gauging stations (four-(4) sites in the basin. Proposed observation items: rainfall, temperature, humidity, wind velocity, wind direction, atmospheric pressure and pan-evaporation).

Water Level Gauging Stations

(6) Continuation of daily water level observation at the Ban Hatkham water level gauging station.

(7) Installation of an automatic water level gauge at the Ban Hatkham gauging station (pressure/bubble/float type, every 10 minute automatic measuring)

(8) It is possible to conclude the observation at the Ban Thahua water level gauging station in the Nam Xao River.

Discharge Observation

(9) Continuation of discharge measurement at the Ban Hatkham gauging station (once in 3-month).

(10) Update of stage-flow (H-Q) curves at the Ban Hatkham gauging station using above observation data.

(11) Installation of concrete anchor points at both riversides (around 1.0 m pitch) to suspend rope/wire across the river for sectional survey of discharge measurement.

Sediment Survey

(12) As an additional survey on the sediment yield, suspended and bed load sampling at the Ban Hatkham water level gauging station and laboratory tests are proposed. The water samplings should be conducted at the same time as discharge measurement.

Hydrological Analysis

(13) Depending on the above additional/continual observed data, hydrological analysis should be re-conducted and updated.

General

(14) There are a number of difficulties noticed regarding the operation of the rainfall/meteorological observations, including incorrect setting of the recording papers/pens, battery troubles, forgotten or missed recording of the date, etc. Also in the Lao PDR, it is difficult to maintain supplies of recording papers/pens for each type of the rain/meteorological gauges. It is recommended that automatic data logger systems be used with manual observation by operators.

(15) Improvements and modifications are required to the gauges at the Ban Hatkham water level gauging station.

Safety Care

(16) Safety precautions must be improved when undertaking discharge measurements and sediment sampling.

(i) All staff must wear a life jacket (include observers, boatman, other assistant staff).

(ii) When boarding the boat, staff must take off their shoes

(iii) A minimum of two boats are required for the discharge observation when the water level is high (one for observation and the other for emergency rescue). The rescue boat should also be at the measuring site.

(iv) The rescue boat should be equipped with a motor, ropes, life buoys (rings), long poles, spare life jackets and other necessary equipment. A minimum of two staff are required in addition to the boatman on the rescue boat.

(v) When the water level is high, the water velocity will be measured by the float method (not current meter method).

(vi) The observations should be finished before 3:00 PM. Staff must not be aboard boats in the evening or night.

(vii) First-aid kits/medicines, radiotelephone/satellite telephone should be kept at B.Hatkham water level gauging station.

(viii) Emergency contact lists and rescue team-member lists should be checked and updated regularly.

(ix) Other necessary safety actions should be regularly reviewed.

6. ENVIRONMENTAL SURVEY

6.1. GENERAL

The environmental impact assessment survey was carried out during the Phase I Study (1998-2000). The survey results shown below are quoted from Chapter 3: First Environmental Impact Assessment and Chapter 4: Preliminary Resettlement Plan in Final Report, Vol.2: Executive Summary. Accordingly, every survey items were assessed between the large-scale alternative (FSL.360m) and the medium-scale alternative (FSL.320m).

Meanwhile during the Phase II study, the field survey of resettlement potential area was carried out in July 2002 for the resettlers of four (4) villages in case of the medium-scale alternative (FSL.320m). The summary of survey results are attached to the end of this chapter.

6.2. EXECUTION OF WORKSHOP

The workshops were held during both the Phase I Study and the Phase II Study. The Study has been affected by the workshops.

The Phase I Study (July 1998 to March 2000)

No.	Workshop	Date	Place	Agenda	Participants
1.	1st General Workshop	November 1998	Vientiane	Inception Report	110
2.	2nd General Workshop	June 1999	Pakxan	Interim Report	120
3.	3rd General Workshop	December 1999	Vientiane	D/Final Report	120
4.	1st Site Workshop	March 1999	Don/Sopyouk/Muanmai	Inception Report	50, 30
5.	2nd Site Workshop	June 1999	Don/Sopyouk/Muanmai	Interim Report	40
6.	3rd Site Workshop	December 1999	Don/Sopyouk/Muanmai	D/Final Report	200, 170, 70

The Phase II Study (March 2001 to November 2002)

No.	Workshop	Date	Place	Agenda	Participants
1.	1st General Workshop	June 2001	Vientiane	Inception Report	110
2.	2nd General Workshop	March 2002	Pakxan	Interim Report	100
3.	3rd General Workshop	September 2002	Vientiane	D/Final Report	130
4.	1st Site Workshop	June 2001	Don/Sopyouk/Muanmai	Inception Report	No Record
5.	2nd Site Workshop	March 2002	Don/Sopyouk/Muanmai	Interim Report	50, 40, 100
6.	3rd Site Workshop	September 2002	Sopyouk	D/Final Report	40

6.3. ENVIRONMENTAL IMPACT ASSESSMENT

6.3.1. CONTEXT OF FIRST EIA STUDY

Environmental field investigations were carried out from November 1998 to September 1999 in order to establish the information base line by reference to which potential impacts may be estimated. An Initial Environmental Examination (IEE) was produced in October 1998. Preliminary impact assessment and conclusions were presented in an Interim Report in March 1999. Both documents were subject to public presentation and extensive discussions with the Environmental Assessment Committee (EAC) and Department of Electricity (DOE) of the Ministry of Industry and Handicraft (MIH).

The first EIA report has been prepared in accordance with the recommendations of the major international agencies as JICA, ADB and World Bank. The following chapters have been developed in the main First EIA report:

(i) The institutional and legal framework for environmental management in Lao PDR,

(ii) A summary description of the Project components,

(iii) The baseline information on present environmental and social conditions,

(iv) The analysis of impacts and the presentation of mitigation measures,

(v) A summary of the Environmental Management plan,

(vi) A summary of the Preliminary Resettlement plan, and

(vii) A summary of the Public Consultation and Participation activities carried out.

6.3.2. BASELINE INFORMATION ON PROJECT AREA

(1) CLIMATE AND METEOROLOGY

The proposed dam site is located about 54km upstream the confluence of the Nam Ngiep River with the Mekong River. The controlled catchment at dam site is 3,700km^2, or 82% of the total river catchment (4,510km^2).

Rainfall is 1,873mm/year in average in the catchment area, as against 1,259mm/year at the dam site. More than 90% of the rainfall is concentrated into the wet season from May to October.

Mean annual discharge at dam site is estimated at 147.2m^3/s, based on a run-off coefficient of 0.67. For the purpose of the study, series of flow at dam site have been generated over a 30 years period. Average for 30 years are summarized below:

Table 6.3.1 River Discharge at Dam Site (Runoff Coefficient = 0.67)

Item	Unit	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Annual
Basin Rainfall	mm	8.0	16.8	37.6	104.4	231.2	360.6	402.3	379.7	230.0	85.9	12.9	3.9	1,873.4
Average Runoff	m^3/s	76.1	64.8	56.9	65.5	112.3	215.4	272.3	291.6	254.7	157.0	110.0	90.4	147.2
Average Runoff	mm	55.1	42.4	41.2	45.9	81.3	150.9	197.1	211.1	178.4	113.6	77.0	65.4	1,259.4

(2) WATER QUALITY

Water quality of the river was investigated in 4 sampling stations during 4 sampling campaigns in January, March, June and late August 1999. The water quality of the Nam Ngiep River is good. Close to neutral pH, nutrients content and dissolved solids in the low to medium range during the dry season. During the rainy season, nutrient content is slightly higher because of the run-off collecting organic matter and dust deposited on the ground surface. However, these values remain on the low side, thus reducing the long term risk of eutrophication in the reservoir. Some coliform pollution from fecal origin is observed downstream, resulting from the presence of villages and the slow flow of the river.

(3) AQUATIC ECOLOGY AND FISHERIES

Fish samples were collected, observed and identified from 21 stations along Nam Ngiep River and its tributaries, including 9 stations of the Upper Reservoir, 5 stations in the Lower Reservoir area and 7 stations in the downstream area. Two surveys were carried out during dry season in January 1999 and wet season in July 1999.

During the first survey, 115 species were collected and identified. During the second survey, 19 additional species were collected, raising the biodiversity of the basin to 134 species. This total of 134 fish species compares well with other nearby river basins as the Nam Leuk basin (122 species) and the Nam Theun/Xe Bang Fay basin (165 species). Most of the species found are widely distributed in the region. However, some species not identified at species (only genus) level may have more restricted distribution. Additional investigation on that matter is recommended for the next stage of the study. Some species observed in the Upper or Lower reservoir have been already reported from other rivers in the Mekong basin to be migratory. During the field surveys, fish migration for spawning was reported by the villagers, but the exact timing of the migrations, location and distance of the migrations is still not known.

In coordination with the socio-economic survey, a specific questionnaire was developed in order to get a clear picture of the subsistence fisheries as an economic activity of the local communities.

Fishing activities are present in all of the 31 surveyed villages with an average of more than one person fishing in each household. Most of the villagers fish about 2-3 days a week and reported that in the Nam Ngiep River, fish catches are at peak in November-December. Less than 33% of the investigated households have a boat. Gillnet with hook and lines represent the most popular fishing gears.

The quantity of fish catches is in average of 0.7kg/fishing time/hh. The average fish consumption per household and per year has been established at 137kg/hh/year in the downstream area. No consistent information was gathered from the upstream area, but where it should not be much different than from the downstream area. This figure is particularly close to the result of a 3-year fishery monitoring for the Nam Leuk Project, which comes to an average of 133kg/hh/year (or 50-60 grs/capita/day). There is limited fish culture practices in the Project area.

(4) VEGETATION AND WILDLIFE

The field work related to the terrestrial ecology was designed i) to provide a preliminary information on the present condition of wildlife and habitats in the project area and ii) to provide a preliminary information on the vegetation biomass and commercial timber volumes available in the reservoir area. A first field work campaign was carried out from January 22 to February 20, 1999 by a team of 7 persons followed by a second field work campaign from April 1 to 12, 1999.

The identification of the trees observed indicate that the areas of catchment surveyed have low species diversity in comparison to other woodlands in Lao PDR (Xaignabouli, Vientiane Province, Attapu). The level of diversity is comparable to the degraded woodlands of the Nam Leuk catchment. More than 160 plant species belonging to 40 families have been identified. The forest area visited within the limits of the future reservoir consists mostly of secondary degraded forest, with sometimes a dense bamboo cover.

All the catchment areas experience or have experienced in the past hunter-gatherer degradation pressures, which can be significant. The potential for development in the catchment is variable according to the system considered, taking into consideration the local vegetation, geology, soils and topography, as presented in the attached figure.

The results from preliminary estimate of commercial timber in the reservoir area suggest that there could be approximately $30cm^3$/ha to be removed. However, there may be less potential considering that areas in the upper reservoir have already been extensively logged.

The overall fresh above ground biomass density of 278.5t/ha is comparable to findings of the Nam Leuk biomass survey (289.8 undried above ground biomass density). Of critical importance in terms of water quality is the rapidly degradable biomass which will play an important role in the early oxygen demand in the new reservoir water body.

The areas traversed outside the inundation zone appeared reasonably rich in terms of animal species diversity and high in terms of density and could be described as a "rich community". Two areas of interest have been identified: North of B.Sopphoun up to B.Nakang is one area. The second area is directly south of B.Sopyouk and east of the Nam Ngiep River, outside the reservoir area. The later appeared particularly rich, with evidence of at least two separate herds of Asiatic Elephant of approximately 12 and 6 individuals respectively.

During the surveys, 100 bird species, 48 mammal species and 9 reptile species have been reported from the visited parts of the catchment area. From these, 16 mammal species and 3 reptile species have already special conservation significance (International or National).

6.3.3. IMPACT SCREENING

Anticipated impacts are summarized in Tables 6.3.2, categorizing the impact with proposed mitigation at each development stage.

6.3.4. IMPACTS DURING CONSTRUCTION PHASE

The project construction sites are all located around the dam site, with the exception of some quarry sites not yet identified. It is anticipated a total requirement of 250 to 500ha, mainly in a non agricultural and non populated area. No resettlement or significant compensation for land is expected for construction sites.

Both alternatives require only 10km of new access road (or about 20ha of land including disposal and borrow areas) and the construction of a 110km long transmission line. The cost of land acquisition for road and TL towers has been estimated at about US$110,000.

In case of inappropriate handling or storage of chemicals or petroleum products on the construction site, accidental release in the river water may affect more than 5,000 persons living in the downstream area, and which use river for drinking and cooking. The same may happen with inappropriate sanitation system in the workers camps with release of pathogens.

Preventive measures will include strict enforcement of safe handling and storage procedures by the Contractor(s), and the implementation of alternative water supply systems for the downstream villages. Based on one hand pump for 20 households, the estimated cost is US$250,000. For remaining impacts on fish and fisheries, a penalty system may be implemented, making the contractor(s) responsible for accidental spill and in charge of paying a compensation for fishery loss to downstream villagers.

Transport of equipment and materials will increase truck traffic on the roads with higher accident hazard for population. Traffic signs, speed limit, maintenance of trucks and roads will be required from contractor. Increased dust emission will be controlled by regular watering of construction sites and roads inside the villages. Grass cover on spoil areas may limit dust emission by wind.

6.3.5. IMPACTS DURING FILLING PHASE

The filling event is probably the most important and impacting stage of a hydropower project.

Indeed, this is the short time during which i) the hydrology of the downstream system is abruptly modified, ii) the water quality of the system is strongly altered and iii) the wildlife in the reservoir must migrate out.

As soon as the dam is closed, the downstream area faces significant change in flow, even with a $20m^3/s$ riparian flow released at dam site, as shown in table below:

Table 6.3.3 Change in Flow during Filling with $20m^3/s$ Riparian Release (Mean year)

(Mean year situation)		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Muangmai	Before	69	58	50	46	80	217	276	680	419	196	124	76
	After	30	28	27	27	32	52	60	119	81	48	38	31
Mekong Conf.	Before	72	61	53	49	84	228	290	714	440	206	130	80
	After	33	31	30	29	36	63	74	154	102	59	44	35

Simulation of reservoir filling shows that with a $20m^3/s$ riparian release, the FSL.360m reservoir fills in 13 to 25 months according to the year (wet or dry) and in 16 months for a mean year. The FSL.320m reservoir fills similarly in 3 to 12 months, with only 3 months for a mean year. Increasing the riparian release to $50m^3/s$ will result only in minor increase of filling time: +2 months for FSL.360m, +1 to +2 months for FSL.320m. The difference is not so large to give the opportunity to adapt at best the riparian release for the benefit of population and project. It is recommended that a study is carried out during next stage of the Project development in order to optimize the riparian release during the filling period.

(1) IMPACTS ON LAND

Land cover in the reservoir area is presented below for both alternatives.

Table 6.3.4 Distribution of Land Use in Inundation Zone

Land cover	Area (ha)	
	FSL.360m	FSL.320m
Evergreen forest	830	450
Deciduous forest	8,950	4,480
Forest regrowth	1,200	380
Shrubland	2,890	1,770
Cultivated land	950	310
Total area	14,820	7,390

The alternative FSL.360m affects almost twice more land than the alternative FSL.320m, and 3 times more cultivated land. All compensation costs related to this area are detailed in the Preliminary Resettlement Plan.

Table 6.3.2(1/2) IMPACTS IN DOWNSTREAM AREA AND CONSTRUCTION ZONES

DEVELOPMENT PHASE	IMPACTED FIELD	TYPE OF IMPACT	CAUSES	CONSEQUENCES	CRITERIA CONSIDERED FOR ASSESSMENT	PROPOSED MITIGATION
CONSTRUCTION PHASE	AQUATIC SYSTEM	Water pollution by accidental release of chemical	Storage and handling of chemicals on construction site (mainly oil products)	Temporary effect on aquatic ecology and fisheries	Type of pollutant Dilution of pollutant at various distance from release	Appropriate storage & handling of chemicals Compensation
					Occurrence of event and severity Local fish consumption	Compensation
		Water pollution by release of pathogens in river	Inappropriate sanitation system of workers camps	Hazardous use of river as source of domestic waterbh	Type of pathogens (survival time) Flow velocity Population at risk Water use	Design of sanitation system Contract obligation for contractor Compensation
		Excessive sediment load	Inappropriate prevention measures during earthworks	Temporary effect on aquatic ecology and fisheries	Load SS Period (DS more affected) Occurence	Construction methods Compensation
		Permanent pollution by chemicals	No treatment of effluents from batching plant before release in the river	Effect on aquatic ecology and fisheries	SS and pH of river water Distance from release	Sedimentation and buffering ponds
	LAND SYSTEM	Impact on land use at construction sites	Implementation of project sites: construction sites, camps, quarries, disposal areas	Loss of natural resources Loss of grazing land Loss of agricultural land	Areas required & location Land use	Design to minimize needs Land acquisition & compensation
			Construction of access roads and Transmission lines	Loss of natural resources Loss of grazing land Loss of agricultural land Disturbance to wildlife	Areas required & location Land use Areas of interest for wildlife	Adjust route to minimize effects on valuable land Land aquisition
	SOCIAL	Local employment and income	Opportunities for unskilled workforce: earthworks, clearing	Improved income for local population	Workforce availability in the villages according to season Priority to local villagers Recruitment procedure	Give priority to local villagers for employment on project sites
		Public safety	Transport of equipment and materials, intense truck traffic	Noise Dust emission Accidents and injuries risk for villages crossed by road	Measures required to minimize the risk	Design Traffic regulations and signs Watering of roads during DS Reduce traffic at night
			Concentration of in-migrants in the construction area	Risk of epidemic diseases Dissemination of HIV and water related diseases	Prevention program and monitoring	Public Information and awareness program
					Design and organization of camps facilities	Hygiene in the camps Medical control, equipment, monitoring
RESERVOIR FILLING	AQUATIC SYSTEM	Reduction of river flow	Impounding of the reservoir	If no riparian release (RR), 100% of aquatic habitat and fisheries destroyed for 3-5 years If riparian release, part of fisheries and habitats preserved	Appropriate RR Duration of filling and period Expected reduction of fish catches	Compensation
				Water shortage downstream	Alternative water supply	Compensation
				Irrigation impaired	% of affected rainfed and irrigated production	Compensation for loss
		Alteration of water quality	Flooding of vegetation and soils in the reservoir	Water anoxic after few months of filling	Duration of filling Organic matter available in reservoir and decay kinetic	Partial only Reservoir clearing
				Unsuitable for domestic use Unsuitable for livestock use	Alternative water supply Village/HH numbers	Compensation
	SOCIAL	Resettlement of reservoir population	Impounding of the reservoir	Potential impacts on land use and on host population	Location and availability of land, Development planning of host or nearby villages	Mitigation measures to be addressed in RAP
		Employment and regional economy	End of construction works	Reduction of workers population and related local economic activities	Number of workers Average contribution to local economy	Public information
		Impaired river transport	Reduction of flow during filling	River transport impossible because of low flow, even with riparian release of 20 cumecs	Number of boats on the river Contribution to the local economy	Compensation
RESERVOIR OPERATION	AQUATIC SYSTEM	Irregular daily flows	Production of intermediate & peak energy (16 hrs/day)	Destruction of aquatic habitats and fisheries Erosion of river channel	100% loss of fisheries 100% loss river transport	Re-regulation pond or compensation
				Danger for people and livestock	High risk of accident	Warning system Re-regulation pond
		Regular seasonal flows	Energy production is stable year long	Improve dry season flow of Mekong	NNG flow as % of MKG flow	Not required
				Improve river transport in dry season	Number boats Increased level of river	Not required
				Provides high potential for dry season irrigation during both wet & dry season	Average discharge Land suitability Location for pumping station(s)	Not required
		No significant increase of flow in wet season	Run off is stored in the reservoir	No attraction of migrating fishes in early wet season Loss for fisheries	Nb of migrating species observed Importance in catches	Compensation for loss
		Low to very low sediment load in the water	Sediment is deposited in the reservoir	Water flow more erosive, mainly during dry season Risk of river bed erosion	Role of backwater effects from Mekong Risk possibly minimized by slow velocity of flow	River protection structures if required
		Short term anoxic water release	Decomposition of flooded vegetation & soil organic matter	Short term release of anoxic water, unsuitable for domestic & livestock	Expected duration of problem is 4 to 7 years according to FSL alternative	Pre-impoundment reservoir clearing Res. Management
				Destruction of D/S fisheries as function of DO level	Re-aeration rate of water DO concentration at distance from dam	Alternative fisheries development Financial compensation
		Long term seasonal release of anoxic water	Stratification of reservoir Reservoir management	Unsuitable water for domestic and livestock use Effect river fisheries	Period of event: probably October to January, when reservoir level highest	Multi level water intake
		Long term accidental or permanent pollution of water	Development of population and industries around reservoir and in catchment	Unsuitable water for domestic use or for other uses.	Level of risk Type of pollution	Strategic plan for watershed control
	LAND SYSTEM	Loss of river bank gardens	Increase of river level by about 1 m in dry season with potentially more erosive waters	Loss of lower part of the river bank gardens (flooding or erosion)	Initial area of gardens potentially impacted Average crop production	Compensation

Table 6.3.2(2/2) IMPACTS IN INUNDATION ZONE AND CATCHMENT AREA

DEVELOPMENT PHASE	IMPACTED FIELD	TYPE OF IMPACT	CAUSES	CONSEQUENCES	CRITERIA CONSIDERED FOR ASSESSMENT	PROPOSED MITIGATION
CONSTRUCTION PHASE	AQUATIC SYSTEM	No significant impact anticipated				
	LAND SYSTEM	Impact on land use	Implementation inside the future reservoir of quarries, camps and disposal sites	Localized loss of natural resources, grazing land	Limited impact; areas required for construction purposes	Early compensation and land acquisition procedures
	SOCIAL	Local employment and income	Clearing of reservoir Collection of forest products	Improved income for local population	Workforce availability in the villages according to season Priority to local villagers Recruitment procedure	
		Resettlement of affected population	Flooding of the reservoir area	Development of new sites for resettlement to be completed before reservoir impoundment	Population, ethnic groups, needs for livelihood re-development	Resettlement Plan & Compensation for transitory period
RESERVOIR FILLING	AQUATIC SYSTEM	Loss of river habitats as permanent stream and rapids	Creation of reservoir	Loss of fast water habitats Disruption of river integrity	Presence of migratory species	Compensation by contribution to conservation trust fund
		Alteration of water quality	Flooding of areas rich in organic matter	Anoxic conditions of water resulting in fish kills Fish population taking refuge in upper tributaries	Carrying capacity of initial river area	Compensation by contribution to conservation trust fund
				Possible loss of rare fish species	Presence of rare species	Conservation of areas of similar biological value
				Water inadequate for domestic supply purpose (drinking/bathing)	Existing/resettled population around reservoir	Alternative water supply
				Water inadequate for livestock supply	Population around reservoir & estimated number livestock heads	Alternative water supply if required
	LAND SYSTEM	Loss of terrestrial habitats with associated flora and fauna	Inundation of the reservoir area	Loss of rare plant species	List of plants observed in the area	Conservation of substitute habitats
				Loss riverine habitats rich in bird diversity	Length of river flooded Areas of interest for biodiversity	Conservation of substitute habitats
				Loss of rare terrestrial fauna	List of animal species with conservation status	Conservation of substitute habitats
				Drowning of animals during inundation phase	Large mammals possibly at risk Velocity of flooding Pre-impoundment clearing Presence of islands	Pre impoundment program (clearing) Animal rescue program during reservoir filling
		Loss of forest products	Inundation of the reservoir area	Loss of existing forest timber	Type & location of forested areas Commercial timber density	Pre-impoundment logging
				Loss of existing non-timber forest products	Type & location of forested areas Importance in population income	Collection program associated with pre-impoundment vegetation clearing
		Loss of production systems and dwellings	Inundation of the reservoir area	Loss of houses, built-up private & community structures & infrastructures, of cultivated areas and grazing land	(See details in operation stage)	Planned resettlement and compensation
		Loss of mineral production	Inundation of the reservoir area	Loss of sand and gravel production; Possibly gold (not reported)?	Population affected Areas of interest	Provide households with substitute income
		Floating debris	Inundation of cleared area; Only part of wood biomass totally burnt	Threat for water intake and later for boat transport and fishing	Volume of trunks/branches Areas for landing and transforming	Preparation and implementation of a removal program
	SOCIAL	Population livelihood not yet re-established	Displacement of population to new sites just before flooding	New production systems to be implemented	Resettlement Action Plan	Assistance and compensation
RESERVOIR OPERATION	AQUATIC SYSTEM	River system permanently flooded	Creation of the reservoir	Loss of river aquatic products	Area of flooded river system	No mitigation
		Low water quality after filling (short term)	Decay of vegetation biomass and soil organic matter	Problem expected to last 4 (FSL 320) to 7 (FSL 360) years	Evaluation of vegetation biomass Pre-impoundment clearing plan	Vegetation biomass clearing may reduce duration of problem
				No reservoir fisheries until the end of water quality problem	Possible duration of problem Time required in other reservoirs to reach stable reservoir fisheries conditions	Net protein compensation to affected population
		Seasonal long term low water quality	Turn over of stratified reservoir	May limit intensification of fish production using floating cages	Risk of seasonal turn over due to the physiognomy of reservoir	Adjust production schedule in accordance with turn over occurence
		Gain of aquatic resources	Creation of the reservoir; Improvement of epilimnion quality	Increased productivity and potential for fisheries	Potential yield after stabilization of reservoir conditions	Development of a reservoir fisheries program
				Gain from fisheries intensification	Fish cages, fish species production according to management	Preparation of a reservoir fisheries intensification plan
		Increased sediment load in the water	Uncontrolled development in the catchment area resulting in increased erosion	Reduction of reservoir storage and related project life	Dead volume of the reservoir Erosion rate per km²	Strategic plan for watershed control
				Increased sedimentation at the tail of the reservoir May result in higher backwater effects with flooding of fields and built up assets	Hydraulic engineering of river levels Resettlement levels	Decrease FSL or increase resettlement level
		Presence of a long water body	Reservoir creation	Potential for transport of goods and persons	Lakeshore population	Not justified
		Reservoir access restricted by seasonal draw down of 30 m.	Reservoir management for energy production	Loss of potential benefit from transport part of the year (dry season)	Distance from lake shore in wet and dry season	Appropriate berthing facilities adapted to 30 m draw down
		Creation of temporary draw down areas	Reservoir management for energy production	Impaired landscape, possible sites for water related diseases	Draw down area is 54 km² (FSL 360) or 44 km² (FSL 320)	Management Plan for draw down areas
		Reservoir safety	Safety of public transport boats and on reservoir shores	Risk of drowning	Magnitude of transport on the reservoir	Installation of signs Inspection of boats for public transport
		Creation of new wetlands	Reservoir management for energy production	Potential for increased production of aquatic products and improvement of aquatic biodiversity	Location of potential wetlands Draw down area & topography	Management of wetland production Conservation status for key areas
		Creation of new spawning areas	Reservoir management for energy production	Increased fish production and biodiversity	Location of potential areas	Conservation status for key areas
		Improvement of reservoir water quality	Stabilization of reservoir water quality after 10 years	Economic gain of clean domestic water supply	Lakeshore population after 10 years estimated 12 per km of perimeter.	Not justified
				Economic gain of water supply for livestock	Livestock population based on human population;	Not justified
				Economic gain for reservoir side gardens irrigation	75% lakeshore household have garden (or 1.5 garden/km of reservoir bank)	Not justified
				Economic gain for irrigation along reservoir side	1 ha irrigation/km of reservoir shore	
		Long term eutrophication of reservoir	Nutrient inflow from a developed catchment	Development of aquatic weeds and floating vegetation which affects turbines, evaporation and reservoir productivity	Expected Phosphorus loading Magnitude of draw down Residence time for water	Watershed control Removal of vegetation if required
	LAND SYSTEM	Economic loss of future land resource harvest	Reservoir creation	Economic loss of timber resource	Area flooded, type of forest Annual average production	No mitigation
				Economic loss of non timber resource	Area flooded, type of forest Average annual value	No mitigation
				Economic loss for bamboo	Area flooded Density of bamboo	No mitigation
				Economic loss of future rainfed crop production	Area flooded Average production	No mitigation
				Economic loss of future dry season irrigated production	Area flooded Average production	No mitigation
				Economic loss of riverbank gardens	Household affected Average annual production	No mitigation
				Economic loss of grazing area	Number of livestock & cattle to move reflects grazing area	No mitigation
		Financial loss of developed land by displaced people	Reservoir creation	Loss of rainfed paddy fields	Area	Compensation for unmovable asset and 3 years production
				Loss of irrigated paddy fields	Area	Compensation for the unmovable assets plus 3 years
				Loss of gardens (fruits and vegetables gardens)	Area or unit	Compensation for unmovable assets plus

The flooding of the forest represents an economic loss for all the flooded forest products: timber, non timber forest products (medicinal plants, fruits, material, value for animals and conservation) and more globally, the forest as a carbon storage participating in the greenhouse effect reduction. At FSL.360m, 9,780ha of forest representing a timber volume of 290,000m^3 will be flooded against only 148,000m^3 for FSL.320m (4,930ha forest).

As the water level will raise fast during the first few months of the filling (about 140m in 3 months, 2.3m/day the first month), it is probable that animals become trapped on temporary islands or stranded. It is recommended to implement a rescue program for animals during filling.

(2) IMPACTS ON WATER QUALITY

This is a key impact of this stage, unfortunately not limited to the filling period. The alteration of water quality will probably last for few years during the operation phase.

The main cause of water alteration is the decay of the organic matter contained in the flooded vegetation and the upper layer of the soil. It is estimated that the degradable carbon content of above ground vegetation together with the first 5 cm of topsoil is about 2.4 million tons Carbon for FSL.360m alternative and 1.2 million tons Carbon for FSL.320m alternative.

About 21% of this biomass is soft and is rapidly degraded in about 2 to 3 years. The remaining part of the biomass consists in wood parts (timber, large branches, large roots) which decay slowly over 15 to 20 years or even more.

The critical period is the decay of soft biomass, as large quantities of methane gas released from anaerobic degradation will consume all the dissolved oxygen in water, affecting the aquatic life. There is no effective solution to avoid this temporary alteration of water, but only to limit its intensity and its duration. One possibility is a pre-impoundment clearing, combined with a commercial logging. Based on the recent clearing experience of the Nam Leuk reservoir, clearing and burning may reduce the soft above ground vegetation biomass by about 70% to 80%. For hard biomass, the clearing and logging operations can hardly remove more than 50% of the original volume. No practical solution exists to reduce the biomass from the soil. A mitigation measure may be to implement a water re-aeration device at the level of the tailrace channel. These options have to be investigated during next stage of *Feasibility*.

The Nam Leuk reservoir (1,300ha) was totally cleared by hand by the local population (400 persons) in 5 months, at an average cost of US$420/ha. On this basis, a clearing cost of about US$5-6 millions for the FSL.360m and about US$3 millions for FSL.320m may be expected. This cost is largely balanced by the reduction of the Global Warming Potential (GWP) of the greenhouse gas emission, and by benefits for future uses of the reservoir (fisheries, tourism).

Because the release of low oxygen water downstream will affect fisheries, it is recommended to prepare a fishery intensification program which will provide to the population a fish production system independent from the river.

If the situation of water quality will be unsurprisingly acute at short term, various computations show that the improvement of water quality will be fast and that the situation in the reservoir will be reasonably good in the long term, at least for the active superficial layer of the reservoir.

6.3.6. IMPACTS DURING OPERATION PHASE

(1) THE DRAW DOWN AREAS

The reservoir will be a highly dynamic system with regular changes of level and area according to season and to the inflow conditions. The draw down areas, seasonally exposed to the air, may be suitable for land development: agriculture, grazing, wet land. The maximum draw down area expected for each alternative is about the same, around 4,000ha. However, only a part of this area is exposed at least 5 months, a suitable duration for paddy production: about 1,000ha for FSL.360m and 1,500-1,800ha for FSL.320m. The lowest option is the most promising on this subject.

(2) THE RESERVOIR

As other deep reservoir, the Nam Ngiep will probably stratify. This means that a superficial layer of water, about 15-20m thick will become quickly well oxygenated. This is the layer where plankton and fish development occurs. Below this layer, the remaining part of the water body will receive no oxygen and will be the place where no fish or other aquatic life develop, except anaerobic bacteria releasing methane gas and sulfur hydrogen. This water shows also a lower temperature and a lower pH, which may create corrosion problems for the equipment.

It is possible that, as observed in the Nam Ngum reservoir, this stratification turns over once a year, when colder flow and colder air temperature affect the water body. There is a mixing, detrimental for the upper layer but positive for the bottom layer which liberates part of its dissolved gas and receives some oxygen, thus reducing the corrosiveness of the water. Further studies are required during next stage.

The risk of eutrophication of the upper layer in the long term is low because the residence time of water in the reservoir is short (13.2 months for FSL.360m and only 3.6 months for FSL.320m) and natural Phosphorus loading rate is low (0.45gP/m²/year for FSL.360m and 0.90gP/m²/year for FSL.320m).

The water intake will be situated a large part of the year more than 15-20m below the reservoir level, thus releasing downstream anoxic water. If no multilevel intake is considered, because of high cost, re-aeration device and fishery intensification program downstream become priorities.