CHAPTER 5 HYDROLOGY AND RESERVOIR OPERATION

5.1 HYDROLOGY

5.1.1 GENERAL

(1) Purpose of the Hydrologic Survey

The purpose of the hydrologic survey is to assess the present condition and to prepare the basic hydrologic data for the project planning. The scope of works for the hydrological survey are as follows.

1) To collect and review the hydrological data from the past studies,
2) To collect and review the recorded hydrological data during the operation of the existing facilities, and
3) To prepare the basic hydrological data for the preparatory Survey

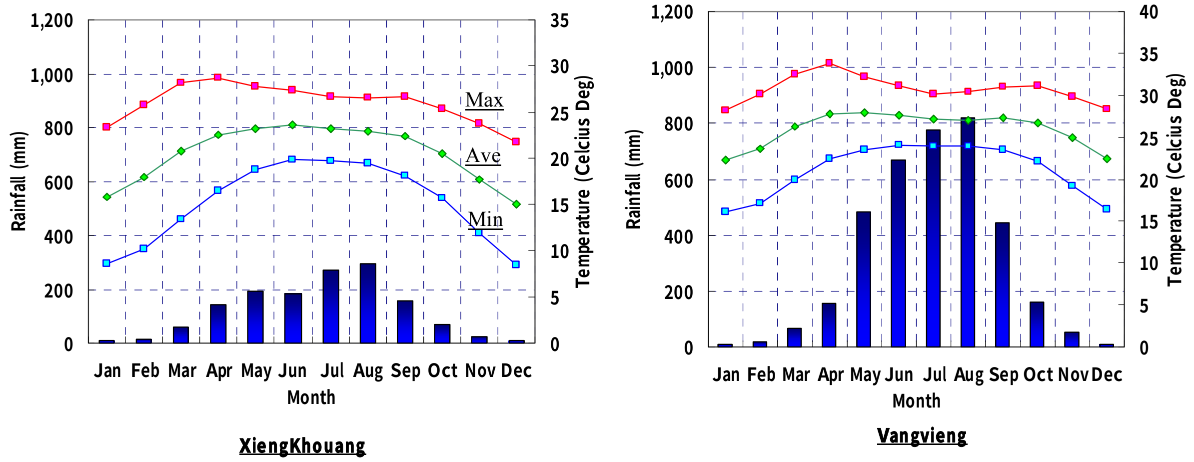
(2) Climate of Nam Ngum River basin

The Nam Ngum River originates in Xieng Khouang plateau and extends to the confluence of the Mekong River. It extends up to 345 km with a river basin area of 16,841 km^2 which is the fourth largest river basin area in the Lao PDR. The Nam Ngum River basin has tropical monsoon climate, dominated by the wet southwest monsoon from mid-May to early October and the dry northeast monsoon from early November to April. The recorded annual rainfall in the region ranges from 1,420 mm in Xieng Khouang to 3,500 mm in Vangvieng, over 75% of which falls during the rainy season. The amount of annual rainfall is not uniformly distributed over the basin.

Ref: EdF, “PARSIFAL Modeling of the NNRB System,” pp 14/56

Isohyet Map of NNRB

The annual average maximum temperature reaches 34 °C in the downstream plain area, and 28 °C in the upstream mountainous area. The average minimum temperature is 8 °C in the upstream mountainous area and 16 °C in the downstream plain area. The monthly rainfall and temperature in the upstream of the Nam Ngum River of Xieng Khouang and Vangvieng are shown in Figure 5.1.1.

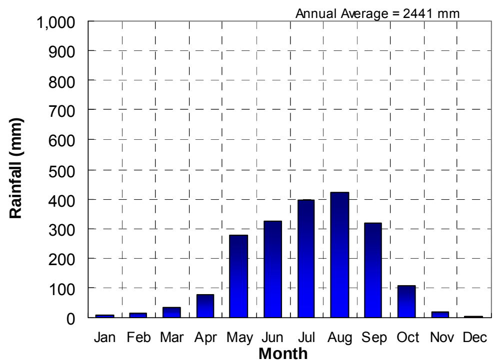


Data source: DMH

Figure 5.1.1 Monthly Rainfall and Temperature at Xieng Khouang and Vanvieng

(3) Outline of hydrological condition for the hydropower in Nam Ngum River basin

Nam Ngum dam is located 140 km upstream from the confluence of the Nam Ngum and the Mekong Rivers and has 8,275 km^2 of catchment area[1] with an annual rainfall of 2,441 mm. Nam Ngum dam catchment area has a distinct rainy and dry seasons. The annual rainfall observed at the Nam Ngum power station is shown in Figure 5.1.2.



Data source; DOE

Figure 5.1.2 Monthly Rainfall Observed at NN1 Dam Site

The Nam Ngum River basin has three existing hydropower stations including the Nam Ngum 1 (NN1) and the other three hydropower stations which are under construction such as Nam Ngum 2 (NN2). Completion of these hydropower stations are expected to regulate the river flow and change the flow regime through the year.

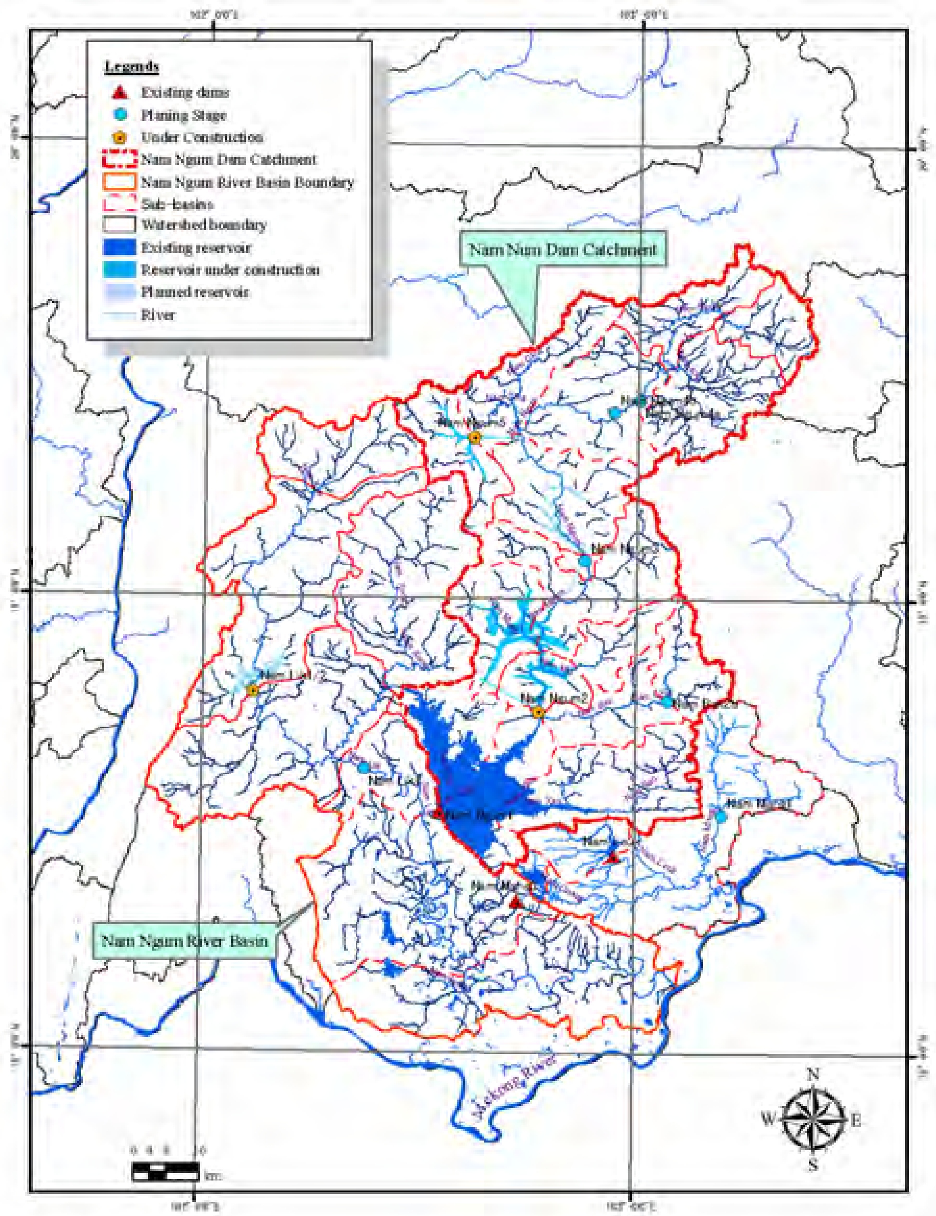
The annual average rainfall and catchment area of the existing and planned dams in the Nam Ngum River basin are shown in Table 5.1.1. The location of the hydropower stations and in the Nam Ngum River basin area is shown in Figure 5.1.3.

[1] Referred to NNRBDSP Report (2009). The area shown in the NN1 Completion Report (1972) is 8,460 km^2.

Table 5.1.1 Catchment Area and Annual Precipitation of Hydropower Schemes in NNRB

NNRB Dam Site	Catchment Area (km^2)	Average Rainfall (mm)
Nam Ngum 5	420(1)	2200
Nam Ngum 3	3769	1540
Nam Ngum 2	5688	1766
Nam Bak2 CA = 320.7	298	2900
Nam Bak 1 CA= 560	(550)	2800
Nam Ngum 1	8275	2022
Nam Song Diversion	1316	3662
Nam Lik 2	2048	2550
Nam Lik1	4921	2896
Nam Leuk	274+49	2700
Nam Mang 3	68+14	2700

Source: Output report on Activity 2.2: Basin Modeling

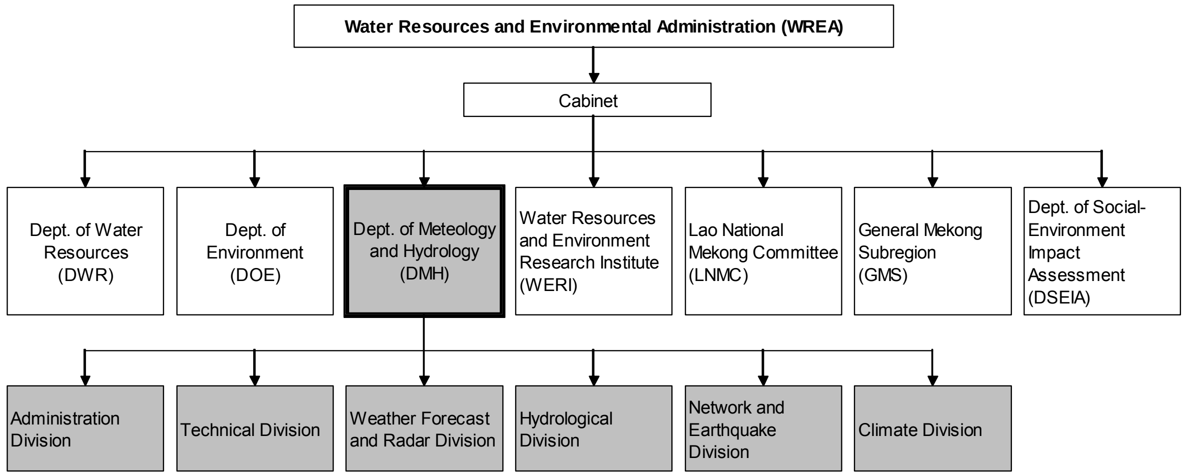


Prepared by the Survey Team using "GIS shapefiles" obtained from National Geographic Department.

Figure 5.1.3 River Basin Boundaries and Locations of Hydropower Scheme

5.1.2 COLLECTION OF HYDROLOGIC DATA

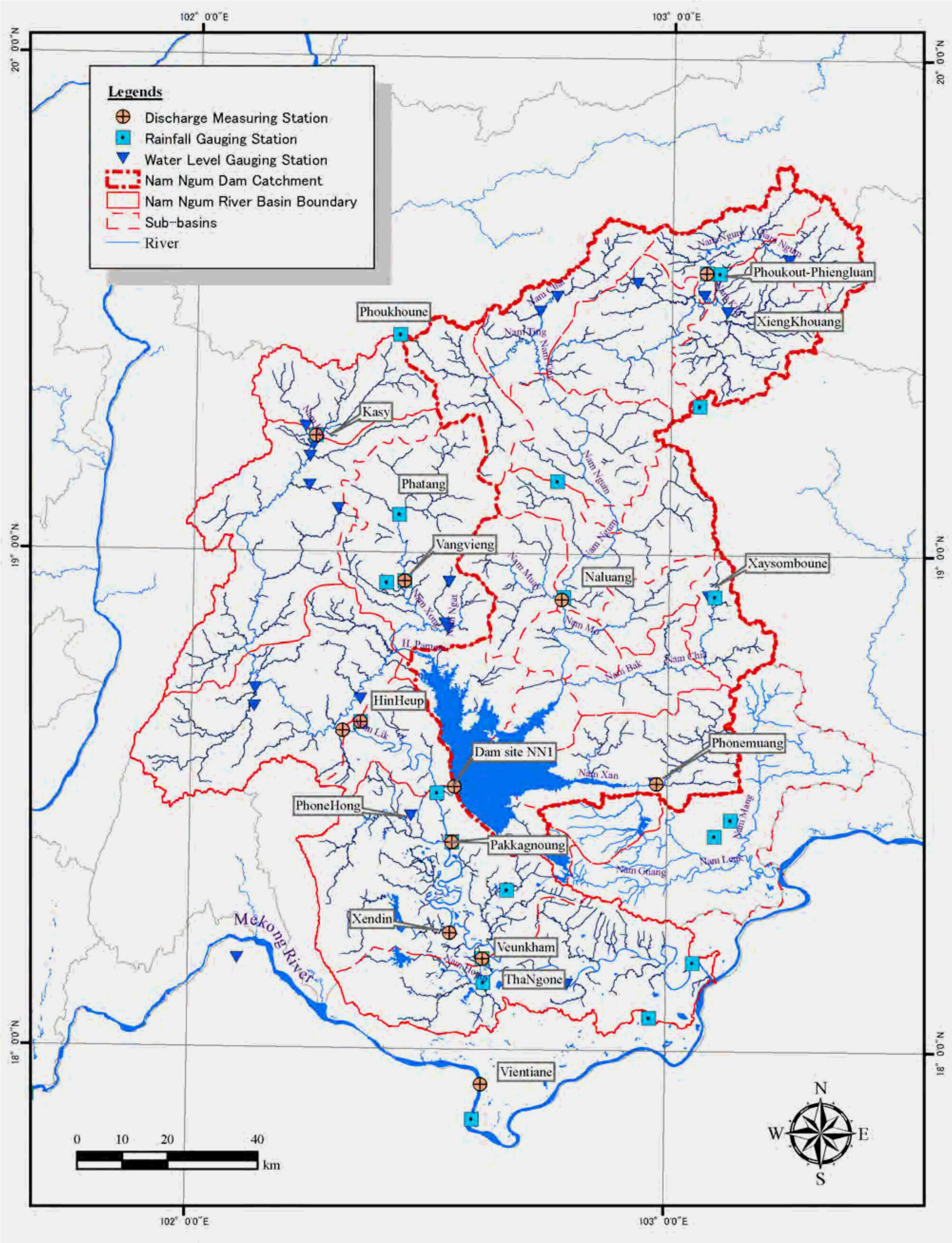
The hydrologic data, i.e. rainfall, discharge and other meteorological data, are monitored in the hydrologic gauging stations operated by the Department of Meteorology and Hydrology (DMH) under the Water Resources and Environmental Administration (WREA). The organization chart of DMH is shown in Figure 5.1.4. The hydrologic data managed by DMH are collected, and its observation errors are corrected by the consultant, Électricité de France (EdF) in the Nam Ngum River basin Development Sector Project (NNRBDSP) Components 2 under ADB and ADF cooperation.



Source: DMH

Figure 5.1.4 Organization Chart of WREA and DMH

In the Nam Ngum River basin, the rainfall and discharged data are also monitored in the existing hydropower stations (NN1, Nam Leuk, Nam Mang 3). The location map of the water level, discharge and rainfall gauging stations are shown in Figure 5.1.5.



Data Source: NNRBDSP Component 2, Map prepared by JICA Survey Team

Figure 5.1.5 Meteorological Stations in the Nam Ngum River Basin

(1) Rainfall data

1) Rainfall gauging station

The rainfall gauging stations in the Nam Ngum River basin are listed in Table 5.1.2.

Table 5.1.2 List of Rainfall Stations in Nam Ngum River Basin

Seq. No.	Station	River Name	Latitude	Longitude	Duration of data series	Manager
1	Dam site Nam Ngum1	Nam Ngum	18.53000	102.55333	1972 to now	EDL
2	Hai	Nam Ngum	18.41797	102.54995	65 to 68,1970 to 77,1990 to now	DMH
3	Hatdokkeo		17.86000	102.59806	1985 to now	MAF
4	HinHeup	Nam Lik	18.65800	102.35467	1968 to now	DMH
5	Kasy	Nam Lik	19.23389	102.25306	1969 to now	DMH
6	Khoune	Nam Kuang	18.93898	102.40526	2006 up to now	DMH
7	Naluang	Nam Ngum	18.91333	102.77833	1987 up to now	DMH
8	Napheng	Nam Ngum	18.32139	102.66694	2003 to now	DMH
9	Nasone		18.06667	102.96667	1966 to 76/79/82/91 to now	DMH
10	Pakkagnoung	Nam Ngum	18.41767	102.55000	65 to 68,1970 to 77,1990 to now	DMH
11	PakNgum	Nam Ngum	18.17833	103.05667		DMH
12	Phatang	Nam Ngum	19.07604	102.43024	64 to 79, 1994 to 2002, 2004	DMH
13	Phaxay	Nam Ngum	19.30000	103.06000	96 to 2000	DMH
14	PhoneHong	Nam Ngum	18.46667	103.13333	1971 to now	DMH
15	Phoukoune		19.43917	102.42667	1996 to now	DMH
16	Phoukout-Phiengluang (automatic)	Nam Ngum	19.56778	103.10000	88 to now	DMH
17	Phoukout-Phiengluang (manual)	Nam Ngum	19.56972	103.07250	88 to now	DMH
18	Sanakham	Mekong	17.90000	101.66667	2006 to now	DMH
19	Tad Leuk	Nam Leuk	18.43333	103.10000	1991 to now	EDL
20	Thalat	Nam Ngum	18.51667	102.51667	1980/82/85/87 to 89, 95 to now	DMH
21	ThaNgone	Nam Ngum	18.13466	102.61869	65 to 2004	DMH
22	Vangvieng	Nam Ngum	18.94278	102.44333	88 to 2007	DMH
23	Veunekham	Nam Ngum	18.18333	102.61667	1990 to 92, 94 to now	DMH
24	Xaysomboune	Nam Cha	18.91556	103.09583	1987 to now	DMH
25	XiengKhouang		19.14611	102.76167	1982 to now	DMH
26	Xiengneun		19.76028	102.18111	1998 to 2005	DMH
27						

Source; NNRBDSP, Output Report on Activity 2.1: Data Base and Monitoring Network

As shown in the above table, there are 25 rainfall gauging stations in the Nam Ngum River basin. All of them except Hatdokkeo and Tad Leuk are belong to DMH.

2) Rainfall data

The rainfall data at the rainfall gauging stations are collected by the consultant (EdF) in the NNRBDSP component 2. The collected data are examined by visiting the gauging station, and cross checking the data consistency with the other rainfall gauging stations using double-mass-curve analysis. The Survey Team received the verified data and hydrological study report of NNRBDSP through DOE. The Survey Team checked the methodology and procedure of verification of the rainfall data. The method of the data verification is appropriate and such data can be used for the Survey.

(2) Discharge data

The discharge data in the Nam Ngum River basin is available in the NNRBDSP hydrological study as well as in the past studies of the hydropower station developments. The operation data with the discharge record of the existing hydropower stations are also used in the Survey. The available discharge data sets are described below.

- Verified Data in the NNRBDSP

In the Nam Ngum River basin, the discharge and water level of the rivers are monitored by DMH. The list of the discharge and water level gauging stations are shown in Table 5.1.3.

The accuracy of the collected data was also verified by EdF. The Survey Team received the verified data through the DOE. The verification procedures carried out by the EdF, i.e. site visiting and reviewing the rating curves, are appropriate, and the verified data can be used for the Survey.

Table 5.1.3 List of Discharge and Water Level Measuring Stations

Station	River Name	Latitude	Longitude	Duration of Data Series	Manager
Discharge					
(1) Dam site Nam Ngum1	Nam Ngum	18.5300000	102.5533333	88-2004	EDL
(2) HinHeup upstream	Nam Lik	18.6408853	102.3171377	1987 up to now	DMH
(3) HinHeup	Nam Lik	18.6580000	102.3546667	1987 up to now	DMH
(4) Kasy	Nam Lik	19.2338889	102.2530556	1987 up to now	DMH
(5) Mo	Nam Mo	18.8786111	103.9202778	2006 up to now	DMH
(6) Naluang	Nam Ngum	18.9080000	102.7736667	1987 - now	DMH
(7) Pakkagnoung	Nam Ngum	18.4176667	102.5500000	65-68, 1970-77 90- now	DMH
(8) Phoonemuang	Nam Xan	18.5391667	102.9775000	2006 up to now	DMH
(9) Vangvieng	Nam Song	18.9427778	102.4433333	1988-95, 97-now	DMH
(10) Veunkham	Nam Ngum	18.1833333	102.6166667	1989 up to now	DMH
(11) Vientiane-km4	Mekong	17.9308333	102.6158333		WAD
(12) Xendin	Nam Ngum	18.2342885	102.5466035	2006 up to now	DMH
(13) Phiengluang (Ban Leum)	Nam Ngum	19.5683333	103.0713889	1986 -now	DMH
Water Level					
(1) Ban Nong	Nam Kei	19.2513889	102.2305556	2006 up to now	DMH
(2) Done	Nam Tong	18.6863889	102.1311111	2006 up to now	DMH
(3) Kasy	Nam Lik	19.2141667	102.2477778	1969-76, 88 => now	DMH
(3) Kasy-NamKay	Nam Kay	19.0861111	102.3016667	2006 up to now	DMH
(4) Kasy-NamPang	Nam Pang	19.1327778	102.2405556	2006 up to now	DMH
(4) KhangKhai	Nam Gnuane	19.4808333	103.2494444	2005 up to now	DMH
(5) Khoune	Nam Kuang	18.9407727	102.5364639	2006 up to now	DMH
(5) Khualek	Nam Meuy	29.5183333	102.7561111	2006 up to now	DMH
(6) Latbouak	Nam Ngum	19.5944444	103.2447222	2006 up to now	DMH
(6) Latgon	Nam Kho	19.4894444	103.1158333	2006 up to now	DMH
(7) Muang Fuang	Nam Lik	18.7233333	102.1321667	2006 up to now	DMH
(7) Nabong	Nam Ngum	18.1316667	102.7927778	1982-85/95 2006-now	DMH
(8) Nam Chat	Nam Chat	19.4877778	102.7208333	2006 up to now	DMH
(8) Nam Cheng	Nam Cheng	18.4694444	102.4630000	2006 up to now	DMH
(9) Nam Mone	Nam Mone	18.8563889	102.5291667	2006 up to now	DMH
(9) Nam Sana	Nam Sana	19.1905556	102.2405556	2006 up to now	DMH
(10) PakNgum	Nam Ngum	18.1788889	102.1016667	2002 up to now	DMH
(10) Pakvang	Nam Song	18.7038889	102.3538889	2006 up to now	DMH
(11) Phiengluang (Ban Leum)	Nam Ngum	19.5219444	103.0669444	96-now	DMH
(11) Phonemouang	Nam Xan	18.5391667	102.9725000	2006-now	DMH
(12) Thalat	Nam Ngum	18.5166667	102.5166667	1966-now	DMH
(12) ThaNgone	Nam Ngum	18.1346553	102.6186857	1965- now	DMH
(13) Vangheua	Nam Ngat	18.8466667	102.5358333	2006 up to now	DMH
(13) Xay	Nam Soui	19.5469444	102.9258333	2006 up to now	DMH
(14) Xaysomboune	Nam Cha	18.9155556	103.0819444	2006-now	DMH

Source; NNRBDSP, Output Report on Activity 2.1: Data Base and Monitoring Network

- Discharge data in the past studies

The discharge data are available from the past studies which includes NN1 extension study and Nam Leuk hydropower stations by Lahmeyer International (LI). These discharge data will be used for the Survey after being reviewed by the Survey Team. The available discharge data from the past studies are as follows:

Table 5.1.4 List of Available Discharge Data from the Past Studies

Data Reference	Type of Data	Duration of Available Data
Nam Ngum 1 Hydropower Extension Feasibility and Engineering Study (1995) by Lahmeyer International	NN1 Inflow Nam Leuk Diversion flow Nam Song Diversion flow	1949 to 1994
Nam Mang 3 Hydropower Development Feasibility Study (1994) by Lahmeyer International	Nam Mang 3 Inflow	1949 to 1993
Nam Lik Hydropower Project Feasibility Study Report (2005) by China International Water & Electric Corp.	Nam Lik 1/2 Inflow	1968 to 1974 1988 to 2003
Nam Bak 1-2 Hydro Power Project Technical Feasibility Report	Nam Bak 1-2 Inflow	1972 to 2003

Prepared by JICA Survey Team

Except from the data listed above, the Survey Team received the estimated discharge data from the Nam Ngum 2 (NN2) hydropower station by Southeast Asia Energy Limited, the developer of NN2 project. The data received from NN2 are also used in the Survey after being reviewed by the Survey Team.

- Operation record of the existing hydropower stations

The Survey Team received the operation record from NN1, Nam Leuk, and Nam Mang 3 hydropower stations as well as Nam Song diversion. The Survey Team extracted the discharge data from the operation records received and used in the Survey.

The available operation records of the existing hydropower stations and their data duration are as follows.

Table 5.1.5 List of the Operation Data Available for the Survey

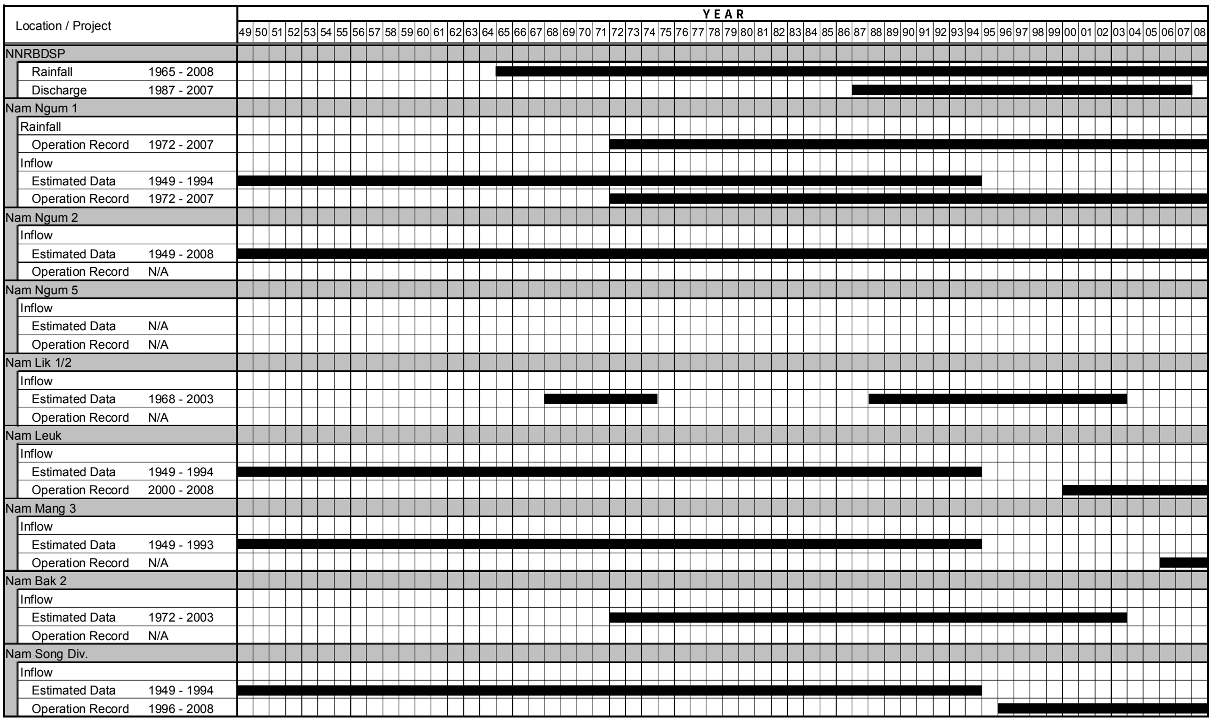
Data Reference	Duration of Available Data
(1) Operation Record ofNN1 Hydropower Station	1972 to 2008
(2) Operation Record of Nam Leuk Hydropower Station	2000 to 2008
(3) Operation Record of Nam Mang 3 Hydropower Station	2006 to 2008
(4) Operation Record of Nam Song Diversion	1996 to 2008

Prepared by JICA Survey Team

5.1.3 HYDROLOGIC ANALYSIS

(1) Necessary duration of hydrological data for the base of hydropower planning

The Survey Team collected the hydrological data from NNRBDSP, past studies and operation records of the existing hydropower stations as described in Chapter 5.1.2. Figure 5.1.5 shows availability of the discharge and rainfall data.



Preparer by JICA Survey Team

Figure 5.1.6 Duration of Hydrological Data Available for the Survey

As shown in Figure 5.1.6, the duration of the hydrological data are not identical. In order to prepare the basic hydrological data for NN1 expansion planning, it is necessary to define the duration of the basic hydrological data considering the overlaps of each hydrological data duration, accuracy and reliability.

The Survey should consider the operation of the hydropower station not only the NN1 hydropower station but also other hydropower stations that supply electricity to C1 area. Therefore, the hydrologic data should cover the hydropower stations including domestic IPP hydropower such as Nam Lik 1/2. However, the rainfall data is available from 1965 which makes difficult to verify or generate the hydrological data for other hydropower stations from 1949 that is the hydrologic beginning year of the F/S report in 1995.

While, the guidelines for the necessary duration of the hydrological data are, 10 years for hydropower planning in Japan [2], and 30 years[3] in the US army corps of engineers.

In the Survey of the NN1 hydropower station, the duration of the basic hydrological data are determined considering 1) the operation record of the NN1 hydropower station is available for more than 30 years, 2) rainfall data are available from 1965, and 3) hydrological data in the IPP hydropower project are limited. Considering the above conditions, it was decided that the basic hydrologic data to be adopted is the 36 years duration starting from 1972 to 2007.

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[2] New Energy Foundation, Hydropower Department, "Middle and small scale hydropower guidebook", Japan (title translated from Japanese)

[3] US Army Corps of Engineers, Engineer Manual, No.1110-2-1701, Engineering and Design, Hydropower

(1) Rainfall data observed at NN1 hydropower station

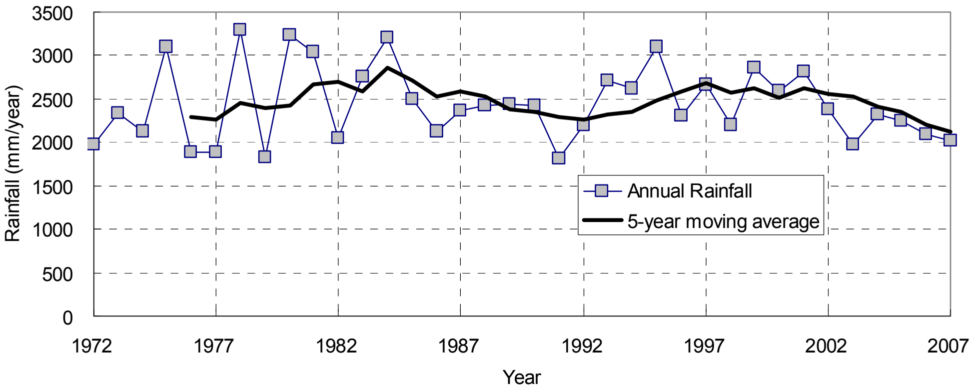
The recorded average monthly rainfall observed in the NN1 hydropower station from 1972 to 2007 is shown in Table 5.1.6.

Table 5.1.6 Observed Rainfall Data at NN1 Hydropower Station

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
1972	0	0	50	138	106	384	275	510	198	300	15	0	1975
1973	0	0	109	15	349	224	582	389	650	15	4	0	2337
1974	2	1	25	145	229	264	431	423	202	332	72	1	2127
1975	56	28	26	45	495	686	559	717	213	249	19	0	3092
1976	0	4	0	112	384	320	260	546	185	71	7	0	1889
1977	57	0	32	123	233	152	284	480	461	38	27	0	1886
1978	0	19	42	226	704	638	702	491	388	78	7	0	3295
1979	0	4	0	117	370	286	260	536	245	10	0	0	1828
1980	0	53	20	17	721	602	1016	311	478	16	0	0	3233
1981	0	90	83	266	192	239	832	597	281	424	31	0	3035
1982	0	17	36	80	198	292	262	527	518	100	26	0	2056
1983	63	0	5	25	290	496	644	518	415	263	31	0	2751
1984	0	54	46	49	369	424	733	788	347	339	47	0	3196
1985	45	25	0	105	333	571	422	403	459	109	29	0	2500
1986	0	0	0	92	375	433	503	382	218	99	0	23	2125
1987	0	64	14	91	170	431	261	477	625	155	79	0	2366
1988	0	21	8	102	313	356	642	633	191	162	0	0	2428
1989	22	4	15	56	442	468	343	463	450	146	35	0	2444
1990	2	19	70	72	368	431	404	417	454	111	69	0	2416
1991	0	0	94	34	269	304	476	257	343	28	0	8	1813
1992	34	29	0	0	503	366	408	483	297	41	0	45	2205
1993	0	0	6	146	484	463	854	230	520	8	1	0	2713
1994	0	19	121	42	439	617	361	538	251	202	13	18	2620
1995	1	15	7	115	304	425	794	1050	295	85	0	0	3092
1996	0	32	44	276	174	409	331	408	356	129	145	0	2302
1997	1	4	50	122	121	264	827	594	449	227	0	0	2658
1998	0	1	23	47	271	353	384	663	355	87	16	0	2199
1999	6	0	61	130	496	453	323	656	532	178	6	14	2853
2000	0	6	9	158	430	538	245	633	538	22	4	0	2584
2001	1	0	274	9	350	303	508	718	480	167	4	0	2813
2002	3	4	15	54	377	353	398	576	359	168	32	38	2376
2003	5	5	28	51	242	367	344	442	487	11	1	0	1981
2004	3	47	57	173	358	317	439	441	468	10	0	0	2312
2005	0	31	3	47	112	589	473	468	484	11	25	0	2241
2006	0	5	65	71	338	188	598	369	306	160	0	0	2100
2007	0	26	0	44	307	255	220	416	546	204	3	0	2020
Mean													
1972 - 1980	13	12	34	104	399	395	485	489	336	123	17	0	2407
1981 - 1990	13	29	28	94	305	414	505	521	396	191	35	2	2532
1991 - 2000	4	11	42	107	349	419	500	551	393	101	18	9	2504
2001 - 2007	2	17	63	64	298	339	426	490	447	104	9	5	2263
Statistics for 1972 - 2007													
Mean	8	17	40	94	339	396	483	515	390	132	21	4	2441
Max	63	90	274	276	721	686	1016	1050	650	424	145	45	3295
Min	0	0	0	0	106	152	220	230	185	8	0	0	1813
STDV	18	22	51	67	143	133	207	156	129	108	30	11	427

Source; NN1 hydropower Station

According to the observed data from NN1 hydropower station, the average rainfall from 1972 to 2007 is calculated at 2,441 mm. The 10-year average rainfall from 1972 to 2000 range between 2,400 mm to 2,500 mm, while the average rainfall in the year 2001 to 2007 is 2,263 mm, which is lower than the previous years. Variation of annual average rainfall in the NN1 hydropower stations are shown in Figure 5.1.7.



Prepared by JICA Survey Team

Figure 5.1.7 Annual Rainfall and 5-year Moving Average

The five-year moving average of the annual rainfall is superimposed on the graph. The annual average rainfall and the five-year moving average line indicate that the annual rainfall is generally around 2,500 mm but decreased to 2000 mm in the year 2007.

(2) Annual average rainfall in the Nam Ngum River basin

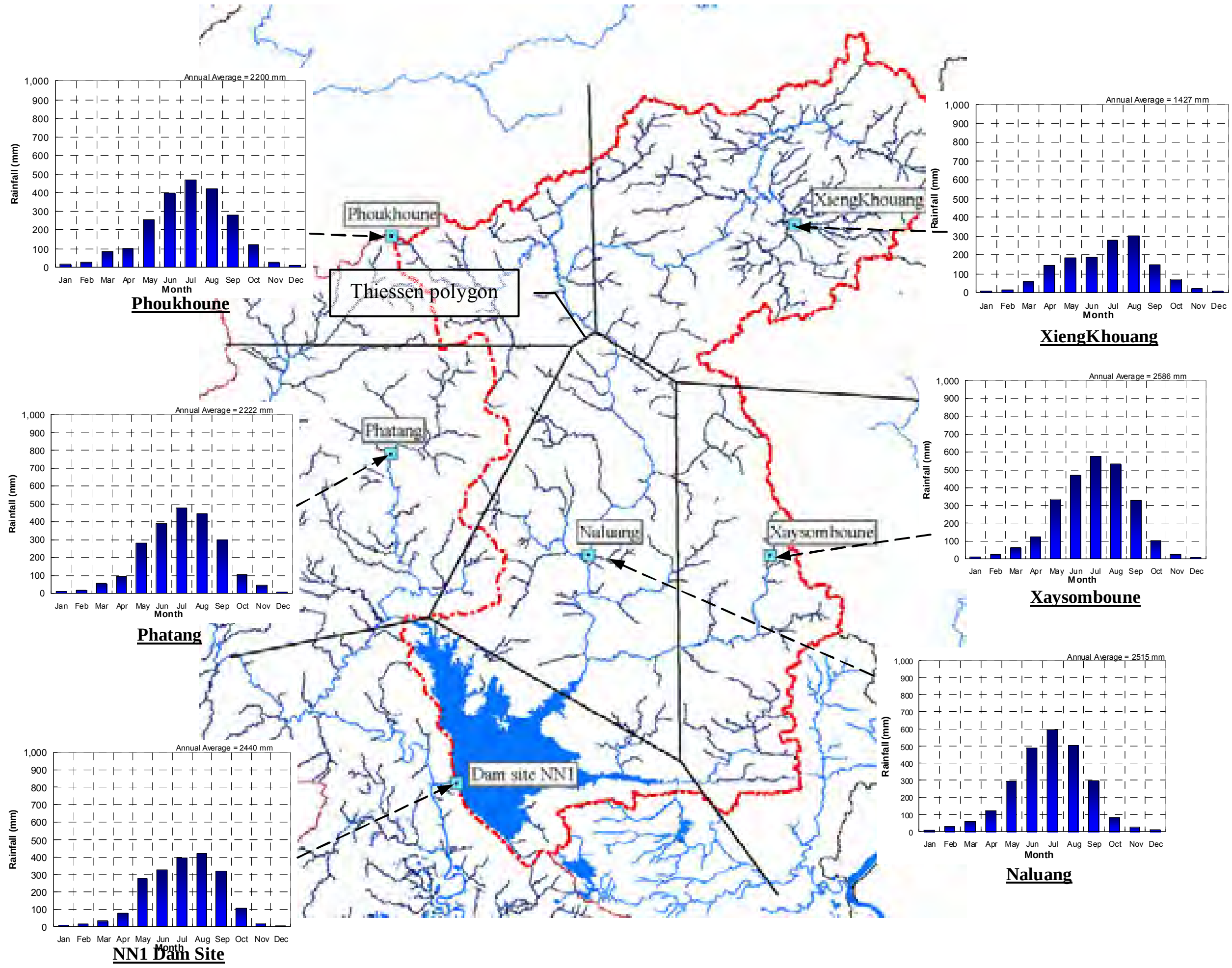
In the NNRBDSP, the accuracy and reliability of the rainfall data were examined. As the result, the Survey Team employs the rainfall data listed in Table 5.1.7.

Table 5.1.7 List of Rainfall Station Used in the Survey

Seq. No.	Station	River Name	Latitude	Longitude	Duration of data series	Manager
1	Dam site Nam Ngum1	Nam Ngum	18.53000	102.55333	1972 to now	EDL
2	Naluang	Nam Ngum	18.91333	102.77833	1987 up to now	DMH
3	Phatang	Nam Ngum	19.07604	102.43024	64 to 79, 1994 to 2002, 2004	DMH
4	Phoukoune		19.43917	102.42667	1996 to now	DMH
5	Xaysomboune	Nam Cha	18.91556	103.09583	1987 to now	DMH
6	XiengKhouang		19.14611	102.76167	1982 to now	DMH

Source; NNRBDSP, Output Report on Activity 2.1: Data Base and Monitoring Network

The annual average rainfall in the basin is calculated using Thiessen method. The location of the gauging stations and Thiessen polygon is shown in Figure 5.1.8.



Data Source: NNRBDSP Component 2, Map prepared by JICA Survey Team

Figure 5.1.8 Location of the Rainfall Gauging Station, Monthly Rainfall and Thiessen Polygon

Table 5.1.8 shows the area of Thiessen polygon covered by each rainfall gauging station as indicated in Figure 5.1.8.

- Thiessen polygon area covered by NN1 Hydropower Station

Table 5.1.8 Area of Thiessen Polygon

No.	Station	River Name	Thiessen Polygon Area (km^2)
1	Dam site NN1	Nam Ngum	1,079
2	Naluang	Nam Ngum	2,081
3	Phatang	Nam Ngum	232
4	Phoukoune		836
5	Xaysomboune	Nam Cha	1,560
6	XiengKhouang		2,574

Prepared by JICA Survey Team

The average rainfall of the NN1 dam catchment is calculated by the weighted average of polygon area and rainfall amount as shown in the following equation.

$$R_{ave} = \frac{\sum_{i=1}^{n} A_i R_i}{\sum_{i=1}^{n} A_i}$$

Where,

R_{ave} : Basin average rainfall (mm)
A_i : Area held by the gauging station i (km^2)
R_i : Annual rainfall of the gauging station i (mm)

Using the above formula, the annual average basin rainfall is calculated at 2,079 mm.

(3) Correlation of rainfall data

The relativity among the monthly rainfall data is checked by the correlation coefficients. The correlation coefficients of each rainfall gauging station are shown in Table 5.1.9

Table 5.1.9 Correlation of Rainfall Data

	Station Name								
	XiengKhouang	Xaysomboune	Phoukoune	Naluang	Phatang	NN1	Hinhuep	N Leuk	Thangone
XiengKhouang		0.846	0.781	0.820	0.832	0.785	0.772	0.799	0.716
Xaysomboune	0.846		0.861	0.941	0.922	0.914	0.876	0.899	0.845
Phoukoune	0.781	0.861		0.834	0.866	0.809	0.814	0.800	0.747
Naluang	0.820	0.941	0.834		0.892	0.862	0.811	0.885	0.805
Phatang	0.832	0.922	0.866	0.892		0.854	0.854	0.867	0.797
NN1	0.785	0.914	0.809	0.862	0.854		0.850	0.933	0.897
Hinhuep	0.772	0.876	0.814	0.811	0.854	0.850		0.832	0.774
N Leuk	0.799	0.899	0.800	0.885	0.867	0.933	0.832		0.918
Thangone	0.716	0.845	0.747	0.805	0.797	0.897	0.774	0.918	

Prepared by JICA Survey Team

As shown in the above table, the correlation coefficients are generally high. This means the rainfall pattern in the Nam Ngum River basin is almost similar over the basin.

(4) Correlation of discharge data

Similar to the analysis of the rainfall data, the correlation among the discharge data are also checked. The correlation among the discharge data are shown in Table 5.1.10

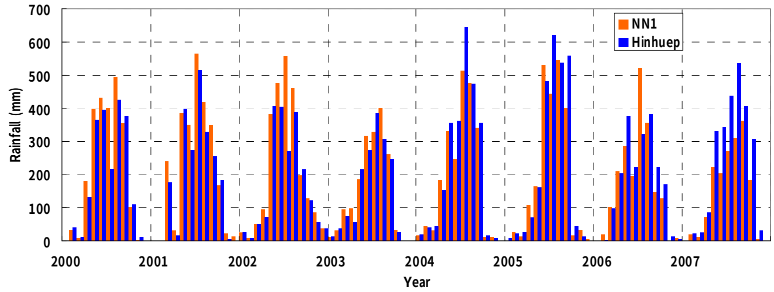
Table 5.1.10 Correlation of Discharge Data

	Station Name							
	Hinhuep	Van Vieng	Kasy	Naluang	NN1	NL	NM3	Nam Song
Hinhuep		0.899	0.909	0.927	0.939	0.869	0.849	0.917
Van Vieng	0.899		0.805	0.924	0.935	0.893	0.814	0.943
Kasy	0.909	0.805		0.889	0.858	N/A	N/A	0.848
Naluang	0.927	0.924	0.889		0.973	0.840	0.840	0.951
NN1	0.939	0.935	0.858	0.973		0.849	0.875	0.970
Nam Leuk	0.869	0.893	N/A	0.840	0.849		0.802	N/A
Nam Mang 3	0.849	0.814	N/A	0.840	0.875	0.802		N/A
Nam Song	0.917	0.943	0.848	0.951	0.970	N/A	N/A	

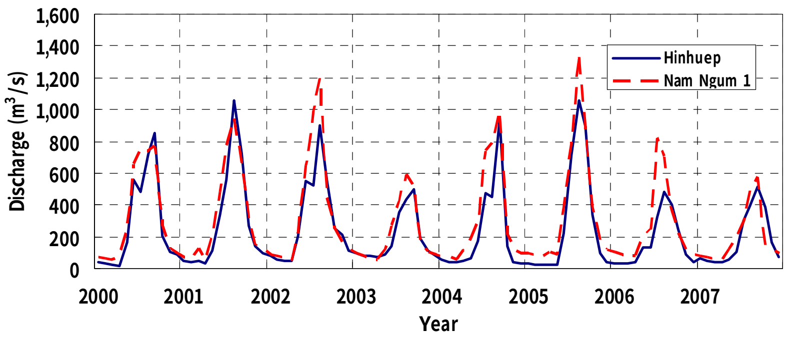
Prepared by JICA Survey Team

"N/A" in Table 5.1.10 indicates that the two discharge data do not have data in the same period.

As shown in the above table, all of the correlation coefficients shown in the table are high value. This indicates that the discharge data is highly correlated with each other in the Nam Ngum River basin. The reason for such high correlation values is that the rainfall patterns have similarity over the basin, therefore the resultant runoff is also correlated. The monthly discharge and rainfall graph of Hinhuep and NN1 dam site can exemplify the phenomena as shown Figure 5.1.9.



Rainfall



Discharge

Source: NNRBDSP, Component 2

Figure 5.1.9 Comparison of Hydrograph between Hinhuep and NN1 Hydropower Station

As shown in Figure 5.1.9, the rainfall and runoff patterns are similar between NN1 hydropower station and Hinhuep.

(5) Discharge duration and average discharge at each discharge measuring station

The annual average discharge at each gauging station is shown in Table 5.1.11.

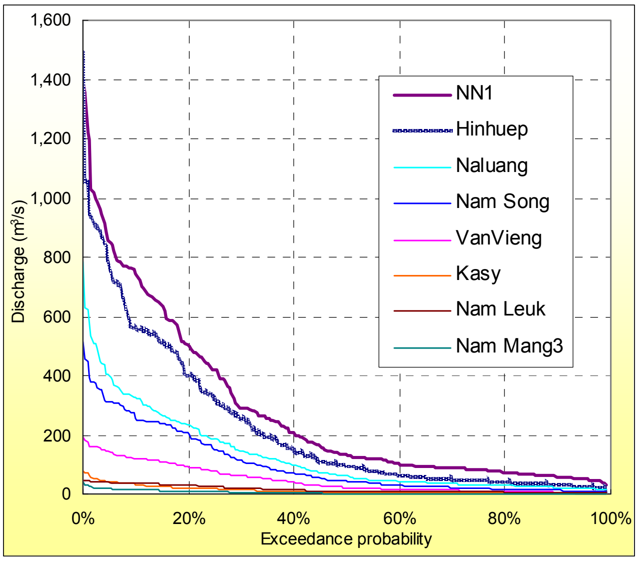
Table 5.1.11 Monthly Discharge at the Discharge Measuring Stations

	Rainfall (mm)	Catchment Area* (km^2)	Average Inflow (m^3/s)
Hinhuep	1,941	5,115	221
Van Vieng	2,222	2,062	48
Kasy	2,177	374	13
Naluang	1,853	4,852	127
NN1[1)]	2,079	8,275	280
Nam Leuk	2,566	323	17
Nam Mang 3	2,325	116	5
Nam Song	2,229	3,082	98

1) NN1flow indicates the inflow into NN1 Rerservoir from the NN river, which exclude Nam Song and Nam Leuk diversion flow

* Data source; NNRBDSP, Component 2

The duration curve of each station is shown in Figure 5.1.10.



Data source: NNRBDSP, Component 2

Figure 5.1.10 Discharge Duration Curves

The Nam Ngum River basin has tropical monsoon with distinct rainy and dry seasons. Therefore the discharge over the exceedance probability of 25% and 75% has large differences as shown in the figure above.

(6) Runoff coefficients

Runoff coefficients can be obtained from the annual average rainfall and annual average discharge. The runoff coefficients and runoff heights are shown in Table 5.1.12.

Table 5.1.12 Runoff Coefficient of the Nam Ngum River Basin

	Rainfall (mm)	Runoff Height (mm)	Runoff Coefficient
Hinhuep	1,941	1,360	0.70
Van Vieng	2,222	728	0.33
Kasy	2,177	1,090	0.50
Naluang	1,853	826	0.45
NN1	2,079	1,068	0.51
Nam Leuk	2,566	1,654	0.64
Nam Mang 3	2,325	1,449	0.62
Nam Song	2,229	1,008	0.45
Average		1,148	0.53

* Data source; NNRBDSP, Component 2

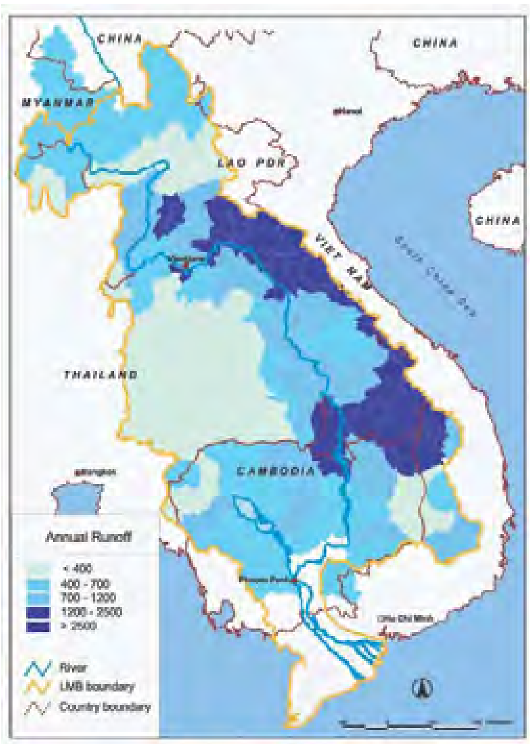
According to the above table, the runoff height of the Nam Ngum River basin is calculated at 1,148 mm.

Mekong River Committee (MRC) issued the hydrological survey report of the Mekong river titled "Overview of the Hydrology of the Mekong River Basin (Nov, 2005)." According to the report, majority of the runoff height in Nam Ngum River Basin ranged from 700 mm to 1,200 mm and there is a part of the region that exceeds 1,200 mm. Although the range of runoff heights is widely spread, the average runoff height of 1,148 mm in the table is within the range of MRC estimates..

(7) Estimation of Discharge from NN2 Hydropower Station

The Survey Team received the estimated discharge from NN2 power station by NN2 developer of Southeast Asia Energy Limited.

The discharged data received from the said developer is shown in Table 5.1.13.



Ref: Mekong River Commission(2005) "Overview of the Hydrology of the Mekong Basin," November 2005, pp 28-29.

Annual Runoff of the Mekong River Basin

Table 5.1.13 Estimated Monthly Average Discharge from Nam Ngum 2 Hydropower Station

unit : m^3/s

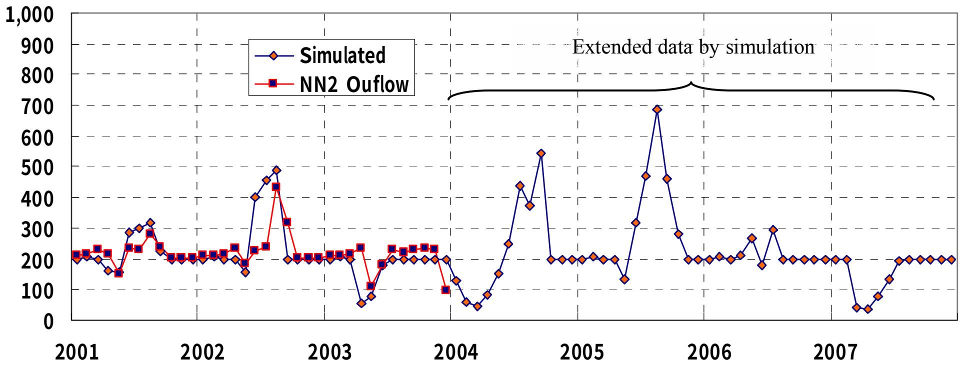
Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Yearly Mean
1972	203.1	213.9	223.5	224.7	101.5	166.8	229.0	391.2	433.0	272.1	202.0	198.3	238.8
1973	207.9	209.6	218.6	218.2	215.9	182.1	229.0	277.8	433.0	282.6	202.2	199.0	239.7
1974	209.1	211.7	214.3	233.2	125.4	204.8	231.2	226.8	214.7	216.5	217.8	217.8	210.2
1975	234.0	140.9	45.0	37.3	80.0	213.8	230.8	265.8	433.3	286.6	193.9	205.9	197.5
1976	208.2	203.2	220.9	232.5	159.0	207.1	226.3	216.6	216.4	204.6	209.9	214.2	210.5
1977	210.0	223.3	235.0	233.3	73.7	81.8	216.9	226.1	222.0	214.1	228.9	237.7	200.1
1978	92.5	46.8	46.7	44.1	82.7	233.5	231.2	430.7	432.6	194.7	203.8	201.3	187.4
1979	211.5	213.4	223.1	224.2	213.3	209.7	225.5	224.6	209.5	216.1	218.9	219.3	217.5
1980	234.9	141.5	44.9	45.9	87.6	222.4	237.9	206.3	281.7	203.7	196.4	209.0	176.6
1981	211.8	214.6	216.0	233.3	140.2	233.5	239.8	433.9	432.6	394.8	194.3	206.5	262.9
1982	200.8	210.1	218.5	226.4	228.1	234.2	232.9	265.5	206.0	243.3	202.5	206.8	223.1
1983	201.0	210.0	218.4	227.4	227.8	154.6	216.9	222.6	214.1	203.9	212.4	218.6	210.8
1984	214.4	230.8	140.6	84.0	79.0	178.1	229.0	278.4	199.9	206.2	206.8	203.2	188.0
1985	212.9	214.8	216.5	233.8	128.3	223.6	227.6	227.0	207.7	213.8	216.2	215.2	211.3
1986	230.0	178.6	45.0	98.8	205.6	224.5	240.3	206.0	212.0	213.4	208.5	225.8	190.9
1987	234.2	140.8	45.0	45.9	66.0	128.1	144.7	216.2	224.8	225.8	220.9	237.4	161.0
1988	92.5	47.1	46.7	45.9	110.0	87.4	152.5	226.7	230.8	226.0	237.8	48.5	129.9
1989	46.2	46.8	46.7	41.2	87.3	233.5	222.2	226.0	220.4	211.5	222.2	223.9	152.9
1990	236.5	46.8	46.7	44.1	109.5	233.5	230.6	219.2	200.3	207.0	207.9	205.1	166.5
1991	216.5	221.6	225.7	106.6	53.1	188.7	226.4	227.0	212.7	222.1	228.5	228.9	196.4
1992	96.0	47.1	32.9	29.9	48.1	117.8	226.6	222.0	230.8	236.5	147.2	48.5	124.3
1993	46.2	46.8	34.1	0.0	108.0	225.1	238.5	270.3	209.5	203.4	213.9	222.5	152.3
1994	220.8	195.3	93.5	45.9	171.0	233.5	231.1	431.5	433.0	272.1	203.2	207.9	228.5
1995	202.3	212.5	223.1	224.4	166.4	232.4	215.9	277.6	433.5	194.7	203.7	200.8	232.0
1996	211.0	215.7	217.6	234.3	118.0	198.6	225.4	245.3	200.2	206.4	207.4	204.1	207.5
1997	215.1	219.4	224.9	157.9	96.7	169.9	237.9	238.7	281.3	202.8	196.0	208.8	204.0
1998	211.3	213.7	215.7	233.5	142.5	177.2	225.5	219.9	229.4	236.2	140.9	48.5	191.0
1999	32.0	0.0	37.3	45.9	191.5	233.5	234.8	215.0	214.6	204.9	215.0	223.3	155.0
2000	222.0	164.3	46.7	83.2	169.9	233.5	231.7	280.3	282.1	195.7	204.5	202.2	193.6
2001	213.2	217.1	228.4	217.0	153.2	233.5	230.2	278.8	241.8	203.1	203.9	201.0	218.4
2002	211.1	213.7	216.0	233.7	183.3	224.5	240.6	432.1	320.2	202.8	204.1	201.1	240.4
2003	211.1	213.7	216.0	233.7	109.8	177.8	231.3	219.5	231.0	232.9	228.3	97.0	199.9
Mean	187.5	166.4	147.6	144.4	132.3	196.8	224.7	267.1	273.3	226.6	206.2	193.4	197.5
Max	236.5	230.8	235.0	234.3	228.1	234.2	240.6	433.9	433.5	394.8	237.8	237.7	262.9
Min	32.0	0.0	32.9	0.0	48.1	81.8	144.7	206.0	199.9	194.7	140.9	48.5	124.3
STDV	60.5	72.2	86.3	89.9	52.8	43.5	21.0	72.7	90.0	39.8	19.6	52.6	32.6

Source: Southeast Asia Energy Limited

The above data originated in the NN2 report of “Upgrading of the pre-feasibility study of Nam Ngum 2 hydropower project” by Nippon Koei in 1993. The discharge data at the NN2 site was estimated using the ratio of the drainage area and annual rainfall of NN1 and estimated NN2 hydrological data.

The data provided by Southeast Asia Energy Limited is finished in the year 2003. It is necessary to obtain the additional four years data from 2004 to 2007 to complete the data set. The Survey Team simulated NN2 operation with reservoir operation curve and reservoir capacity curve received from Southeast Asia Energy Limited.

The result of the simulation by the Survey Team is shown in Figure 5.1.11.



Data Source: Southeast Asia Energy Limited; Prepared by JICA Survey Team

Figure 5.1.11 Simulated Monthly Outflow from NN2 Hydropower Station

As shown in the figure above, the estimated discharge provided by NN2 developer, and the simulated extended data by the Survey Team are almost similar between the year 2001 to 2003. Therefore, in this Survey, the extended simulation data from 2004 to year 2007 are added by the Survey Team.

(8) Diversion from Nam Song diversion

Given by NN1 Hydropower Station

Nam Song Diversion

Nam Song diversion was built in 1996 aiming to increase the inflow into the NN1 reservoir. The operation rule of the Nam Song diversion is; 1) to release water of 6 m^3/s for downstream as minimum maintenance flow, and 2) to divert water with maximum capacity of 210 m^3/s. The Survey Team received the diversion record from the NN1 hydropower station from 1996 to 2008.

To complete the data set as the basic hydrological data for the Survey, it is necessary to estimated the diversion flow from the year 1972 to 1995. For the data between the year 1972 to 1995, the estimated data in the F/S report of the NN1 extension by the LI is used. In the report, the diversion flow was estimated using the hydrological data from 1949 to 1994. The Survey Team confirmed that the diversion flow presented in the F/S report follows the aforesaid diversion rule. Therefore, the diversion data in the F/S report can be used for the Survey. For the year 1995, the diverted water is estimated using the ratio of basin area and annual rainfall of Hunheup where has the high correlation with the Nam Song diversion flow.

Source: JICA Survey Team

Nam Leuk Hydropower Station

(9) Diversion from Nam Leuk Hydropower station

Nam Leuk hydropower station having the installed capacity of 60 MW has commenced its operation in the year 2000. The Nam Leuk hydropower project dams up water of the Nam Leuk River and discharge to NN1 reservoir through the powerhouse. The Nam Leuk River belongs to Nam Mang river system which is a different river system from the Nam Ngum River basin. To complete the data set from the 1972 to 2007, the diversion flow was estimated using the Nam Ngum reservoir inflow which has the highest correlation value with Nam Leuk inflow for the year from 1995 to 1999. For the diversion discharge from 1972 to 1994, the estimated diversion flow presented in the F/S report by LI was used for the Survey.

(10) Inflow from the intermediate basin between NN2 dam to NN1 dam

The intermediate inflow is the inflow between NN1 and NN2 dam. This intermediate inflow can be estimated by taking the difference of the inflow between the NN1 dam and NN 2 dam.

The intermediate inflow can be estimated using the following equation.

$$Q_{intermid}(t) = Q_{NN1}(t) - Q_{NN2}(t) + Evap(t)$$

Where,

$Q_{intermid}(t)$: Intermediate flow at the time *t*

$Q_{NN1}(t)$: Inflow into the NN1 reservoir from the Nam Ngum River which excludes the inflow from Nam Song diversion and Nam Leuk hydropower station

$Q_{NN2}(t)$: Inflow into NN2 dam at the time *t*

$Evap(t)$: Evaporation from the NN1 reservoir

The evaporation of "Evapo(t)" can simply estimated by the following equation.

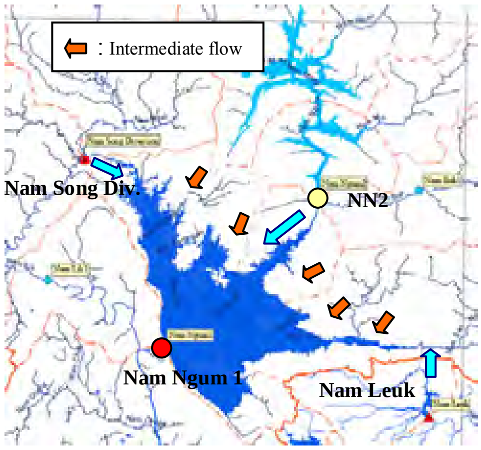
$$Evapo = k\, EG_m - (1\text{-}c)P_{n,m}$$

K : pan coefficient

EG_m : gross evaporation

C : runoff coefficient

$P_{n,m}$: rainfall in the month *m* in the year *n*

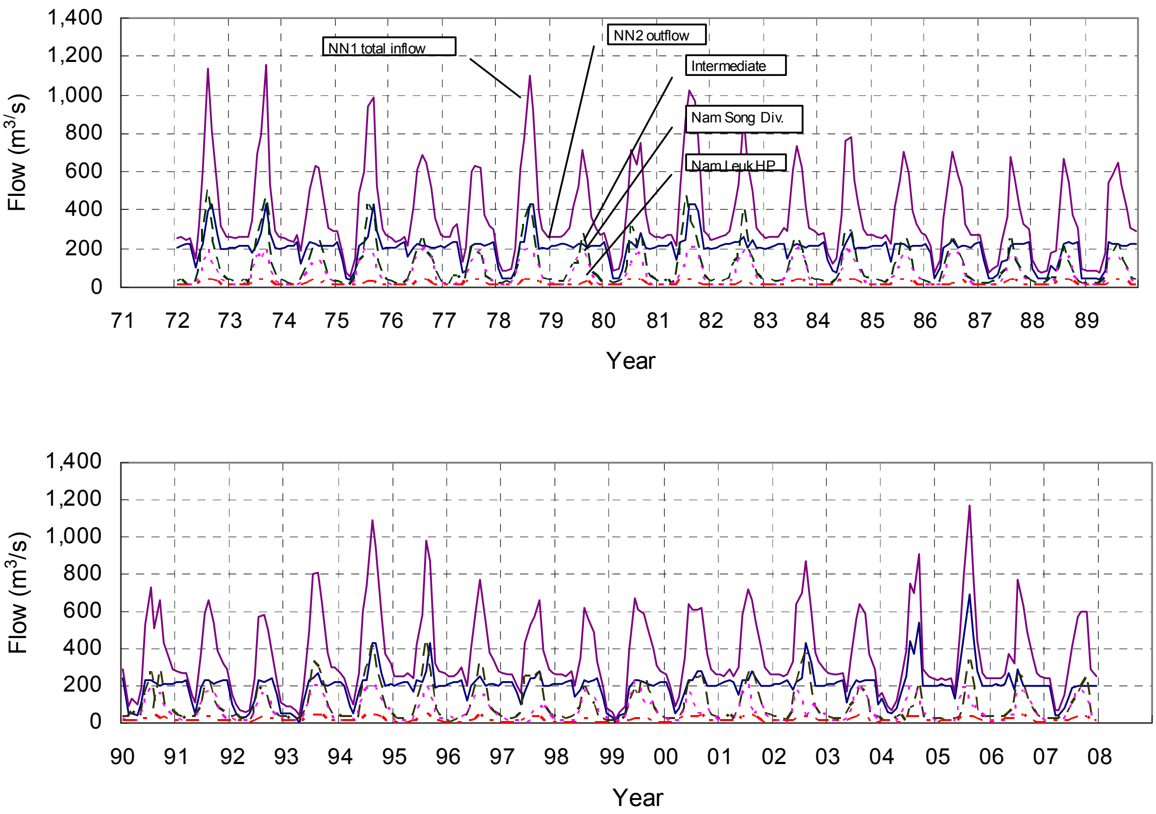


Intermediate inflow

Pan coefficient is 0.7, and runoff ratio is 0.52 which were obtained in the Survey as previously described.

(11) Inflow into the NN1 reservoir

The inflow into the NN1 reservoir consists of NN2 hydropower release, Nam Song diversion flow, Nam Leuk hydropower release, and the inflow of intermediate basin. The hydrograph of those inflows are shown in Figure 5.1.12.

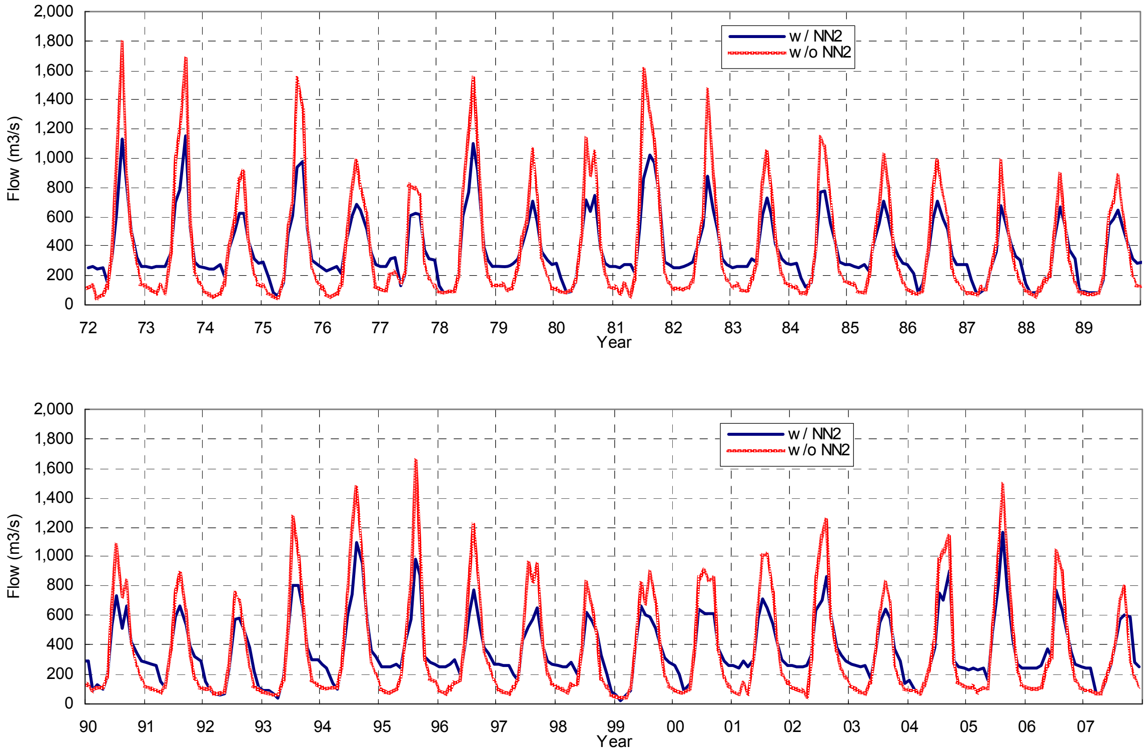


Prepared by JICA Survey Team

Figure 5.1.12 Hydrograph of the Inflow into the NN1 Reservoir from year 1972 to 2007

(12) Change of flow regime due to NN2

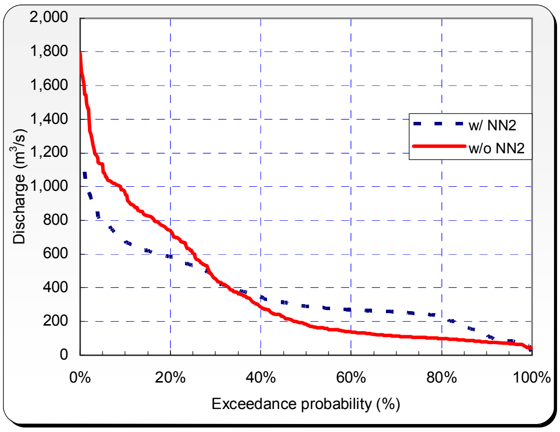
NN2 dam has a large reservoir capacity with effective storage of 2,994 MCM, which can regulate 47% of the annual inflow. This regulating capability will result in smoothing monthly inflow variation. The inflow hydrographs into the NN1 reservoir with and without NN2 are shown in Figure 5.1.13.



Source: Southeast Asia Energy Limited, and prepared by JICA Survey Team

Figure 5.1.13 Comparison of Inflow into the NN1 Reservoir before and after NN2 Hydropower Completion

As shown in Figure 5.1.13, the inflow into the reservoir in dry season is increased as inflow in the rainy season is decreased. The duration curve of the inflow before and after NN2 completion is shown in Figure 5.1.14.



Exceedance Probability (%)	100	95	90	75	50	25	10
Without NN2							
Inflow (m^3/s)	40	70	79	106	183	603	950
With NN2							
Inflow (m^3/s)	21	84	123	246	291	531	676

Data Source: Southeast Asia Energy Limited, JICA Survey Team

Figure 5.1.14 Discharge Duration Curve before and after NN 2 Hydropower Completion

As shown in Figure 5.1.14, the inflow in the rainy season (approximately less than 25% in exceedance probability) is decreased, and the inflow in the dry season (more than 75% in exceedance probability) is increased in "with NN2" case.

(13) Water-use in the Nam Ngum River basin

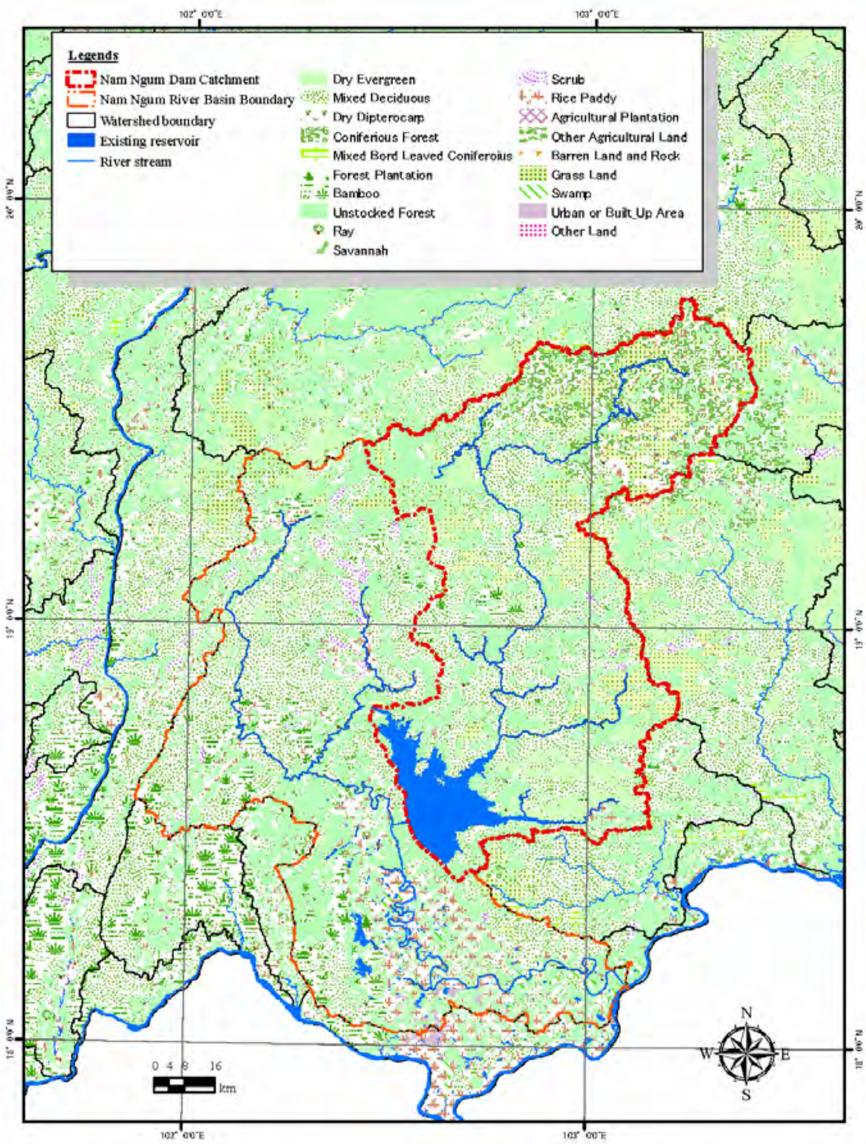
According to the NNRBDSP, the amount of the water-use in the Nam Ngum River basin is 900 MCM/year, and 99% of it is for agricultural use. The type of water-use in the Nam Ngum River basin is shown in Table 5.1.14.

Table 5.1.14 Water Use in the Nam Ngum River Basin

Annual Water Use Volume	900 MCM / year (≈ 28.5 m^3/s)
Agriculture	99 %
Urban	0.48 %
Industrial	0.08 %

Source: NNRBDSP, Component 1, "Nam Ngum River basin Profile"

The majority of the agricultural water is used for paddy irrigation. In the downstream of NN1 dam, most of the paddy fields are located in the suburb of Vientiane city. The land-use of the Nam Ngum River basin is shown in Figure 5.1.15.



Data source: NOFIP (FIPC)

Figure 5.1.15 Land Use Map in the Nam Ngum River Basin

The irrigation area of the Nam Ngum River basin is reported in ”Nam Ngum River Profile, 2004” provided in the NNRBDSP as shown in Table 5.1.15.

Table 5.1.15 Irrigated Area in the Nam Ngum River Basin

Jurisdiction	Wet Season (ha)	Dry Season(Irrigated) (ha)		Total irrigated	
	Rice	Rice	Other Crops	(ha)	(%)
Vientiane Mun.	51,505	21,266	39,497	39,497	50.6
Vientiane Prov.	44,600	5,566	24,155	24,155	30.9
Xiang Khouang	17,060	301	14,399	14,399	18.4

Source: NNRBDSP, Component 1, “Nam Ngum River basin Profile”

The water amount used for the irrigation is not measured, therefore the total amount of irrigation water used in the downstream area can not be specified. However, in the study of NNRBDSP, the generalized simulation model called “IQQM,” which are currently used by Mekong River Committee (MRC), is also introduced in the project. The model presumed the irrigation use and pumping capacity in the basin. In the model, the pumping capacity is estimated to be 32.8 m^3/s.

The irrigation demand per hectare in the region is approximated in the environmental study[4] for the Nam Ngum 3 project under ADB support. In the study, the irrigation demand was assumed to be 15,000 m^3/ha in dry season, and 5,000 m^3/ha in wet season. If these figures are applied to the current irrigation area in the Nam Ngum dam downstream, the irrigation demand is estimated to be 26 m^3/s in dry season and 31 m^3/s in the rainy season.

According to the NNRBDSP component 1, if the current irrigation development continues in the future, 61,000 ha will be irrigated by the year 2027[5]. The project estimated the required additional pumping capacity of 43 m^3/s.

The maximum irrigation demand can be estimated by aggregating the current and the additional future pumping capacity. In this case the total irrigation requirements in the downstream can be reckoned to 75.8 m^3/s (= 43 m^3/s + 32.8 m^3/s). This amount is assumed to be the maximum demand of the irrigation in the downstream of the NN1 dam.

5.2 ESTIMATION OF FIRM DISCHARGE

5.2.1 ESTIMATING FIRM DISCHARGE BY MASS-CURVE ANALYSIS

The firm discharge is the stably available discharge throughout a year for a specific water use, i.e. hydropower in this case. The quantity of the firm discharge is an important factor to determine the plant size of the hydropower station. In this study, the firm discharge is estimated by a mass-curve analysis using the inflow into the NN1 reservoir with NN2 hydropower operation. In addition to the NN2 discharge data, the following inflow data set is used in the mass-curve analysis which was prepared in the hydrological study.

- Diversion from Nam Song Diversion
- Diversion from Nam Leuk Hydropower Station
- Intermediate Inflow

The NN1 reservoir has a large capacity that can regulate 48% of the total inflow. Therefore, in the mass curve analysis, the operation of the Nam Ngum reservoir is assumed to recover the full supply level once in several years.

The mass curve of the NN1 reservoir using the inflow data from 1972 to 2007 with reservoir operation curve are shown in Figure 5.2.1.

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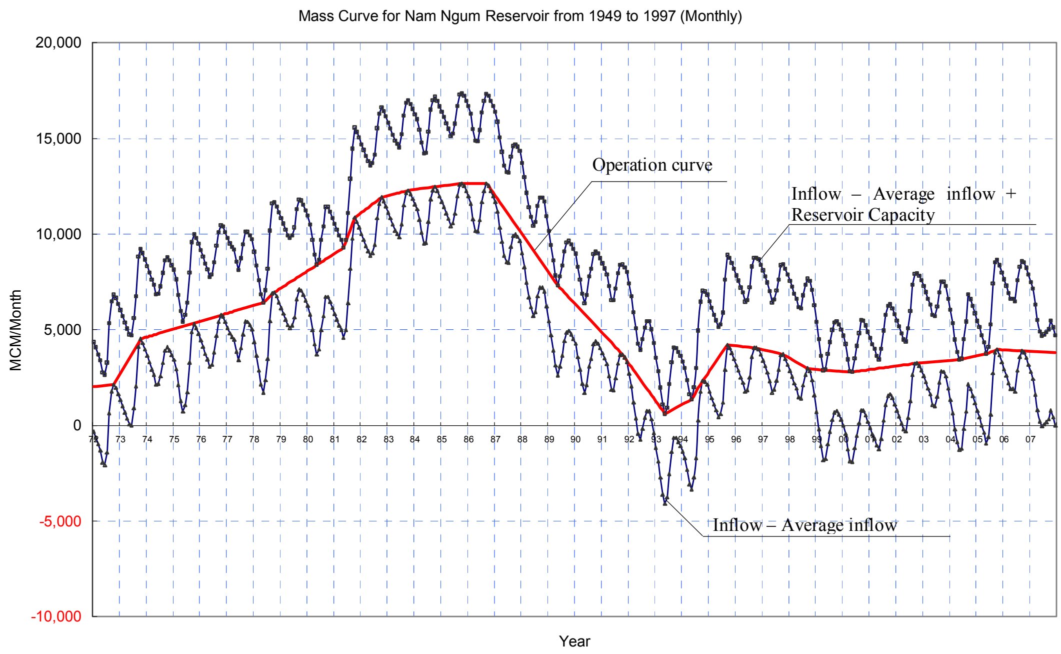
[4] Vattenfall Power Consultant AB in association with Ramboll Natura AB and Earth Systems Lao "Preparing the Cumulative Impact Assessment for the Nam Ngum 3 Hydropower Project", February 2008, Asian Development Bank.

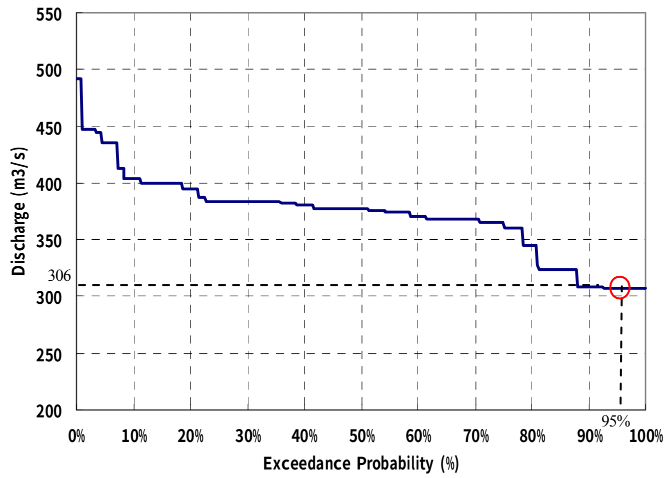
[5] Nam Ngum River Basin Development Sector Project, "Hydrological Analysis of Development Scenarios, Nam Ngum River Basin," January 2008, Water Resources and Environment Administration, pp-22



Prepared by JICA Survey Team

Figure 5.2.1 Mass Curve Analysis for the NN1 Reservoir

The red curve shown in Figure 5.2.1 indicates the idealized normal operation of the NN1 hydropower station, and its slope is correspondent to the hydropower discharge. From the result of the mass curve analysis, the firm discharge is calculated by taking 95% exceedance probability discharge. The hydropower discharge are rearranged to the discharge duration curve as shown in Figure 5.1.2, the guaranteed discharge is calculated at 306 m^3/s.



Prepared by JICA Survey Team

Figure 5.2.2 Power Discharge Duration Curve given by Mass Curve Analysis

The firm discharge is the guaranteed discharge available for operation for the 24 hours. The maximum peak discharge is calculated based on the firm discharge and peak hour duration by the following equation.

$$Q_p = Q_{firm} \frac{24}{T} \ (m^3/s)$$

where,

Q_p : maximum peak discharge (m^3/s)

Q_{firm} : firm discharge (m^3/s)

T : peak hour duration (hour)

If the peak hour duration is presumed at 10 hours, the maximum peak discharge is calculated at 734.4 m^3/s.

$$Q_p = 306 \frac{24}{10} = 734.4 (m^3/s)$$

This maximum peak discharge can be the maximum discharge capacity of the power plant after expansion. The existing power plant has the maximum discharge capacity of 465.3 m^3/s. Therefore the subtracting the existing maximum plant discharge capacity from the maximum peak discharge can be the available plant discharge capacity of the expansion plant, which is to be 269.1 m^3/s (= 734.4 – 465.3) in case of 10-hour-peak operation.

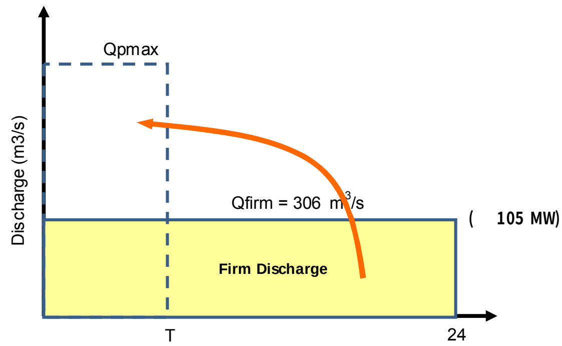


Figure 5.2.3 Firm Discharge and Maximum Peak Discharge

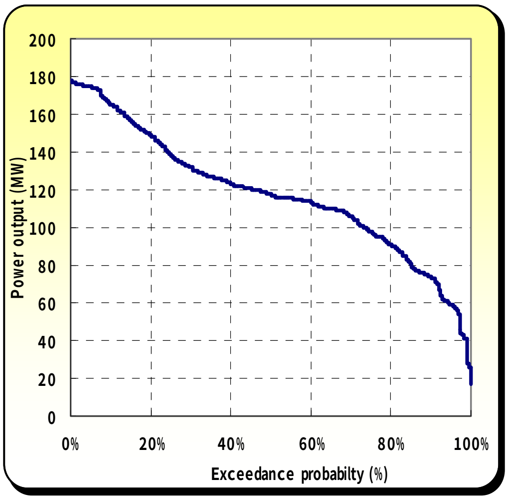
5.2.2 FIRM DISCHARGE AND POSSIBLE EXPANSION SCALE

(1) Operation with firm discharge

In this section, possible expansion scale and generation patterns after expansion are examined. The maximum plant discharge for the existing units are as follows.

- Unit discharge of No.1&2	57	m^3/s
- Unit discharge of No.3, 4,&5	117.1	m^3/s
- Total discharge	465.3	m^3/s

According to the operation records, NN1 hydropower generates electricity for 24 hours without stopping the running generators. Figure 5.2.4 shows the duration curve of hourly power output of NN1 powerhouse for the recent 5 years operation. As shown in the graph, the power output has never been "0", which means that stopping all generators, and the lowest power output recorded for recent five years is 17 MW. Ninety-five percent of the power output for the recent five years is around 59.5 MW.



Data Source: NN1 Hydropower Station

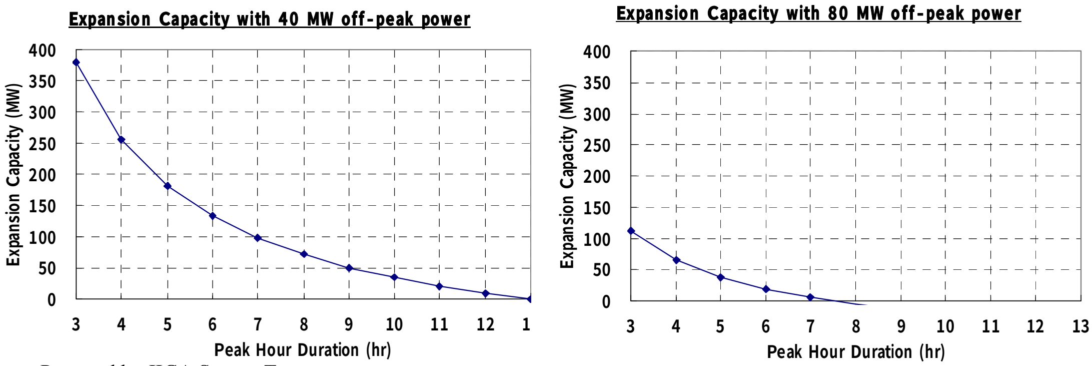
Figure 5.2.4 Duration Curve of NN1 HP Power Output

According to the staffs of NN1 hydropower station, they have to generate power during off-peak to meet electricity demand as well as considering the downstream impact. Therefore there would be an effect to the downstream inhabitant if the off-peak discharge is less than for generating 40 MW.

The effect to the downstream due to the change of discharge pattern was studied in the "Initial Environment and Social Examination (IESE)" in parallel with the NN1 expansion survey as described in Chapter 6. IESE confirmed that there will be adverse impact to the downstream inhabitants if the discharge quantity is less than 117.1 m^3/s. Therefore, it is assumed that the NN1 hydropower station should run at least one generator among units No. 3, 4, or 5 at full capacity during off peak hours.

On the other hand, the possible power output of the expanded NN1 hydropower station is inversely proportional to the peak hour duration. That is, the available water is limited, therefore the power output decreased as peak hour duration become longer.

Using the firm discharge derived from the mass-curve analysis, the relation between peak hour duration and the peak power output for expansion plant is shown in Figure 5.2.5 when the off-peak power output is set to 40 MW or 80 MW.



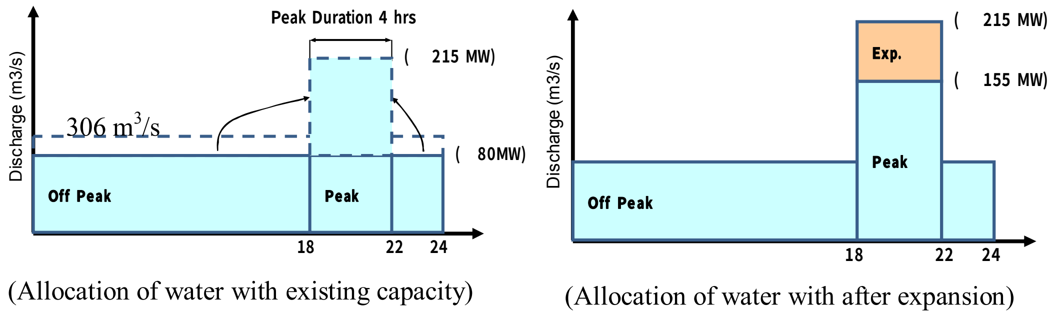
Prepared by JICA Survey Team

Figure 5.2.5 Relation Between Expansion Capacity and Off-peak Power

Left graph shows the relation of expansion capacity and peak hour duration when the off-peak power output is fixed to 40 MW. Meanwhile the right graph is the case when the off peak output is fixed to 80 MW. If the off-peak power output is 40 MW, the peak power output for the expansion plant becomes “0” when the peak hour duration is 13 hours. This means that the water is not available for the expansion plant when the peak hour duration is more than 13 hours. TOU has 13 hours of peak hour duration, therefore, it may not be adequate to apply TOU peak hour duration because of limited availability of water.

If the peak power output is set to 80 MW, then the peak power output becomes “0” when the peak hour duration is 7.5 hours.

At present, the domestic electricity demand in C1 area is peaked from 18:00 to 22:00 in weekdays. If the NN1 peak power supply operation concentrates in the night peak, then the peak hour duration is four hours. In case of off-peak power output is 80 MW, then the peak power output is 215 MW and the capacity of the expansion plant needs 60 MW.



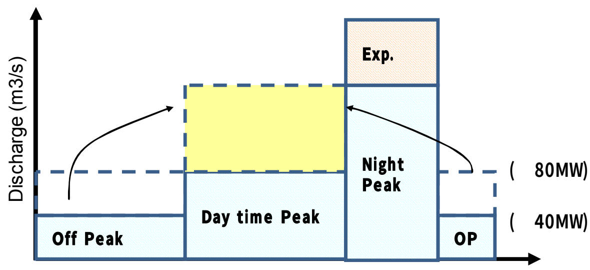
Prepared by JICA Survey Team

Figure 5.2.6 Operation Pattern of NN1 after Expansion with Firm Discharge (Night Peak)

According to Figure 5.2.5, it can be possible to expand the 250 MW with firm discharge. However, adding 250 MW will result in NN1 hydropower station to operate in night peak only and keep 40 MW output for the rest of 20 hours. This fact leads to the import of large quantity of energy from Thailand to satisfy the domestic power demand in daytime. This consequence is opposite to the Laos power supply policy that power demand should be firstly covered by the domestic power sources. Therefore 250 MW scale expansion does not meet to Laos power policy and is not practical.

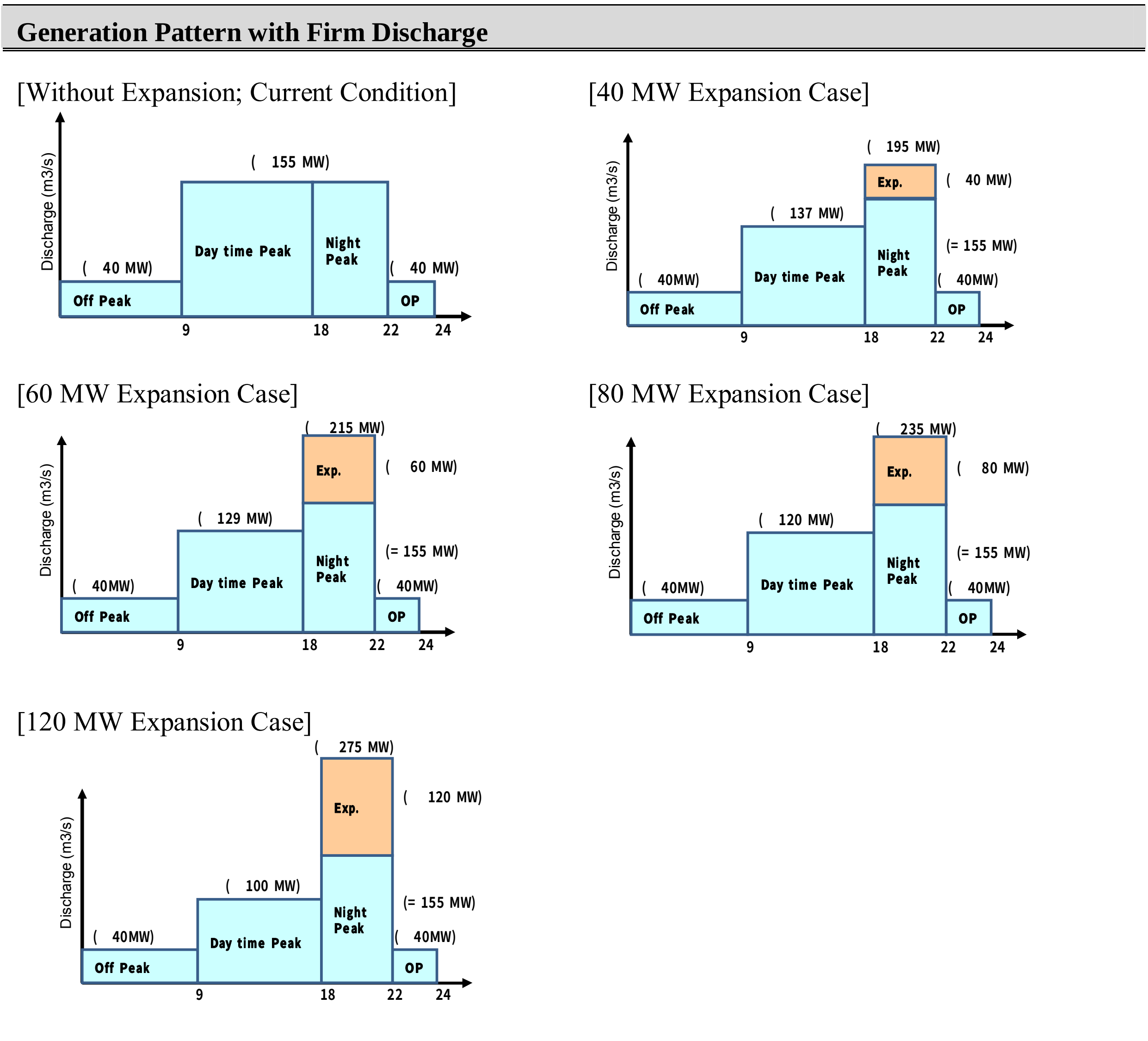
The aforesaid generation patterns of the NN1 hydropower station after expansion is assumed that the power station is mainly served for night peak. However, current operation of the NN1 power station also allocates energy also in the day time peak, and this operation pattern will be continued in the future operation.

Figure 5.2.7 shows the water allocation from the off-peak to day time peak. Operation pattern for each expansion scale is presented in Figure 5.2.8, when the day time peak is 40 MW, 60 MW, 80 MW and 120 MW.



Prepared by JICA Survey Team

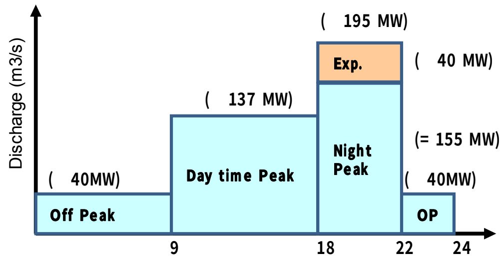
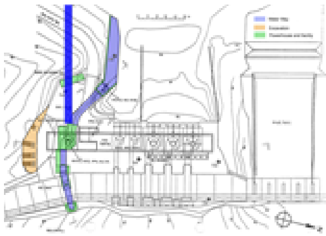
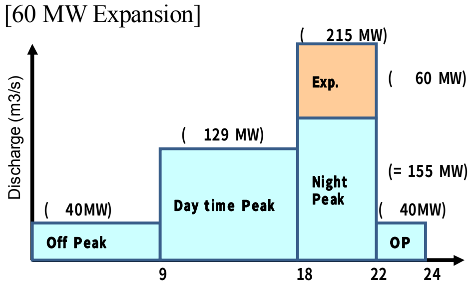
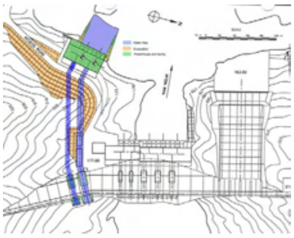
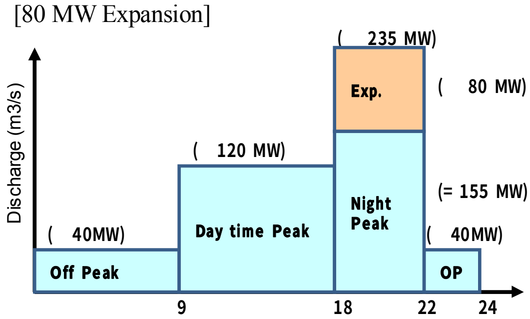
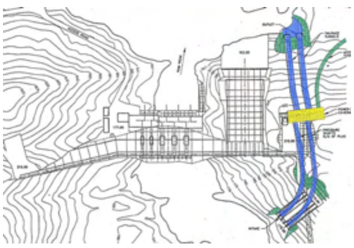
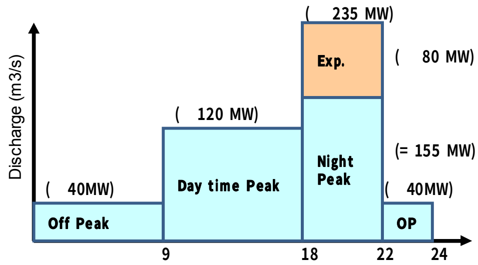
Figure 5.2.7 Typical Operation Pattern for Night and Day time

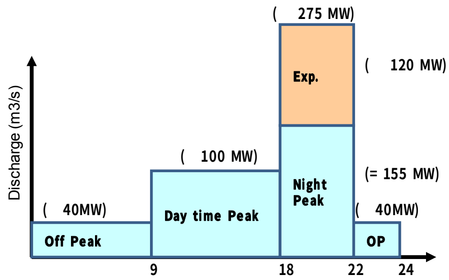
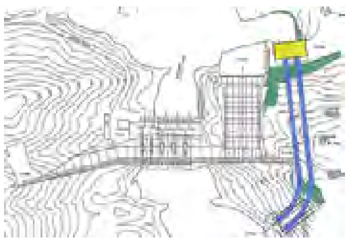


Prepared by JICA Survey Team

Figure 5.2.8 Operation Pattern of NN1 after Expansion with Firm Discharge

To enable the power generation during the daytime peak, it should correspond to the current load curve of the day. However, as shown in Figure 5.2.8, the daytime peak output decreases as the night time peak power output increases. These generation patterns are applied to each alternative as shown in Figure 5.2.9.

<table>
<tr><th>Alternative</th><th></th><th>Generation Pattern</th></tr>
<tr><td>A1-A2</td><td>
Unit : 1 or 2 unit
Power output : 40 to 60 MW</td><td>[40 MW Expansion]

</td></tr>
<tr><td>A4</td><td>
Unit : 1 unit
Power output : 40 to 60 MW</td><td>[60 MW Expansion]

</td></tr>
<tr><td>B2</td><td>
Unit : 2 unit
Power output : 80 MW</td><td>[80 MW Expansion]

</td></tr>
<tr><td rowspan="2">D1 or D2</td><td>
Unit : 2 or 3 unit
Power output : 80 to 120 MW</td><td rowspan="2">[80 MW Expansion]


[120 MW Expansion]

</td></tr>
<tr><td>
Unit : 2 or 3 unit
Power output : 80 to 120 MW</td></tr>
</table>

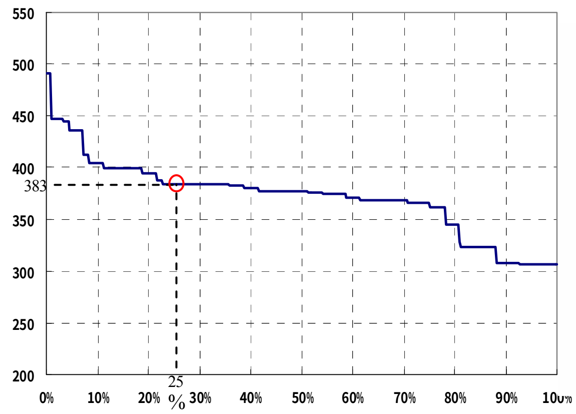
Prepared by JICA Survey Team

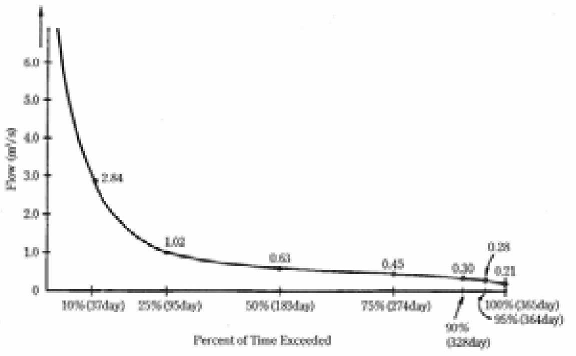
Figure 5.2.9 Operation Pattern of NN1 after Expansion for each Alternatives

5.2.3 OPERATION IN RAINY SEASON

One of the benefits accrued by the expansion of NN1 is the allocation of the energy from secondary to primary. The power discharge for rainy season can be estimated from the 25% discharge of the power discharge duration curve as shown in the mass-curve analysis.

The duration curve of the power discharge is re-presented in Figure 5.2.10

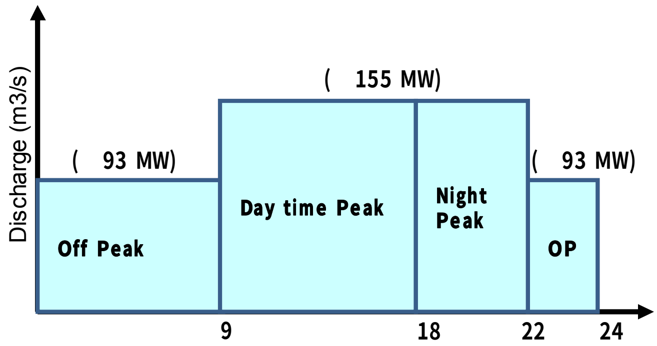




Ref; "Guide Manual for Development Aid Programs and Studies of Hydro Electric Power Projects"

Figure 5.2.10 Expected Power Discharge in the Rainy Season

The "25 %-discharge" is obtained at "383 m^3/s" in this case. This "383 m^3/s" would be the typical discharge available in the rainy season. The operation of the existing NN1 hydropower station with 25% discharge is shown in Figure 5.2.11

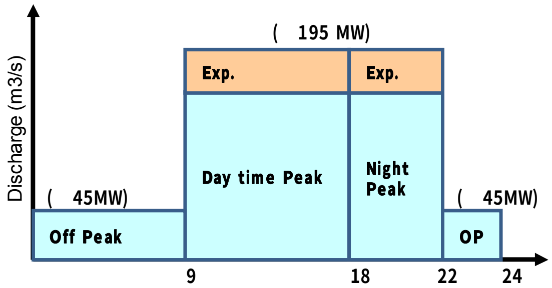


Prepared by JICA Survey Team

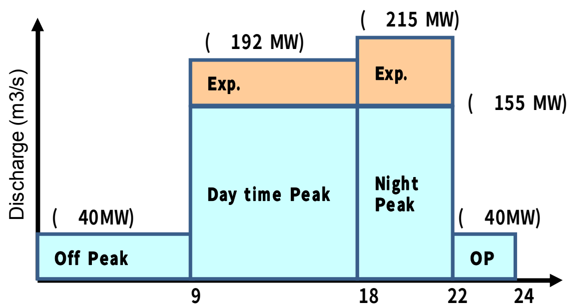
Figure 5.2.11 Typical Operation Pattern in Rainy Season without Expansion

The expansion of NN1 will not increase the energy production because the available water is the same. However, the energy in the peak hours in TOU can be increased. Figure 5.2.12 shows the generation pattern after expansion for 40MW, 60MW, 80MW, and 120 MW in rainy season.

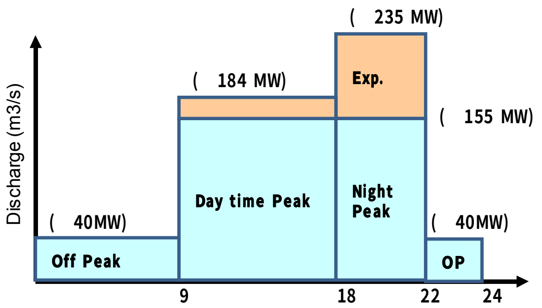
Generation Pattern	Increment of Primary Energy by Expansion
[40 MW expansion]	40 MW x 13 hr = <u>520 MWh/day</u>



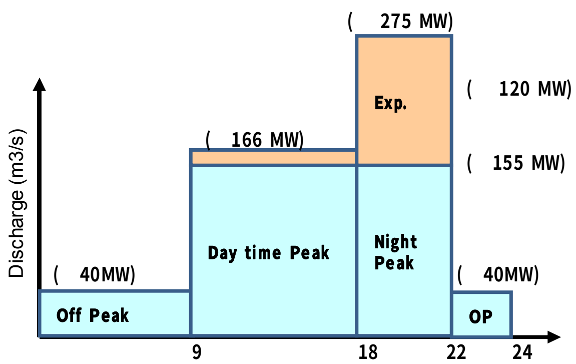
Generation Pattern	Increment of Primary Energy by Expansion
[60 MW expansion]	60 MW x 4 hr = 240 MWh (192-155) x 9 hr = 333 MWh Total = <u>573 MWh/day</u>



Generation Pattern	Increment of Primary Energy by Expansion
[80 MW expansion]	80 MW x 4 hr = 320 MWh (184-155) x 9 hr = 261 MWh Total = <u>581 MWh/day</u>



Generation Pattern	Increment of Primary Energy by Expansion
[120 MW expansion]	120 MW x 4 hr = 480 MWh (166-155) x 9 hr = 261 MWh Total = <u>579 MWh/day</u>



Prepared by JICA Survey Team

Figure 5.2.12 Typical Operation Pattern in Rainy Season with Expansion

The figures show that 40 MW to 60 MW expansion increases primary energy slightly. However, if the expansion scale is more than 60 MW, the primary energy does not increase significantly.

5.3 PRESENT NAM NGUM 1 RESERVOIR AND NAM NGUM RIVER HYDROPOWER OPERATION

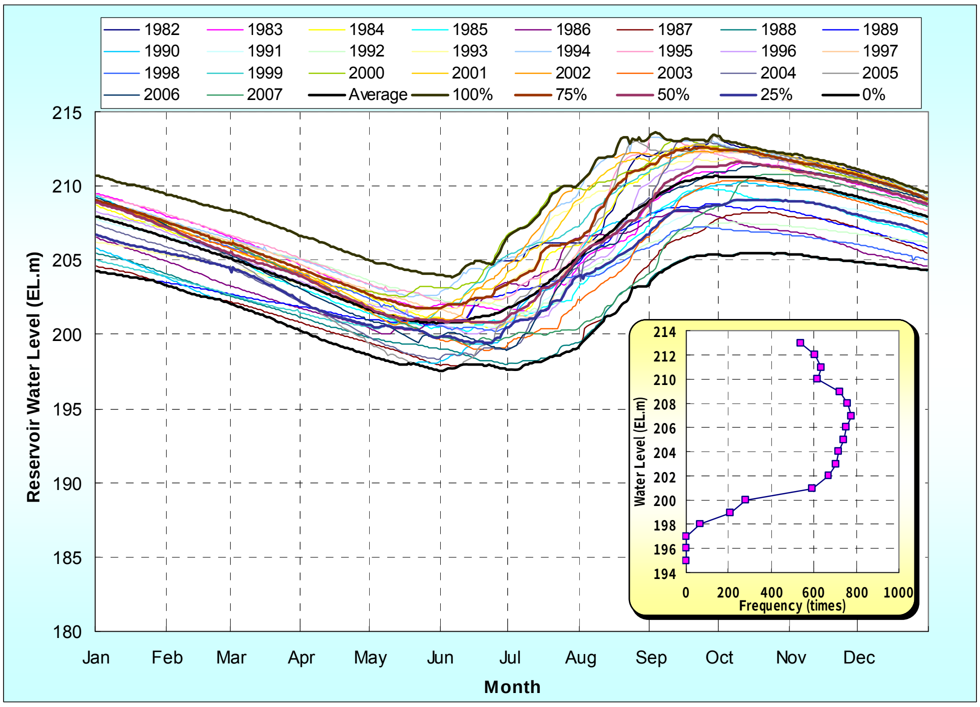
5.3.1 RECORD OF NAM NGUM 1 RESERVOIR OPERATION

The principal feature of the Nam Ngum reservoir is shown in Table 5.3.1.

Table 5.3.1 Principal Feature of NN1 Reservoir

Items		
Catchment area	:	8,460 km^2
Annual average inflow	:	382 m^3/s
Plant capacity	:	155 MW
Effective storage	:	7030 MCM
Storage area	:	370 km^2
Dam height	:	75 m
Dam crest length	:	468 m
Dam volume	:	360,000 m^3

The daily water level fluctuation of the NN1 reservoir received from the NN1 hydropower station is shown in Figure 5.3.1.



Data Source: NN1 Hydropower Station

Figure 5.3.1 Daily Water Level Record of NN1 Reservoir (1982 - 2007)

According to the water level record from the year 1982 to 2007, the frequency of water level is peaked in the range between 206 m to 207 m. This water level range occurs 777 days in 26 years which is equivalent to 8.2% of total duration.

The water level records show that the water level of the NN1 reservoir goes down to around EL.200 m at the end of May, then the water level rises until October.

The statistics of the monthly water level is shown in Table 5.3.2.

Table 5.3.2 Statistics of Water Level Record of the NN1 Reservoir

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
MEAN	206.3	205.0	203.6	202.1	201.4	202.6	206.0	209.4	210.3	209.8	208.9	207.7
MAX	210.8	209.4	208.3	208.1	208.5	212.2	212.7	213.4	213.4	212.2	212.1	211.9
MIN	202.8	202.1	200.2	198.6	197.6	197.7	199.2	203.5	205.3	204.6	203.6	203.2
25%	204.1	202.8	202.2	201.4	200.5	200.9	204.6	207.4	208.2	208.3	207.2	206.2
50%	207.3	205.4	203.9	201.9	201.2	202.8	206.1	209.0	211.7	211.2	210.1	208.9
75%	207.6	206.1	204.3	202.7	202.1	204.2	207.1	211.7	212.4	211.7	210.8	209.1

Data Source: NN1 Hydropower Station

The recorded yearly maximum and minimum water levels during the year 1981 to 2008 is shown in Table 5.3.3.

Table 5.3.3 Record of Maximum and Minimum Water Level of the NN1 Reservoir

Year	Maximum Water Level (masl)		Minimum Water Level (masl)	
	Reservoir Water Level	Date	Reservoir Water Level	Date
1981	213.16	Sep 04	201.40	May 20
1982	213.38	Sep 30	203.80	Jun 07
1983	211.54	Oct 12	201.54	Jul 13
1984	212.58	Sep 13	200.43	Jun 26
1985	209.86	Sep 25	200.16	Jun 13
1986	208.30	Sep 20	199.98	May 09
1987	208.25	Oct 23	197.61	Jul 04
1988	205.49	Oct 10	200.63	May 27
1989	208.84	Sep 28	197.92	May 16
1990	210.25	Oct 10	198.00	May 14
1991	209.15	Oct 26	200.49	Jun 25
1992	207.57	Oct 04	201.30	Jul 08
1993	211.81	Oct 05	201.51	May 22
1994	213.31	Sep 02	202.54	May 18
1995	213.60	Sep 03	202.07	Jun 07
1996	212.32	Sep 27	200.01	Jun 12
1997	212.33	Sep 28	200.65	Jun 25
1998	207.24	Sep 24	200.16	Jun 26
1999	212.61	Sep 24	200.36	May 05
2000	213.19	Sep 15	202.56	May 14
2001	212.74	Sep 23	201.01	May 20
2002	212.43	Oct 07	200.62	May 12
2003	210.40	Oct 13	198.86	Jun 21
2004	213.12	Sep 16	198.30	May 30
2005	213.47	Sep 29	197.52	Jun 02
2006	211.35	Oct 21	198.93	Jun 30
2007	210.80	Oct 22	199.34	Jun 16
2008	212.59	Sep 24	201.24	Jun 01

Source; Nam Ngum 1 Hydropower Station

The maximum water level appears from the 2nd half of September to October, and the minimum water level appears from 2nd half of May to June. The lowest water level experienced by the NN1 reservoir is at EL.197.52 m which occurred in June 2nd, 2005.

5.3.2 PAST STUDIES ON THE OPTIMUM RESERVOIR OPERATION

(1) LITHO

The reservoir operation rule was developed in the “Study to Improve Operation of the Nam Ngum

Hydropower Station Laos" in 1990. The reservoir operation is further studied in "Nam Ngum 1 Hydropower Station Extension Feasibility and Engineering Study" in 1995. Both studies applied the generalized stochastic dynamic programming software developed by LI named LITHO (Lahmeyer International Hydro-Thermal Optimization).

LITHO is a generalized software package applying the stochastic dynamic optimization technique aiming at cost minimization for the hydro-thermal power source system. LITHO was adopted by the EdL system for the NN1 study to derive optimum reservoir operation on the Time Of Day (TOD) tariff system. In the study, the inflow time series data is decomposed to discretized value with probability. LITHO program used the discretized inflow and carried out optimization to minimize the expected system cost.

The objective function forms the recursive cost function. LITHO minimizes the following system cost.

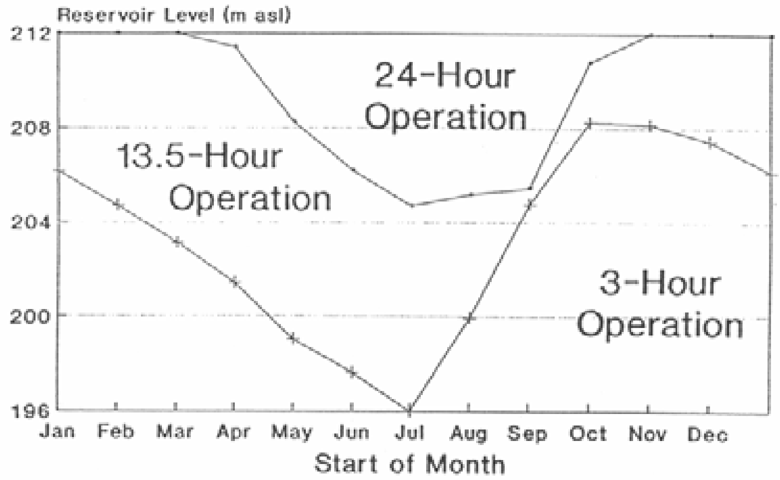
$$C_i(S_i) = C_i^T(E_i^T) + C_{i-1}^*(S_{i-1})$$

where,

S_i	: reservoir storage at the time *i*
E_i^T	: power demand at the time *i*
$C_i(S_i)$	: system cost at the reservoir storage of *Si* at the time *i*
$C_i^T(E_i^T)$	: cost of thermal power plant at the time *i*
$C_{i-1}^*(S_{i-1})$	: minimum system cost at the time *i-1*

LITHO is an optimization program for the hydro-thermal mix system. However, there was no large thermal plant to supply electricity in C1 area. Therefore, the power purchase cost from Thailand resembles to the thermal plant cost (Dummy thermal plant), and the power demand divided to peak, partial peak, off peak, are assumed as pseudo-demand called Artificial Load Duration Curve (ALDC). Then, LITHO gave the reservoir operation rule so called "switching curve" which gives the operation pattern corresponding to the reservoir water level.

Figure 5.3.2 shows the "switching curve" for the NN1 reservoir provided by LITHO.



Source ; Nam Ngum 1 Hydropower Station Extension Feasibility and Engineering Study (1995)

Figure 5.3.2 Reservoir Switching Curve Produced by LITHO in 1995

The NN1 hydropower station used LITHO program to derive the "Switching Curve" by updating the inflow data series and starting reservoir level in the year. However, LITHO does not run in the recent computers, therefore it is now difficult to use LITHO by the NN1 hydropower station. On the other hand, the reservoir operation optimization software PARSIFAL is developed and provided to EdL and DOE in the NNRBDSP component 2. The role of providing reservoir operation rule of the NN1 reservoir will be substituted by PARSIFAL from LITHO.

(2) PARSIFAL

The component 2 of the study in Nam Ngum River basin Development Sector Project (NNRBDSP) aims to model the river basin system for hydrology and reservoir operation and to training its personnel to use the models. A generalized reservoir optimization software package called PARSIFAL (Prévision de l'Actif des Réservoirs par Simulation Face aux ALéas: reservoir revenue forecasting by simulation with random events) was provided to DOE and EdL for reservoir operation optimization. PARSIFAL were developed by the consultant EdF who is main consultant in the component 2 in NNRDBDSP.

PARSIFAL applies stochastic dynamic programming with linear programming function. Therefore, PARSIFAL is a kind of hybrid optimization method. The program searches the optimum operation policy of the Hydro-Thermal combination system by maximizing the revenue. The mainframe of the program was developed using stochastic dynamic programming. The linear programming is used in searching the best value in the recursive cost function from stage t to $t-1$ or $t+1$ in forward type DP for each discretized water volume. The random variables considered in the program are hydrological data, system breakdown, variables influenced by hydrologic conditions such as electricity demand, and etc.[6]

PARSIFAL is a generalized software packages for hydro-thermal mix power source system. The objective of the optimization is to minimize the system cost in the hydro-thermal mix system, or to

[6] EdF, "PARSIFAL Methodological guidelines," EdF pôle industrie, division ingenierie et services, 2000, France

maximize the revenue of the hydro power system.

PARSIFAL has two modes, one is optimization mode and another is simulation mode that uses the rule developed from the result of the optimization mode, and simulates the hydropower generation.

The components 2 of the NNRBDSP concentrates on providing modeling and transfer of the knowledge of the optimization tool. Therefore, the study on optimum operation policy of the Nam Ngum hydropower stations was limited.

Currently LITHO has not been functioning in the current computers, therefore, hydropower operation study should be carried out by EdL or DOE staffs using PARSIFAL.

The principal features of PARSIFAL and LITHO are summarized in Table 5.3.3.

Table 5.3.4 Principal Features of LITHO and PARSIFAL

Method	LITHO	PARSIFAL
Optimization Method	Stochastic Dynamic Programming	Stochastic Dynamic Programming with Linear Programming function
Objective	Minimizing the system cost	Maximizing the revenue
Hydrological data used	1949 - 1994	1987 – 2007
Tariff Structure	TOD Peak; 18:00 – 21:30 Partial Peak; 8:00 – 18:00 Off Peak; 21:30 – 8:00	TOU Peak; 9:00 – 22:00 Off Peak; 22:00 – 9:00
Maximum Number of Reservoirs to be Optimized	Not Specified	2 reservoirs in the same time
Project name	"Study to Improve Operation of the Nam Ngum Hydropower Station Laos"(1990) Nam Ngum 1 Hydropower Station Extension Feasibility and Engineering Study (1995)	Nam Ngum River basin Development Sector Project (2009)
Development by	Lahmeyer International (Germany)	EDF (France)

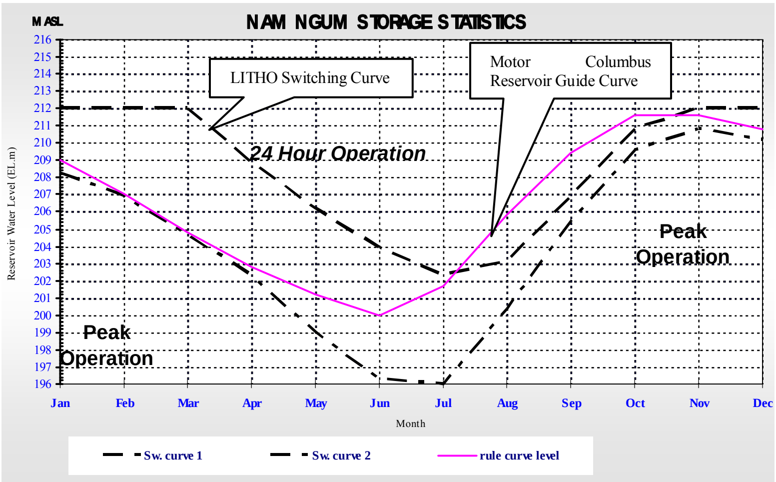
Source: "Study to Improve Operation of the Nam Ngum Hydropower Station Laos, Final Report", LI, 1990.
"PARSIFAL Methodological Guidelines", EDF, 2000.

LITHO and PARSIFAL carry out the reservoir optimization following TOD and TOU tariff structure, respectively. The detail of the TOD and TOU tariff and history of the export and import tariff change is described in Chapter 2.2.3.

5.3.3 CURRENT RESERVOIR OPERATION RULE OF NAM NGUM 1 RESERVOIR

Currently, NN1 hydropower station uses the switching curve, which is provided by the reservoir optimization program LITHO, to refer the operation hours with respect to the water level of the Nam Ngum reservoir, as well as the reservoir guide curve proposed by the Motor Columbus to refer the target water level in the next time period. Then, approximately every two weeks, the Nam Ngum hydropower station decides its operation policy considering on the power demand and supply balance and the expected inflow into the reservoir. However, the switching curve provided by LITHO is based on the TOD tariff, therefore if the water level is within the partial peak zone in the switching curve, then the NN1 hydropower station decides the operation policy considering the inflows and power supply and demand.

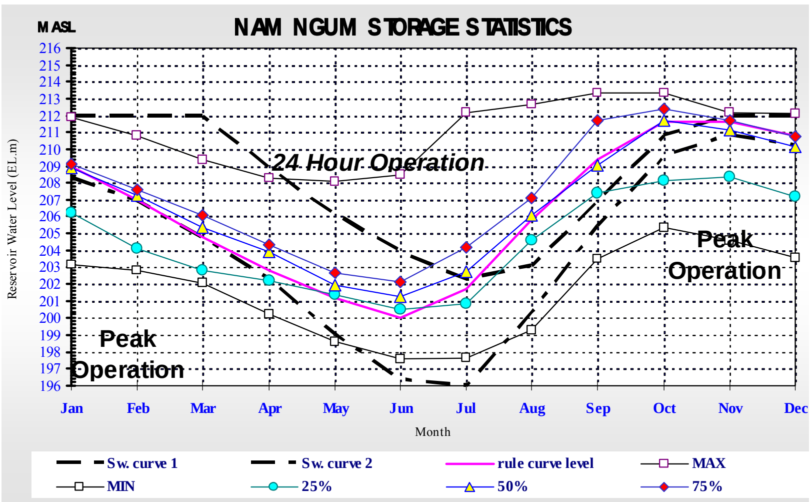
The guide curve prepared by Motor Columbus was prepared when the No.5 turbine and generator was placed in the NN1 hydropower station. However, the report that describes the development of the guide curve was not kept in the NN1 hydropower station or in the library of the DOE. In summery, the current reservoir operation rule referred by the NN1 Hydropower station is the switching curve provided by LITHO and the guide curve proposed by Motor Columbus as shown in Figure 5.3.3.



Source: NN1 Hydropower Station

Figure 5.3.3 Current Reservoir Operation Rule for NN1 Reservoir

The reservoir operation history is superimposed on the reservoir rule on Figure 5.3.3 as presented in Figure 5.3.1.



Data Source: NN1 Hydropower Station

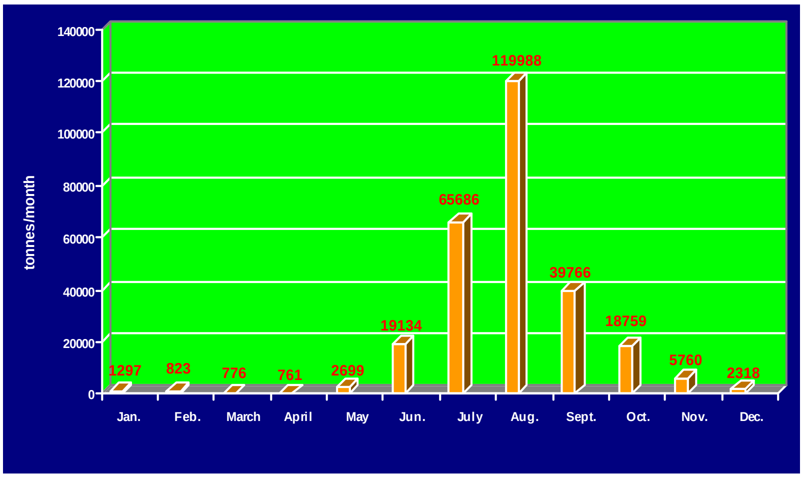
Figure 5.3.4 Current Reservoir Operation Rule and Actual Operation Statistics

As shown in the figure, median of reservoir water level (50% line) is almost coincides to Motor Columbus guide curve.

However, the guide curve and rules do not follow the current TOU tariff structure. It is expected that the reservoir operation will be studied by EdL and DOE using PARSIFAL for the future operation.

5.3.4 SEDIMENTATION IN THE RESERVOIR

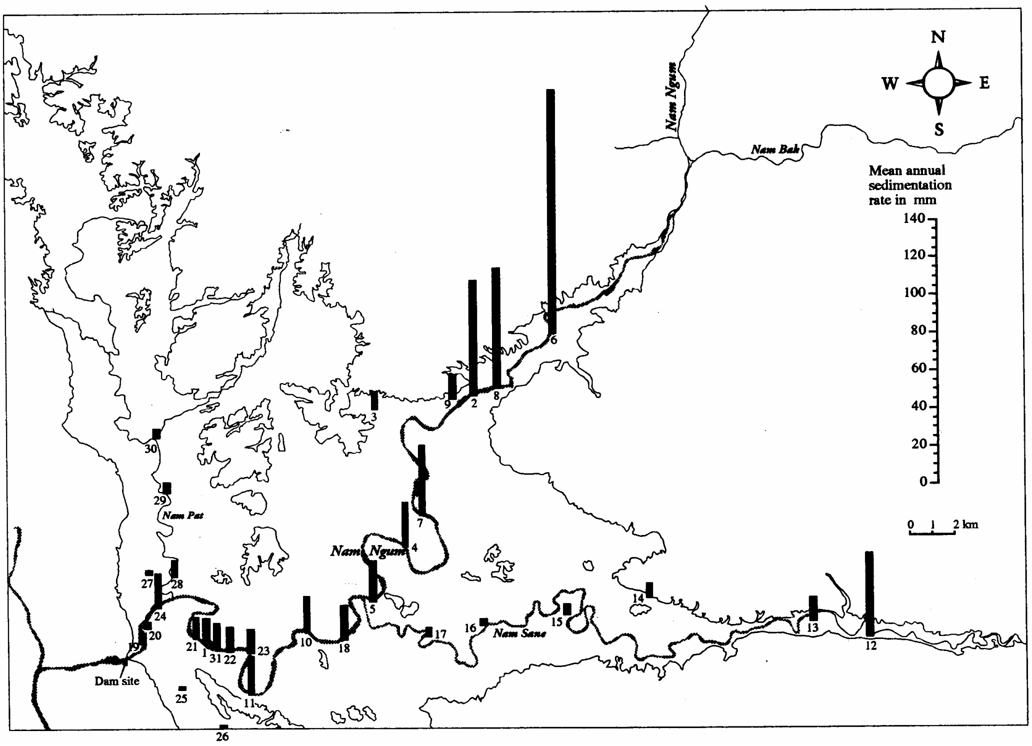
The Survey Team receives the sedimentation data from NN1 hydropower station. In the NN1 reservoir, sediment load inflows to the reservoir heavily in rainy season and settled in the confluence of the reservoir. Figure 5.3.5 shows the monthly sediment load of the Nam Ngum River.



Data Source: NN1 Hydropower Station

Figure 5.3.5 Monthly Sediment Load into the NN1 Reservoir

The sedimentation in the reservoir monitored in 1987 and 1990 are shown in Figure 5.3.6.



Data Source: NN1 Hydropower Station

Figure 5.3.6 Sediment Monitoring Result of the NN1 Reservoir

Currently, the sedimentation in the reservoir is not issued for NN1 hydropower operation.

5.3.5 PRESENT RESERVOIR OPERATION OF THE EXISTING HYDROPOWER STATION IN THE NAM NGUM RIVER BASIN

In the Survey, the operation of the existing Nam Leuk hydropower and Nam Mang 3 hydropower is considered. Also Nam Lik 1/2 hydropower station that is under construction is considered. The principal features of these hydropower projects are shown in Table 5.3.5.

Table 5.3.5 Principal Features of the Existing/Under Construction Hydropower Station Considered in the Survey

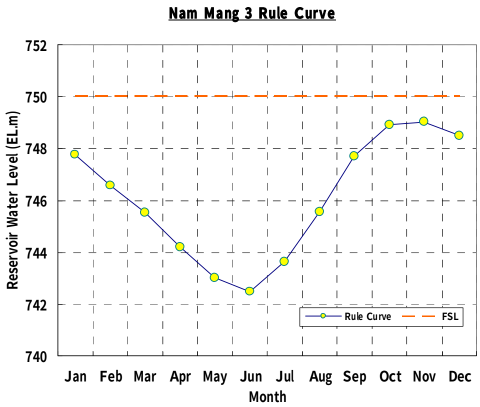
Item/Project	Nam Leuk	Nam Mang 3	Nam Lik 1/2
Status	Existing	Existing	Under Construction
Main Developer	EdL	EdL	China International Water & Electric Corp.
Planned Commencement of Power Generation	2000	2004	2010
Principle Feature			
Catchment area (km^2)	274	65	1,993
Storage at FSL (MCM)	154	45	1,095
Average annual inflow (MCM)	438	-	2,690
Type of Dam	Rockfill	RCC	CFRD
Dam Height (m)	46.5	22	101.4
Design flood of spillway (m^3/s)	2,100	57	2,080
Powerhouse type	Surface type	Surface type	Surface type
Rated output (MW)	60	40	100
Average annual energy	230	134	395

Prepared by JICA Survey Team

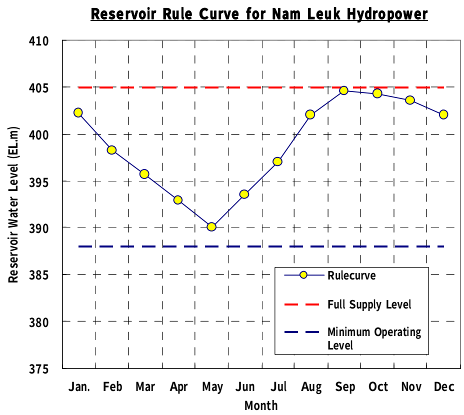
(1) Reservoir operation of the existing hydropower stations

The existing hydropower station of Nam Mang 3 and Nam Leuk hydropower station which is in the Nam Mang 3 River basin commenced their operation from the year 2000 and 2006 respectively.

The existing reservoir operation rule curve of Nam Mang 3 and Nam Leuk reservoir is shown in Figure 5.3.7.



[Nam Mang3 Reservoir Operation Rule]

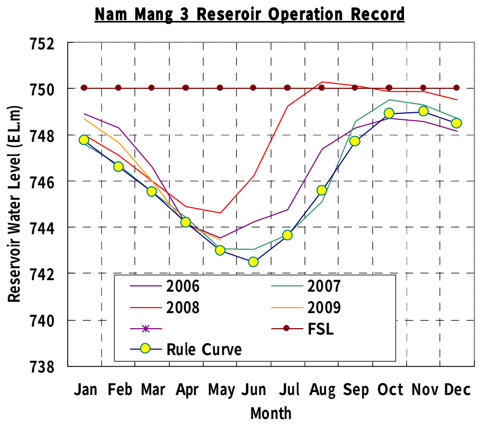


[Nam Leuk Reservoir Operation Rule]

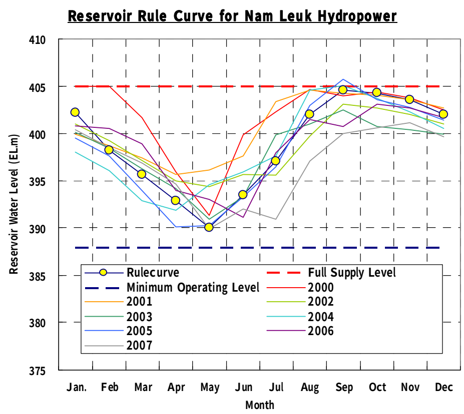
Source: Nam Mang 3 Hydropower Station, Nam Leuk Hydropower Station

Figure 5.3.7 Operation Rule of Nam Mang 3 and Nam Leuk Reservoir

The water level record of the Nam Mang 3 and Nam Leuk reservoir that are provided from the both hydropower stations superimposed in the reservoir operation rule as shown in Figure 5.3.8.



[Nam Mang3 Reservoir Operation Rule]



[Nam Leuk Reservoir Operation Rule]

Source: Nam Mang 3 Hydropower Station, Nam Leuk Hydropower Station

Figure 5.3.8 Reservoir Water Level Record of Nam Mang 3 and Nam Leuk Reservoir

As shown in the figure, the water level of the reservoirs seems to targeting the reservoir operation rule curve although there are some deviations observed in some years.

(2) Nam Lik 1/2 Hydropower Project

Nam Lik 1/2 is an IPP hydropower project aiming to sell electricity to EDL. The project is planned to commence its operation in the year 2010. According to the feasibility study report of the project, Nam Lik 1/2 has relatively large capacity reservoir with effective storage of 826 MCM and inflow regulation ratio of 31 % to annual average inflow of 85.2 m^3/s. In the feasibility study report, there is no description of the detail of the reservoir operation and discharge pattern. However, the operation of the hydropower station can be estimated to 10 hours/day for peak hours by referring to the annual operation hours of 3,954 as mentioned in the report.

As the Nam Lik 1/2 is an IPP project, therefore the operation of the hydropower station is not as flexible as the other EDL owned hydropower stations such as Nam Leuk or Nam Mang 3 hydropower station. However, the operation of the Nam Lik 1/2 is also included in the hydropower operation studies as it was requested by the DOE.

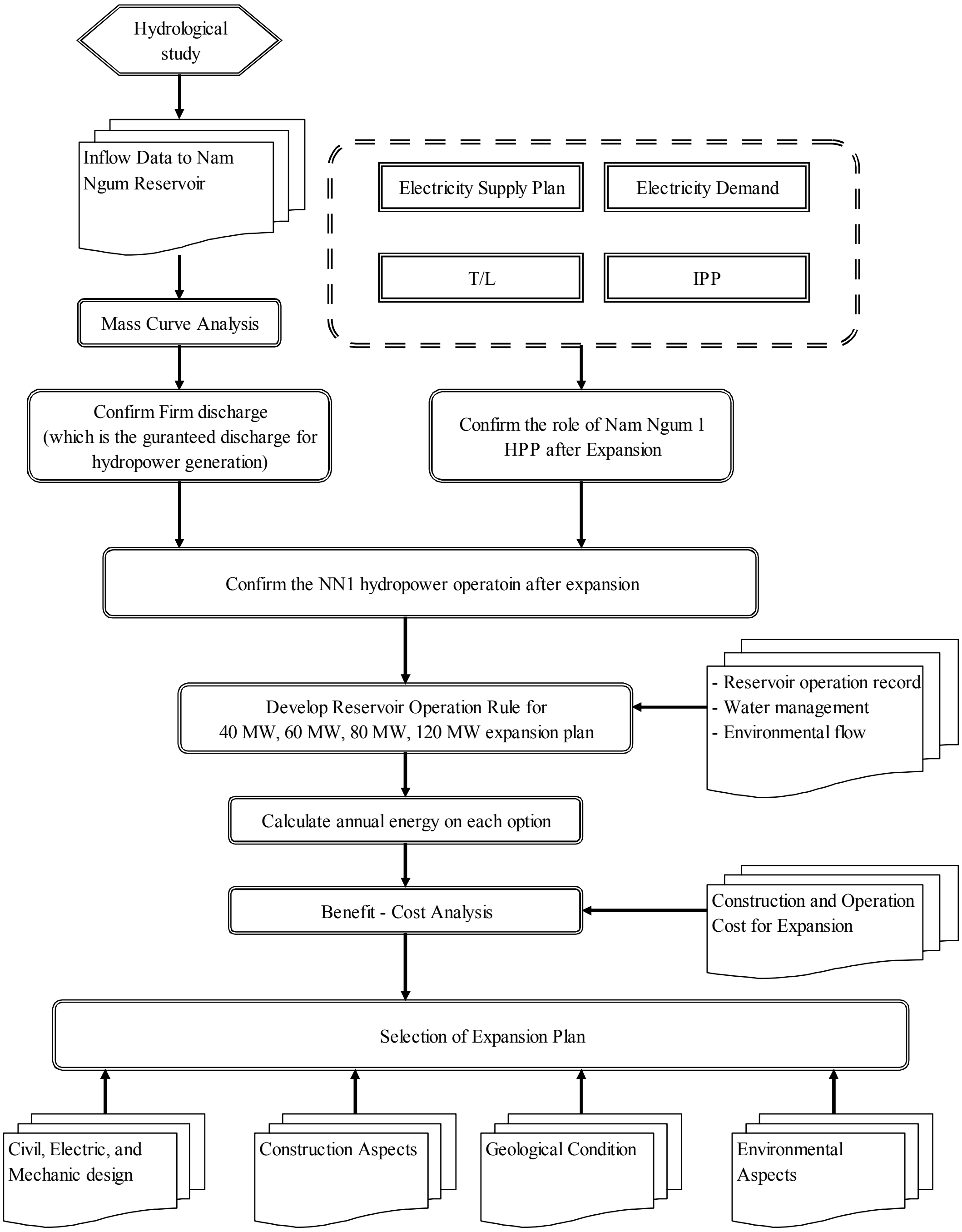
5.4 RESERVOIR OPERATION FOR SELECTION OF OPTIMUM ALTERNATIVE PLAN

5.4.1 GENERAL

In this section, the reservoir operation rules are presented for the selection of the optimum alternative plan. The reservoir operations are developed for each expansion scale, and then the corresponding annual energy of each option is calculated using the developed operation rule corresponding to the magnitude of the expansion scale. The results of the power energy calculations are used as the main indicators of alternative expansion plans for detailed and in-depth comparisons as described in Chapter 8.

5.4.2 RESERVOIR OPERATION POLICY AFTER EXPANSION

In this Survey, the operation rule after NN2 hydropower commencement is studied first. Then the reservoir operation rule for each alternative is developed. The developed reservoir operation rules are utilized for the hydropower generation simulation to calculate the annual energy and dependable capacity for each alternative option. The study flow from the hydrological study until selection of the best option is shown in Figure 5.4.1.



Prepared by JICA Survey Team

Figure 5.4.1 Study Flow of Selection of the Best Option from the Alternatives

After selection of the best alternative, the reservoir operation is studied further by increasing the accuracy of specification for the selected expansion option such as a turbine or a generator.

The Survey Team discussed with EdL about the method of optimization, objectives and time step for reservoir operation optimization after expansion. The conditions included in the analyses agreed with EdL are summarized in Table 5.4.1.

Table 5.4.1 Method and Conditions for the Reservoir Operation Optimization for the Selection of Alternatives

Item	Method
Purpose	Maximization of export and import power revenue with minimizing electricity supply shortage Max (Export Power – Import Power) and Min (Demand - Supply)
Method	Implicit Stochastic Optimization Method with Deterministic Dynamic Programming
Constraint	Reservoir capacity, discharge capacity of turbines.
Decision variables	Discharge from NN1 hydropower station
State variables	NN1 Reservoir storage
Conditions and assumptions	- Duration of inflow is 36 years from year 1972 to 2007 - Time Step is monthly - Operation of at least one unit among No.3, 4, or 5 operation during off-peak hours is mandatory required as maintenance flow - The priority of the power demand is in the order of 1) the night peak (18:00 to 22:00), 2) day time peak (9:00 to 18:00), 3) off peak (22:00 to 9:00). - TOU tariff structure is employed. - Target year is 2015 for selection of alternative. - Power demand and supply refers to the latest PDP.
Software	CSUDP[7] (Generalized Dynamic Programming Software)

Prepared by JICA Survey Team

To determine the optimum reservoir operation by dynamic programming (DP), dynamic programming computer software called CSUDP is used in the study. CSUDP is a generalized dynamic programming software package developed in Colorado State University in the United States. The custom codes linked to CSUDP state and decision variables are specifically developed with C computer language by the Survey Team. The custom codes describe hydrological data reading, state/decision variables, and the hydropower station characteristics in the Nam Ngum River basin.

Loads in a day that are to be covered by NN1 hydropower station are divided into four blocks. Each block of load represents the average load in the peak and off-peak divided by two in the TOU system. The duration of block includes 1) the night peak (18:00 to 22:00), 2) day time peak (9:00 to 18:00), 3) night off peak (22:00 to 0:00), and 4) daytime off-peak (0:00 to 9:00).

Each block is represented by the average of the load as shown in Figure 5.4.2.

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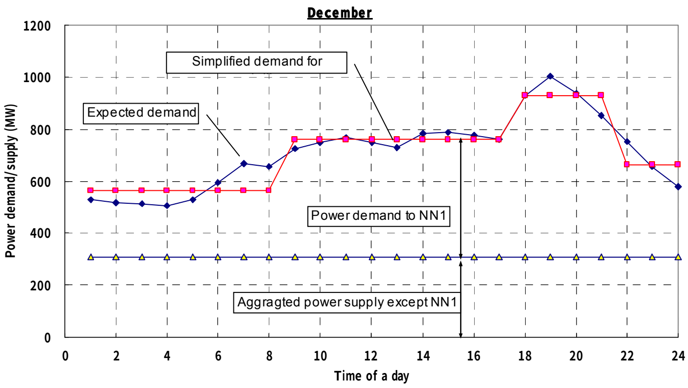
7 Labadie, J.W., (2003) "Generalized dynamic programming package: CSUDP." Documentation and user manual, Department of Civil Engineering, Colorado State University, Fort Collins, Colorado.



Prepared by JICA Survey Team

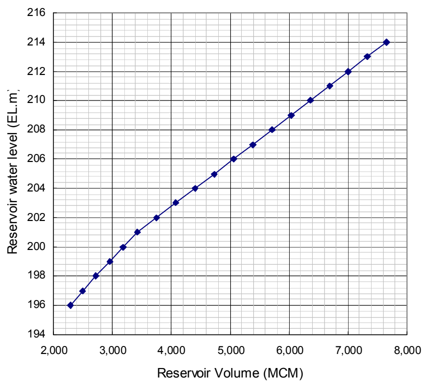
Figure 5.4.2 Simplified Load Curve for Modeling of Dynamic Programming

The optimization of the reservoir operation requires the reservoir characteristics such as storage capacity curve, and turbine/generator efficiency curves. For the selection of the alternatives, the characteristics of the existing turbines and generators of unit No.3, 4, 5 is applied to 40 MW expansion option. While the alternatives over 60 MW size uses the standard characteristics of turbine and generators.

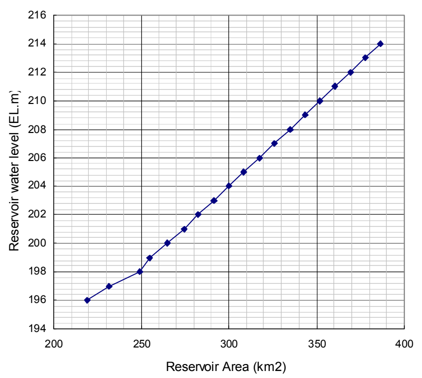
The relationship between the reservoir volume and water level, and reservoir area and water levels are shown below.

Elevation (m asl)	Area (km2)	Volume (1000m3)	Volume (MCM)
164	0.0	0	0
196	219.0	2,296,000	2,296
197	231.5	2,501,000	2,501
198	249.0	2,724,000	2,724
199	255.0	2,967,000	2,967
200	265.0	3,193,000	3,193
201	274.5	3,428,000	3,428
202	282.5	3,754,000	3,754
203	291.5	4,079,000	4,079
204	300.0	4,405,000	4,405
205	308.5	4,730,000	4,730
206	317.5	5,057,000	5,057
207	326.0	5,382,000	5,382
208	335.0	5,708,000	5,708
209	343.5	6,033,000	6,033
210	352.0	6,359,000	6,359
211	360.5	6,685,000	6,685
212	369.5	7,010,000	7,010
213	378.0	7,336,000	7,336
214	386.5	7,661,000	7,661

Data



Reservoir Vol. – WL curve

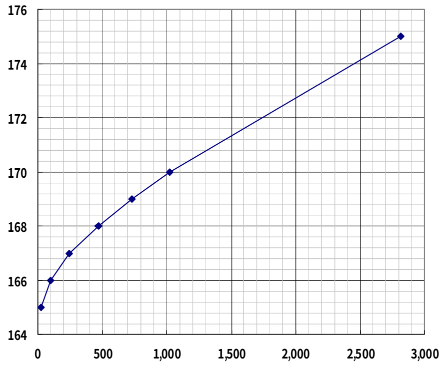


Reservoir Area – WL curve

Source: NN1 Tender Drawings, Feb 1968

Figure 5.4.3 Reservoir Area, Volume and Area Curves

The tail water level rating curve is shown in Figure 5.4.4.



Tail water Level – Discharge curve

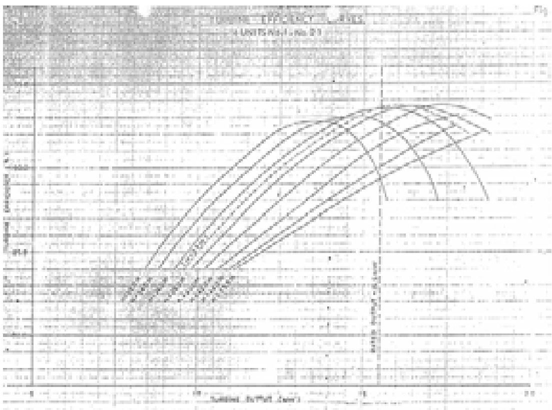
Elevation (m asl)	Discharge (m^3/s)
164	0
165	24
166	105
167	247
168	467
169	735
170	1,025
175	2,815

Data

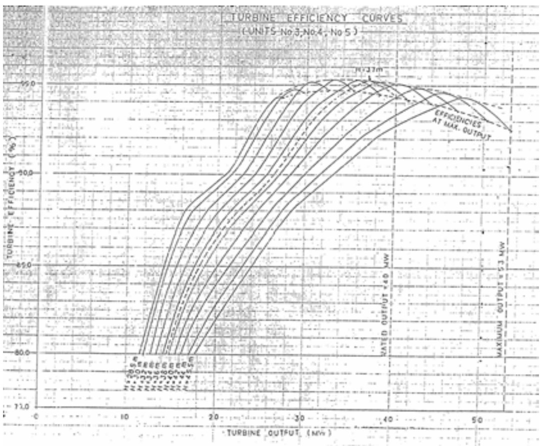
Source:NN1 Tender Drawings, Feb 1968

Figure 5.4.4 Tail Water Level Curves

The efficiency curves of the existing turbines of units 1, 2, 3, 4, and 5 are shown in Figure 5.4.5.



No.1, 2

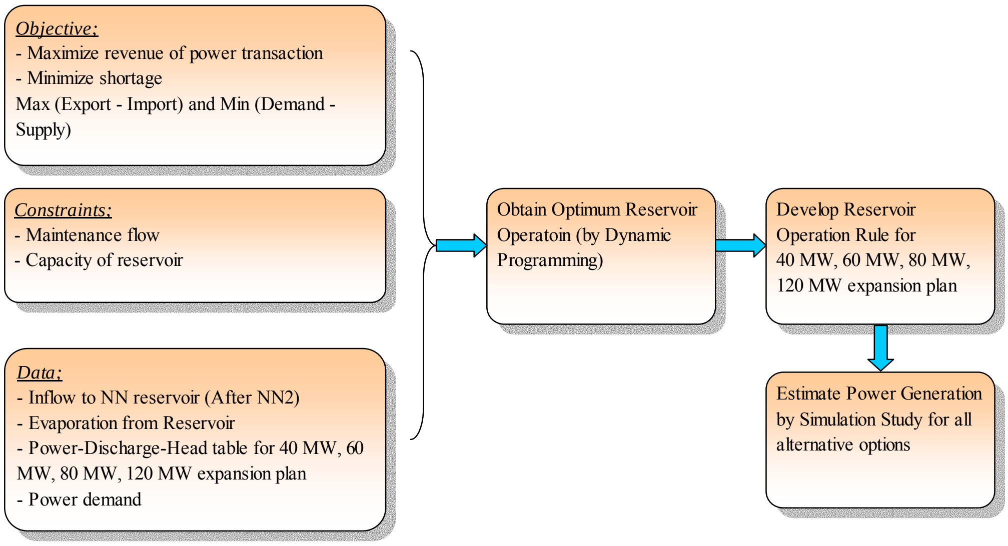


No.3, 4, 5

Source: "Study and suggestion on the operation of the Nam Ngum hydroelectric power station, Mar. 1992"

Figure 5.4.5 Turbine Efficiency Curves

The study flow of the reservoir operation optimization is shown in Figure 5.4.6.



Prepared by JICA Survey Team

Figure 5.4.6 Study Flow of the Reservoir Optimization in the NN1 Expansion Survey

5.4.3 RESERVOIR OPERATION RULE CORRESPONDING TO ALTERNATIVE OPTIONS

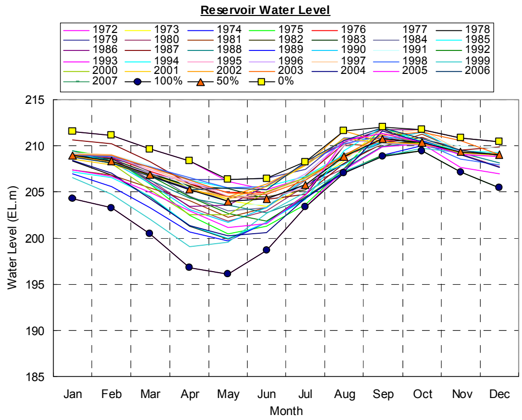
(1) Optimum Reservoir Operation

In this section, the Survey Team develops the reservoir operation rule for deliberated alternative options. The reservoir operation is given to each magnitude of the expansion scale. The different conditions between each option are the maximum plant discharge, and turbine/generator efficiency. The objective function and hydrological conditions are the same for the all cases. The other miscellaneous conditions for the optimization are listed in Table 5.4.1.

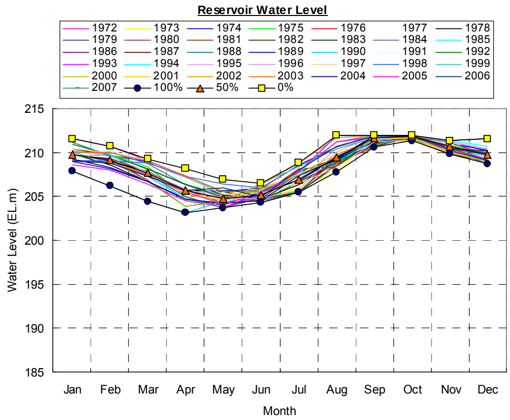
The Survey Team carried out the reservoir operation optimization of NN1 and the result is shown below.

Optimum Reservoir Water Level

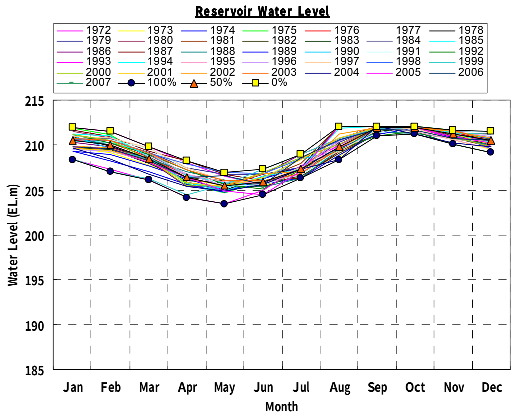
[Without Expansion]



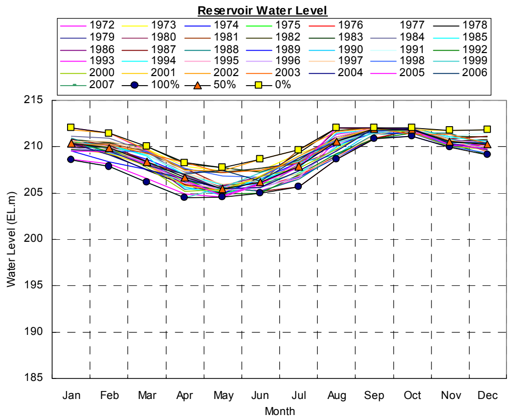
[40 MW Expansion Case]



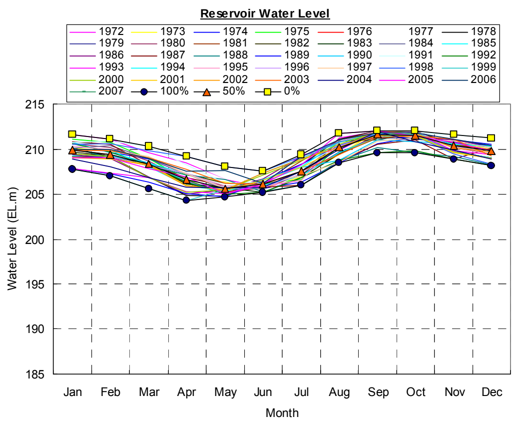
[60 MW Expansion Case]



[80 MW Expansion Case]



[120 MW Expansion Case]



Prepared by JICA Survey Team

Figure 5.4.7 Optimum Reservoir Water Level for Each Expansion Scale

As show in the figure, the reservoir water level stays high water level as the maximum plant discharge increases. This scenario occurred since the reservoir can store sufficient water in the dry season without increasing spilling in the rainy season. However, increasing this benefit is limited til 80 MW since the optimum reservoir water level for 120 MW and 80 MW are almost the same.

(2) Reservoir Operation Rule

In the optimization of the reservoir operation rule, the Survey Team adopted the Implicit Stochastic Optimization (ISO) method. ISO differs to the standard (Explicit) Stochastic Optimization (ESO), as latter assumes the inflow as a random variable and transformed to discretized value, while former directly uses the inflow data. The ISO method is similar to the deterministic optimization method. However, ISO conducts statistical analysis using the deterministic optimization result. The merit of the ISO is fast and simple for calculation process.

In this study, the reservoir operation rules are developed for water level or discharge patterns analyzed by the regression analysis. The following are examples of the operation rules for 40 MW expansion cases.

Jan	Vol_t	=	0.831	x $(Qin+Vol_{t-1})$	+	490
Feb	Vol_t	=	0.799	x $(Qin+Vol_{t-1})$	+	695
Mar	Vol_t	=	0.745	x $(Qin+Vol_{t-1})$	+	706
Apr	Vol_t	=	0.703	x $(Qin+Vol_{t-1})$	+	638
May	Vol_t	=	0.713	x $(Qin+Vol_{t-1})$	+	689
Jun	Vol_t	=	0.640	x $(Qin+Vol_{t-1})$	+	1,080
Jul	Vol_t	=	0.805	x $(Qin+Vol_{t-1})$	+	159
Aug	$Qout_t$	=	0.635	x $(Qin+Vol_{t-1})$	+	-3,539
Sep	$Qout_t$	=	0.816	x $(Qin+Vol_{t-1})$	+	-5,413
Oct	$Qout_t$	=	0.966	x $(Qin+Vol_{t-1})$	+	-6,713
Nov	Vol_t	=	1.021	x $(Qin+Vol_{t-1})$	+	-1,333
Dec	Vol_t	=	0.847	x $(Qin+Vol_{t-1})$	+	163

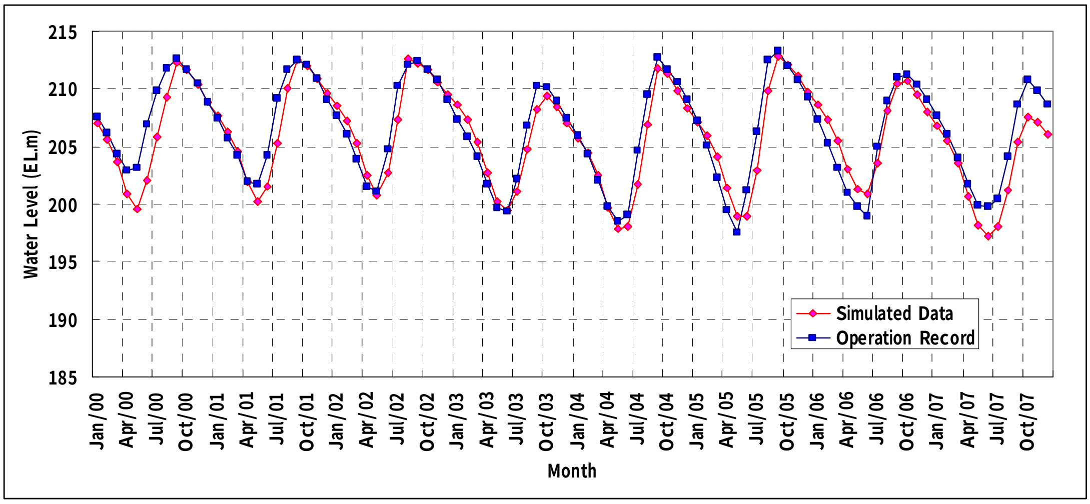
In the 40 MW case, the DP result gives high correlation between reservoir inflow with water storage, and the water storage in the succeeding month. The above example shows that the total reservoir inflow and water storage in January to July and November to December are correlated to the next month's storage, while August to October are correlated to the discharge in for the succeeding month.

In the selection of alternative option, the operation rule was developed for each alternative option by the method mentioned above.

(3) Energy calculation

The energy and power output of each option is calculated using the operation rule described above. The calculation is quite simple and considers the water balance of the reservoir. Therefore it can be calculated using the macro functions in Microsoft Excel.

The water levels from the year 2000 to 2007 are compared for the simulated and actual water level record as shown in Figure 5.4.8.



Source: Data from NN1 Hydropower Station and data prepared by JICA Survey Team

Figure 5.4.8 Comparison of Water Level between Simulation and Actual Record

As shown in the figure, the simulated data and the water level records are almost the same. In this case the water balance model can duplicate actual reservoir operation and can be used in the analysis.

The head loss coefficients and maximum plant discharge applied for each alternative are tabulated in Table 5.4.2.

Table 5.4.2 Maximum Plant Discharge and Head Loss Coefficient

Expansion Scale	Alternative Name	Maximum Plant Discharge (MW)	Head Loss Coefficient a of a*Q^2 (GWh)
Before Expansion (w/o NN2)		117	6.88*10^{-5}
Before Expansion (w/ NN2)		117	6.88*10^{-5}
40 MW			
	A1	117	6.88*10^{-5}
	A4-1	117	8.95*10^{-5}
	A4-3	117	9.78*10^{-5}
	D2-1	117	7.52*10^{-5}
60 MW			
	A2	177	3.13*10^{-5}
	A4-2	177	4.35*10^{-5}
	A4-4	177	4.75*10^{-5}
	D2-2	177	3.04*10^{-5}
80 MW	B2-1	236	1.79*10^{-5}
	D2-3	236	2.90*10^{-5}
120 MW	B2-2	354	0.763*10^{-5}
	D2-4	354	1.27*10^{-5}

Prepared by JICA Survey Team

The energy and dependable power output of the alternative options are summarized in Table 5.4.3.

Table 5.4.3 Result of Simulation: Annual Energy, Peak Energy and Off-Peak Energy

Expansion Scale	Alternative Name	Dependable Capacity (MW)	Annual Energy (GWh)	Peak Energy (Average) (GWh)	Off Peak Energy (GWh)
Before Expansion (w/o NN2)		96	980	455	525
Before Expansion (w/ NN2)		111	1,068	473	595
40 MW					
	A1	144	1,120	573	547
	A4-1	144	1,119	572	547
	A4-3	144	1,119	572	546
	D2-1	144	1,120	573	547
60 MW					
	A2	162	1,123	616	507
	A4-2	161	1,121	615	506
	A4-4	161	1,120	615	506
	D2-2	162	1,123	616	507
80 MW	B2-1	189	1,135	642	493
	D2-3	188	1,131	639	491
120 MW	B2-2	227	1,140	718	422
	D2-4	225	1,134	713	421

Prepared by JICA Survey Team

The results show that 40 MW case have additional 52 GWh energy. Annual energy slightly increases as the expansion scale increases for 60 MW, 80 MW, and 120 MW expansion case.

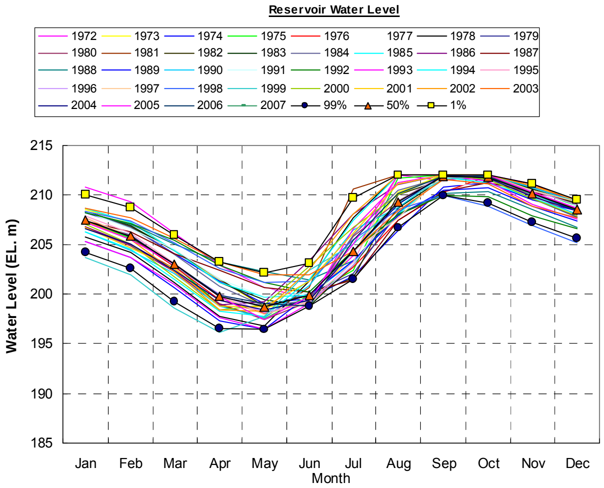
5.5 EFFECT OF NAM NGUM 2 OPERATION

As described previously, the NN2 hydropower regulates the inflow into the NN1 reservoir. In this section, the NN2 effect to the reservoir optimum operation rule is confirmed and described in details. The scenario considered in the analysis is existing NN1 conditions therefore: the expansion of NN1 is not considered here.

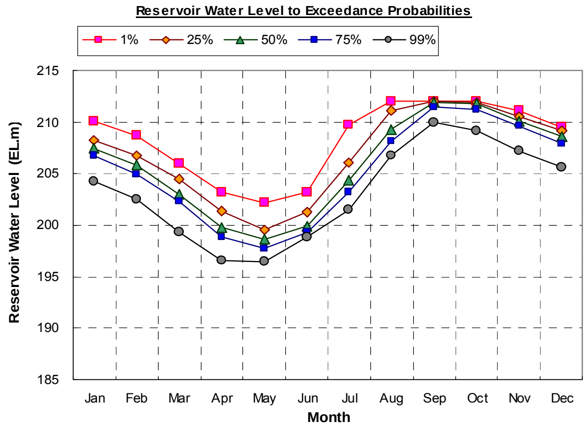
At first, the NN1 hydropower reservoir operation is optimized using the hydrological data from the year 1972 to 2007 with the objective function of revenue maximization together with minimization of power supply shortage.

- Before NN2 completion

In this section, the inflow into the NN1 reservoir considers the natural flow condition. Therefore, the water is not regulated in NN2 reservoir. The results of the DP with the water level at 1%, 25%, 50%, 75% and 99% exceedance probability are shown in Figure 5.5.1.



[DP result]



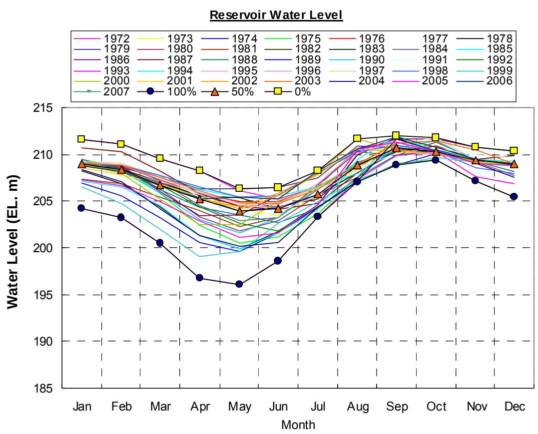
[WL exceedance probability]

Prepared by JICA Survey Team

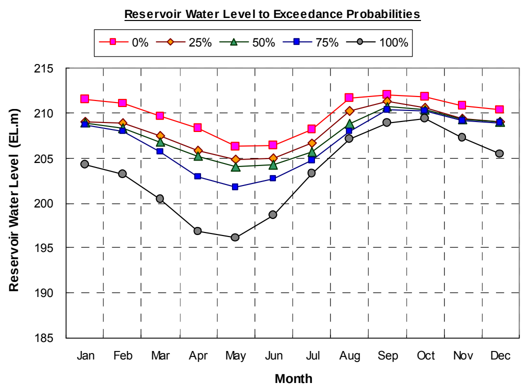
Figure 5.5.1 Reservoir Optimum Operation Presented by Dynamic Programming for without-NN2 Case

- After Completion of NN2

In this case, the river flow is regulated at NN2 reservoir. The dynamic programming provides the following results.



[DP Result]



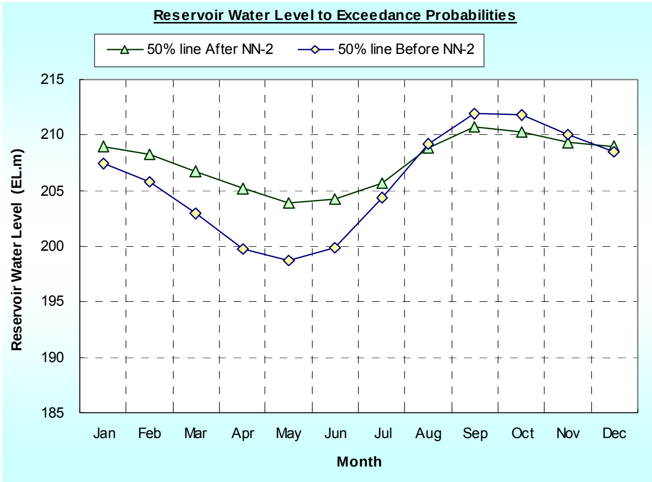
[WL exceedance probability]

Prepared by JICA Survey Team

Figure 5.5.2 Reservoir Optimum Operation Presented by Dynamic Programming for with-NN2 Case

- Comparison of reservoir operation for "before" and "after" NN2 completion

The results of the median of the water level for the before and after NN2 completion are plotted as shown in Figure 5.5.3.

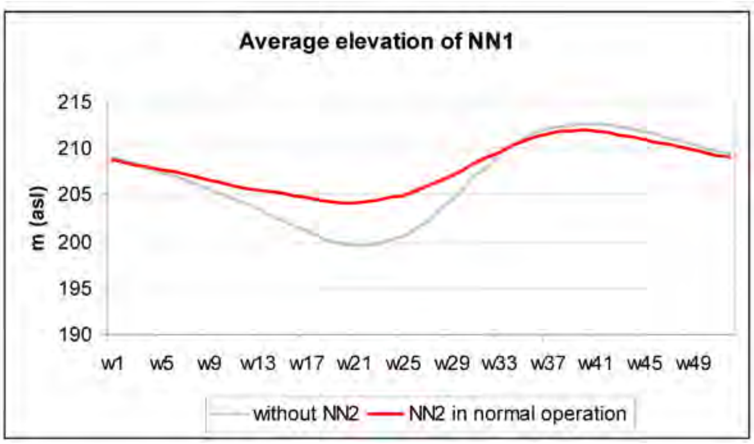


Prepared by JICA Survey Team

Figure 5.5.3 Comparison of Optimum Reservoir Operation between with and without NN2

As shown in the figure above, based on the change of the flow regime due to NN2 Hydropower operation, the water level in the dry season remains in the higher water level of EL.204 m than before NN2 completion case. In the rainy season, the water level is lower than that before NN2 case because the spillage is reduced due to expansion.

The effect of the NN2 operation to the NN1 reservoir operation is also studied in the NNRBDSP. The reservoir guide curve of NN1 reservoir provided by PARSIFAL is shown in Figure 5.5.4.



Source: NNRBDSP, Component 2, "Output Report on Activity 2.3: Reservoir Management"

Figure 5.5.4 Optimum Reservoir Operation with and without NN2 Studied by PARSIFAL

It is noted that the result of the reservoir guide curve provide by PARSIFAL is similar to the curve obtained by the Survey Team. Both results show that the water level in May goes down to around EL.204 m and rises in October.

5.6 OPERATION STUDY OF NN1 RESERVOIR AND HYDROPOWER STATIONS IN THE NAM NGUM RIVER BASIN AFTER NN1 EXPANSION

5.6.1 GENERAL

For the selection of the optimum expansion option, the expansion scale of 40 MW is selected as described in Chapter 8. The selected alternative option is further studied for additional turbine and generator in the basic design in Chapter 9. The reservoir operation is again studied using the specification of the additional turbine and generator determined in the basic design.

Prior to undertaking reservoir operation study, the Survey Team examines the progress of introducing Integrated Water Resources Management (IWRM) to the Nam Ngum River basin within the NNRBDSP component 1 framework. Then the allocation of the compensation flow among the hydropower entities is clarified. The determined compensation flow is adopted to the subsequent reservoir operation study. The purpose and condition of the reservoir operation optimization study is discussed in this section.

5.6.2 IWRM OF THE NAM NGUM RIVER BASIN

(1) Introducing IWRM to NNRB Development Sector Project

NNRBDSP Component 1 aimed to introduce IWRM in Lao PDR. In this framework, the regulatory agency of Water Resources and Environmental Agency (WREA) was established in 2007. This agency supervises the water-use such as hydropower or irrigation and environmental impact. WREA has just set up recently, but is expected to expedite efficient water-use and better governance of water-use.

The concept of water-use with hydropower and other type of water use under the IWRM is shown in Figure 5.6.1.

Under NNRBDSP component 3, the current status of the water-use in the Nam Ngum River basin is surveyed by the Department of Planning Integrated Watershed Management Unit (IWMU) under the Ministry of Agriculture and Forestry. IWMU is the main unit to prepare watershed baseline data profiles of the Nam Ngum River basin[8]. However, the details of the outcomes are not yet available during the time of the Survey.

The water-use after introduction of the IWRM is expected to be well coordinated for the competed water-use under regulatory and administrative agencies. Specifically, the downstream irrigation and domestic demands will be fulfilled by compensation flow released from the hydropower dams in the upstream, if the dams operation deteriorates the water-use in the downstream.

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8 http://pid.adb.org/pid/LoanView.htm?projNo=33356&seqNo=01&typeCd=3 (Nam Ngum River Basin Development Sector Project, Information Documents, ADB)

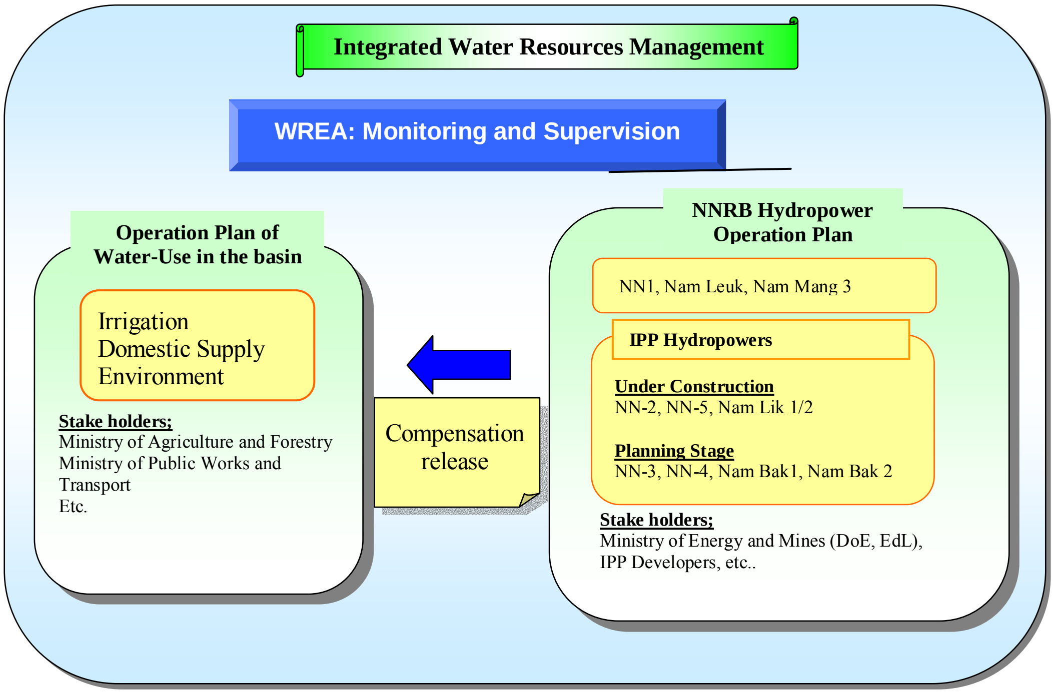

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Figure 5.6.1 Concept of Integrated Water Resources Management to the Nam Ngum River basin

(2) Water rights

The water rights in Lao PDR is described in Law on Water and Water Resources (No.02/96, 1996). The water resources are recognized as the property of the national community, and water-users need to get approval from the government for their exploitation except for small-scale water-use. The large scale water-uses such as hydropower should request approval together with feasibility study and environmental impact assessment reports. The water rights in Lao PDR is similar to riparian water rights since the priority of water-use and allocation of water resources are not specified and it is under a government control matter.

For the Nam Ngum River basin case, the hydropower operation will change the flow regime in the downstream of the NN1 dam and it may affect to the downstream inhabitant. The water-use in the downstream of the NN1 dam is assumed as vested rights, therefore expansion of NN1 should not undermine the existing water use. The degree of the impact and affect to the downstream inhabitants are assessed in Initial Environmental and Social Examinations (IESE) as described in Chapter 6.

(3) Water use and release for irrigation

As described in chapter 5.1, 99% of the water-use in the Nam Ngum River basin is for agriculture, and the most of it is for irrigation to paddy field. The irrigation area in the upstream from the NN1 dam is located around Xieng Khouang plateau which is located in the upstream of NN2 and Nam Ngum 5 dams. Therefore the operation of the hydropower will not affect to the irrigation in the NN1 dam upstream area.

For the downstream of the NN1 dam, the current irrigation pump capacity is estimated to approximately 32.8 m^3/s, and additional 43 m^3/s pump capacity is required for additional 61,000 ha development by 2027 as described in Chapter 5.1. In this case, the pump capacity total is 75.8 m^3/s and this figure can be fulfilled when NN1 hydropower release water in the off-peak with full capacity operation (around 117 m^3/s) of a unit between No.3, 4 and 5.

Therefore, the current downstream demand does not compete with upstream hydropower operation. The coordination of compensation flow among the hydropower dams is not necessary so far.

(4) Nam Ngum River Compensation Flow and Its Allocation

The Nam Lik River joins Nam Ngum River at the 5 km downstream from the NN1 dam. The Nam Lik 1/2 hydropower project is located 89 km upstream from the confluence of the Nam Lik River and Nam Ngum River.

The flow regime of the Nam Ngum River from the confluence is dependent on the discharge pattern of the NN1 hydropower station and Nam Lik 1/2 hydropower station. In order to understand the discharge pattern of the Nam Lik 1/2 hydropower station, the Survey Team referred to the environmental impact assessment report of the project, and interviewed with the Nam Lik 1/2 office staffs. However it was found that the details of the discharge pattern of a day can not be available. Hence in the Survey, the draught discharge (90% discharge of the duration curve) is tentatively applied as the maintenance flow of the Nam Lik River. The draught discharge of the Nam Lik River is estimated at 29.1 m^3/s as described in Chapter 6. According to the F/S report of the Nam Lik 1/2 hydropower project, the annual operation hours is 3,954 hours. It infers that Nam Lik 1/2 is operated in 10 hour/day, and this discharge will be greater than the dry season discharge. Therefore, the maintenance flow will be satisfied if the Nam Lik 1/2 hydropower operates with full capacity at 10 hours/day.

In the Survey, the required discharge for the downstream reach is proposed in Chapter 6 through Initial Environment and Social Examination (IESE). IESE studies the effect to the local irrigation, boat transportation, and fishery due to water level and discharge variation by NN1 expansion. IESE concluded that the NN1 hydropower station should release water as compensation flow for 117.1 m^3/s that is the maximum plant discharge of units No. 3, 4, or 5. Therefore, the study of the reservoir operation is based on the minimum release of 117.1 m^3/s in order to minimize the impact to the downstream inhabitant and to fulfill the downstream irrigation requirement.

However, as described in Chapter 6, this discharge requirement presumes the maintenance flow is based on that the Nam Lik River flow at least equals to the draught discharge. If the discharge is less than the draught discharge, IESE confirmed that the reduction of the flow will affect to the downstream inhabitants. Therefore, the actual release from the Nam Lik 1/2 should be monitored under DOE supervision to determine whether the discharge pattern of the Nam Lik 1/2 does not cause adverse effect to the downstream inhabitants.

5.6.3 PRINCIPLES ON RESERVOIR OPERATION STUDY

The study on the NN1 reservoir consisted of two approaches. One approach aims for efficient utilization of natural resources that leads to economic and financial evaluation of the project. Another approach aims to focus on the revenue maximization of selling electricity to the domestic and EGAT that leads to the accounting valuation of the electricity production. For the reservoir operation for the former case, it mainly focuses on the economic aspects as efficient natural resource utilization rather than the evaluation in monetary forms of a financial evaluation. The reasons are;

- In general, the economic evaluation and financial evaluation is not solely independent from each other. They complement each other since both are important for the project evaluation. However, since the expansion project like NN1 expansion has generally no increment in the energy production by expansion, the financial viability is less important than the economic evaluation as financial evaluation generally focuses on the increment energy surplus.
- The reservoir operation rules for economic and financial evaluation are usually identical. For the NN1 expansion project, as the evaluation is more focused on the economic than financial aspects, reservoir operation study aims to maximize the energy production while securing firm capacity. In this case, energy production of the project which is derived from the economic analysis should be used in the financial evaluation as well.

Meanwhile, reservoir operation study on the revenue maximization is evaluated in monetary form using the domestic and export/import tariffs.

In summary, the energy maximization is applied to economic and financial evaluations which are identical to the project evaluation, while the case considering accounting revenue aims to maximize revenue. However, if the reservoir operation is solely targeting energy maximization or revenue maximization, the results call for importing electricity in dry season and generated electricity for export in wet season to maintain reservoir water level in high elevation. The Lao PDR policy is that the power import from EGAT should be as less as possible and the domestic electricity demand should first be served by Lao’s power sources. Therefore, both of energy and revenue maximization should be prerequisites of the imported energy minimization. The energy and revenue maximization is to be the second priority. The optimization forms as the multi-objective optimization consisting of energy minimization and revenue or energy maximization.

The expansion of the NN1 hydropower station may affect the operation of the other hydropower stations which supply electricity to C1 area. Therefore the reservoir operation study on economic and financial evaluation considers the NN1 reservoir operation including the EdL-owned hydropower stations, Nam Mang 3 and Nam Leuk hydropower stations.

5.6.4 PRINCIPLES ON HYDROPOWER OPERATION STUDY IN THE NAM NGUM RIVER BASIN

The Survey Team considers the NN1 reservoir operation for the electric power selling for the case of after expansion. The study includes the other hydropower stations which provide electricity to C1 area.

As aforementioned, the study of the reservoir operation focused on the revenue maximization by selling electricity to domestic and EGAT. As the energy import minimization is a prerequisite for reservoir operation optimization, the relationship between the energy import and revenue balance is presented in the study.

The subject hydropower stations are the EDL-owned NN1, Nam Mang 3, and Nam Leuk. Nam Lik 1/2 hydropower station which is a domestic IPP project is also considered as it was requested by the Lao side.

In the study, the following three cases are envisaged.

1) NN1 Reservoir operation is the only variable.
2) NN1 Reservoir, Nam Leuk Reservoir, and Nam Mang 3 Reservoir are the variables.
3) NN1 Reservoir, Nam Leuk Reservoir, Nam Mang 3 Reservoir, and Nam Lik 1/2 are the variables.

For the above three cases, the Survey Team conducted the reservoir operation study applying the power demand and supply balance for the year 2015, 2020 and 2025.

Respect to the Nam Ngum 5 Hydropower Project, the project is a run-of-river hydropower which has a small capacity reservoir to regulate inflow. Moreover, the project is an IPP project and its operation is less flexible than EdL hydropower stations. Therefore, the project was not included in the reservoir operation study. However, the Survey Team received the estimated monthly electric energy of NN5 provided by DOE. The estimated energy is included in the supply capacity of the electricity for the domestic consumers.

5.6.5 POWER DEMAND USED IN THE STUDY

In the calculation of the reservoir operation, power demands power demand of the year 2015, 2020, and 2025 is used in the reservoir optimization. The power demand and supply refers to the latest PDP, and the outline of supply balance in each year is as follows.

(1) Year 2015

In the year 2015, it is anticipated that the power supply hardly catch up the rapid growth of power demand in C1 area. The shortage of the power supply will be covered by the power import from Thailand.

(2) Year 2020

According to the latest PDP, the night and daytime peak in the dry season will have some shortages in both weekdays and holidays. However, it is expected that the whole of the power demand are covered by the domestic supply especially in the rainy season.

(3) Year 2025

In the year 2025, it is also anticipated that the power supply can not catch up rapid growth of power demand. The power supply can not fulfill the demand and have to rely on the power import from Thailand. The power demand and supply balance is similar to that of year 2015.

5.6.6 (DRAFT) RESERVOIR OPERATION PLAN FOR ECONOMIC/FINANCIAL EVALUATION

(1) General

The reservoir operation study for the economic/financial evaluation employs revenue maximization while securing firm power output as the objective function. According to the NN1 hydropower station, the weekly power generation plan for C1 area power supply is formulated with coordination among NN1, Nam Leuk, and Nam Mang 3 hydropower stations. It is expected that the coordination among the three hydropower stations are continued after the NN1 expansion. Therefore Nam Leuk and Nam Mang 3 hydropower stations are also included in the reservoir operation study for economic evaluation. IPP projects are not included in the study, because the operation of the IPP hydropower stations is less flexible than Nam Mang 3 or Nam Leuk.

(2) Study Conditions

The conditions of reservoir operation studies for the economic/financial evaluation are summarized below.

Table 5.6.1 Method and Conditions for the Reservoir Operation Optimization for the Economic Evaluation

Item	Method
Purpose	Maximization of annual energy production with securing firm power output and minimizing energy import from EGAT (Objective function forms as multi-objective function) Objective function; *Maximize* $\sum_{t=1}^{T}\sum_{n=1}^{N}\mathrm{Ene}(n,t) - \sum_{t=1}^{T}(Demand - Supply)$ Where, *Ene(n, t)* : Energy output of the n[th] hydropower station (MWh) at the time "t". *(Demand - Supply)* : Power demand shortage. It is only functioned when demand exceeds supply (Demand > Supply). Power demand shortage is covered by the energy imported from EGAT. Therefore, it is equivalent to the imported energy. *T* : Number of time step. (T = 432) *N* : Number of hydropower station. (N = 3, i.e. NN1, Nam Mand 3 , and Nam Leuk) Energy is calculated by the following equation. Energy = $g \times Q_{power} \times He \times \varepsilon \times t$ Where, g : gravity acceleration (m/s^2) Q_{power} : power discharge (m^3/s) He : effective head (m) ε : combined efficiency t : generation hour (hr)
Examined Year	2015, 2020, 2025
Case	(1) After Expansion, (2) Before Expansion w/ NN2, (3) Before Expansion w/o NN2
Method	Implicit Stochastic Optimization Method with Deterministic Dynamic Programming
Constraints	Reservoir capacity, discharge capacity of turbines.
Decision variables	Discharge from NN1 hydropower station, Nam Leuk hydropower station, and Nam Mang 3 hydropower station
State variables	Reservoir storage of NN1, Nam Leuk and Nam Mang 3
Conditions and assumptions	- Duration of inflow is 36 years from year 1972 to 2007 - Time Step is monthly - Irrigation demand of Nam Mang 3 should be fulfilled. - At least one unit among No.3, 4, or 5 operation during off-peak hours is mandatory required as maintenance flow - The priority of the power demand is in order of 1) the night peak (18:00 to 22:00), 2) day time peak (9:00 to 18:00), 3) off peak (22:00 to 9:00). - TOU tariff structure is employed. - Target year is 2015 for selection of alternative. - Power demand and supply refers to the latest PDP. - Power demand is divided to four blocks as exemplified in Figure 5.4.2. - Currently power interchange capacity is 100 MW between EGAT and Laos North Central. However, interchange over 100 MW is allowed in the model for both import and export.
Software	CSUDP (Generalized Dynamic Programming Software)

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The efficiency curve of existing turbines and generators data used in the selection of the optimum option is also used in this study. The efficiency curve for additional unit No.6 is adjusted referring to the basic design in Chapter 9.

The DP calculation is done using CSUDP which is a generalized DP software package developed in

Colorado State University in the United States. The custom codes of CSUDP describing the characteristics of the Nam Ngum hydropower stations are developed by the Survey Team.

(3) Result of the Optimum Reservoir Operation

Using the power demand and supply balance for the year 2015, 2020, and 2025, and by using the hydrological data from 1972 to 2007, the result of the optimum reservoir operation of the three reservoirs are shown in the following figure and table.

- Reservoir water level curve ： Figure 5.6.2 to Figure 5.6.4
- Energy import and revenue balance summary table ： Table 5.6.2

[After Expansion]

Year	NN1 Reservoir	Nam Leuk Reservoir	Nam Mang 3 Reservoir
2015			
2020			
2025			

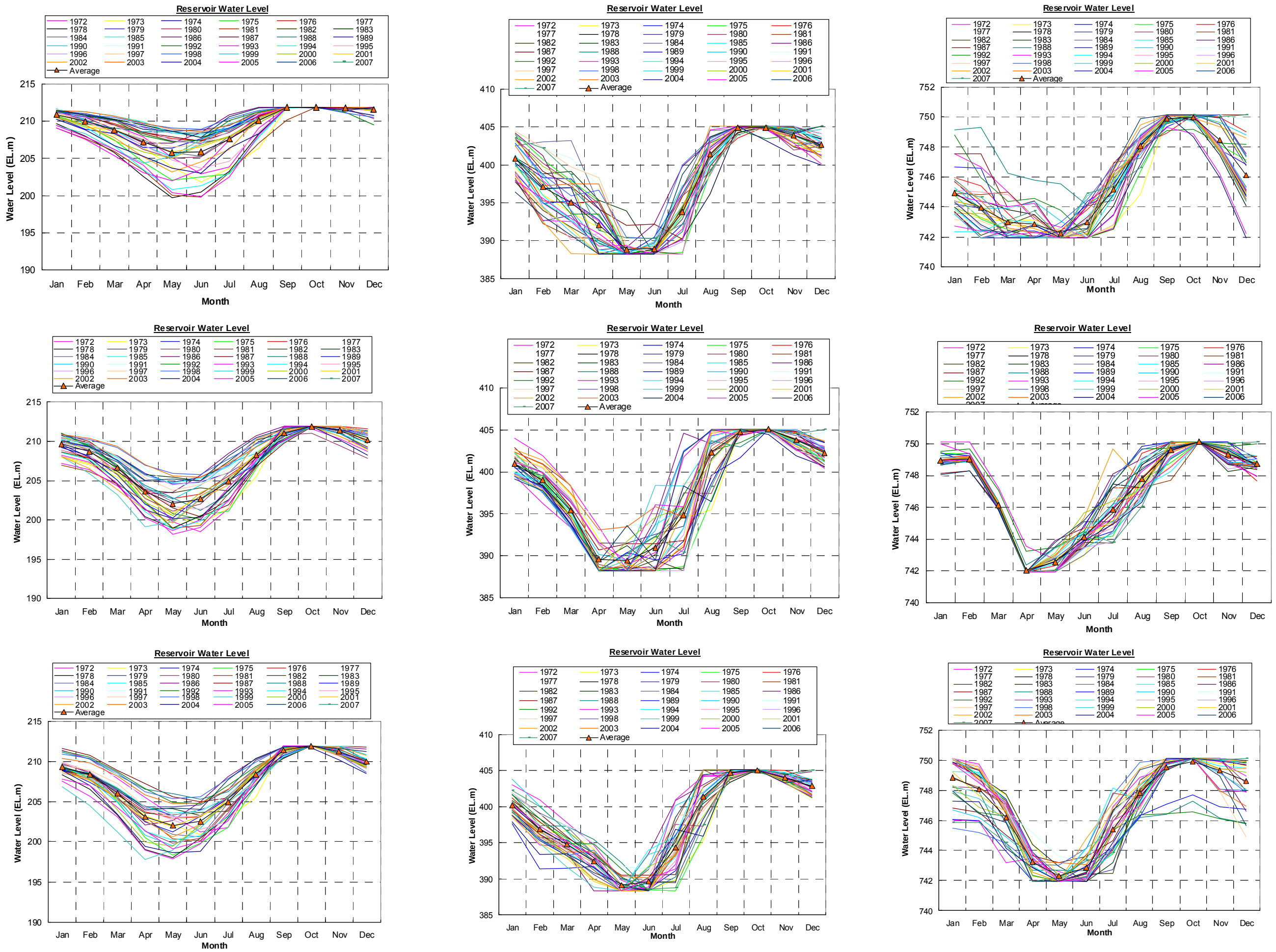

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Figure 5.6.2 Optimized Reservoir Operation Curve for After Expansion Case

[Before Expansion with NN2]

Year	NN1 Reservoir	Nam Leuk Reservoir	Nam Mang 3 Reservoir
2015			
2020			
2025			

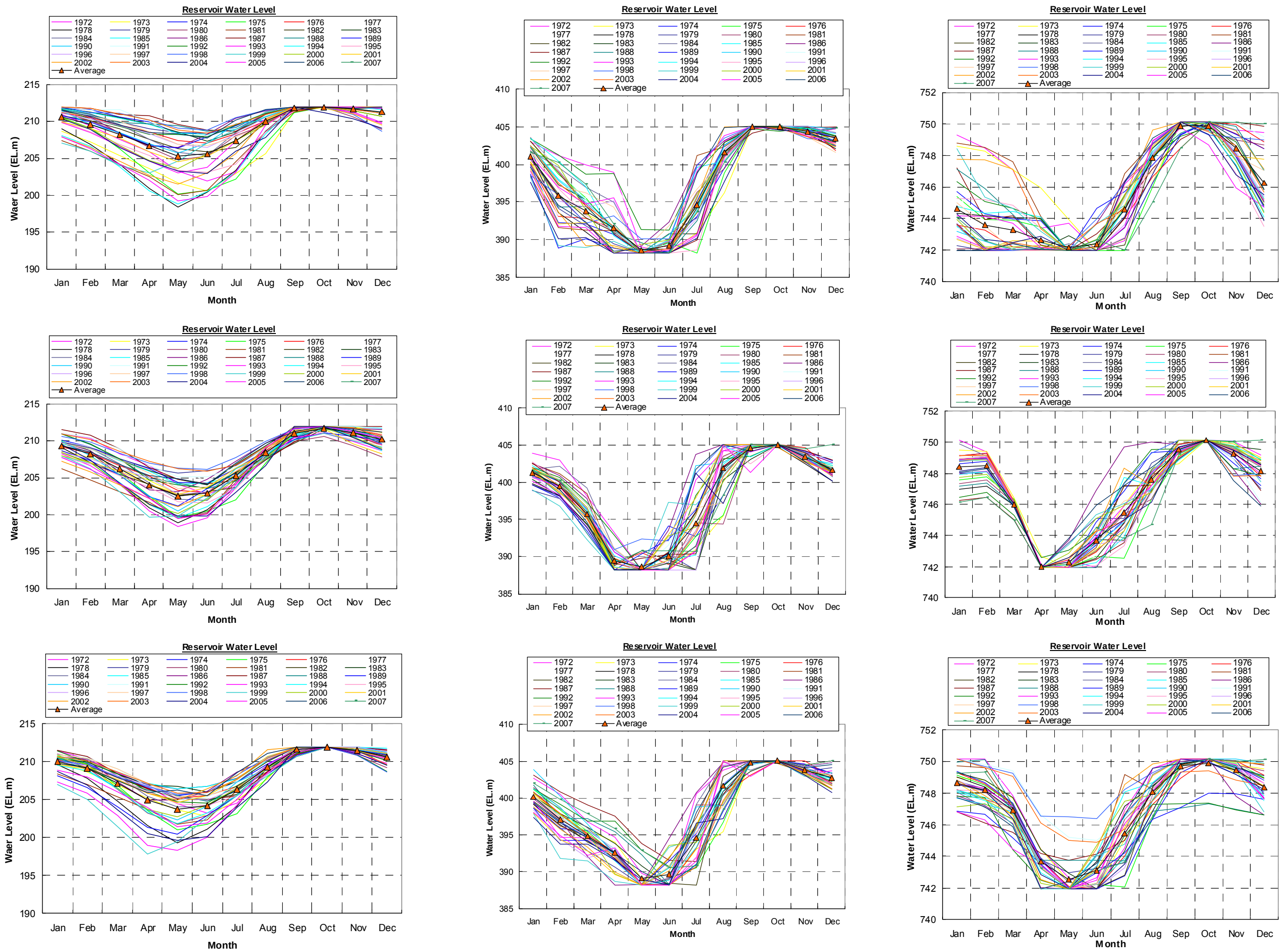

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Figure 5.6.3 Optimized Reservoir Operation Curve for Before Expansion with NN2 Case

[Before Expansion without NN2]

Year NN1 Reservoir Nam Leuk Reservoir Nam Mang 3 Reservoir

2015

2020

2025

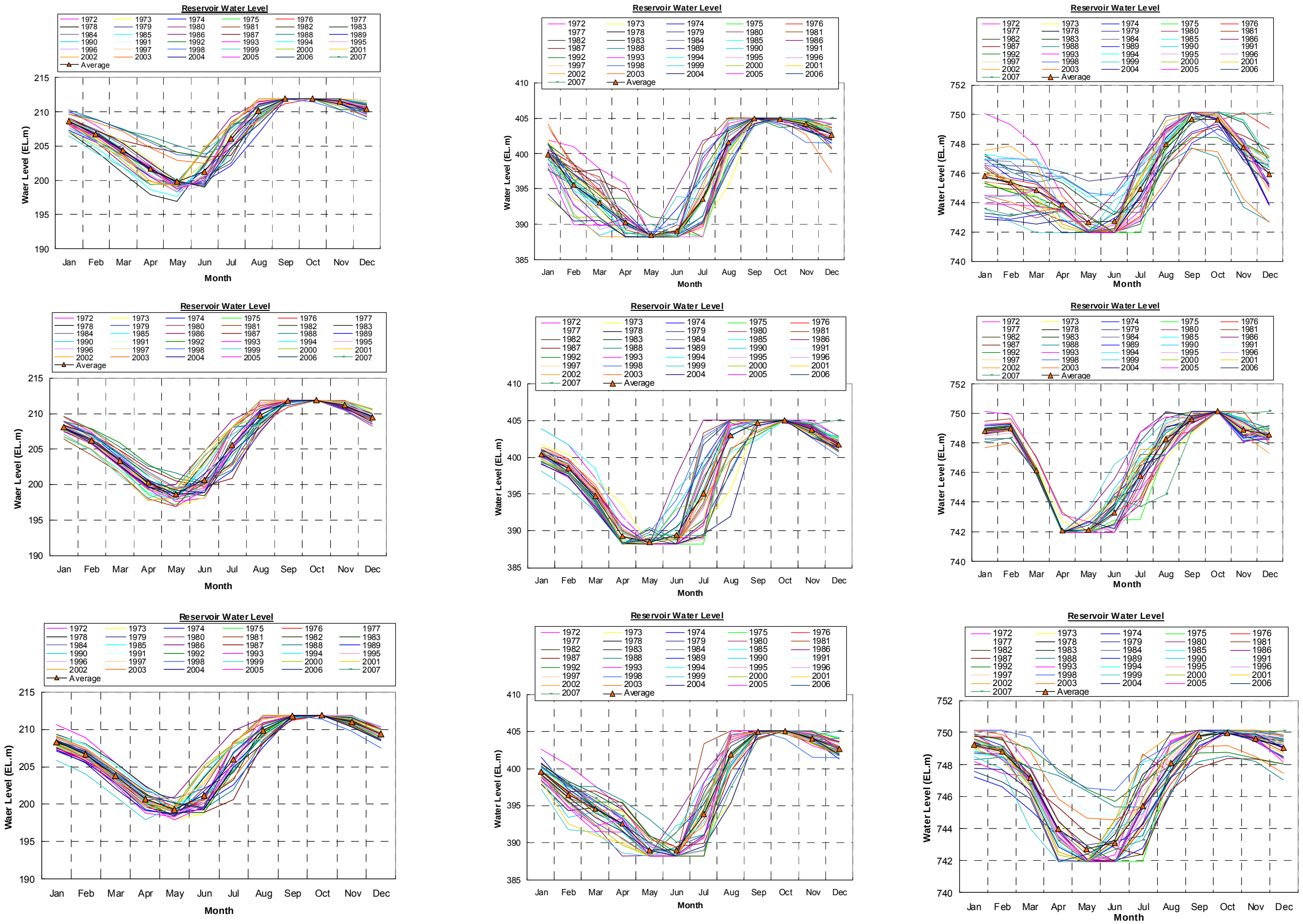

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Figure 5.6.4 Optimized Reservoir Operation Curve for Before Expansion without NN2 Case

Table 5.6.2 Result of Optimization for Each Case in Each Year

	(Unit)	2015			2020			2025		
		with 40 MW expansion	Before Expansion (w/ NN2)	Before Expansion (w/o NN2)	with 40 MW expansion	Before Expansion (w/ NN2)	Before Expansion (w/o NN2)	with 40 MW expansion	Before Expansion (w/ NN2)	Before Expansion (w/o NN2)
(1) Nam Ngum 1, Nam Mang 3 and Nam Leuk										
Average hydropower energy	(GWh/year)	1,561	1,558	1,562	1,487	1,481	1,531	1,491	1,509	1,533
Revenue for domestic sale	(1000 USD/year)	96,699	96,575	96,586	45,660	42,944	42,315	78,576	74,392	72,507
(2) Import from EGAT										
Average import energy	(GWh/year)	1,840	1,842	1,842	78	122	132	624	692	722
Average import power	(MW)	327	367	368	57	78	81	242	272	278
Maximum import energy	(GWh/month)	279	286	265	36	50	53	189	190	181
Maximum import power	(MW)	500	569	518	224	233	249	499	518	532
Average import expense	(1000 USD/year)	85,316	86,908	87,014	3,984	6,236	6,735	30,911	34,724	36,267
Revenue selling import energy to domestic	(1000 USD/year)	114,276	114,400	114,389	4,845	7,561	8,190	38,777	42,961	44,846
(3) Export to EGAT										
Average export energy	(GWh/year)	3	3	7	1,320	1,357	1,417	446	532	586
Average export power	(MW)	2	1	3	249	255	268	131	140	152
Maximum export energy	(GWh/month)	23	19	23	292	292	292	177	184	179
Maximum export power	(MW)	92	100	103	565	580	580	430	464	469
Average export revenue	(1000 USD/year)	118	109	237	49,924	50,475	52,557	15,998	18,919	20,821
(4) Excess charge										
Average excess charge	(1000 USD/year)	56,198	54,327	54,828	0	0	0	6,586	5,320	4,255
Maximum excess charge	(1000 USD/year)	74,037	69,693	63,702	0	0	0	15,958	15,636	14,867
(5) Total annual revenue	(1000 USD/year)	211,093	211,084	211,212	100,429	100,980	103,062	133,351	136,272	138,174
(6) Total annual expense	(1000 USD/year)	141,514	141,236	141,841	3,984	6,236	6,735	37,497	40,044	40,522
(7) Annual balance	(1000 USD/year)	69,579	69,848	69,371	96,445	94,744	96,327	95,854	96,228	97,652

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The result of the optimization can be summarized as follows;

- In 2020, the energy sold to domestic consumers is small, and the surplus of the energy is exported to EGAT.
- In the years 2015, 2020, and 2025, the maximum import reaches to 500 MW, 244 MW and 499 MW respectively. This indicates that the current capacity of 100 MW is not sufficient. Although the maximum imported power of 500 MW in the year 2015 is less than the future expansion of interchange with EGAT of 600 MW. It is recommended that capacity of interchange connection with EGAT should be reinforced as soon as possible.
- In the year 2020, the energy export can reach 565 MW at maximum.
- If power sources are steadily developed corresponding to the current PDP, the excess charge will not be accrued in the year 2020.
- The total revenue in the year 2015 is the largest among other year cases. This is due to increment of the revenue of selling the imported energy to domestic. This accounts to almost half of the total revenue. (The import tariff is lower than domestic tariff in C1 north area, therefore revenue increases as import energy increases)

(4) Comparison of Before and After Expansion

The monthly average reservoir water level of the three reservoirs (NN1, Nam Mang 3 and Nam Leuk) for the years 2015, 2020, and 2025 for each case (after expansion, and with or without NN2 in before expansion) is shown in Figure 5.6.5

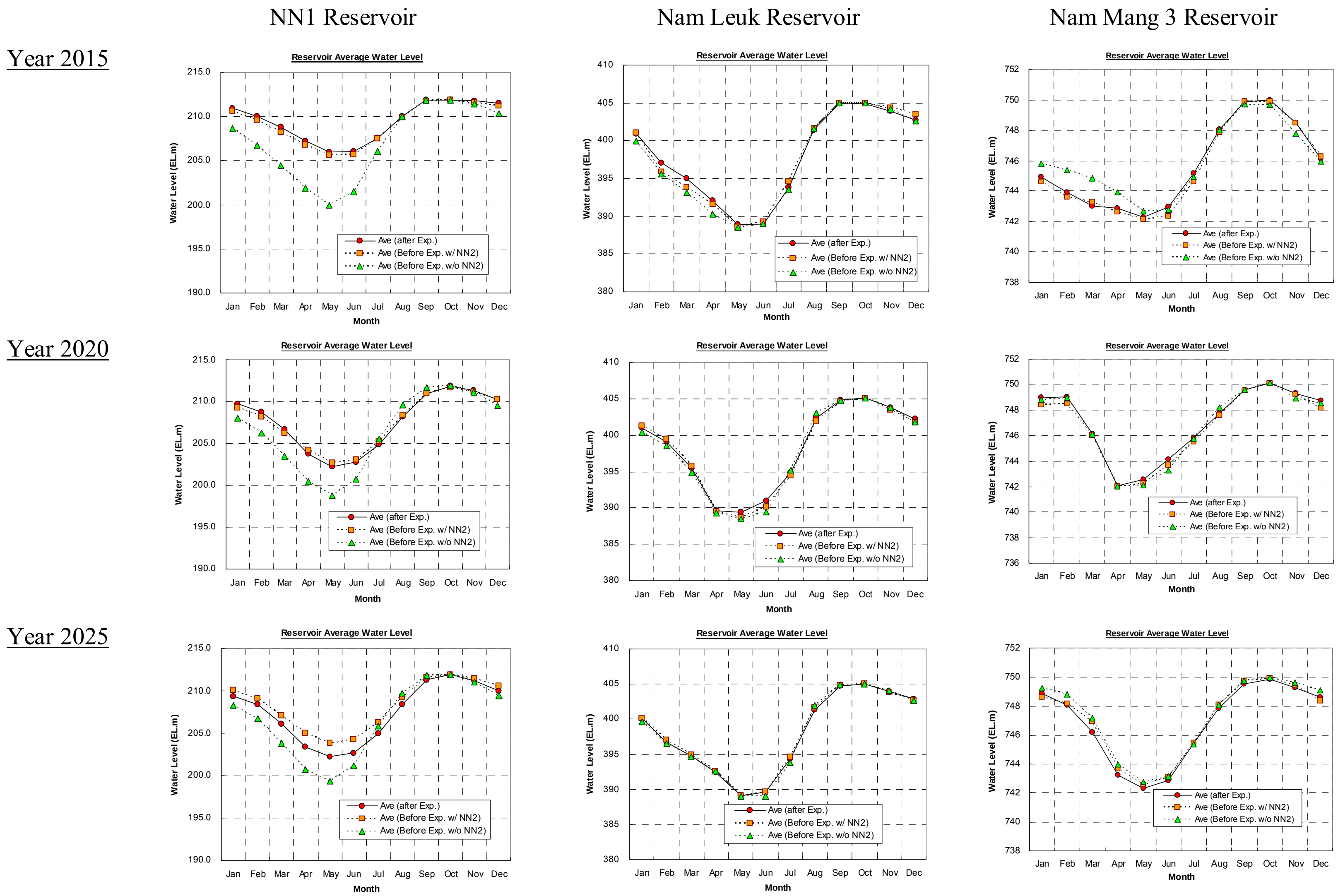

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Figure 5.6.5 Result of Optimization for Each Case in Each Year

The average reservoir water level is shown in Table 5.6.3.

Table 5.6.3 Monthly Average Water Level for Each Case

[NN1 Reservoir]

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2015												
Before Exp. w/o NN2	208.7	206.8	204.5	201.9	200.0	201.5	206.1	210.0	211.9	211.9	211.5	210.4
Before Exp. w/ NN2	210.6	209.6	208.2	206.8	205.6	205.7	207.4	209.9	211.8	211.9	211.7	211.2
After Expansion	210.9	210.0	208.8	207.2	206.0	206.0	207.6	210.1	211.8	211.9	211.8	211.6
2020												
Before Exp. w/o NN2	208.1	206.3	203.5	200.4	198.7	200.7	205.5	209.7	211.7	211.9	211.2	209.6
Before Exp. w/ NN2	209.3	208.2	206.3	204.2	202.7	203.0	205.3	208.4	211.0	211.7	211.1	210.2
After Expansion	209.7	208.7	206.7	203.7	202.2	202.7	204.9	208.2	211.0	211.9	211.4	210.2
2025												
Before Exp. w/o NN2	208.3	206.7	203.8	200.7	199.3	201.2	205.9	209.7	211.8	211.9	211.1	209.5
Before Exp. w/ NN2	210.0	209.1	207.1	205.0	203.9	204.3	206.3	209.2	211.6	211.9	211.5	210.6
After Expansion	209.4	208.4	206.1	203.3	202.3	202.7	205.0	208.4	211.3	211.9	211.2	210.0

[Nam Leuk Reservoir]

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2015												
Before Exp. w/o NN2	399.9	395.6	393.1	390.3	388.5	389.0	393.6	401.6	405.0	404.9	404.1	402.6
Before Exp. w/ NN2	401.0	395.9	393.8	391.5	388.6	389.2	394.6	401.6	405.0	405.0	404.3	403.5
After Expansion	400.9	397.1	395.0	392.1	388.9	388.9	393.8	401.4	404.9	404.9	403.9	402.7
2020												
Before Exp. w/o NN2	400.4	398.6	394.8	389.3	388.5	389.5	395.1	403.0	404.7	405.1	403.8	401.8
Before Exp. w/ NN2	401.3	399.5	395.8	389.5	388.7	390.1	394.5	401.9	404.6	405.1	403.5	401.7
After Expansion	401.0	399.0	395.4	389.6	389.5	391.0	394.8	402.3	404.8	405.0	403.8	402.2
2025												
Before Exp. w/o NN2	399.6	396.5	394.6	392.6	389.1	389.0	393.8	402.0	404.9	405.0	404.0	402.7
Before Exp. w/ NN2	400.1	397.1	394.9	392.6	389.2	389.7	394.6	401.7	404.8	405.1	403.8	402.7
After Expansion	400.2	396.8	394.7	392.4	389.1	389.6	394.3	401.3	404.7	405.0	404.0	402.9

[Nam Mang 3 Reservoir]

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2015												
Before Exp. w/o NN2	745.8	745.4	744.8	743.9	742.7	742.8	744.9	748.0	749.7	749.7	747.8	745.9
Before Exp. w/ NN2	744.6	743.6	743.3	742.7	742.1	742.4	744.6	747.9	749.9	749.9	748.5	746.3
After Expansion	743.3	742.2	741.9	741.9	741.6	742.0	743.8	747.2	749.6	749.6	747.3	744.1
2020												
Before Exp. w/o NN2	748.8	749.0	746.1	742.1	742.1	743.3	745.8	748.2	749.6	750.1	748.9	748.5
Before Exp. w/ NN2	748.4	748.5	746.0	742.0	742.3	743.7	745.5	747.6	749.5	750.1	749.3	748.2
After Expansion	749.0	749.0	746.1	742.0	742.5	744.1	745.8	747.8	749.6	750.1	749.3	748.7
2025												
Before Exp. w/o NN2	749.2	748.8	747.2	744.0	742.7	743.1	745.4	748.1	749.8	750.0	749.6	749.1
Before Exp. w/ NN2	748.6	748.2	746.9	743.7	742.6	743.1	745.5	748.1	749.7	749.9	749.4	748.4
After Expansion	748.9	748.1	746.2	743.2	742.3	742.9	745.4	747.8	749.5	749.9	749.3	748.6

Prepared by JICA Survey Team

The result of the comparison is summarized as follows.

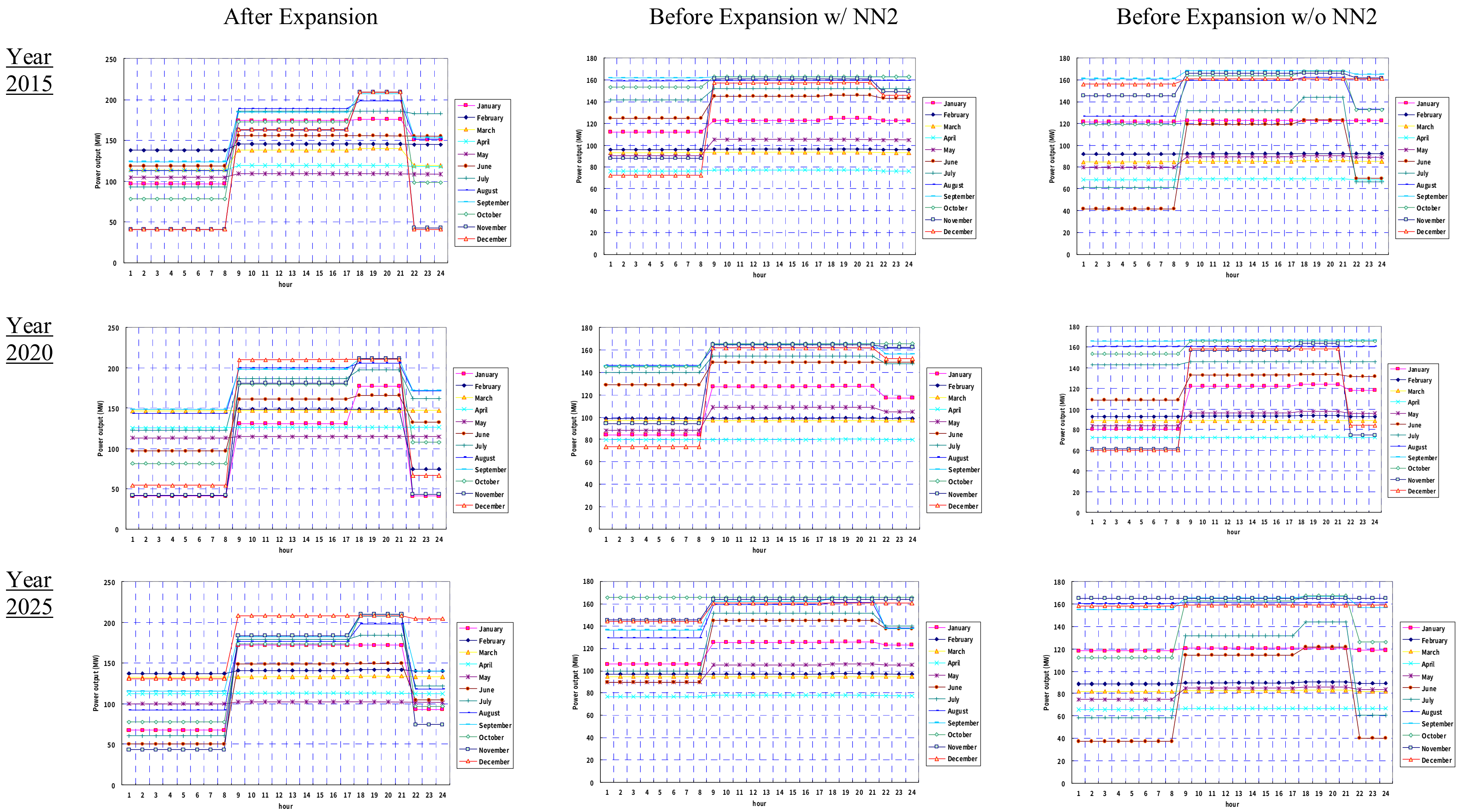
- The average water level of NN1 reservoir is different between with and without NN2 cases.
- Nam Leuk and Nam Mang 3 reservoir water levels also exhibit some changes in the dry season in the year 2015 between with and without NN2 cases.
- Expansion of the NN1 hydropower station changes the reservoir operation of Nam Leuk and Nam Mang 3 within one meter, which is less than one percent of total head.
- Consequently, the changes in annual energy of Nam Mang 3 and Nam Leuk hydropower due to NN1 expansion are less than one percent. Therefore changes in energy production are negligibly small.

(5) Generation Pattern after Expansion

The monthly average power output in a day by NN1 hydropower station for the year 2015, 2020, and 2025 for each case(after expansion and w/ or w/o NN2 in before expansion) is shown in Figure 5.6.6.

The combined output of the three hydropower stations (NN1, Nam Leuk and Nam Mang 3) in January, as representing dry season, and in September, as representing rainy season, are shown from Figure 5.6.7 to 5.6.9.

It is noted that NN1 can be operated for 24 hours a day with full capacity of generators for the before expansion as shown in Figure 5.6.6. However, for the after expansion case, the water is allocated more on the peak hours in TOU system. Therefore 24 hours with full capacity operation is seldom realized after expansion.



Prepared by JICA Survey Team

Figure 5.6.6 Monthly Average Power Output of the NN1 Hydropower Station

[After Expansion]

January September

Year 2015

Year 2020

Year 2025

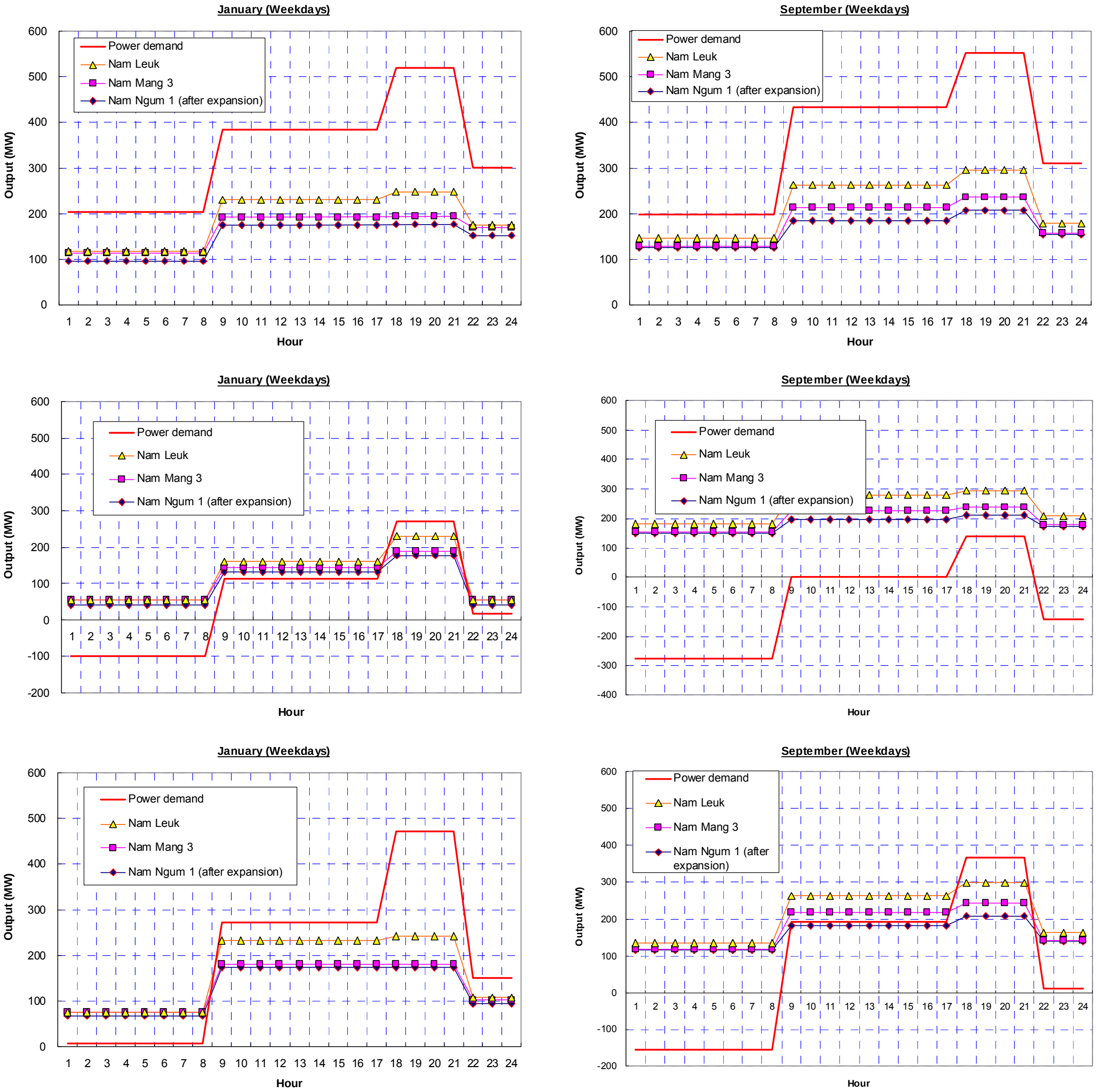


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Figure 5.6.7 Combined Power Output of the NN1, Nam Mang 3 and Nam Leuk Hydropower Station for After Expansion Case

[Before Expansion with NN2]

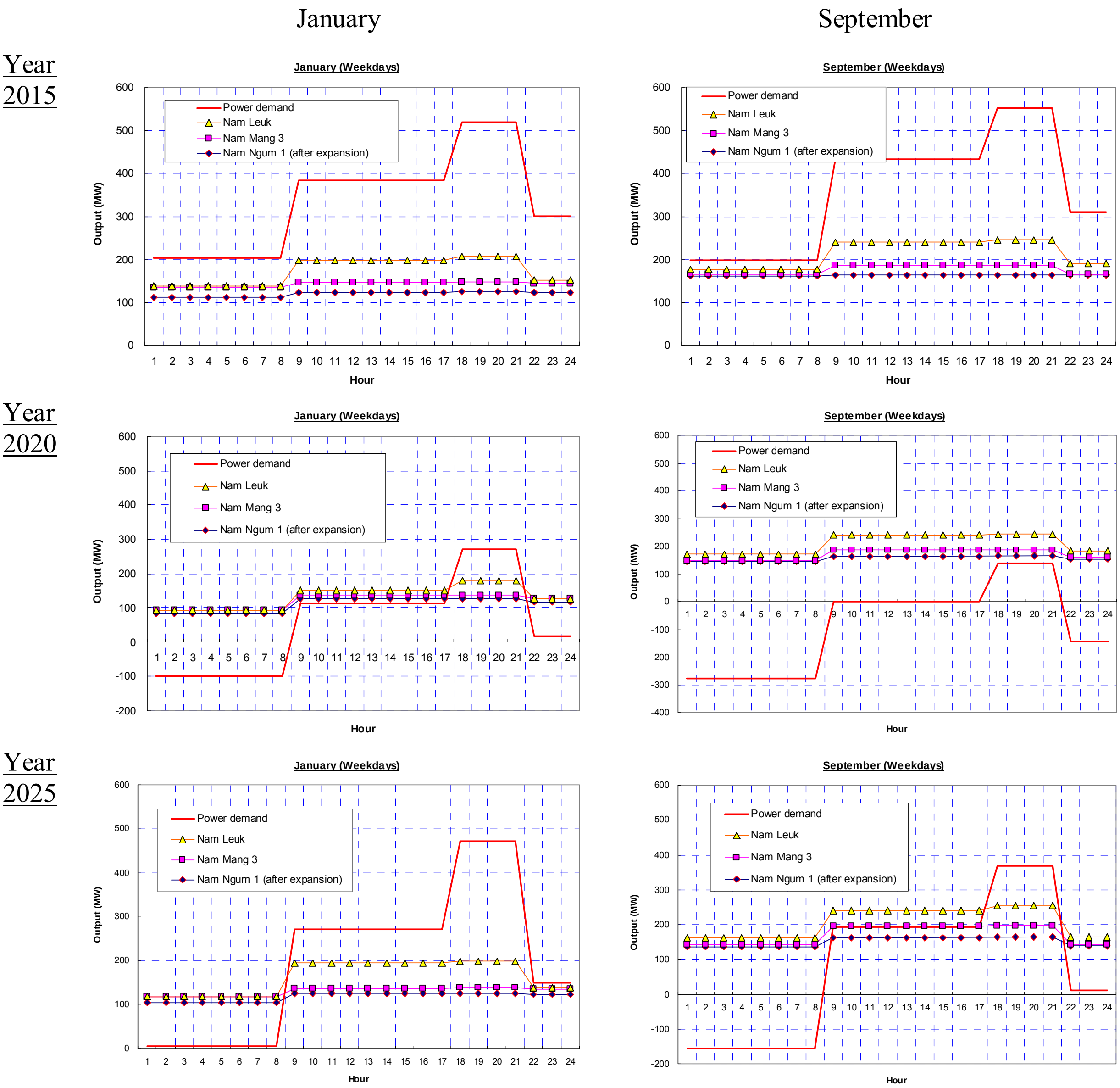

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Figure 5.6.8 Combined Power Output of the NN1, Nam Mang 3 and Nam Leuk Hydropower Station for Before Expansion with NN2 Case

[Before Expansion without NN2]

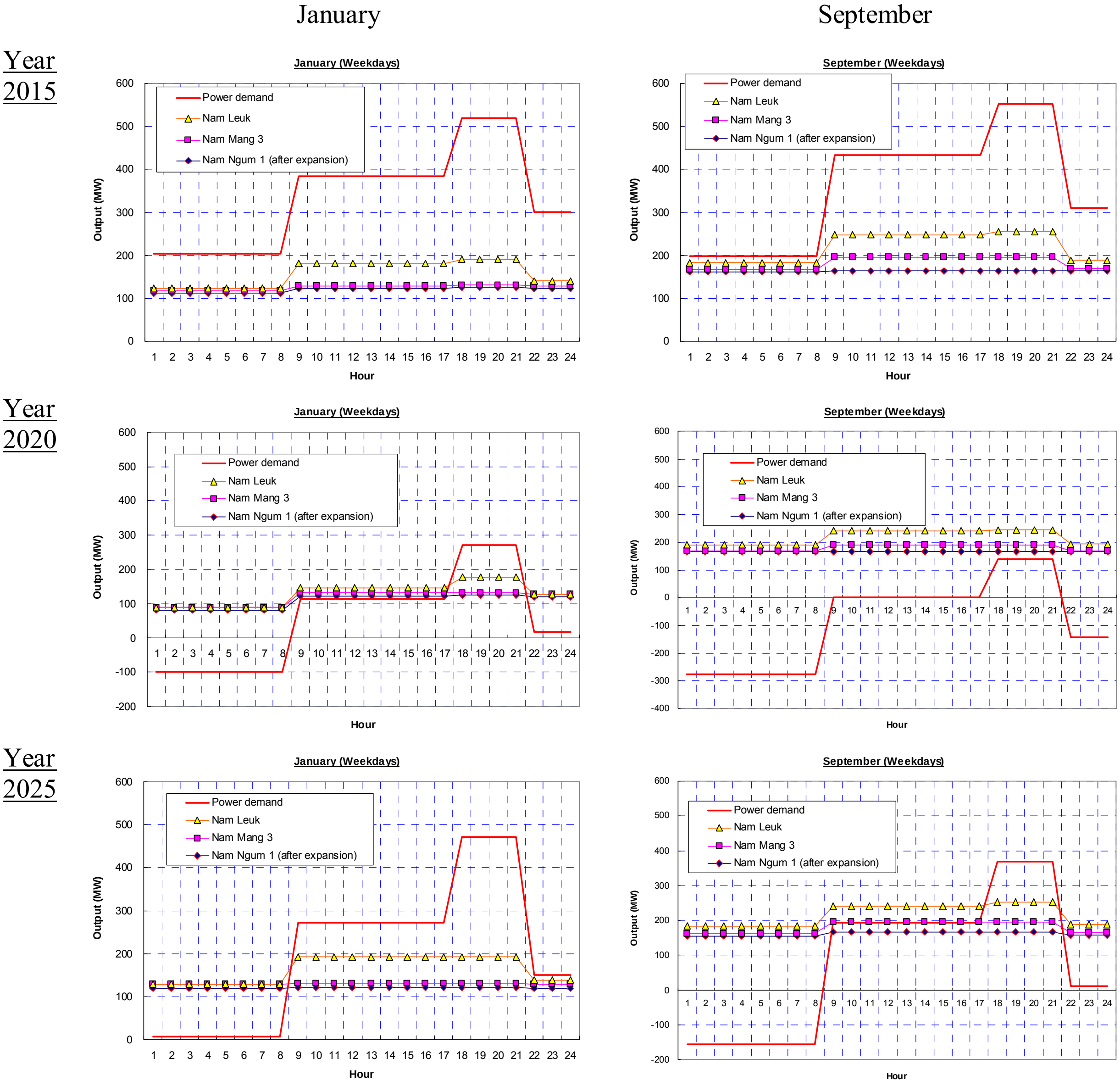

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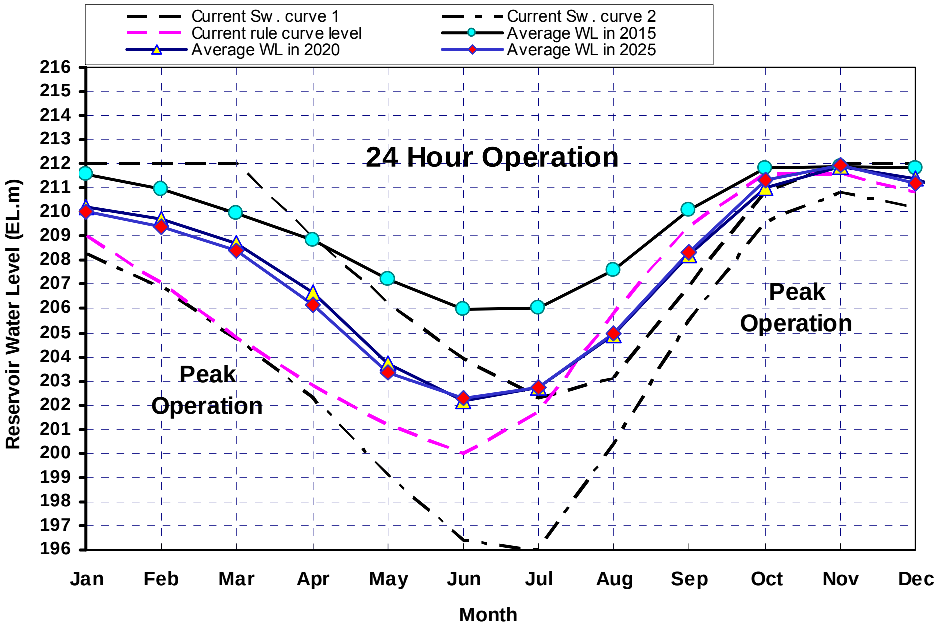
Figure 5.6.9 Combined Power Output of the NN1, Nam Mang 3 and Nam Leuk Hydropower Station for Before Expansion without NN2 Case

(6) Comparison with Present Reservoir Operation Rule

In this section, the optimum reservoir water level obtained in this study is compared to the existing reservoir rule curves.

1) NN1 Reservoir

The NN1 Reservoir current rule curve and average of optimum reservoir water level of after expansion case are combined for comparison as shown in Figure 5.6.10.



Source:NN1 Hydropower Station, JICA Survey Team

Figure 5.6.10 Comparison of Current Rule and Switch Curve to Average of Optimum Reservoir Water Level

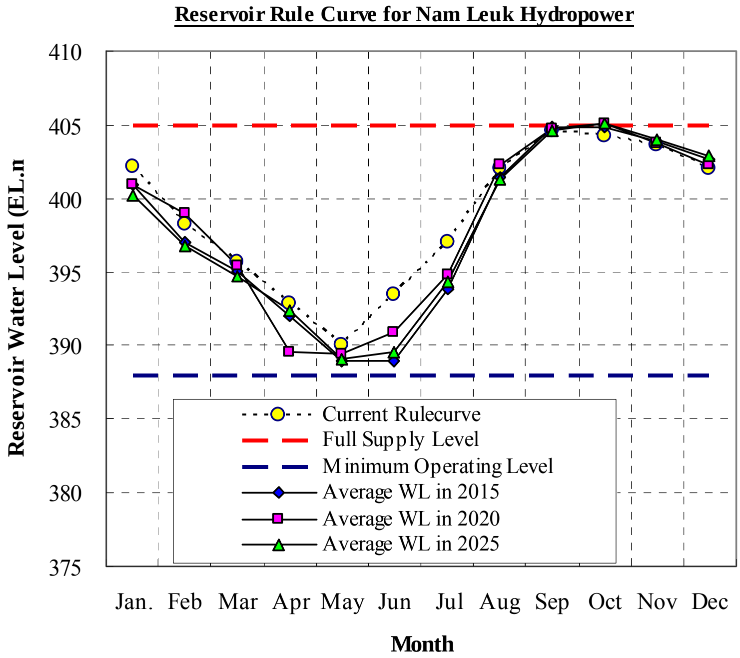
As shown in Figure 5.6.10, the optimization result lowers the average water level to EL. 206 m in June and July for the year 2015 case, while the years 2020 and 2025 cases together falls to EL. 202 m in June. The reasons behind the high water level for the year 2015 are conceived as follows;

- In the year 2015, the electricity supply is in deficit constantly throughout the year. Therefore the minimization of energy imports can not be improved even if NN1 keep generating electricity in the dry season.
- Meanwhile, in general, higher reservoir water level enables the power plant to generate more energy with the same quantity of water.
- Therefore, in order to reduce the energy imports as much as possible, the water level should remain high to produce large energy.

All of the three year cases has higher water level than the rule curve in the dry season as shown in Figure 5.6.10.

2) Nam Leuk Reservoir

The current operation rule curve of the Nam Leuk reservoir and average optimum reservoir water level obtained in this study are compared as shown in Figure 5.6.11.



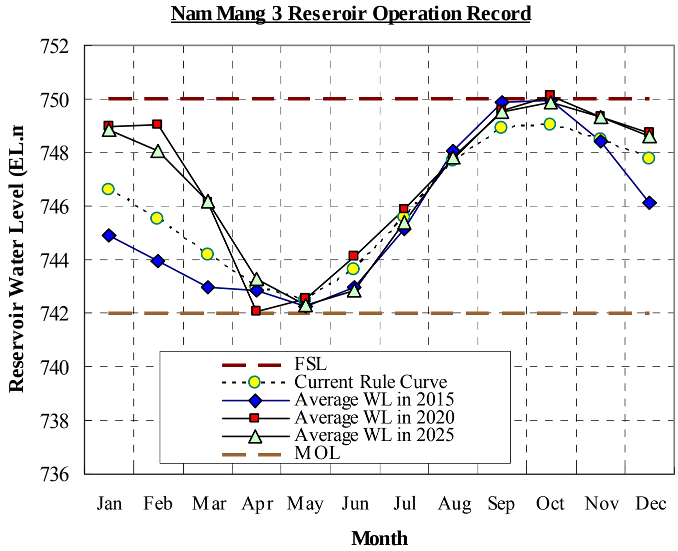
Source: Nam Leuk Hydropower Station, JICA Survey Team

Figure 5.6.11 Comparison of Current Rule Curve to Average of Optimum Reservoir Water Level of Nam Leuk Reservoir

As shown in the above Figure 5.6.11, the optimum reservoir water level has similar profile with current rule curve during the draw down in the dry season. However, the average water level is lowered during the rising of water level in the rainy season.

3) Nam Mang 3 Reservoir

Nam Mang 3 reservoir water level has some difference in the dry season between the current and optimum reservoir water level in this study. Meanwhile, the water levels are almost the same in the rainy season. Nam Mang 3 is a multi-purpose dam utilized for hydropower as well as irrigation supply. The deviation of the water level in the dry season may be caused by the irrigation supply in the dry season.



Source: Nam Mang 3 Hydropower Station, JICA Survey Team

Figure 5.6.12 Comparison of Current Rule Curve to Average of Optimum Reservoir Water Level of Nam Mang 3 Reservoir

(7) Switch Curve

As shown in Figure 5.6.6, the operation of the expanded NN1 hydropower station is in full capacity on the peak hour operation in TOU rather than generating 24 hours with full capacity in the rainy season. In this case, NN1 hydropower station will generate four hours in the night peak with full capacity, and generates in daytime peak with a discharge derived by the operation rule, followed by the off-peak hour operation.

Current reservoir operation considers the switching curve that was developed by Lahmeyer International (LI), and reservoir water level. After the expansion, the NN1 will basically be operated for 13 hours peak with adjustment output in daytime peak, and 11 hours off-peak. For reference, the revised switch curve after expansion, which is to supersede the current switch curve, is presented by specifying the reservoir operation range obtained in the optimization calculation.

The switching curve after expansion for the respective examined year is shown in Figure 5.6.13.

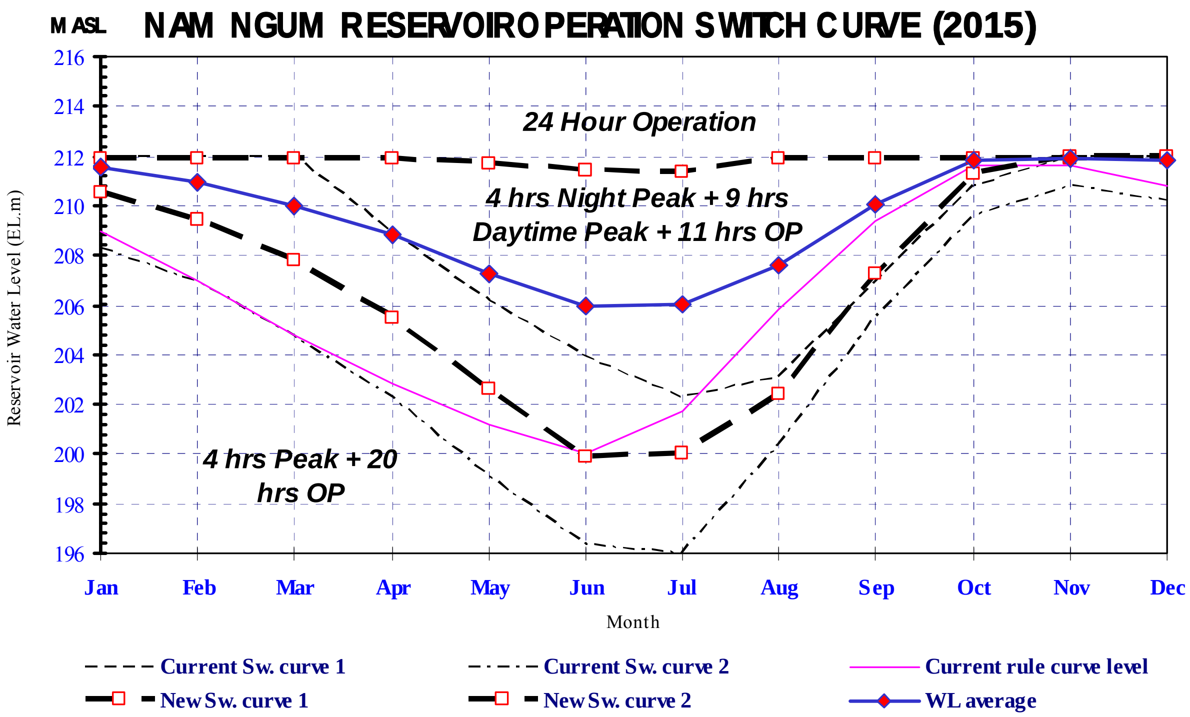


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Figure 5.6.13 Current and Revised Switch Curve and Water Level for the year 2015

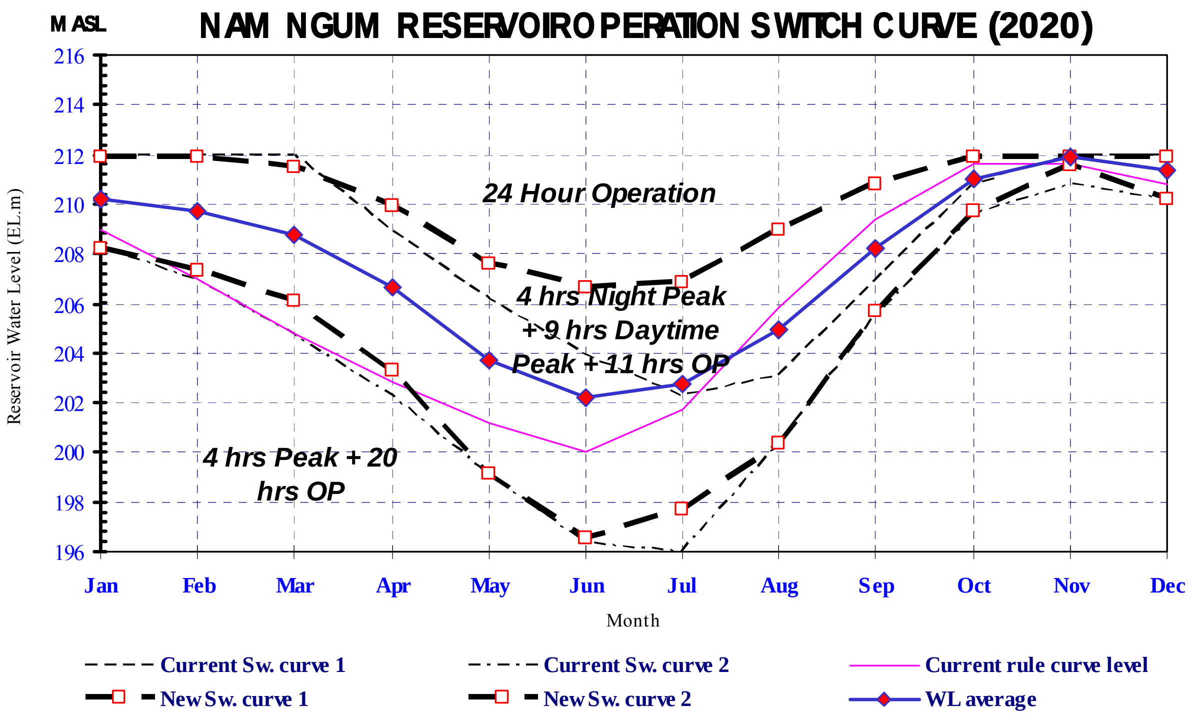

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Figure 5.6.14 Current and Revised Switch Curve and Water Level for the year 2020

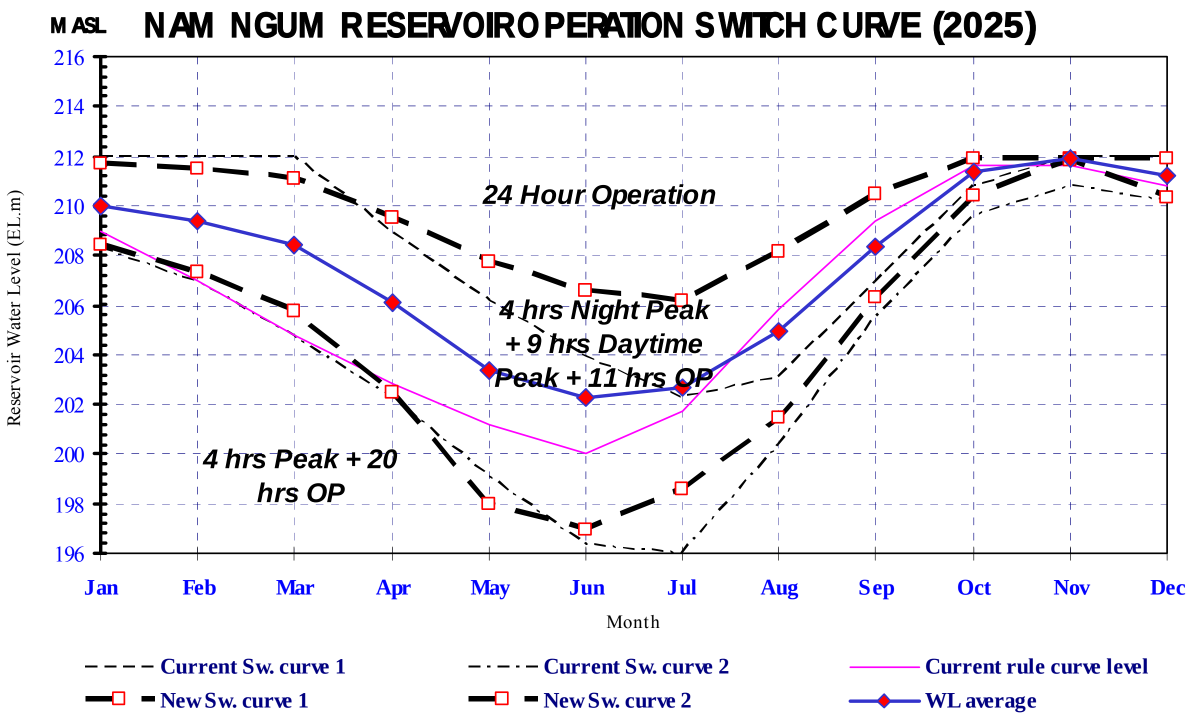

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Figure 5.6.15 Current and Revised Switch Curve and Water Level for the year 2025

As shown in Figure 5.6.13, the average of reservoir water level generally stays in high elevation in the year 2015. However, in the year 2020 and 2025, the lower limit of the water level is close to LI's switching curve level. The upper limit line is generally higher than the LI's switching curve level which is due to the effect of the NN2 operation.

(8) Annual Energy Calculation

The annual energy is calculated by deterministic DP method which presumes that the future inflow is perfectly predictable. However, in the actual operation, it is difficult to predict the exact inflow in the future. Therefore, this deterministic DP result is statistically analyzed and the reservoir operation rule is developed. The DP results indicate that reservoir operation can generally be explained by the expected inflow in the instantaneous future (a month ahead in this case) or reservoir storage at the previous time step. Therefore, in this study, the reservoir operation rule is formed by multiple regression line developed using analysis of variance method (well known as *ANOVA*).

The obtained reservoir operation rule and the coefficients of the multiple regression lines are presented in Appendix B.

In this section, the annual energy is calculated for the all cases (after expansion and with or without NN2 in before expansion) for the examined years 2015, 2020, and 2025. The energy calculation also considers the expected maintenance schedule since the decrease of the maintenance frequency is also an important factor for the NN1 expansion project.

The result of annual energy calculation is tabulated in Table 5.6.4.

Table 5.6.4 Calculated Annual Energy and Dependable Power

Before Expansion without NN2

Year	Anual Energy (GWh)	Average Energy		Dependable Energy Weekday		Dependable Capacity (MW) (95%)							
		in Peak hours (GWh)	in Off-Peak hours (GWh)	Night Peak (GWh)	Daytime Peak (GWh)	Weekday				Holiday			
						18:00-22:00	9:00-18:00	22:00-0:00	0:00-9:00	18:00-22:00	9:00-18:00	22:00-0:00	0:00-9:00
2015	1,009	435	574	70	70	67	67	33	31	67	34	30	30
2020	1,021	442	579	64	60	61	58	41	29	59	41	28	28
2025	1,006	428	578	66	66	63	63	30	30	63	32	29	29

Before Expansion with NN2

Year	Anual Energy (GWh)	Average Energy		Dependable Energy Weekday		Dependable Capacity (MW) (95%)							
		in Peak hours (GWh)	in Off-Peak hours (GWh)	Night Peak (GWh)	Daytime Peak (GWh)	Weekday				Holiday			
						18:00-22:00	9:00-18:00	22:00-0:00	0:00-9:00	18:00-22:00	9:00-18:00	22:00-0:00	0:00-9:00
2015	1,068	452	616	71	65	68	62	42	41	64	55	29	29
2020	1,073	463	610	82	82	78	78	49	37	78	69	31	31
2025	1,071	455	616	79	79	76	75	37	34	76	38	31	31

After Expansion with NN2

Year	Anual Energy (GWh)	Average Energy		Dependable Energy Weekday		Dependable Capacity (MW) (95%)							
		in Peak hours (GWh)	in Off-Peak hours (GWh)	Night Peak (GWh)	Daytime Peak (GWh)	Weekday				Holiday			
						18:00-22:00	9:00-18:00	22:00-0:00	0:00-9:00	18:00-22:00	9:00-18:00	22:00-0:00	0:00-9:00
2015	1,121	551	571	113	101	108	97	37	37	108	37	35	34
2020	1,145	573	572	121	112	116	108	38	37	116	39	37	37
2025	1,115	551	564	106	95	101	91	37	34	101	37	31	31

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5.6.7 DRAFT RESERVOIR OPERATION PLAN WITH REVENUE CONSIDERATION (NN1 RESERVOIR ONLY)

(1) General

In this section, the operation of the reservoir is studied considering only the NN1 reservoir operation. Other than NN1 reservoir such as Nam Leuk hydropower, the hydropower output is constant following the latest PDP planed output. The study of the reservoir operation which includes other hydropower operation is described in section 5.6.8 and 5.6.9.

(2) Analysis Conditions

In this section, the reservoir operation is analyzed aiming at revenue maximization. However, the calculation condition is almost the same as the energy maximization optimization as described in section 5.6.6. Different conditions from the section 5.6.6 analysis are 1) the objective function is a combination of revenue maximization and imported energy minimization, and 2) only the NN1 reservoir operation is the variable. The objective function is expressed by the following equation.

Objective function; $Maximize \sum_{t=1}^{T}(\mathrm{Re}venue) - \sum_{t=1}^{T}(Demand - Supply)$

Where,

Revenue : Revenue is the income minus cost at the time "t".

(Demand - Supply) : Power demand shortage. It is only functioned when demand exceeds supply (Demand > Supply). Power demand shortage is covered by the

energy imported from EGAT. Therefore, it is equivalent to the imported energy.

T : Number of time step. (T = 432)

Revenue is calculated by the following equation.

Revenue = (domestic sale) + (export revenue) + (import cost) – (imported energy sold to domestic consumer) – (annual excess charge)

The revenue term uses the following tariff.

- Domestic electricity sale tariff (6.21 cent/kWh)
- Export tariff to EGAT (Peak 4.70 cent/kWh, Off peak 3.52 cent/kWh)
- Import tariff from EGAT (Peak 5.26 cent/kWh, 4.08 cent/kWh)
- Excess charge for EGAT interchange
- Monetary unit is US dollar, and exchange rate is USD1.00 = THB34.054.

The operation and maintenance (O&M) cost is not considered in the revenue balance because most of the cost can be assumed as the fixed cost. Those variable costs and tax are not considered. The imported energy is sold to domestic demands, and the import tariff is cheaper than the domestic selling tariff. Therefore, the margin of the import and domestic tariffs can be counted as surplus revenue. Importing electricity from EGAT tends to increase in revenue of EdL, however, the revenue balance will be deteriorated if too much electricity is imported from EGAT due to increment in excess charge.

The reservoir operation optimization is a multi-objective optimization consisting of revenue maximization together with imported energy minimization. These objectives are not totally independent from each other, but revenue can be increased or decreased based on the imported energy amount. Therefore, these variables are not as well in linear relation in general. To understand the relation of these two functions, the relation of the revenue and imported energy is plotted on graphs in the analysis. The DP calculation for more than two variables with long time step requires enormous computer calculation time. Therefore for practical purposes, the calculation is halted when the calculation achieves a specified convergence tolerance. This procedure sometimes gives some deviations; however, it at least can exhibit some trend of the results.

(3) Analysis case

The analysis uses the years 2015, 2020, and 2025 power demands, and considers the after expansion and with or without NN2 in the before expansion. Imposing heavy weights on imported energy minimization term is categorized “Case 1” while imposing very light or “0” weight is categorized as “Case 2.” The results for the all of the 18 cases are presented in this section.

In addition to the above analysis cases, the relation between energy import and revenue are presented by changing the weight on import energy minimization.

The analysis cases are summarized in Table 5.6.5.

Table 5.6.5 Study Case for Reservoir Operation for the Revenue Maximization

Examined year power demand	w/ Expansion or w/o Expansion	Case 1 (Strong weight for min. import energy) Case 2 (No weight for min. import energy)
2015	After expansion	Case 1
		Case 2
	Before Exp. w/ NN2	Case 1
		Case 2
	Before Exp. w/o NN2	Case 1
		Case 2
2020	After expansion	Case 1
		Case 2
	Before Exp. w/ NN2	Case 1
		Case 2
	Before Exp. w/o NN2	Case 1
		Case 2
2025	After expansion	Case 1
		Case 2
	Before Exp. w/ NN2	Case 1
		Case 2
	Before Exp. w/o NN2	Case 1
		Case 2

Prepared by JICA Survey Team

(4) Analysis Result

The optimum reservoir operation is studied for the calculation of different cases as shown in Table 5.6.5. The imported energy and revenue balance are summarized in this section.

The analysis in this section only considers the operation of the NN1 hydropower station operation, therefore the revenue of the selling energy only accounts for the selling energy produced by NN1. The power export is also considered for NN1 production energy only.

The result of the analysis is described for the examined years 2015, 2020, and 2025.

1) Year 2015

Table 5.6.6 Summary Table of Revenue Maximization Operation in the year 2015 (NN1 Reservoir Only)

		2015					
		After Expansion		Before Exp. w/ NN2		Before Exp. w/o NN2	
		Case 1	Case 2	Case 1	Case 2	Case 1	Case 2
(1) Nam Ngum I Hydropower Station							
Average hydropower energy	(GWh/year)	1,171	1,186	1,159	1,162	1,167	1,165
Revenue for domestic sale	(1000 USD/year)	72,471	71,751	71,785	71,452	71,697	71,422
(2) Import from EGAT							
Average import energy	(GWh/year)	1,891	1,902	1,902	1,907	1,903	1,908
Average import power	(MW)	378	370	412	409	418	415
Maximum import energy	(GWh/month)	284	283	292	268	274	257
Maximum import power	(MW)	543	538	618	542	547	527
Average import expense	(1000 USD/year)	88,987	89,249	90,835	90,904	91,144	91,203
Revenue selling import energy to domestic	(1000 USD/year)	117,423	118,144	118,110	118,443	118,198	118,473
(3) Export to EGAT							
Average export energy	(GWh/year)	4	31	3	12	12	14
Average export power	(MW)	3	13	2	8	9	11
Maximum export energy	(GWh/month)	15	25	10	10	11	11
Maximum export power	(MW)	65	119	75	75	76	76
Average export revenue	(1000 USD/year)	142	1,087	107	414	422	508
(4) Excess charge							
Average excess charge	(1000 USD/year)	54,794	53,562	53,824	54,588	53,003	55,526
Maximum excess charge	(1000 USD/year)	69,708	71,949	68,519	65,695	58,648	59,538
(5) Total annual revenue	(1000 USD/year)	190,037	190,981	190,001	190,308	190,317	190,403
(6) Total annual expense	(1000 USD/year)	143,782	142,811	144,659	145,492	144,147	146,728
(7) Annual balance	(1000 USD/year)	46,255	48,170	45,342	44,817	46,170	43,674

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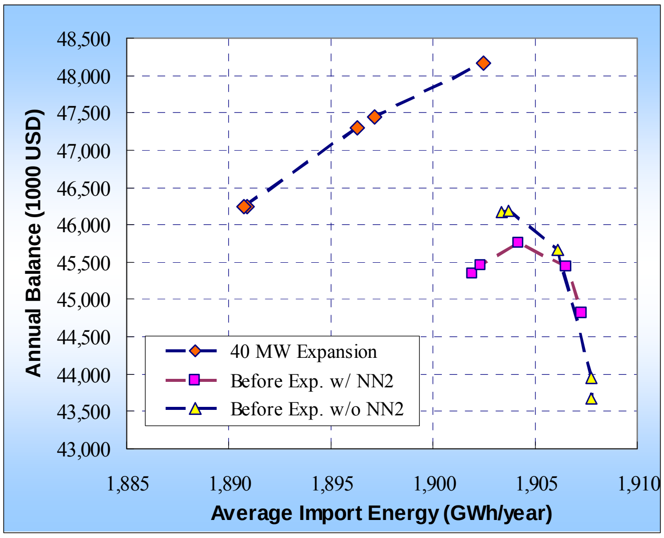
According to the above table, if the energy import is increased in the after expansion case, then the annual revenue balance (Item (7) above) is also increased. This is only the case for the after expansion. For the before expansion cases, both “with” and “without” NN2 cases decreased in annual balance if the imported energy is increased. This is mainly due to the increase in the excess charge.

In the analysis, in order to show the relationship between imported energy versus annual revenue balance, reservoir operation optimization is further conducted while gradually changing the weights on imported energy minimization. The result is shown in Figure 5.6.16.



Prepared by JICA Survey Team

Figure 5.6.16 Relation of Average Import Energy and Annual Balance in the year 2015 (NN1 Only)

As shown in Figure 5.6.16, in the year 2015 case, the decrease in imported energy is limited although NN-2 is considered in the before expansion case. The imported energy and revenue balance is almost proportional for the after expansion case.

The average water level and water level at standard deviation in the after expansion of case 1 and case 2 is shown in Figure 5.6.17.

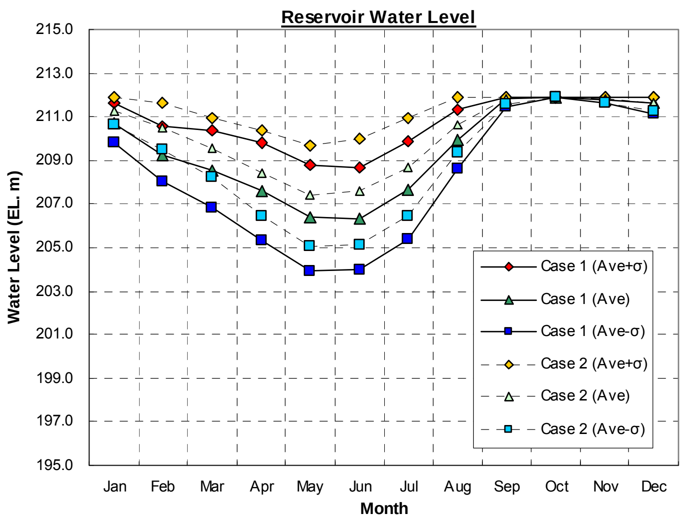


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Figure 5.6.17 Reservoir Average and Standard Deviation Water Level for the year 2015 (NN1 Only)

As shown in the above figure, the average water level in the dry season of case 1 is lower than that of case 2. Therefore, the water level is lowered if the imported energy minimization has heavy weights.

2) Year 2020

Table 5.6.7 Summary Table of Revenue Maximization Operation in the year 2020 (NN1

Reservoir Only)

		2020					
		After Expansion		Before Exp. w/ NN2		Before Exp. w/o NN2	
		Case 1	Case 2	Case 1	Case 2	Case 1	Case 2
(1) Nam Ngum I Hydropower Station							
Average hydropower energy	(GWh/year)	1,057	1,187	999	1,160	973	1,164
Revenue for domestic sale	(1000 USD/year)	31,553	29,632	28,206	27,460	27,530	26,706
(2) Import from EGAT							
Average import energy	(GWh/year)	135	166	189	201	200	213
Average import power	(MW)	81	88	101	103	105	110
Maximum import energy	(GWh/month)	61	78	69	81	71	74
Maximum import power	(MW)	275	310	301	310	301	310
Average import expense	(1000 USD/year)	6,884	8,161	9,668	10,190	10,213	10,860
Revenue selling import energy to domestic	(1000 USD/year)	8,388	10,308	11,734	12,480	12,410	13,234
(3) Export to EGAT							
Average export energy	(GWh/year)	1,286	1,447	1,282	1,455	1,267	1,471
Average export power	(MW)	274	288	274	296	278	305
Maximum export energy	(GWh/month)	280	287	254	255	253	257
Maximum export power	(MW)	590	600	557	556	553	558
Average export revenue	(1000 USD/year)	47,927	54,137	47,341	53,551	46,618	53,990
(4) Excess charge							
Average excess charge	(1000 USD/year)	0	0	0	0	0	0
Maximum excess charge	(1000 USD/year)	0	0	0	0	0	0
(5) Total annual revenue	(1000 USD/year)	87,868	94,077	87,281	93,491	86,558	93,930
(6) Total annual expense	(1000 USD/year)	6,884	8,161	9,668	10,190	10,213	10,860
(7) Annual balance	(1000 USD/year)	80,984	85,916	77,613	83,301	76,345	83,070

Prepared by JICA Survey Team

In the year 2020, electricity demand and supply is almost at equilibrium. Therefore, excess charge is not imposed on the revenue. The result shows that importing more energy gives more flexible operation of NN1 hydropower station. This contributes to the increase in the annual balance of the revenue.

The relationship between the energy import and annual revenue balance is shown in Figure 5.6.18, based on gradually changing the weights on import energy minimization.

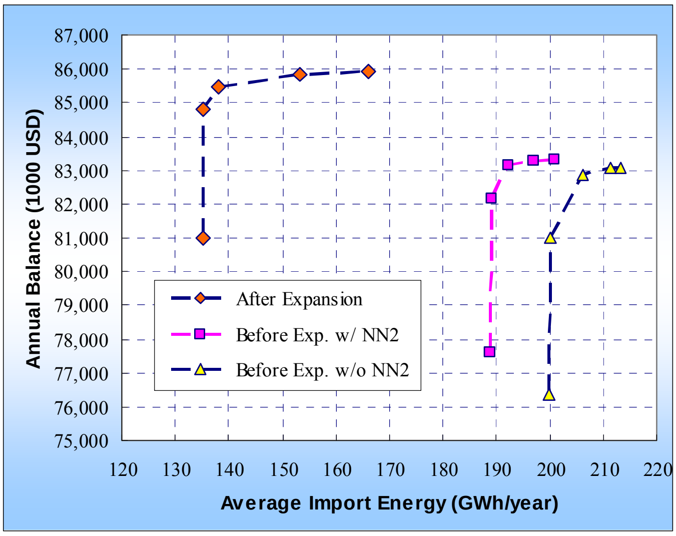

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Figure 5.6.18 Relation of Average Import Energy and Annual Balance in the year 2020 (NN1 Only)

The curves shown in Figure 5.6.18 are based on before expansion without NN2, before expansion with NN2, and after expansion. It shows that the curves are closer to the upper left corner of the chart. This means that expansion of NN1 enables NN1 operation to decrease in imported energy and increase in revenue.

The curves represent two objectives relation, and these curves are seemed to create "pareto optimal surface" which is a series of optimal point of multi-objective function. If NN1 is operated along the optimum operation range, this means the operation is optimal.

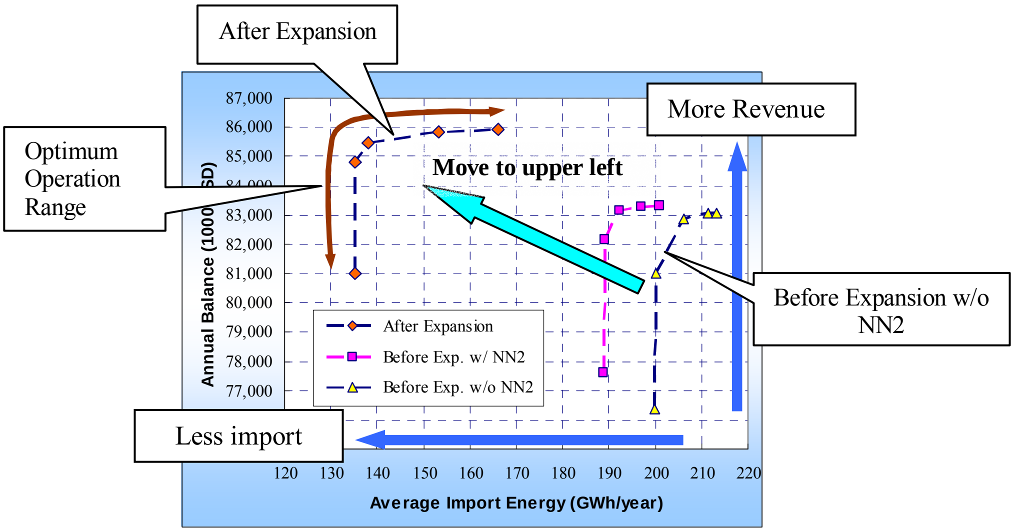

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Figure 5.6.19 Trend of the Relation of Average Import Energy and Annual Balance

The average water level and water level at standard deviation in after expansion case of case 1 and case 2" is shown in Figure 5.6.20.

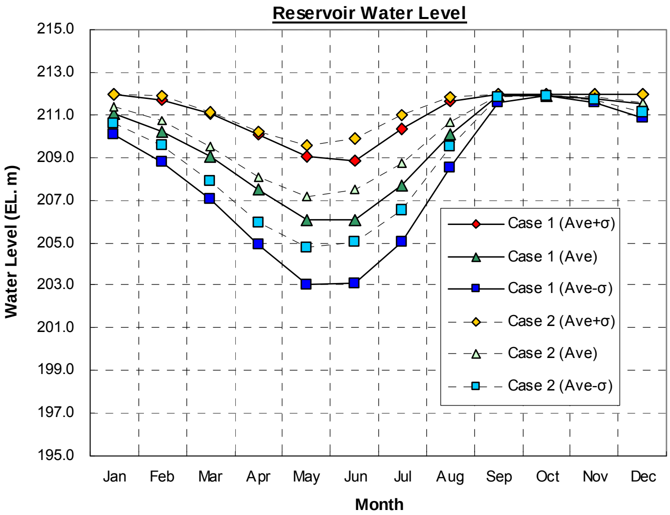

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Figure 5.6.20 Reservoir Average and Standard Deviation Water Level for the year 2020 (NN1 Only)

As shown in the above figure, the average water level in the dry season of case 1 is lower than that of case 2.

3) Year 2025

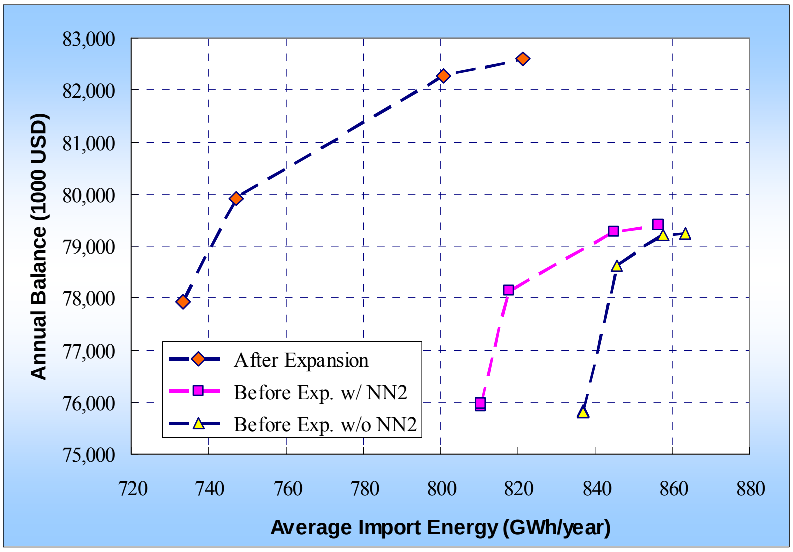
Table 5.6.8 Summary Table of Revenue Maximization Operation in the year 2025 (NN1 Reservoir Only)

		2025					
		After Expansion		Before Exp. w/ NN2		Before Exp. w/o NN2	
		Case 1	Case 2	Case 1	Case 2	Case 1	Case 2
(1) Nam Ngum I Hydropower Station							
Average hydropower energy	(GWh/year)	1,111	1,184	1,099	1,159	1,105	1,163
Revenue for domestic sale	(1000 USD/year)	57,439	51,978	52,644	49,793	51,001	49,367
(2) Import from EGAT							
Average import energy	(GWh/year)	733	821	811	856	837	863
Average import power	(MW)	284	277	318	317	324	325
Maximum import energy	(GWh/month)	242	210	216	213	195	188
Maximum import power	(MW)	649	538	563	548	567	560
Average import expense	(1000 USD/year)	36,691	40,113	40,994	42,852	42,337	43,455
Revenue selling import energy to domestic	(1000 USD/year)	45,540	51,002	50,335	53,186	51,978	53,612
(3) Export to EGAT							
Average export energy	(GWh/year)	515	676	581	687	613	697
Average export power	(MW)	157	178	165	185	173	191
Maximum export energy	(GWh/month)	183	183	156	155	157	157
Maximum export power	(MW)	504	496	454	453	454	454
Average export revenue	(1000 USD/year)	18,364	24,081	20,495	24,225	21,640	24,604
(4) Excess charge							
Average excess charge	(1000 USD/year)	6,724	4,363	6,569	4,960	6,446	4,880
Maximum excess charge	(1000 USD/year)	14,255	14,018	12,347	13,463	11,823	10,377
(5) Total annual revenue	(1000 USD/year)	121,343	127,060	123,474	127,205	124,619	127,583
(6) Total annual expense	(1000 USD/year)	43,415	44,476	47,563	47,812	48,783	48,335
(7) Annual balance	(1000 USD/year)	77,928	82,584	75,911	79,392	75,837	79,248

Prepared by JICA Survey Team

The tendency is the same with year 2020 case since the increment in energy imports results in increment in total production of energy, since importing energy in the dry season enables NN1 to maintain reservoir water level close to Full Supply water Level (FSL).

The relationship between the energy import and revenue balance is shown in Figure 5.6.21.

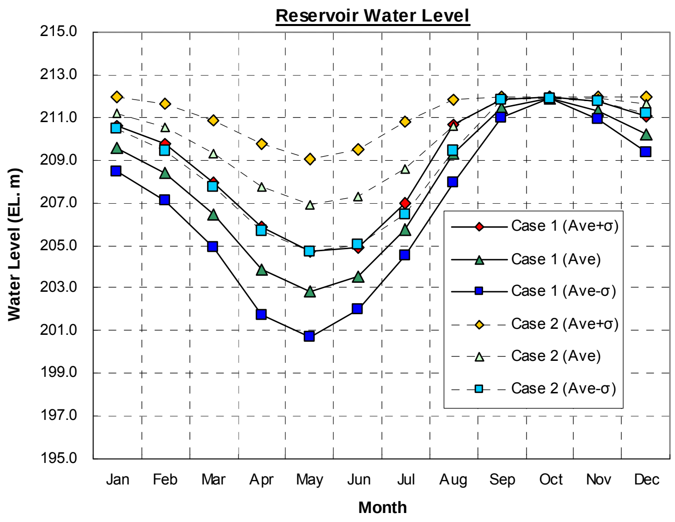


Prepared by JICA Survey Team

Figure 5.6.21 Relation of Average Import Energy and Annual Balance in the year 2025 (NN1 Only)

The relationship of the annual balance and energy import show similar trends in the year 2020 case. The curves are closer to the upper left corner of the chart as the NN1 is expanded. This means that the revenue and energy imports are both improved because of expansion. Especially, the optimum operation range is widely spread due to expansion. This means that the NN1 expansion will enable to be more flexible operation due to the increase of the capacity.

The average water level and water level at standard deviation in the after expansion case of case 1 and case 2 is shown in Figure 5.6.22.



Prepared by JICA Survey Team

Figure 5.6.22 Reservoir Average and Standard Deviation Water Level for the year 2025 (NN1 Only)

As show in the above figure, the average water level in the dry season of case 1 is lower than that of case 2.

5.6.8 (DRAFT) RESERVOIR OPERATION PLAN WITH REVENUE CONSIDERATION (NN1, NAM LEUK, NAM MANG 3 RESERVOIRS)

(1) General

In this section, the operation of the reservoir is studied considering EdL-owned hydropower stations NN1, Nam Leuk, and Nam Mang 3 reservoir operations. The objective of the optimization is to maximize revenue while minimizing imported energy. The study presents the operation of three reservoirs, and relation of the imported energy and revenue balance.

(2) Analysis conditions and analysis case

The analysis conditions and analysis case in this section are the same as NN1 reservoir operation study in the previous section 5.6.7.

(3) Result of analysis

The results of the analysis for each case in each examined year are shown below.

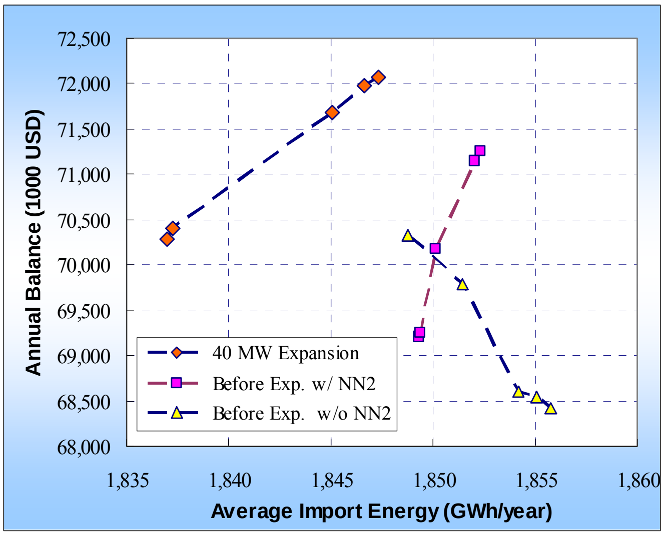
1) Year 2015

Table 5.6.9 Summary Table of Revenue Maximization Operation in the year 2015 (NN1 Reservoir, Nam Mang 3, and Nam Leuk)

		2015					
		After Expansion		Before Exp. w/ NN2		Before Exp. w/o NN2	
		Case 1	Case 2	Case 1	Case 2	Case 1	Case 2
(1) Nam Ngum I Hydropower Station							
Average hydropower energy	(GWh/year)	1,564	1,571	1,551	1,552	1,556	1,550
Revenue for domestic sale	(1000 USD/year)	96,900	96,255	96,132	95,946	96,166	95,733
(2) Import from EGAT							
Average import energy	(GWh/year)	1,837	1,847	1,849	1,852	1,849	1,856
Average import power	(MW)	341	324	373	361	391	382
Maximum import energy	(GWh/month)	282	266	289	263	270	270
Maximum import power	(MW)	563	493	570	483	562	563
Average import expense	(1000 USD/year)	85,408	85,451	87,332	87,070	87,984	87,954
Revenue selling import energy to domestic	(1000 USD/year)	114,075	114,720	114,843	115,029	114,809	115,242
(3) Export to EGAT							
Average export energy	(GWh/year)	4	21	3	7	7	8
Average export power	(MW)	2	8	1	4	4	5
Maximum export energy	(GWh/month)	32	39	20	25	20	26
Maximum export power	(MW)	123	135	88	107	88	109
Average export revenue	(1000 USD/year)	142	750	96	251	244	283
(4) Excess charge							
Average excess charge	(1000 USD/year)	55,422	54,204	54,544	52,910	52,908	54,890
Maximum excess charge	(1000 USD/year)	73,898	76,703	69,768	69,329	61,021	62,718
(5) Total annual revenue	(1000 USD/year)	211,117	211,725	211,071	211,226	211,219	211,258
(6) Total annual expense	(1000 USD/year)	140,830	139,655	141,876	139,980	140,892	142,844
(7) Annual balance	(1000 USD/year)	70,287	72,070	69,195	71,247	70,327	68,414

Prepared by JICA Survey Team

The relation between energy import and revenue balance is shown in Figure 5.6.23.

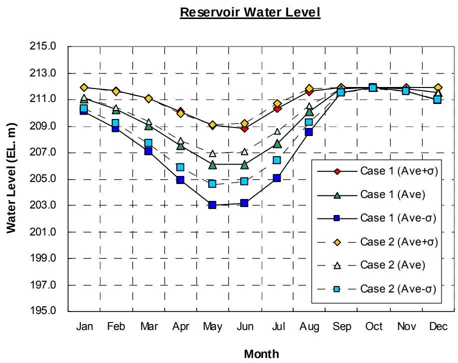


Prepared by JICA Survey Team

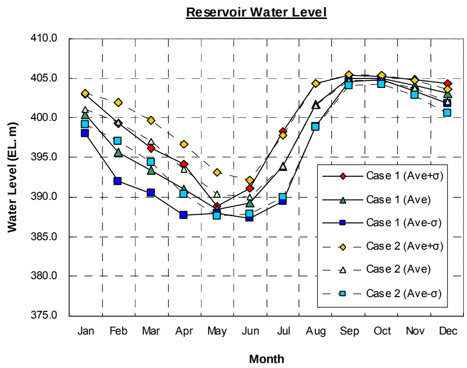
Figure 5.6.23 Reservoir Average and Standard Deviation Water Level for the year 2015 (NN1 Reservoir, Nam Mang 3, and Nam Leuk)

If the three hydropower stations' operations are considered simultaneously, the revenue and import energy curves are different to the case where NN1 is the only operational reservoir. If the three hydropower stations are simultaneously considered, the before expansion case with NN2 curve is changed to the right–up line in the chart. The reason is that the cooperated operation of the three hydropower stations successfully enables to decrease the excess charge. The without NN2 case, the relation profile is right-down line. This means that excess charge is increased as being increased in energy import. In this case, the increment of excess charge deteriorates the annual balance. This tendency of the result is the same as the NN1 only case.

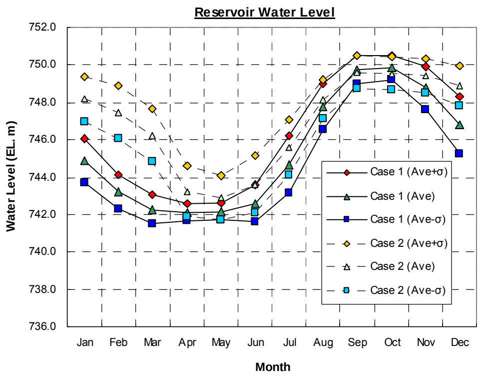
The average water level and water level at standard deviation in the after expansion of case 1 and case 2 is shown in Figure 5.6.24.



NN1



Nam Leuk



Nam Mang 3

Prepared by JICA Survey Team

Figure 5.6.24 Reservoir Average and Standard Deviation Water Level for the year 2015 (NN1 Reservoir, Nam Mang 3, and Nam Leuk)

As shown in the above figure, the reservoir water level is low when the energy imports weigh heavily. The effect is especially significant in Nam Mang 3 reservoir in dry season.

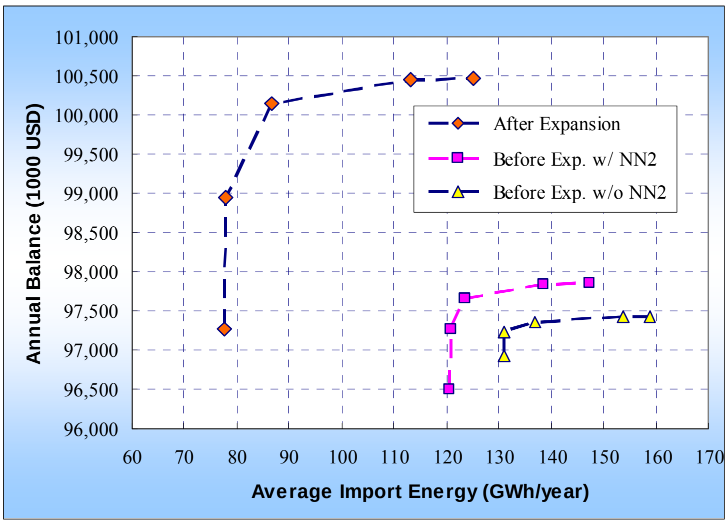
2) Year 2020

Table 5.6.10 Summary Table of Revenue Maximization Operation in the year 2020 (NN1 Reservoir, Nam Mang 3, and Nam Leuk)

		2020					
		After Expansion		Before Exp. w/ NN2		Before Exp. w/o NN2	
		Case 1	Case 2	Case 1	Case 2	Case 1	Case 2
(1) Nam Ngum I Hydropower Station							
Average hydropower energy	(GWh/year)	1,509	1,583	1,526	1,555	1,546	1,559
Revenue for domestic sale	(1000 USD/year)	45,677	42,728	43,016	41,355	42,371	40,637
(2) Import from EGAT							
Average import energy	(GWh/year)	78	125	121	147	131	159
Average import power	(MW)	59	75	77	79	80	83
Maximum import energy	(GWh/month)	41	80	51	74	58	74
Maximum import power	(MW)	207	307	242	268	263	305
Average import expense	(1000 USD/year)	3,964	6,008	6,173	7,368	6,689	8,010
Revenue selling import energy to domestic	(1000 USD/year)	4,828	7,777	7,489	9,150	8,134	9,868
(3) Export to EGAT							
Average export energy	(GWh/year)	1,341	1,462	1,401	1,457	1,431	1,473
Average export power	(MW)	265	266	276	273	291	285
Maximum export energy	(GWh/month)	316	321	290	289	291	292
Maximum export power	(MW)	649	633	610	589	614	591
Average export revenue	(1000 USD/year)	50,722	55,970	52,161	54,716	53,121	54,942
(4) Excess charge							
Average excess charge	(1000 USD/year)	0	0	0	0	0	0
Maximum excess charge	(1000 USD/year)	0	0	0	0	0	0
(5) Total annual revenue	(1000 USD/year)	101,227	106,475	102,666	105,221	103,626	105,447
(6) Total annual expense	(1000 USD/year)	3,964	6,008	6,173	7,368	6,689	8,010
(7) Annual balance	(1000 USD/year)	97,263	100,467	96,493	97,853	96,937	97,437

Prepared by JICA Survey Team

The relationship between the imported energy and annual balance is shown in Figure 5.6.25.

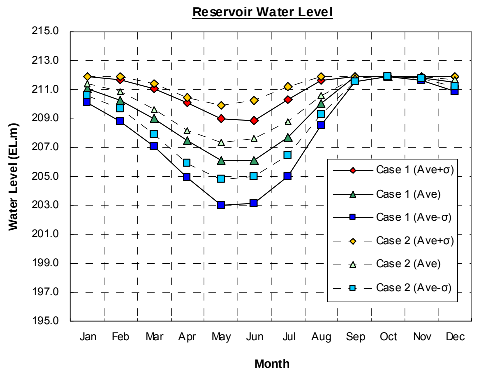


Prepared by JICA Survey Team

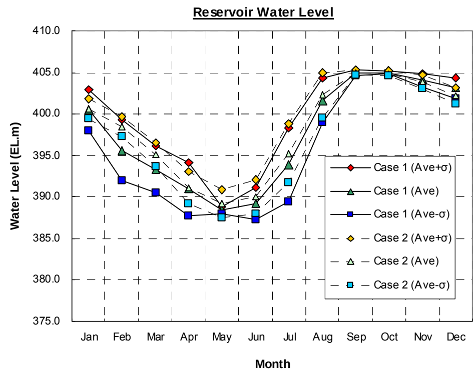
Figure 5.6.25 Relation of Average Import Energy and Annual Balance in the year 2020 (NN1 Reservoir, Nam Mang 3, and Nam Leuk)

The result of the three hydropower operation study in the 2020 shows that the profile of the relation curve is similar to the case of NN1 only case in section 5.6.7. The curves are closer to the upper left corner in the chart which means that the revenue and imported energy can be improved after expansion and with the NN2 case. The optimum operation range is widely spread due to expansion.

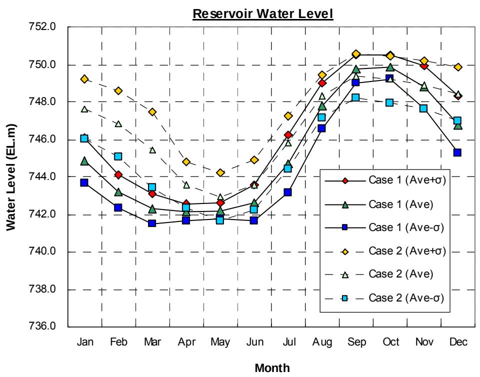
The average water level and water level at standard deviation in the after expansion of case 1 and case 2 is shown in Figure 5.6.26.



NN1



Nam Leuk



Nam Mang 3

Prepared by JICA Survey Team

Figure 5.6.26 Reservoir Average and Standard Deviation Water Level for the year 2020 (NN1 Reservoir, Nam Mang 3, and Nam Leuk)

As shown in the above figure, the reservoir water level is low when the energy imports weigh heavily. The effect is especially significant in Nam Mang 3 reservoir in the dry season.

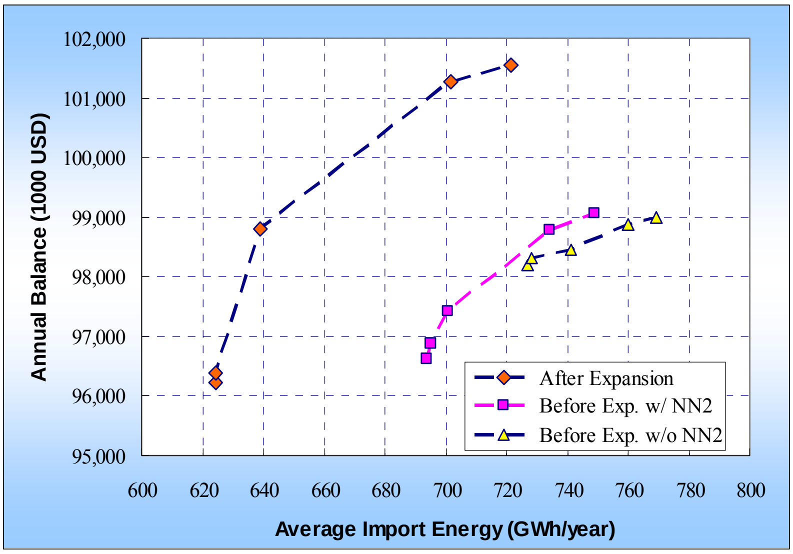
3) Year 2025

Table 5.6.11 Summary Table of Revenue Maximization Operation in the year 2025 (NN1 Reservoir, Nam Mang 3, and Nam Leuk)

		2025					
		After Expansion		Before Exp. w/ NN2		Before Exp. w/o NN2	
		Case 1	Case 2	Case 1	Case 2	Case 1	Case 2
(1) Nam Ngum I Hydropower Station							
Average hydropower energy	(GWh/year)	1,503	1,580	1,518	1,555	1,543	1,558
Revenue for domestic sale	(1000 USD/year)	78,587	72,551	74,283	70,845	72,208	69,574
(2) Import from EGAT							
Average import energy	(GWh/year)	624	721	694	749	727	769
Average import power	(MW)	247	235	274	269	283	283
Maximum import energy	(GWh/month)	206	229	198	223	190	201
Maximum import power	(MW)	549	565	578	525	567	572
Average import expense	(1000 USD/year)	30,926	34,603	34,800	36,942	36,501	38,284
Revenue selling import energy to domestic	(1000 USD/year)	38,766	44,802	43,070	46,508	45,145	47,779
(3) Export to EGAT							
Average export energy	(GWh/year)	458	632	543	635	601	659
Average export power	(MW)	141	158	153	164	166	174
Maximum export energy	(GWh/month)	215	212	187	184	188	186
Maximum export power	(MW)	552	529	508	485	510	488
Average export revenue	(1000 USD/year)	16,390	22,876	19,289	22,629	21,329	23,451
(4) Excess charge							
Average excess charge	(1000 USD/year)	6,598	4,071	5,216	3,975	3,977	3,515
Maximum excess charge	(1000 USD/year)	16,332	17,761	15,435	16,713	14,488	12,940
(5) Total annual revenue	(1000 USD/year)	133,743	140,229	136,642	139,982	138,682	140,804
(6) Total annual expense	(1000 USD/year)	37,524	38,674	40,016	40,917	40,479	41,800
(7) Annual balance	(1000 USD/year)	96,219	101,555	96,626	99,066	98,203	99,004

Prepared by JICA Survey Team

The relationship between the imported energy and annual balance is shown in Figure 5.6.27.

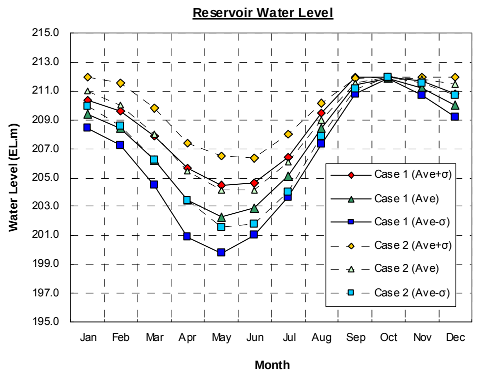


Prepared by JICA Survey Team

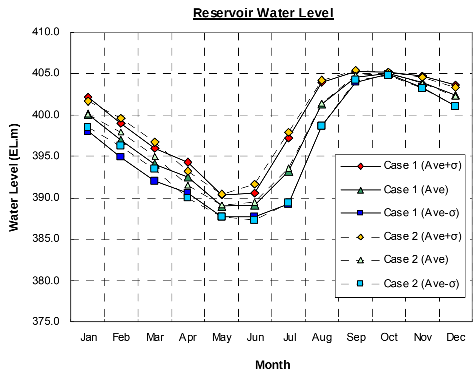
Figure 5.6.27 Reservoir Average and Standard Deviation Water Level for the year 2025 (NN1 Reservoir, Nam Mang 3, and Nam Leuk)

The curves are closer to the upper left in the chart which means that the revenue and imported energy can be improved after the expansion, and before expansion with NN2 case. The optimum operation range is widely spread due to expansion.

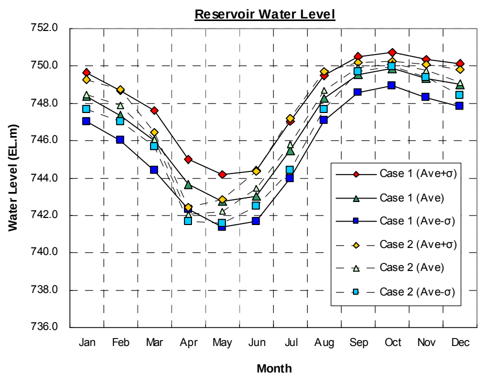
The average water level and water level at standard deviation in the after expansion of case 1 and case 2 is shown in Figure 5.6.28.



NN1



Nam Leuk



Nam Mang 3

Prepared by JICA Survey Team

Figure 5.6.28 Reservoir Average and Standard Deviation Water Level for the year 2025 (NN1 Reservoir, Nam Mang 3, and Nam Leuk)

As shown in the above figure, Nam Mang 3 and Nam Leuk has almost the similar water level for “Case 1” and “Case 2“. While the water level of NN1 is lowered in the dry season in “Case 1.”

5.6.9 (DRAFT) RESERVOIR OPERATION PLAN WITH REVENUE CONSIDERATION (NN1, NAM LEUK, NAM MANG 3, AND NAM LIK 1/2 RESERVOIRS)

(1) General

In this section, the operation of the reservoir is studied considering EdL-owned hydropower stations of NN1, Nam Leuk, Nam Mang 3 and Nam Lik 1/2 reservoir operation. The objective of the optimization is to maximize revenue while minimizing imported energy, which is the same as the analysis in sections 5.6.7 and 5.6.8. The examined year is the same as years 2015, 2020, and 2025. The study presents the operation of four reservoirs, and relation of the imported energy and revenue balance.

However, Nam Lik 1/2 is IPP project therefore it lacks the flexibility to meet EdL needs. It may be impractical to request Nam Lik 1/2 project entity to change the operation rule contrary to the Power Purchase Agreement (PPA). Therefore in this analysis, the hydropower operation including Nam Lik 1/2 is only conducted for the after expansion case as a trial calculation.

Same scenarios are considered that are to impose heavy weight on import energy minimization term case 1 and imposing very light or "0" weight on the imported energy minimization term case 2.

(2) Result of analysis

The result of the analysis is shown for each examined year. To understand the difference between including and excluding Nam Lik 1/2 operation, the result of three reservoir case (NN1, Nam Leuk and Nam Mang 3) in section 5.6.8 is also shown in the same table for comparison purposes.

1) Year 2015

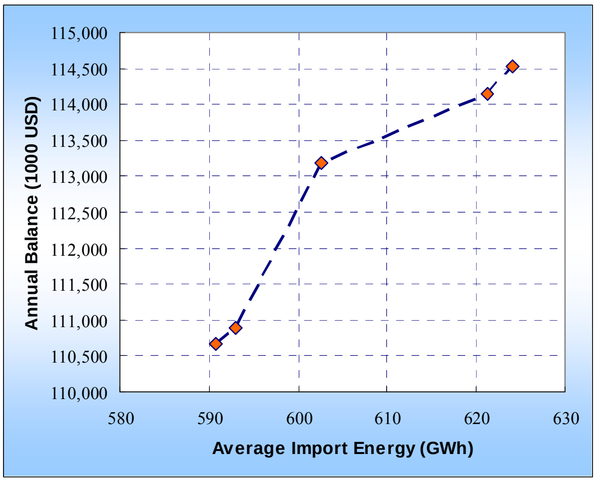
Table 5.6.12 Summary Table of Revenue Maximization Operation in the year 2015 (NN1 Reservoir, Nam Mang 3, Nam Leuk and Nam Lik 1/2)

		2015 (w/ NL1/2)		2015 (w/o NL1/2)	
		After Expansion		After Expansion	
		Case 1	Case 2	Case 1	Case 2
(1) Nam Ngum I Hydropower Station					
Average hydropower energy	(GWh/year)	1,955	1,997	1,564	1,571
Revenue for domestic sale	(1000 USD/year)	118,374	116,301	96,900	96,255
(2) Import from EGAT					
Average import energy	(GWh/year)	591	624	1,837	1,847
Average import power	(MW)	191	156	341	324
Maximum import energy	(GWh/month)	139	155	282	266
Maximum import power	(MW)	355	382	563	493
Average import expense	(1000 USD/year)	27,296	28,568	85,408	85,451
Revenue selling import energy to domestic	(1000 USD/year)	36,683	38,756	114,075	114,720
(3) Export to EGAT					
Average export energy	(GWh/year)	49	125	4	21
Average export power	(MW)	18	39	2	8
Maximum export energy	(GWh/month)	119	112	32	39
Maximum export power	(MW)	289	267	123	135
Average export revenue	(1000 USD/year)	1,783	4,607	142	750
(4) Excess charge					
Average excess charge	(1000 USD/year)	18,883	16,571	55,422	54,204
Maximum excess charge	(1000 USD/year)	33,038	36,091	73,898	76,703
(5) Total annual revenue	(1000 USD/year)	156,841	159,665	211,117	211,725
(6) Total annual expense	(1000 USD/year)	46,179	45,138	140,830	139,655
(7) Annual balance	(1000 USD/year)	110,662	114,527	70,287	72,070

Prepared by JICA Survey Team

According to the above table, the imported energy is significantly reduced if the Nam Lik 1/2 is operated simultaneously with the other three hydropower stations. The Nam Lik 1/2 may even contribute to increasing export to EGAT.

The relationship of the annual balance and average imported energy is shown in Figure 5.6.29.

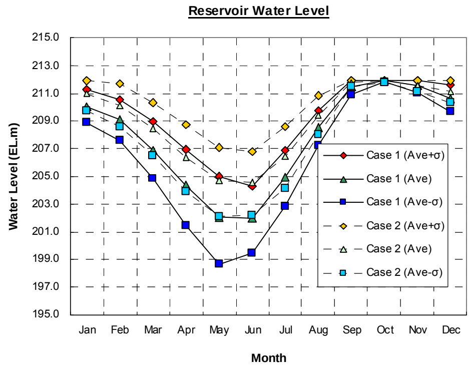


Prepared by JICA Survey Team

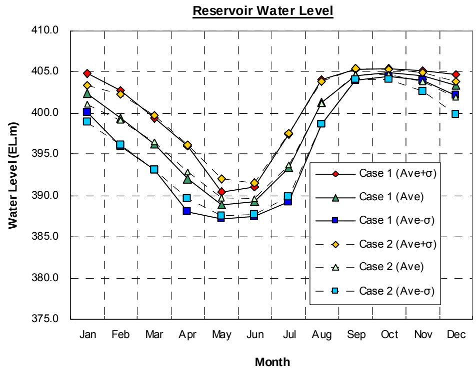
Figure 5.6.29 Reservoir Average and Standard Deviation Water Level for the year 2015 (NN1 Reservoir, Nam Mang 3, Nam Leuk and Nam Lik 1/2)

The tendency is the same with other analysis which implies that increase in import energy also increase annual balance of revenue.

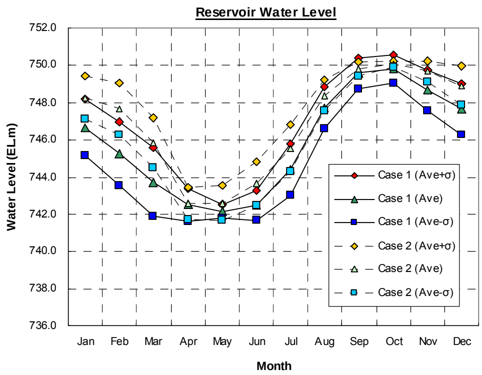
The average water level and water level at standard deviation in the after expansion of case 1 and case 2 is shown in Figure 5.6.30.



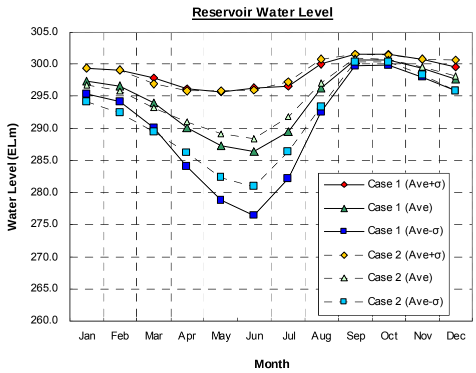
NN1



Nam Leuk



Nam Mang 3



Nam Lik 1/2

Prepared by JICA Survey Team

Figure 5.6.30 Reservoir Average and Standard Deviation Water Level for the year 2015 (NN1 Reservoir, Nam Mang 3, Nam Leuk and Nam Lik 1/2)

The result shows that reservoir water level of case 1 is lower than that of case 2. However, the water level remains in high water level when compared to water level shown in Figure 5.6.24.

2) Year 2020

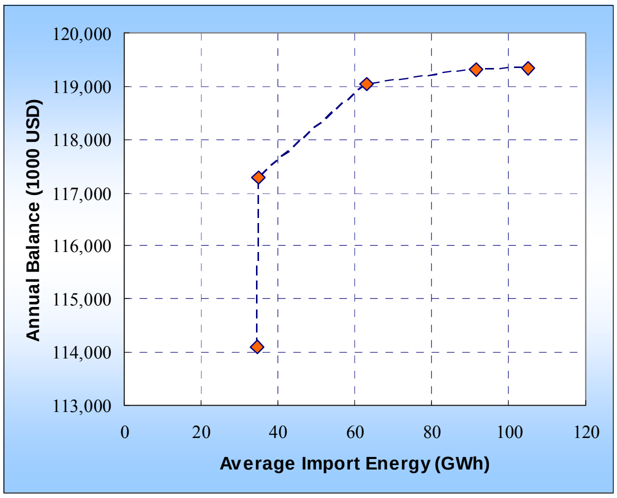
Table 5.6.13 Summary Table of Revenue Maximization Operation in the year 2020 (NN1 Reservoir, Nam Mang 3, Nam Leuk and Nam Lik 1/2)

		2020 (w/ NL1/2)		2020 (w/o NL1/2)	
		After Expansion		After Expansion	
		Case 1	Case 2	Case 1	Case 2
(1) Nam Ngum I Hydropower Station					
Average hydropower energy	(GWh/year)	1,921	2,045	1,509	1,583
Revenue for domestic sale	(1000 USD/year)	63,588	59,220	45,677	42,728
(2) Import from EGAT					
Average import energy	(GWh/year)	35	105	78	125
Average import power	(MW)	31	71	59	75
Maximum import energy	(GWh/month)	25	73	41	80
Maximum import power	(MW)	178	297	207	307
Average import expense	(1000 USD/year)	1,754	4,729	3,964	6,008
Revenue selling import energy to domestic	(1000 USD/year)	2,147	6,516	4,828	7,777
(3) Export to EGAT					
Average export energy	(GWh/year)	1,296	1,490	1,341	1,462
Average export power	(MW)	233	248	265	266
Maximum export energy	(GWh/month)	328	338	316	321
Maximum export power	(MW)	610	660	649	633
Average export revenue	(1000 USD/year)	50,116	58,343	50,722	55,970
(4) Excess charge					
Average excess charge	(1000 USD/year)	0	0	0	0
Maximum excess charge	(1000 USD/year)	0	0	0	0
(5) Total annual revenue	(1000 USD/year)	115,851	124,078	101,227	106,475
(6) Total annual expense	(1000 USD/year)	1,754	4,729	3,964	6,008
(7) Annual balance	(1000 USD/year)	114,098	119,349	97,263	100,467

Prepared by JICA Survey Team

In the year 2020 case, the involving Nam Lik 1/2 can contribute to adding the total annual energy of around 410 to 460 GWh and the revenue is increased for the increment of energy. However, effect to the increase in export and decrease in import is limited.

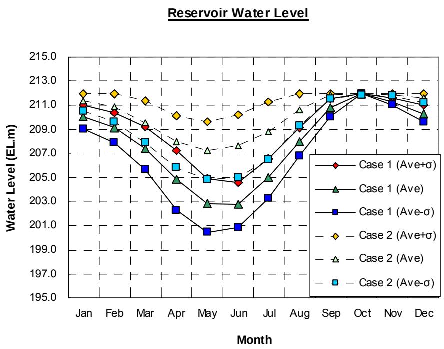
The relationship of the annual balance and average imported energy is shown in Figure 5.6.31.



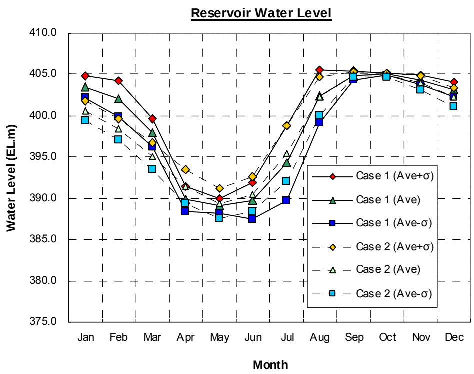
Prepared by JICA Survey Team

Figure 5.6.31 Reservoir Average and Standard Deviation Water Level for the year 2020 (NN1 Reservoir, Nam Mang 3, Nam Leuk and Nam Lik 1/2)

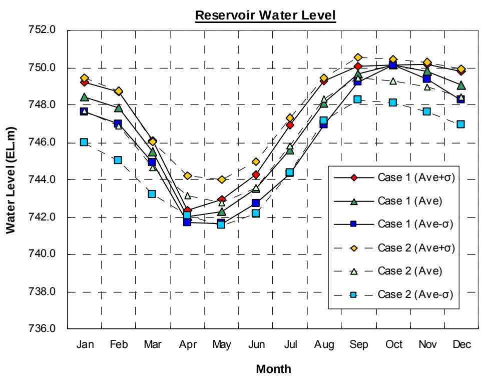
The average water level and water level at standard deviation in the after expansion of case 1 and case 2 is shown in Figure 5.6.32.



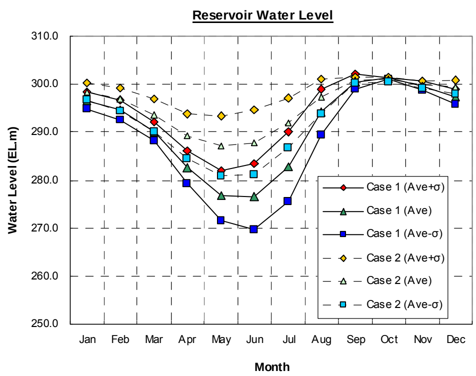
NN1



Nam Leuk



Nam Mang 3



Nam Lik 1/2

Prepared by JICA Survey Team

Figure 5.6.32 Reservoir Average and Standard Deviation Water Level for the year 2020 (NN1 Reservoir, Nam Mang 3, Nam Leuk and Nam Lik 1/2)

The result shows that involving Nam Lik 1/2 operation contributes to reducing the water level changes of Nam Mang 3 and Nam Leuk between case 1 and case 2.

3) Year 2025

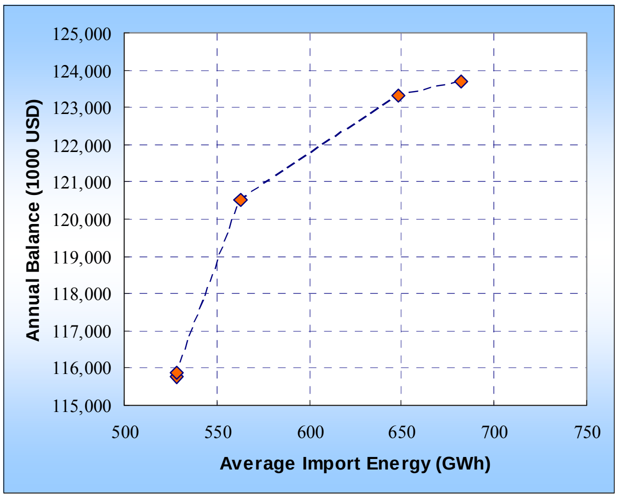
Table 5.6.14 Summary Table of Revenue Maximization Operation in the year 2025(NN1 Reservoir, Nam Mang 3, Nam Leuk and Nam Lik 1/2)

		2025 (w/ NL1/2)		2025 (w/o NL1/2)	
		After Expansion		After Expansion	
		Case 1	Case 2	Case 1	Case 2
(1) Nam Ngum I Hydropower Station					
Average hydropower energy	(GWh/year)	1,917	2,040	1,503	1,580
Revenue for domestic sale	(1000 USD/year)	103,014	93,430	78,587	72,551
(2) Import from EGAT					
Average import energy	(GWh/year)	528	683	624	721
Average import power	(MW)	208	198	247	235
Maximum import energy	(GWh/month)	171	219	206	229
Maximum import power	(MW)	482	494	549	565
Average import expense	(1000 USD/year)	25,590	31,660	30,926	34,603
Revenue selling import energy to domestic	(1000 USD/year)	32,803	42,386	38,766	44,802
(3) Export to EGAT					
Average export energy	(GWh/year)	362	640	458	632
Average export power	(MW)	110	143	141	158
Maximum export energy	(GWh/month)	223	229	215	212
Maximum export power	(MW)	570	556	552	529
Average export revenue	(1000 USD/year)	13,063	23,667	16,390	22,876
(4) Excess charge					
Average excess charge	(1000 USD/year)	7,522	4,124	6,598	4,071
Maximum excess charge	(1000 USD/year)	18,908	20,271	16,332	17,761
(5) Total annual revenue	(1000 USD/year)	148,880	159,483	133,743	140,229
(6) Total annual expense	(1000 USD/year)	33,112	35,784	37,524	38,674
(7) Annual balance	(1000 USD/year)	115,768	123,700	96,219	101,555

Prepared by JICA Survey Team

Year 2025 case shows almost the same result that utilizing Nam Lik 1/2 can contribute to adding the total annual energy but has limited effects to the increase in export and decrease in import.

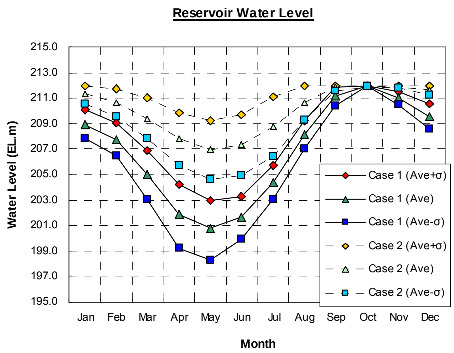
The relation of the annual balance and average import energy is shown in Figure 5.6.33.



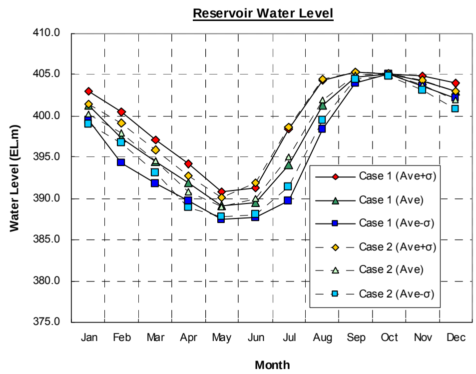
Prepared by JICA Survey Team

Figure 5.6.33 Reservoir Average and Standard Deviation Water Level for the year 2025 (NN1 Reservoir, Nam Mang 3, Nam Leuk and Nam Lik 1/2)

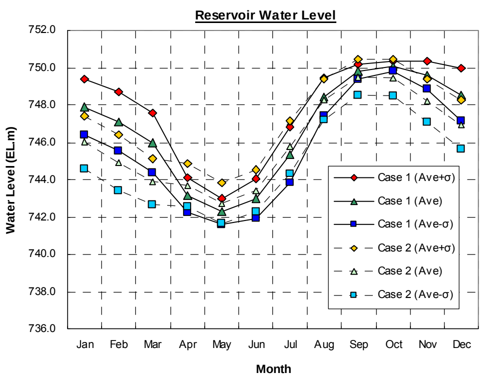
The average water level and water level at standard deviation in the after expansion of case 1 and case 2 is shown in Figure 5.6.34.



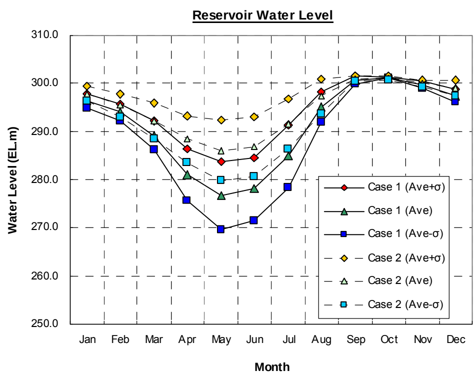
NN1



Nam Leuk



Nam Mang 3



Nam Lik 1/2

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Figure 5.6.34 Reservoir Average and Standard Deviation Water Level for the year 2025 (NN1 Reservoir, Nam Mang 3, Nam Leuk and Nam Lik 1/2)

The result shows that considering Nam Lik 1/2 operation contributes to reducing the water level changes of Nam Mang 3 and Nam Leuk between case 1 and case 2.

(3) Comparison of reservoir water level change with and without Nam Lik 1/2

In this section, the changes in the average water level of NN1, Nam Leuk and Nam Mang 3 is checked for with and without Nam Lik 1/2 hydropower station involved in simultaneous operation.

The average water level is compared for the years 2015, 2020, and 2025 for case 1 and case 2.

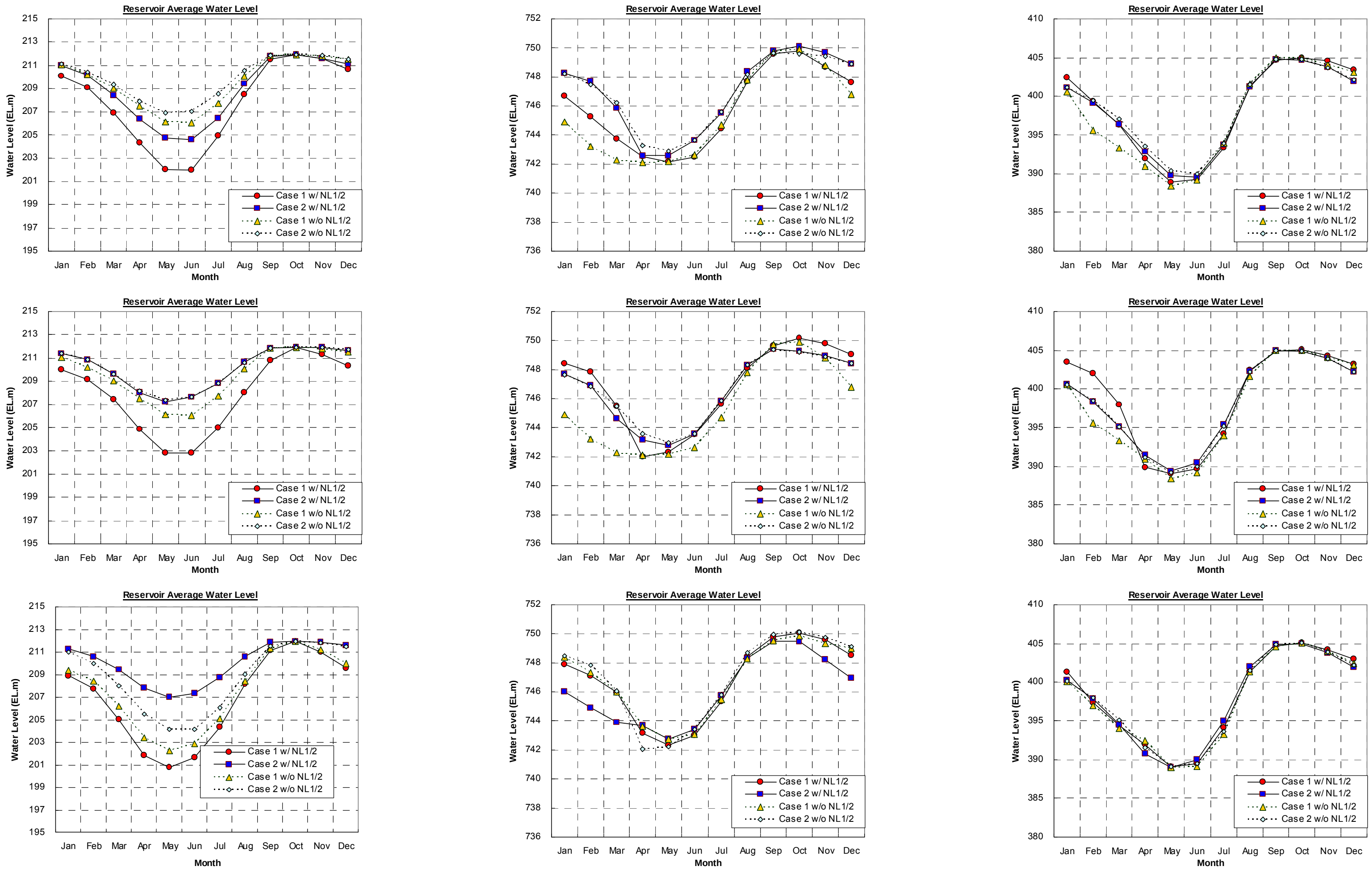
The average reservoir water level is shown in Figure 5.6.35.

NN1 Reservoir | Nam Mang 3 Reservoir | Nam Leuk Reservoir

Year 2015

Year 2020

Year 2025



Prepared by JICA Survey Team

Figure 5.6.35 Comparison of Reservoir Average Water Level for with and without Nam Lik 1/2

It is noted that there are no distinct trends for the change in NN1 reservoir operation when Nam Lik 1/2 is utilized. However, the water level of Nam Mang 3 and Nam Leuk reservoirs is raised when the Nam Lik 1/2 is involved in the operation.

5.6.10 SUMMARY OF RESERVOIR OPERATION PLAN

The main points on reservoir operation study are summarized below.

1) According to the reservoir operation study, the NN1 expansion will enable the more flexible operation due to the increase of the capacity. It is confirmed that the optimum operation range is spread due to expansion.
2) After the NN1 expansion, NN1 seldom generates 24 hours with full capacity in the rainy season. The operation will be in full capacity in the night peak (18:00 to 22:00), and adjusted power output in the daytime peak (9:00 to 18:00) depending on the reservoir operation rule.
3) The effect of NN1 expansion to Nam Leuk and Nam Mang 3 hydropower reservoir operation is limited. The annual energy production of both power plants is almost the same between before and after NN1 expansion.
4) The revenue balance and imported energy is generally trade-off relation. Increase of import energy in the dry season may contribute to the increase in annual revenue. However, in the year 2015, importing too much energy from EGAT results in increase of excess charge that will worsen the annual revenue balance.
5) The NN1 are used to operated for 24 hours a day with full capacity of generators for the before expansion. However, if the NN1 is expanded, the water is allocated more on the peak hours in TOU system. Therefore 24 hours with full capacity operation is seldom realized after expansion.
6) If Nam Lik 1/2 is simultaneously operated with NN1, Nam Leuk and Nam Mang 3, it will contribute to reduce energy import significantly in the year 2015. However, for the case of years 2020 and 2025, the effect of involving Nam Lik 1/2 operation is just to add energy production and resultant revenue. Therefore, its effect is limited in 2020 and 2025.
7) NN1, Nam Leuk and Nam Mang 3 hydropower stations have been operated in close coordination and organized together for the supply of electricity. It will be desirable that this coordinated operation is continued in the future. However, although the operation is coordinated, it is expected that supply of energy is in deficit close to 560 MW in 2015. Therefore it is recommended that capacity of interchange connection with EGAT should be reinforced as soon as possible.

CHAPTER 6 ENVIRONMENTAL AND SOCIAL CONSIDERATIONS

6.1 LEGISLATION AND INSTITUTIONAL FRAMEWORK

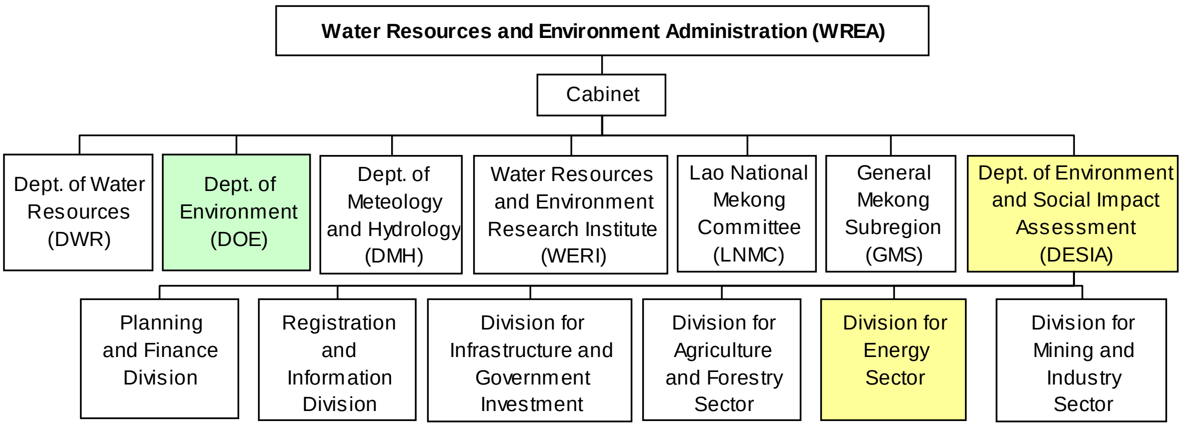
6.1.1 INSTITUTION AND ORGANIZATION

The Government of Lao People Democratic Republic (PDR) has formulated a wide range of laws and regulations on environmental protection and assessment. "The Environmental Protection Law, 1999" stipulates responsibilities of the national agencies for environmental administration.

(1) Water Resource and Environmental Agency (WREA) and Environmental and Social Impact Assessment Department (ESIAD)

The administrative organization in charge of environmental matters in Lao PDR is WREA which is under the control of the Prime Minister Office. Previously, Science, Technology, and Environment Agency (STEA) was the agency responsible for environmental administration. Subsequently, WREA was established in 2007 taking over such tasks. Under WREA, Department of Environment plays the role for formulating policies, regulations and standards. Meanwhile, the department in charge of the administration of environmental assessment (EA) is ESIAD, which was previously under the Department of Environment in WREA, ESIAD later became independent in August 2008. Out of six divisions of ESIAD, four are in charge of processing EA of respective sector development project. Division of Energy Sector in ESIAD will be in charge of EA of the expansion project.

The organizational structure of WREA is shown in figure below.



Source: WREA, 2009

Figure 6.1.1 Organizational Structure of WREA

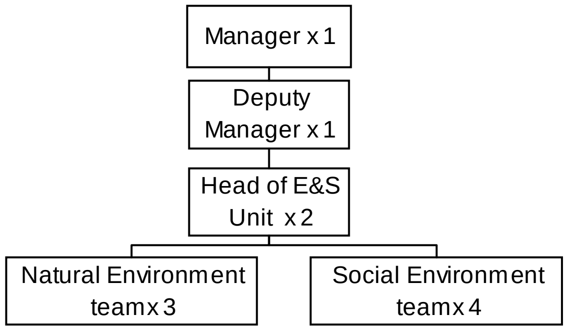
The total number of staff in WREA is 339 as of February 2009. ESIAD reinforced the existing number of staff up to 75, mainly consists of college graduates with environmental science background.

(2) Social and Environmental Management Division of DOE/MEM

The organization responsible for environmental administration of development project for power sector is Social and Environmental Management Division under DOE of MEM. It formulates environmental standards for implementation and monitoring of electricity development project. It also examines, reviews, and endorses Initial Environmental and Social Examinations (IESE), Environmental and Social Impact Assessment (EISA) and Environmental and Social Management Plan (ESMP) prior to the final approval and issue of ECC by WREA[1]. The division also implements inspection, monitoring, validation and evaluation requirements. It has six permanent staffs and already has extensive experiences on EA for electricity projects such as construction of hydropower and distribution and transmission lines.

(3) Environmental Office, Technical Department of EdL

EdL is the Project Owner of the expansion plan of Nam Ngum 1 Hydropower (NN1). Environmental Office under Technical Department is the main body for environmental procedure for EA including preparation of IESE/EISA and ESMP report on environmental monitoring. It has two units, namely, the monitoring unit for Natural Environment and monitoring unit for Social Environment. The office takes the role related to all environmental procedures concerning EA of EdL project including hydropower, transmission and distribution lines, and substations. It consists of 11 staffs with environmental and social study background. It also dispatches a staff to take up master course on environmental study.



Source: Environmental Office, EdL

Figure 6.1.2 Environmental Office

6.1.2 ENVIRONMENTAL LAWS AND REGULATIONS

"Law on Environmental Protection (No.02-99 1999)" and "Decree on the Implementation of the Environmental Protection Law (No.102, 2001)" are ordinances on environmental governance in Lao PDR. WREA and ministries responsible for development projects are reforming above ordinances, and are enforcing several regulations and standards by sector.

The ministry ordinance concerning EA, "Regulation on Environment Assessment in the Lao PDR (No.1770/STEA)", is the ongoing regulation for stipulating EA procedure. "Draft Decree of Environment and Social Assessment" is being prepared to update this regulation, which is submitted to Prime Minister Office in February 2009 and currently under review. The Decree is already started to apply recent projects.

[1] The terms "IESE", "ESIA", "ESMP" and "STEA" correspond to "IEE", "EIA", "EMP" and "WREA" respectively in Lao PDRNo.1770/STEA, which is being updating as a new Decree. In this document, terms for "IESE", "ESIA", "ESMP" and "WREA" is applied since those are already widely used in official documents in Lao PDR.

“The Law of Electricity (No. 02/97, 1997)” stipulates that the undertaking of electricity business shall ensure economic efficiency, take into account an assessment of its impact on the natural environment and ecological system, and limit impacts to society and wildlife habitats. For the development project of electricity sector, the main regulation for EA is “Regulation on Implementing Environmental Assessment for Electricity Project (No.447/MIH DOE, 2001)”. Based on this regulation, “Environmental Management Plans for Electricity Project (No.584/MIH DOE, 2001)” and “Environmental Impact Assessment for Electricity Project (No.585/MIH DOE, 2001)” stipulate the procedure of EA and “Environmental Management Plans for Electricity Project, 2001”. These also provide detailed requirements of ESMP in electricity projects. These documents prescribe the procedure of EA for Project Screening, Project Description, IESE, EISA, ESMP, compensation, requirement for identification of Significant Environmental Impact (SEI) and alternative plans, and Public Involvement. In addition, the expansion project needs to refer to laws and regulations for environmental issue for forest, water quality, wildlife and aquatic animals, land, water use, and compensation according to necessity. For water rights, “Law on Water and Water Resources (No.02/96, 1996)” stipulates ownership of water resources, national and river basin planning, monitoring, and assessment and allocation of water resources. The regulation did not prioritize respective types of water use but stipulates the promotion of the development and the use of water resources in the production of electricity power, where there are suitable conditions (Article 25).

Tables below summarize laws and regulations concerning Nam Ngum 1 expansion work.

Table 6.1.1 Environmental Laws and Regulations related to Expansion Project (1)

Regulations concerning Environmental Issue	Date	Descriptions concerning NN1 Expansion Project
Laws for Environment and other sector		
Law on Environment Protection	April 1999	Obligation for pollution control, protection of natural and social environment, rights and duties of concerned ministries.
National Strategy on Environment to the years 2020 and Action plan for years 2006-2020	2004	Status of environment for land, water ,forest, biodiversity, social matter. International and regional cooperation, environmental strategy and goals for the year 2020.
Degree on the Implementation of the Environmental Protection Law	2002	Obligation, general EA requirement, standard, management and monitoring units, and inspection
Regulation on Environment Assessment in the Lao PDR, STEA	2002	EA process, screening, IEE, EIA, monitoring, requirement and flow of project for environment procedure. (under revise and need to obtain new version to be issued in April 2009)
Draft Decree of Environment and Social Assessment, WREA	Feb 2009	The draft version submitted to Prime Minister Office. New EISA/IESE criteria, format for project description, IEE, and EMP, environmental certificate, monitoring
Forestry Law	May 2008	Categorization of forest and allowable development activities for each category
Law on Aquatic Life and Wild Animal	May 2008	Conservation of endangered species
Forestry Strategy to the Year 2020 of the Lao PDR	July 2005	Forestry classification, sustainable management, solid and water conservation, act for tree cut
Law on Agriculture	Nov 1998	Agricultural activities, right of agriculture, building and management of irrigation
Law on Water and Water Resources	2001	Right to use water resourcee, ownership of water resources, monitoring, and assessment and allocation of water resources.
Land Law	Oct 2003	Use of water area land and construction land, compensation of land losses

Prepared by JICA Survey Team

Table 6.1.2 Environmental Laws and Regulations related to Expansion Project (2)

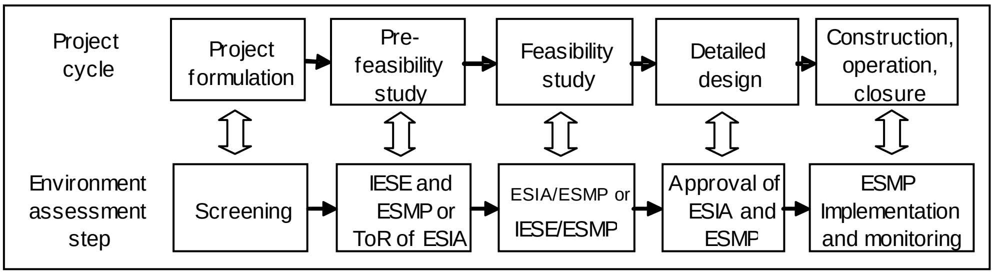
Regulations concerning Environmental Issue	Date	Descriptions concerning NN1 Expansion Project
Laws and Regulation concerning Hydropower Project		
Law on Electricity and Degree	May 1997	Function, ownership, promotion of electricity development, operations, production, import/export, and distribution of electricity
Lao Electric Power Technical Standards, DOE/MIH	Feb 2004	Safety of power structure, stability of dam, prevention of erosion and damage of upstream and downstream catchment
National Policy on Environmental and Social Sustainability of the Hydropower Sector in Lao PDR, DOE/MIH	2007	Environment assessment, watershed management and conservation, disclosure and compliance, requirement for hydropower project
Environmental Management Standard for Electricity Projects, DOE/MIH	Jun 2003	Requirement of EMP, institution and management arrangement, monitoring, EMP, scheduling and cost
Environmental Impact Assessment for Electricity Projects. DOE/MIH	Oct 2001	Specific requirement for EIA such as baseline information, alternatives, impacts, public involvement, and EMP
Regulation on Implementing Environmental Assessment for Electricity Projects in Lao PDR, DOE/MIH	Oct 2001	Requirement of environmental assessment according to project cycle, requirement for project description, IEE, EIA, monitoring and evaluation, award and sanctions.
Environmental Management Plans for Electricity Projects, DOE/MIH	Oct 2001	Categorization of hydropower for each requirement of environmental process, procedure to implement IEE, EIA, and SAP (social action plan)
Degree on Compensation and Resettlement of People Affected by Development Projects	2006	Requirement of social impact assessment
Regulations for Implementing Degree on Compensation and Resettlement of People affected by Development Projects	2006	Social assessment and compensation
Guidelines for Compensating the Loss occurred due to the Transmission Line Projects, DOE/MEM	2005	Impact and issues for social and environmental matter of transmission lines. Guideline for compensation for transmision lines

Prepared by the Survey Team

6.1.3 PROCEDURE FOR ENVIRONMENTAL ASSESSMENT

For environmental clearance, acquisition of Environmental Compliance Certificate (ECC) is the prerequisite to commencement of construction of all development projects. WREA is the organization that issues ECC. The Project Owner needs to conduct EA procedure to obtain ECC.

The EA process in Lao PDR is formed in relation to the general project implementation phases.



Source: Prepared from "Regulation on Environment Assessment in the Lao PDR, 2002"

Figure 6.1.3 EA Processes and Project Cycle

The expansion project is assumed to Category B. For Category B project with Yen loan, it is desirable that WREA approves IESE or ESIA and issue ECC before project examination by JICA. The project schedule should consider this aspect. While the expansion project is at the stage of reviewing the feasibility study, the project needs to follow the process from Project Screening to, EISA, ESMP, and if necessary, EISA. EdL submitted IESE and environmental and social monitoring plan (ESMP) report to DOE on 21 September 2009 and is now under review in DOE.

Responsibilities for conducting the EA process of electricity project are shown in the table below.

Table 6.1.3 Environmental Assessment Process Responsibilities

Organization	Responsibility
DOE/MEM	- Undertake project screening to determine EA requirements. - Reviews, requires revision, and recommends approval of IESEs with ESMSP or ToR of ESIA - Reviews and decides on IESE ESMPs for all projects in its sector area of responsibility - Endorses TOR for ESIA - Concurs in consultants that are proposed to conduct IESE and EISA - Review and endorses EIA and ESIA's ESMP prior to final approval by WREA - Implements inspection, monitoring, validation and evaluation requirements - Implements relevant public involvement requirements - Oversees implementation of ESMPs
Project Owner (EdL)	Implements EA process and prepares the EA reports including - Preparing project descriptions - Implementing public involvement requirements - Implementing IESE and/or EISA requirements and ESMP requirements - Implementing monitoring and evaluation requirements
WREA	- Referring to the regulation on EA in the Lao - Issue of Environmental Compliance Certificate (ECC)

Source: Regulation on Implementing Environmental Assessment for Electricity Projects in Lao PDR

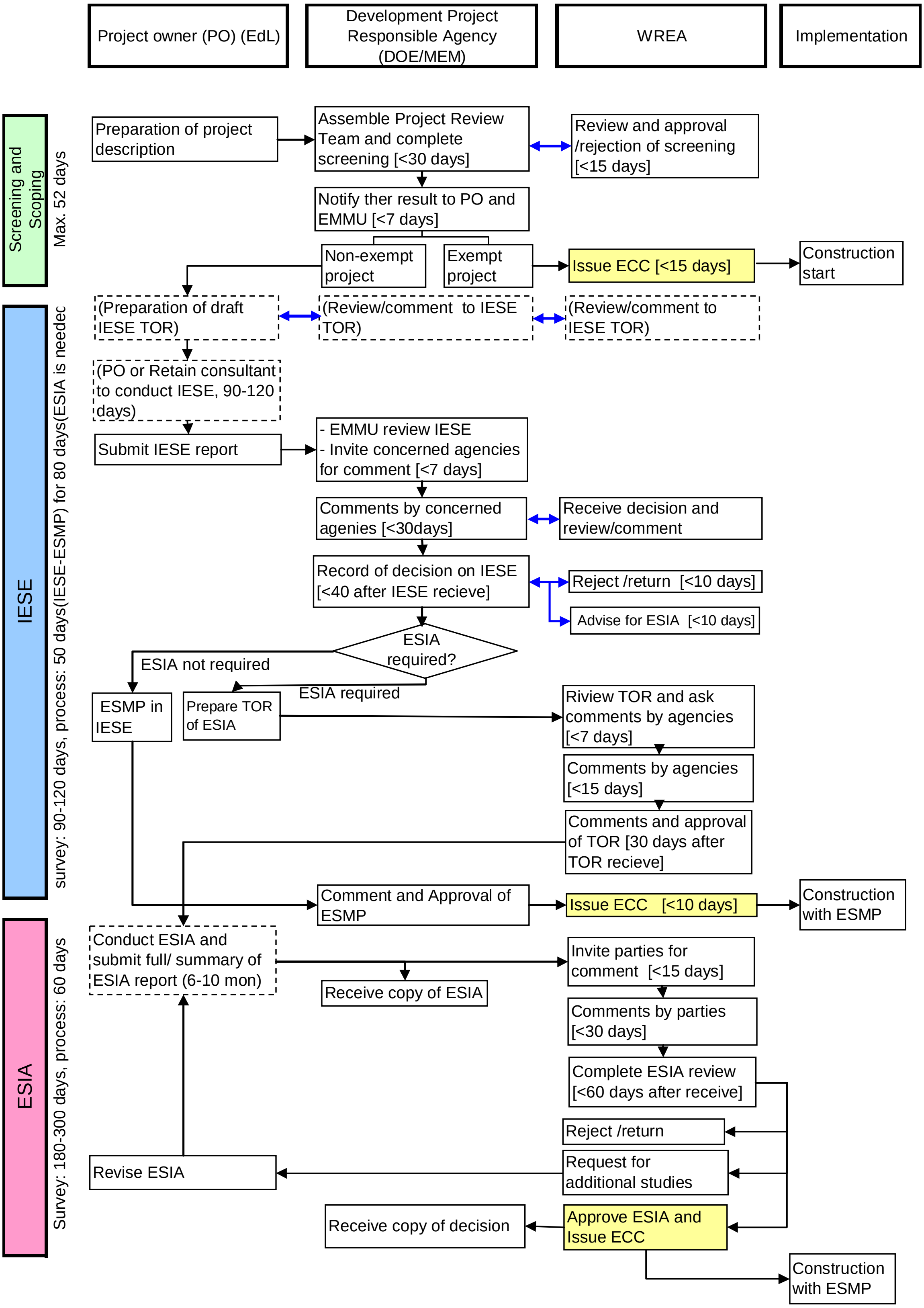
For the project implementation, Development Project Responsible Agency (DPRA) is obliged to establish Environmental Management and Monitoring Units (EMMU). The table below shows the institutional framework for the expansion project following EA procedures and its environmental organization responsibility.

Table 6.1.4 Institutional Framework for Project Implementation

Role	Organization
Project owner (PO):	EdL
Development Project Responsible Agency (DPRA):	Department of Electricity, Ministry of Energy and Mines
Environmental Management and Monitoring Unit for implementation:	Environmental Office, Technical Department, EdL
Environmental Management and Monitoring Unit for inspection:	Social and Environmental Management Division, Department of Electricity, Ministry of Energy and Mines
Issue of Environmental Compliance Certificate (ECC):	Department of Environmental and Social Impact Assessment (ESIAD), Water Resources and Environment Administration

Prepared by JICA Survey Team

It was agreed in the 1st Steering Committee conducted in February 2009 that EA procedures for the expansion project shall be conducted according to the governing EA regulation (i.e., Lao PDR No.1770/STEA), while the new Decree is under preparation. The procedure for the EA prescribed in Lao PDR No.1770/STEA is shown in the following diagram.



* The terms "IESE", "ESIA", "EMP", and "STEA" corresponds to "IEE", "EIA", "ESMP", and "WREA" in Lao PDRNo.1770/STEA. In this figure, terms for "IESE", "ESIA", "ESMP"、 and "WREA" is applied since those are already used in official documents in Lao PDR.

Prepared by JICA Survey Team referring to "Regulation on Implementing Environmental Assessment for Electricity Projects in Lao PDR" and "Regulation on Environment Assessment in the Lao PDR (Lao PDRNo.1770/STEA)",

Figure 6.1.4 Procedure for Environmental Assessment for Hydropower Project

The basic flow of EA procedure for hydropower related projects including the NN1 expansion project is as follows:

1) Project Owner (EdL) prepares Project Description including information such as owner, type, scale, location and product of the project, main environmental and social impacts, and public involvement activities.

2) DOE conducts Screening to determine what kind environmental procedure is required (<30 days).

3) If DOE evaluates that the project is an Exempt Project, WREA issues ECC. Otherwise, EdL conducts Initial Environmental and Social Considerations (IESE).

4) An environmental licensed consultant conducts IESE and prepares IESE report on behalf of EdL. Then, EdL submits the report to DOE. DOE will review and seek comments from local government and concerned agencies and send Record of Discussion to WREA. (<40 days)

5) If DOE evaluates that further study is not needed, i.e., ESIA is not required, DOE assesses ESMP, approves ESMP after review. When ESMP is approved, WREA issues ECC (<10 days).

6) If DOE evaluates that ESIA is required, consultant prepares draft Terms of Reference (TOR) of ESIA. WREA reviews the TOR, requests comments from concerned agencies, and approves the TOR (<30 days).

7) An environmental licensed consultant conducts ESIA according to approved TOR and prepares ESIA report on behalf of EdL, who submits the report to WREA. WREA will review and seek comments from local government and concerned agencies, and determine if project is (i) rejected, (ii) required to perform additional studies, or (iii) approved (<60 days).

8) When ESIA is approved, WREA issues ECC and DOE receives copy of Record of Discussion.

The number of days mentioned above is stipulated in Lao PDRNo.1770/STEA, although it takes longer duration in many projects.

ESMP and environmental management and monitoring plan are integral parts of EA process that describe the measures to be implemented for ensuring appropriate management for project. “Environmental Management Plans for Electricity Project (No.584/MIH DOE, 2001)” provides ESMP procedure for electricity project in Lao PDR. It stipulates that ESMP shall include four types of monitoring as follows:

(i) Ambient Monitoring: for ambient conditions of air, water, soil, animal and plants, etc.
(ii) Validation Monitoring: for project’s impact to ensure that the impacts are as predicted
(iii) Effectiveness Monitoring: for effectiveness of the management measure
(iv) Compliance Monitoring : for implementation of the management measures and ESMP as a whole

An ESMP needs to provide following information:

- Environmental aspect, component, environmental impact and its significance
- Cause and consequences,
- Environmental objectives and standards to be met
- Environmental management measure for methodology, parameter, and data collection
- Locality maps and drawings
- Performance criteria or targets of environmental management measure
- Effectiveness monitoring with data parameters, sampling technique, frequency and timing
- Manpower, training, facilities, equipment, material and supply
- Responsibility of project owner, contractors, and stakeholders and details of stakeholders
- Construction Environmental Management Plan, CEMP
- Public Involvement activities
- Cost estimation and Implementation schedule, and reporting requirement

6.2 ENVIRONMENTAL ASPECT OF EXPANSION PROJECT AREA

6.2.1 NATURAL ENVIRONMENT

(1) Topology and Geology

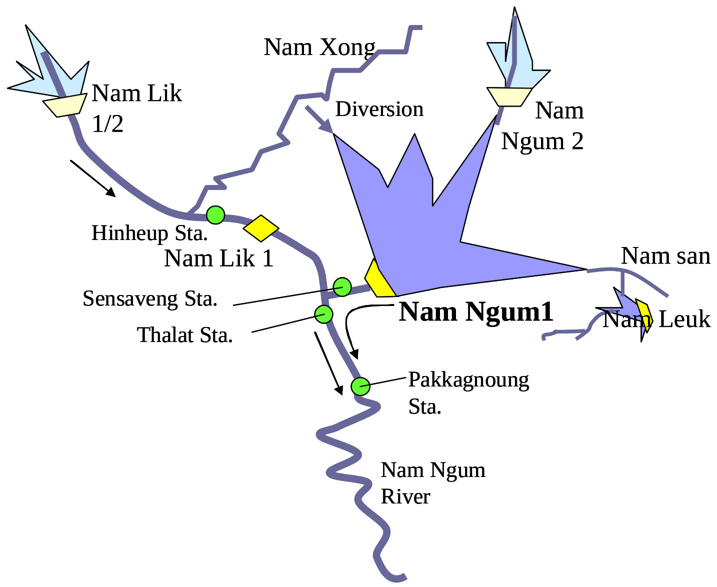
The Nam Ngum dam site is located in the Nam Ngum River approximately 3.5 km upstream of the Nam Lik confluence. The eastern and the northern sides of the reservoir are on the flank of high mountainous regions of over 500 meters altitude, and narrow dike of high mountain ridge bounding the reservoir in the south and west. Plain field extends downstream.

The project area is situated in the platform sediments. Three formations of sediments are seen in the project area with Jurassic to Cretaceous conglomerate, sandstone, siltstone, coaly shale, siltstone, and clay stone, which is covered by Quaternary deposit. The geology of the dam site consists of sandstone and mudstone. Some parts of mudstone are weak and needs improvement to be utilized as base for structural foundations.

(2) Climate and Hydrology around NN1

The Nam Ngum basin has a tropical monsoon climate having wet rainy season with southwest monsoon pouring 75% of annual rainfall over the basin. The dry season starts from November to April having northeast monsoon with little rainfall. The annual rainfall in the region is recorded 3,500 mm in Vangvieng and 1,420 mm in Xinekouang.

Hydrological assessment is the key component of IESE study for the expansion project. The conceptual location of rivers, hydropower, reservoir, and gauging stations are shown in the figure below.



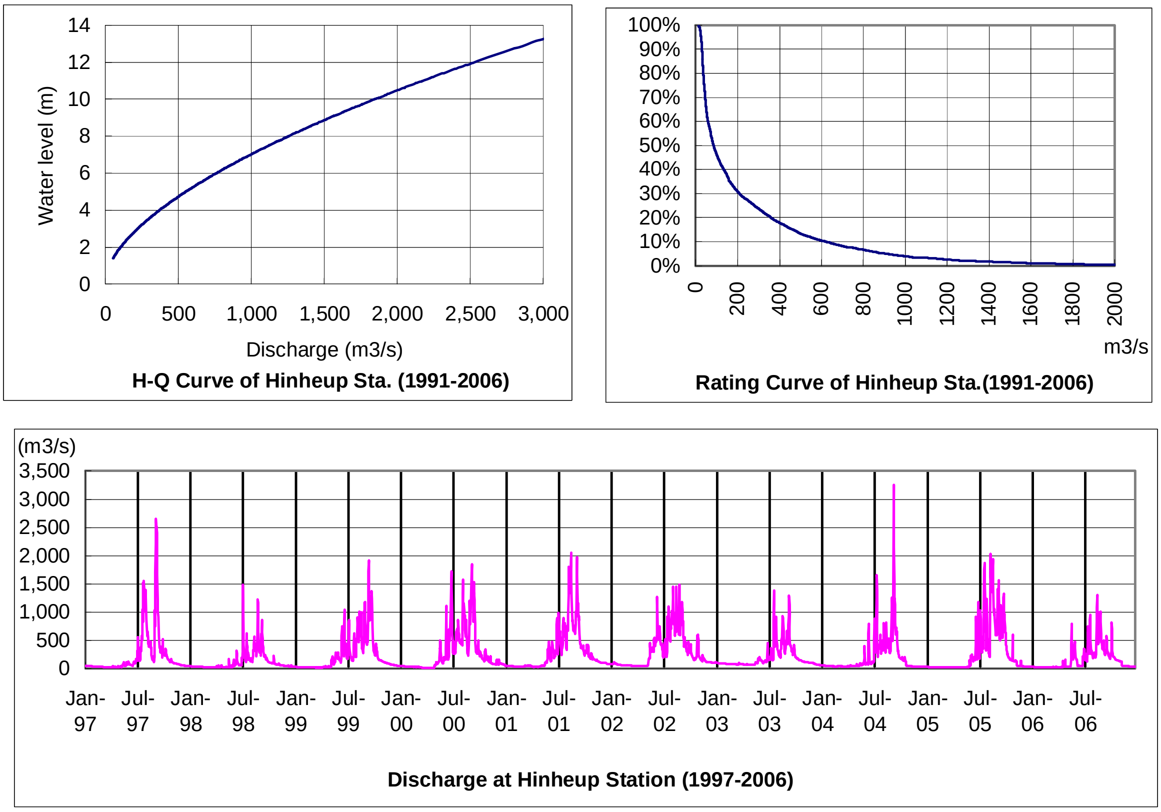
Prepared by JICA Survey Team

Figure 6.2.1 Conceptual Layout of River, Dam, and Gauging Station in NNRB

Of the above, Nam Ngum 2 (NN2) is under construction at the upstream of the Nam Ngum 1 reservoir, and expected to be completed on 2011. NN2 mostly affects NN1 operation due to the function of its new reservoir. It regulates seasonal inflow into the Nam Ngum Reservoir and enables NN1 to utilize more water. Generally, water inflow exceeding storage capacity in rainy season is spilled from the dam. However, after the construction of NN2, seasonal fluctuation will be regulated, that is, some amount of spilled water in rainy season can be used in the dry season at NN1, considering the NN2 storage capacity. This enables NN1 to produce more energy. Discharge in dry season will be increased and flood in rainy season will be mitigated accordingly.

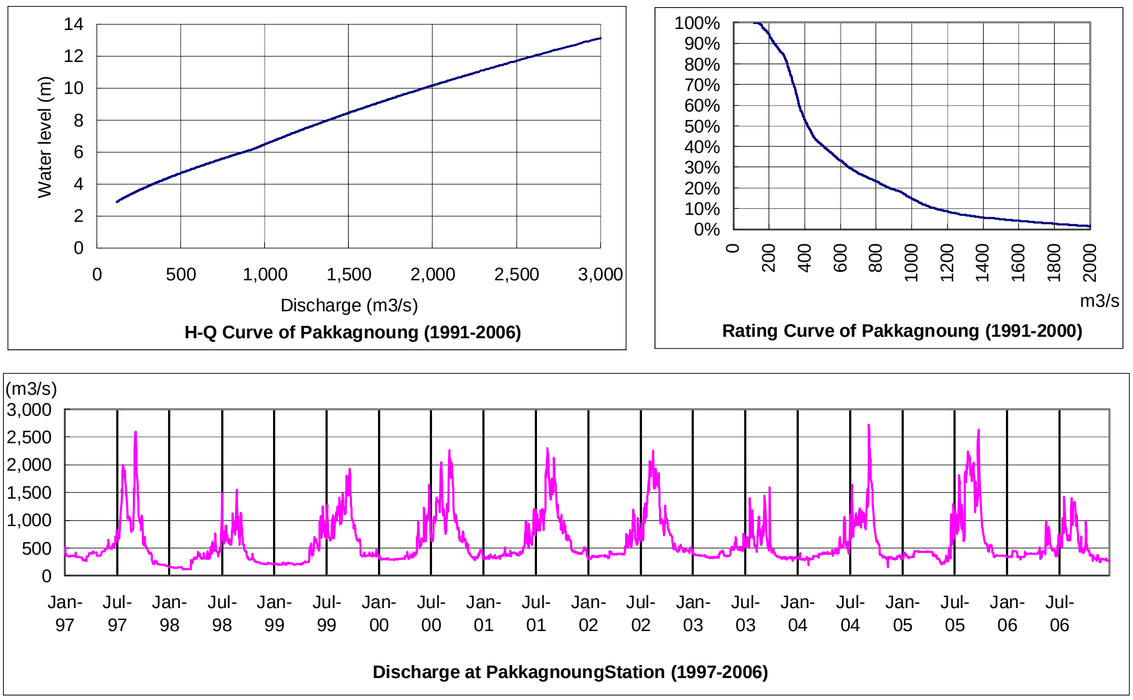
Of the other hand, it needs to consider Nam Lik 1/2 and Nam Lik 1 hydropower to assess the downstream affect of NN1 project. These are located upstream of the Nam Lik River which is the right tributary of Nam Ngum River. The Nam Lik River flows into the Nam Ngum River at the confluence of 3.5 km downstream of NN1. Downstream residents affected by NN1 mainly live in areas lower than this confluence. Accordingly, these are important for downstream hydrology assessment of NN1

As for hydrology stations, Hinheup Station measures the water level of the Nam Lik after the confluence of the Nam Xong River. Pakkagnoung Station measures the water level at 11 km downstream of the confluence of the Nam Ngum River and the Nam Lik River. Hydrology data at these stations was used for downstream water level analysis in IESE. Key hydrological data from these stations are shown in figures below.



Source: DMH

Figure 6.2.2 H-Q Curve, Rating Curve, and 10-years-Discharge at Hinheup Station

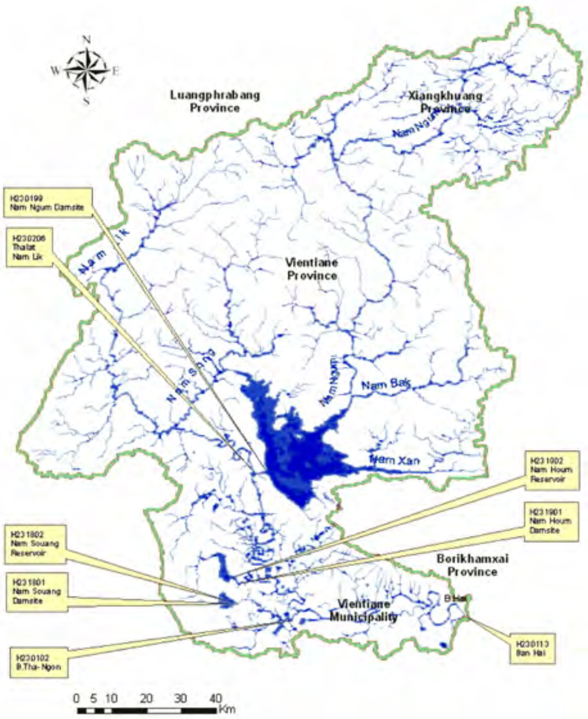


Source: DMH

Figure 6.2.3 H-Q Curve, Rating Curve, and 10-years-Discharge at Pakkagnoung Station

(3) Water Quality

In Lao PDR, surface water is the major water source for urban water supply and groundwater is partly used by rural people. Water Quality Monitoring Network for Lower Mekong Basin was established by the Mekong River Committee in 1985. The Department of Irrigation of MoAF currently manages water quality monitoring station. The analysis is conducted in Water Quality Laboratory. There are nine water quality monitoring stations in the Nam Ngum River basin. This includes the station at NN1 dam site for said river at immediately downstream of NN1 and the station at Thalath for the Nam Lik River. Figure at the left shows the location of water quality monitoring stations. These stations monitor temperature, pH, conductivity, major ions, nutrients, DO, and COD. The water quality management capacity in Lao PDR is limited, having constrains of such as lack of facilities, human resources, skills for analysis, and financial support.



Source: Nam Ngum River Basin Profile

Figure 6.2.4 Location of Monitoring Station

Population at the upstream NNRB is becoming denser. Moreover, activities including agriculture, shifting cultivation, tourism, domestic use, and mining productions may affect the water quality at the downstream of the Nam Ngum River. However, over the past 15 years of monitoring, water quality is reportedly still good and not significantly changed due to such human activities.

(4) Land Use

Perimeter around the project site is covered with upper mixed deciduous, bamboo, unstocked forest, shifting cultivation, savannah, paddy rice, agriculture plantation, other agricultural land, grassland, swamp, and urban or built up areas. Shifting cultivation is performed mainly upstream areas but not much is seen at the downstream plain areas. In the mixed deciduous forest type, the deciduous tree species represent more than 35 % of the area.

The land use of the Nam Ngum River basin and area by each type is shown in the figure below.

Land Use Type and Area in Nam Ngum River Basin

TYPE_NGD	Description	Area (m2)	Percentage
11	Dry Evergreen	625,130,982	3.47%
13	Mixed Deciduous	6,329,778,050	35.12%
15	Dry Dipterocarp	21,887,631	0.12%
17	Coniferious Forest	1,053,055,957	5.84%
18	Mixed Board Leaved Coniferous	65,589,323	0.36%
19	Forest Plantation	8,660,190	0.05%
21	Bamboo	953,578,908	5.29%
22	Unstocked Forest	4,799,335,615	26.63%
24	Ray	433,811,237	2.41%
31	Savannah	14,564,233	0.08%
32	Scrub	187,698,125	1.04%
41	Rice Paddy	1,393,164,959	7.73%
43	Agricultural Plantation	21,236,134	0.12%
52	Grass Land	1,411,313,424	7.83%
53	Swamp	68,022,648	0.38%
54	Urban or Built up Area	43,889,577	0.24%
61	Other land	594,090,066	3.30%
	TOTAL	18,024,807,060	100.00%

Note: The area includes 10 km buffer from NNRB watershed.
Accordingly, total area does not match to the exact catchment area of NNRB.
Source: Prepared using Land Use GIS data from National Geographic Departmer
Land use data was prepared by NGD in 2003 using aerial photo observed in 1999

Prepared by JICA Survey Team using GIS Shapefile Data Obtained from Department of Forest

Figure 6.2.5 Land Use in NNRB

(4) Flora and Fauna

Lao PDR has rich biodiversity of high international significance for animal and plant species. In the review work conducted in 1999[2], 319 species are considered for national or global conservation significance due to their limited numbers and range. In accordance with "Wildlife and Aquatic Law, Article 22", species are categorized into three, namely, "Prohibition", "Management", and "General", as shown in the table below.

Table 6.2.1 Numbers of Species of Wild Life in Each Category

Category	Prohibition Category		Management Category	General Category
Type	Nos	Major species	Nos	Nos
Mammals	44	Lesser Onehorned Rhinoceros, Asian Two-horned Rhinoceros, Kouprey, Asian Elephant, Wild Water Buffalo, Banteng, Gaur, Sunbear, etc.	15	6
Birds	36	Green Peafowl, Great Hornbill, Rufous-necked Hornbill, Wreathed Hornbill, All species of Vulture, Crested Argus, White-winged Duck, etc.	22	5
Reptiles	9	Siamese Crocodile, Chinese Three Striped Box Turtle, Big Headed Turtle., Indochinese Box Turtle, Impressed Tortoise, etc.	13	8
Amphibians	1	Lao Salamader		3
Fishes	6	Giants Catfish, Electric Eel, Croaker, Pa leum, Tiger Perche, and Pa meo	9	18
Insects			7	5

Source: Ministry of Agriculture and Forestry

[2] Wildlife in Lao PDR: 1999 Status Report, Centre for Protected Areas and Watershed Management

Currently, the richness of the Lao PDR's wildlife has kept by the country's low population density and consequently extensive forest cover. Although hunting is a pressure to the wildlife, the relative abundance of habitat, and in some areas, the long distance from human settlements, have provided protection for the wildlife. In the year 2001-2002 the Department of Forestry disseminated the Forestry Law and Convention on International Trade in Endangered Species (CITES) regulations to the central and provincial level. The understanding on wild life protection is becoming disseminated.

The Nam Ngum Reservoir and the Nam Ngum River are important sources of aquatic lives and produces plenty of fishery products. The downstream areas are already affected by human activity such as agriculture, fishery and transportation. According to the interview survey in the downstream area of NN1 conducted in IESE, no rare species were reported. The affect of the expansion project on rare species of wild life is considered to be minimal.

Plants seen in NNRB are the same as generally seen in Lao PDR. Table below shows status of plants widely seen in villages in the Nam Ngum River basin.

Table 6.2.2 Common Plants in NNRB

Trade name	Status
Bamboo shoot	Very common
Bamboo cane	Very common
Rattan shoot	Rare
Rattan cane	Rare
Beberin	Rare
Broom grass	Common
Peuakmeuak	Rare
Dok Lao	Common
Mushrooms	Rare
Wild fruits	Medium
Wild vegetables	Medium

Source: Earth Systems Lao and NUOL, 2005

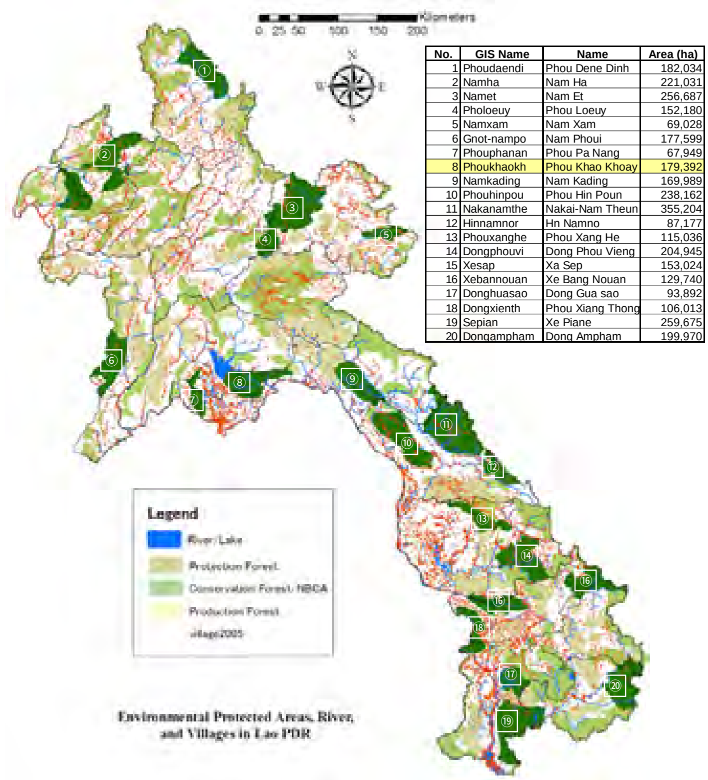
(6) Forest, National Parks and Protected Areas

Ministry of Agriculture and Forestry (MoAF) is authorized to manage forest lands. Forest and protected areas are classified into three categories: (i) Protection Forests, (ii) Conservation Forests, and (iii) Production Forests. The purpose and area of these forests is summarized in the table below.

Table 6.2.3 Purpose of the Categorized Forest

Type	Purpose	Area (ha)
Protection Forests	Function of protecting water resources, river banks, road sides, preventing soil erosion, protecting soil quality, strategic areas for national defense, protection from natural disasters, environmental protection, and so on.	4,260,792
Conservation Forests	Purpose of conserving nature, preserving plant and animal species, forest ecosystems and other valuable sites of natural, historical, cultural, tourism, environmental, educational and scientific research experiments	3,559,908
Production Forests	Natural forests and planted forests classified for the utilization purpose areas for production, and wood and forest product businesses to satisfy the requirements of national socio-economic development.	3,120,489
Total		10,941,190

Source: Forestry Law, December 2007. Area is calculated using GIS database of MoAF (2002)



No.	GIS Name	Name	Area (ha)
1	Phoudaendi	Phou Dene Dinh	182,034
2	Namha	Nam Ha	221,031
3	Namet	Nam Et	256,687
4	Pholoeuy	Phou Loeuy	152,180
5	Namxam	Nam Xam	69,028
6	Gnot-nampo	Nam Phoui	177,599
7	Phouphanan	Phou Pa Nang	67,949
8	Phoukhaokh	Phou Khao Khoay	179,392
9	Namkading	Nam Kading	169,989
10	Phouhinpou	Phou Hin Poun	238,162
11	Nakanamthe	Nakai-Nam Theun	355,204
12	Hinnamnor	Hn Namno	87,177
13	Phouxanghe	Phou Xang He	115,036
14	Dongphouvi	Dong Phou Vieng	204,945
15	Xesap	Xa Sep	153,024
16	Xebannouan	Xe Bang Nouan	129,740
17	Donghuasao	Dong Gua sao	93,892
18	Dongxienth	Phou Xiang Thong	106,013
19	Sepian	Xe Piane	259,675
20	Dongampham	Dong Ampham	199,970

Source: Prepared from GIS Database of Department of Forestry, MoAF (2002)

Conservation Forest consists of National Conservation Forest areas and Conservation Forest areas at provincial, district and village levels. MoAF established 20 National Biodiversity Conservation Areas (NBCA) and two Corridors covering almost 3.4 million hectares, or more than 14% of the country. The expansion project site is apart from NBCA or Biological Corridors which are designated as protected areas by MoAF. The distribution of protected areas is shown at the left figure.

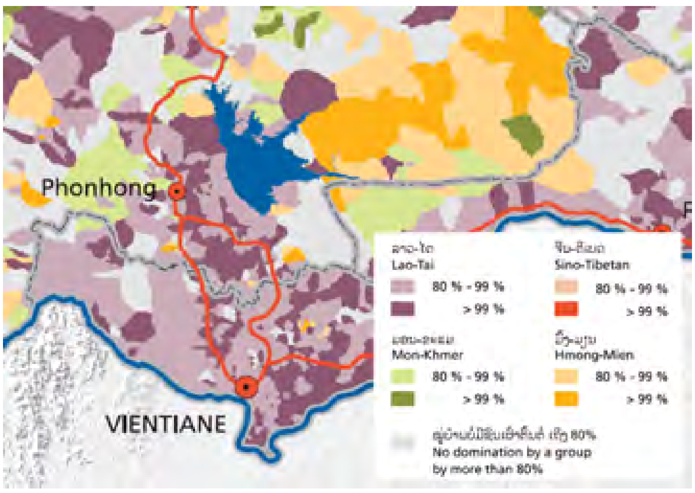
Figure 6.2.6 Distribution of Forests and Protected Areas

Meanwhile, Phou Khao Khouay NBCA, located southeast to Nam Ngum Reservoir, is included in the catchment of the Nam Leuk River, of which water is diverted into the Nam Ngum reservoir. Nam Leuk hydropower was constructed in 2000 and EdL has been allocating 1% of its revenue of the power export to Thailand to support Phou Khao Khouay NBCA since 2001. Although the NBCA is considered to locate upstream of the Nam Ngum reservoir, the project is considered to affect mainly the downstream. Thus, it is considered that the expansion project has little affects to protected areas.

6.2.2 SOCIAL ENVIRONMENT

(1) Population and Ethnicity

The basin has significant ethnic diversity. The residents had been highly mobile but eventually settled in the recent years. As for ethnicity, although Hmong-Mieng lives in the upstream of NNRB, Lao-Thai is the major ethnic group at the downstream of NN1. The distribution of ethnic group is shown at right figure.



Source: Socio-Economic Atlas of the Lao PDR, 2005

Figure 6.2.7 Ethnicity Distribution around NN1

The condition of the area of NNRB was drastically changed after the Indochina War and construction of Nam Ngum Dam. In 1965, 23 villages comprising 579 households and population of 3,242 were identified to be affected by the creation of the Nam Ngum Reservoir. Villages had been established as a result of resettlement from inundation areas. About 15 years later, the number of village was increased to 31 around the reservoir comprising 1,652 households with 9,561 people. . In 1992, the reservoir perimeter is settled by about 40 villages and 2498 households with 15,727 people[3]. At present, estimated population inside NNRB is more than 500,000. Due to the improvement of road access and agricultural land conditions, many had migrated to the area. Estimated provincial population is shown in the table below.

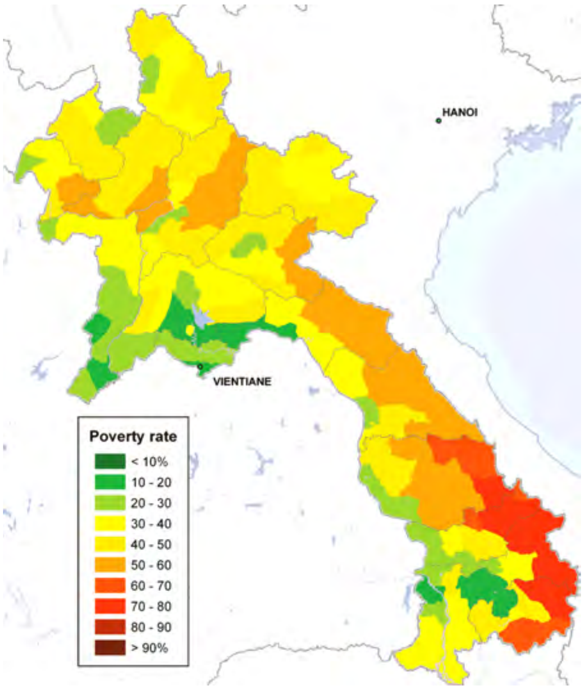
Table 6.2.4 Estimated Provincial Population in NNRB

Provinces	Population	Household
Xiengkouang P.	239,812	69,559
Luang Prapang P.	405,949	5,135
Vientiane P.	409,906	270,785
Vientiane M.	695,473	155,233
Bolixamxai P.	225,167	1,438
Total	1,976,307	502,150

Source: Nam Ngum River Basin Profile, WREA, June 2008

(2) Poverty

The distribution of poverty in Lao PDR is shown in the right figure. Out of 20 districts in NNRB, six districts are identified as "poor", i.e., Pal, Phoanoun, Xaisomboun, Hom, Feng, and Met Districts. However, the economic condition of main affected areas of NN1 downstream is relatively good. This is considered because of good accessibility with transportation infrastructure, proximity to capital, and abundant potential for agricultural and fishery production.



Source: The Geography of Poverty and Inequality in the Lao PDR, NCCR and IFPRI, 2008

Figure 6.2.8 Poverty Rate in Lao PDR

(2) Economic Activity

The people living in the Nam Ngum River basin are highly dependent on agriculture and fishery, which is 70% of the total working population. Especially, fishery is the main commercial activities in the watershed. Hatchery, cage fish culture, and integrated fish livestock farming are widely performed along the riverside. Shifting cultivation practice is still common in mountain communities. The government is providing programs to reduce shifting cultivation. Currently, farmers are more willing to settle with rice cropping. Buffalo husbandry is partially developed. Forestry sector covers commercial logging with private and commercial gathering of fuel wood and non-timber forest products. Local economy also benefits from tourism. Wholesale, retail, hotel and restaurant are prominent in NNRB. Unemployment has not been measured to be a problem in the area. Annual farm

[3] Nam Ngum Dam After 30 Years of Operation, 2006, KRI International

income in Lao PDR is Kip 5.4 million in average, while Kip 4.8 to 6.0 million in NNRB provinces as shown in the table below.

Table 6.2.5 Farmer's Income of NNRB

Unit: 000 Kip

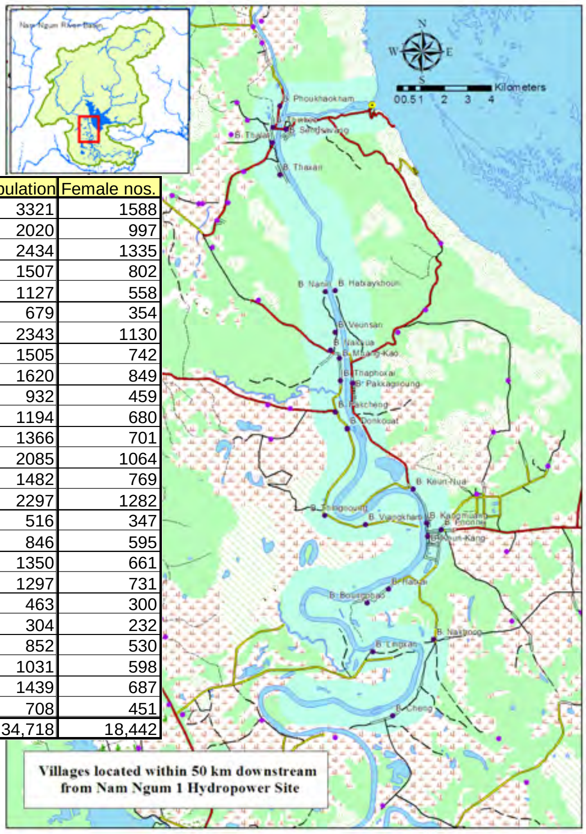
Province	Income						Cost				
	Grain	Veg. and Fruit	Meat	Fish	Forest	Others	Seed and fodder	Equip	Wages	Others	Total Farm income
Vientiane M.	2,224	231	511	435	50	557	298	217	484	424	2,587
Xiengkhuang P.	3,957	976	1,867	602	21	291	644	460	277	252	6,082
Vientiane P.	2,673	553	1,767	811	152	752	402	166	308	369	5,464
Borikhamxay P.	2,471	934	917	1,539	33	98	19	110	155	87	5,621
Luangprabang P.	2,376	678	1,615	425	87	142	143	78	151	96	4,854
Average Lao PDR	**3,129**	**694**	**1,234**	**732**	**40**	**313**	**183**	**137**	**189**	**228**	**5,404**

Source Nam Ngum River Basin Profile, WREA, referring NSC, LECS3-2003,

Socio-economic survey was conducted in this IESE study for 24 villages located along the Nam Ngum River within 50 km downstream from NN1 and 1 km width from the river bank. The area comprises the districts of Keooudom, Viengkham and Thoulakhom. These are considered to be the main affected areas due to the project. Three additional upstream villages in Hom District were surveyed for the purpose of conducting comparison between upstream and those affected areas. In addition, 100 representatives of 100 households have been interviewed, of which 94 households are from the downstream affected areas while the other six households are from upstream.

The location and general feature of the villages are shown in the figure below.

No.	Village Name	Latitude	Longitude	HH	Population	Female nos.
1	B. Kangmuang	18.36643	102.57216	402	3321	1588
2	B. Keun-Nua	18.37982	102.56649	361	2020	997
3	B. Keun-Kang	18.36116	102.57259	473	2434	1335
4	B. Boungphao	18.33459	102.54855	349	1507	802
5	B. Hatxai	18.34005	102.55707	222	1127	558
6	B. Nakhong	18.32055	102.57547	140	679	354
7	B. Cheng	18.29024	102.55956	458	2343	1130
8	B. Lingxan	18.31531	102.55108	300	1505	742
9	B. Phonhe	18.36374	102.57810	323	1620	849
10	B. Thaxan	18.50274	102.51100	167	932	459
11	B. Thalat	18.51543	102.50797	214	1194	680
12	B. Thinkeo	18.52145	102.50801	280	1366	701
13	B. Phoukhaokham	18.52996	102.51068	443	2085	1064
14	B. Sengsavang	18.52064	102.51344	299	1482	769
15	B. Pakkagnoung	18.42086	102.54141	468	2297	1282
16	B. Thaphoxai	18.42184	102.53665	108	516	347
17	B. Muang-Kao	18.43068	102.53614	158	846	595
18	B. Veunsan	18.44083	102.53437	251	1350	661
19	B. Nakhua	18.43380	102.53248	262	1297	731
20	B. Nanin	18.45688	102.53004	87	463	300
21	B. Hatxaykhoun	18.45727	102.53403	54	304	232
22	B. Pakcheng	18.40949	102.53473	147	852	530
23	B. Donkouat	18.40301	102.53965	176	1031	598
24	B. Thingnoung	18.36893	102.53104	280	1439	687
25	B. Viangkham	18.36542	102.54758	126	708	451
	Total			6,548	34,718	18,442



B. Kangmuang was not surveyed because it is included in KengKang village. Accordingly, target village number became 24.
Prepared by JICA Survey Team, using GIS Database of National Geographic Department 2005

Figure 6.2.9 Location of Villages situated at the Downstream 50 km from NN1

Following tables summarize the result of socio economic survey at village level and household level.

Table 6.2.6 Summary of Socio-economic Survey in Downstream Riverside Households

Description	Qty	Unit
Nos of target sample	94	
Education Status		
Primary	41%	
Lower Secondary	17%	
Upper Secondary	29%	
Diploma/ college	2%	
Vocational School	13%	
Settlement History		
Indegenous	86%	
Experience of moving	14%	
Want permanent stay	100%	
Income Source		
Paddy (%)	21%	
Gardening (%)	21%	
Fishery (%)	16%	
Livestock (%)	10%	
Gov. Official (%)	10%	
Labor/ wedge (%)	15%	
Average HH rice consumption		
Rice consumption	116	Kg/hh/ Mo
Owned Vehicle(s)		
No of Motor bike	1.4	nos
No of Car	0.3	nos
Own car	0.1	nos
No of Tractor	0.3	nos
Own tractor	0.3	nos
No of Truck	0.1	nos

Description	Qty	Unit
Average Expenditure		
Per househod	1,286,240	Kip/hh/Mo
Per person	242,099	Kip/per/Mo
Average Income		
Per househod	3,145,063	Kip/hh/Mo
Per person	672,492	Kip/per/Mo
Fishery		
Fishery household	40/94	hh
Average production	5,318	kg/yr
Ave. fish cage income	570,750,000	Kip/yr
Ave. other Fishery income	6,986,535	Kip/yr
Ave. Income dependency	44%	
Riverside Gardening		
Gardening household	67 /94	hh
Average production	5,661	kg/yr
Average income	7,856,385	Kip/yr
Ave. Income dependency	37%	
Boat Transportation		
HH runs boat transportation	4 /94	nos
Passenger: persons	53.8	nos
Passenger: car	15.0	nos
Passenger: Motorbike	58.0	nos
Average Income	2,112,500	Kip/day
Ave. Income dependency	84%	

Source: Survey data conducted by SD&XP Consultants Group Survey Team

Table 6.2.7 Summary of Socio-economic Survey in Downstream Villages of Nam Ngum 1

Description	Qty	Unit
Demorgraphy		
Nos of village	24	nos
Nos of total household	5,800	nos
Nos of total families	6,205	nos
Nos of population	30,347	nos
Nos of women headed household	306	nos
Religion		
Bhuddist	99.9%	
Spirit believe	0.1%	
Christian	0.0%	
River Water Use		
General use	94.4%	
Drinking	1.5%	
Fishing	15.7%	
Boat	38.6%	
Irrigation	31.3%	
Riverside gardening	39.4%	
Income related gardening	26.1%	
Income related fish cage	1.1%	
Infrastructure		
Nos of health facility	8	nos
Nos of primary school	30	nos
Nos of lower secondary school	14	nos
Nos of upper secondary school	4	nos
Nos of collage	1	nos
Nos of temple	37	nos
Nos of tourist spot	3	nos
Nos of cultural spot	0	nos
Nos of pumping station		
Public	7	nos
Private	191	nos
Nos of Irrigation System	7	nos
Nos of waste water treatment	0	nos
Nos of boat/ferry facility	9	nos
Desease		nos
Cold	1st	
Diarrhea	2nd	
Maralia	3rd	
Dengue	4th	
HIV	None	

Description	Qty	Unit
Economic Situation (Household %)		
Low land farming	62.0%	
Home gardenning	37.6%	
Livestock Production	49.8%	
Poultry Production	88.3%	
Fish Production	6.9%	
Employment	34.4%	
Business	23.0%	
Handicraft	7.0%	
Farm labor	13.6%	
Off-farm Labor	10.2%	
Economic Situation (Village nos.)		
Resettlement story	12 /24	nos
Existence of poor hh	14 /24	nos
Existence of village forest	11/24	nos
Existence of spiritual forest	22 /24	nos
Existence of upland rice area	0 /24	nos
Endengered fauna and flora	0 /24	nos
Existence of cultural spot	0 /24	nos
Existence of Pump for water	5 /24	nos
Existence of Irrigation system	4 /24	nos
Existence of water treatment	0 /24	nos
Boat transportation	22 /24	nos
Electricity available	24 /24	nos
Telephone available	24 /24	nos
Paved road available	24 /24	nos
Earth road available	24 /24	nos
Farm Land Ownership		
None	25.7%	
< 5 Rai (8000 m2)	38.6%	
5-10 Rai (8000-16000 m2)	30.1%	
10 to 60 Rai (16000-96000 m2)	5.5%	
60 Rai (> 96000 m2)	0.1%	
Fishing Status		
Nos of fishing household	408	nos
Average fish production	277	kg/Mon
Average price of fish	14,750	Kip/kg
Average distance to market	1.7	km

Source: Survey data conducted by SD&XP Consultants Group Survey Team

According to household interview survey of river side residents, average income of fishery other than fish cage culture is Kip 7 million /year (average of 65 households) and riverside gardening is Kip 7.8 million /year (average of 40 households). For fish cage culture, small number of samples showed the average income of as high as Kip 570 million /year (average of 4 households), but requires large investment and possible location is limited.

The interview sheet used in the above socio-economic village survey is included in Appendix C-3 in the Datafile and detailed result data is included in Appendix C-4 in the Datafile.

(4) Infrastructure/public facilities

In addition to NN1 Hydropower Station, several hydropower stations have been constructed in NNRB to provide domestic and export power supply such as Nam Leuk Hydropower and Nam Lik 1 Hydropower. In the upstream of the Nam Ngum Reservoir, Nam Ngum 2 Hydropower is under construction. Various infrastructures were constructed accordingly. Route nos. 13 and 10 connects Vientiane to local areas of NNRB. Road network has been improved through the construction of hydropower stations in NNRB.

The electrification ratio of downstream villages of NNRB is almost 100%. However, in the upstream areas, 30-60% of people live without electricity, of which the highest non-electrified percentage is Xiengkouang Province at 62.8% followed by Luang Phabang Province at 55.8%.

As for sanitation, the availability of sanitary facilities is still lower in rural areas. Only around 25-50% of households have access to a pit latrine. The Government aims to provide sanitation for 80% of rural dwellers by 2020.

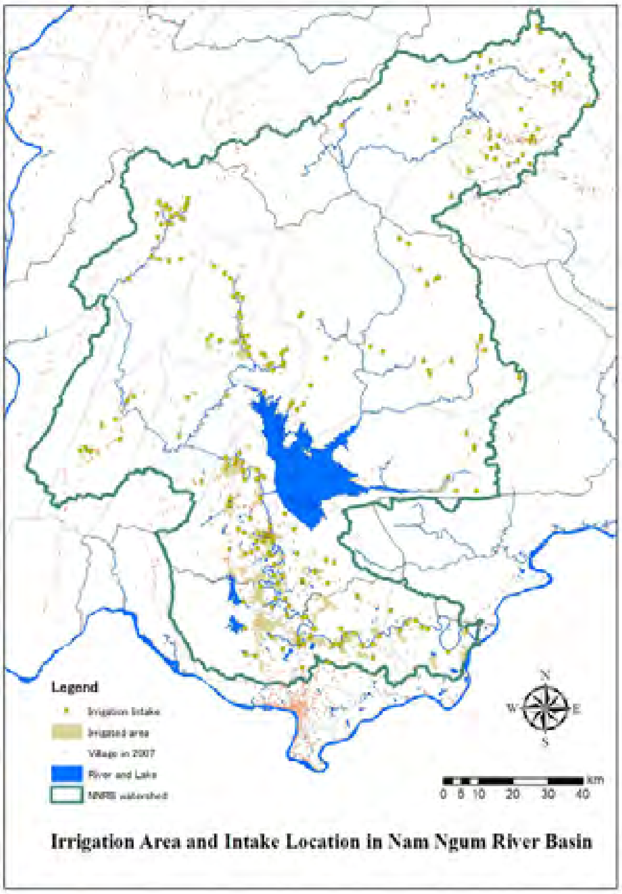
As for education, overall enrolment of young children in primary school is increasing in NNRB. The population that never attended school has decreased from 38% in 1995 to 23 % in 2005. Most villages downstream of NN1 have primary or secondary education. In the downstream with 24 villages of NN1, public infrastructure is relatively sufficient. All villages are electrified, connected with telephone lines, and with paved or earth roads. There are eight health centers, 30 primary schools, 14 lower secondary schools, four upper secondary schools and one college at Ban Keun Village. All of these are public schools.

(5) Water Use and Irrigation

The Vientiane Water Supply Utility estimates that water usage for small villages that have access to piped water is around 40 L/person/day while villages using hand pumps is approximately 20 L/person/day. People in NNRB uses pumped river water or tube well from underground water. Water pumping from the Nam Ngum River downstream NN1 might be affected after the expansion project if level is decreased to more than acceptable level.

For water supply infrastructure, there are 198 pumping stations in 24 downstream villages, of which four have irrigation system. Irrigation infrastructure may also be affected by the project.

Irrigation location in NNRB is shown in the figure below.



Prepared by JICA Survey Team using GIS Shapefiles obtained from Department of Irrigation

Figure 6.2.10 Location of Irrigation Intake and Irrigated Areas in NNRB

6.3 INITIAL ENVIRONMENTAL AND SOCIAL EXAMINATION (IESE)

6.3.1 OVERALL ENVIRONMENTAL AND SOCIAL IMPACT OF THE EXPANSION PROJECT

As the environmental and social considerations for the expansion project, the Survey Team assisted preparation of Initial Environmental and Social Examination (IESE) and Environmental and Social Management Plan (ESMP) based on ”Regulation on Environment Assessment in Lao PDR, STEA, 2002”. Full document of IESE and ESMP are included in Appendix C-7 and C-8 in the Datafile.

No significant and irreversible impacts on social and natural environment are expected in the NN1 Hydropower Station Expansion Project, different from a new dam and hydropower project. The expansion project needs neither creation of reservoir nor construction of new transmission lines. In terms of socio-economic impact, no relocation or land acquisition is required. Compensation is not necessary in the selected optimum scale of the project.

Meanwhile, consideration for prevention of pollution is needed during construction work, but conventional mitigation method for general hydropower construction would be applicable. Consideration was taken at the basic design stage so that environmental impact due to the construction works is minimized such as water quality and land surface. Construction Environmental Management Plan (CEMP) was formulated in IESE for environmental consideration during construction.

Overall impact of social and natural environment is assessed together with the comparison with general new hydropower construction project of the same scale of output as shown in the table below.

Table 6.3.1 Description of Overall Environment and Social Impacts and Pollution

Preparatory Survey on Nam Ngum 1 Hydropower Station Expansion (NN1E) in Lao PDR
Environmental Checklist for Screening (with Comparison of General Hydropower Projects of Reservoir Type)

This checklist is prepared for the comparison of NN1E Project and general hydropower project with storage and install capacity around 40 MW scale.
Rating: A: Serious impact is expected. B: Some impact is expected. C: Impact is unknown. -: No impact. +: Positive impact

No.	Impacts	Rating for General Project	Rating for NN1E Project	Brief Description for NN1E
1. Anti-pollution				
1.1	Air Pollution	-	B	Limited air pollution is expected due to heavy machinery.
1.2	Water Pollution	A or B	B	Temporary water pollution due to concrete mixing, aggregate collection, and excavation during construction is expected. This would be local and small but should be minimized. Water quality monitoring is necessary during operation.
1.3	Waste	B	B	Demolished material needs disposal to adequate site.
1.4	Soil Contamination	-	-	No soil contamination is expected but proper insulation oil treatment is needed.
1.5	Noise and Vibration	A or B	B	Site is away from residential area. No noise and vibration problem from site is expected to local people. Material transportation near access road needs consideration with speed limit.
1.6	Ground Subsidence	-	-	No ground subsidence is excepted.
1.7	Offensive Odor	B or -	-	No offensive odor is expected.
1.8	Bottom sediment	A or B	-	No bottom sediment change is expected since reservoir already exists and no change is added on reservoir condition.
1.9	Accidents	A or B	B	Proper safety management during expansion works needs to be provided at responsibility of contractor with CEMP implementation.
2. Natural Environment				
2.1	Protected area	A or B or -	-	Protected area is not included in downstream.
2.2	Flora, Fauna and Biodiversity	A or B	-	Effect on flora, fauna, nor biodiversity is not expected. Rare species are not reported in affected areas.
2.3	Hydrological Situation	A	B	River discharge will increase during peak generation hours and decrease off-peak hours. Maintenance flow should be secured not to disturb downstream activities such as boat and fishery.
2.4	Topography and Geographical features	A	B	Excavation, spill and wastage embankment give a little change to the geographical feature but not significant.
2.5	Landfill Site Management	A or B	-	Amount of waste for landfill is very small.
2.6	Soil Erosion	A or B	-	Not expected, since the discharge increase in the project would be much smaller than natural flood. Flood already occurred every year after dam construction in 1971. Weak soil have already been flushed away.
2.7	Groundwater	B or -	-	No effect on groundwater is expected.
2.8	Coastal Zone (Mangroves,Tidal flats, etc.)	B or -	-	No effect on coastal zone is expected.
2.9	Meteorology	B or -	-	No effect on meteorology is expected.
2.10	Global Warming	B+	B+	It will has positive impact due to utilization of spilled water in rainy season for energy, which can save fossil fuel in EGAT in Thailand owing to the reduction of power import from EGAT.
3. Social Environment				
3.1	Involuntary Resettlement	A or B	-	No resettlement and compensation is needed.
3.2	Local economy, employment, livelihood	B	B+	Positive impact such as creation of local employment is expected.
3.3	Cultural heritage	A or B or -	-	No cultural heritage is reported in affected areas.
3.4	Landscape	A or B	B	New powerhouse and possible downstream bed rock excavation affects to landscape at the dam site, but this is not significant.
3.5	Indigenous and ethnic minority	B or -	-	People in affected area is highly mobile and no problem on indigenous and ethnic people is reported.
3.6	Land use and utilization of local resources	B	-	No land use nor change of local resources are expected.
3.7	Social institutions and local decision-making institutions	B	-	No social institutions will be affected.
3.8	Existing social infrastructures and services	A or B	B	Facility for labor coming from outside temporary used. Maintenance flow has to be secured not to affect Irrigation during off-peak hours in dry season.
3.9	Misdistribution of benefit and damage	B	-	No misdistribution of benefit and damage is expected.
3.10	Local conflict of interests	B or -	-	No local conflict is expected.
3.11	Water Usage or Water Rights and Rights of Common	A	B	Minimum maintenance flow has to secure to give no affect on Irrigation and water pumping use at downstream in dry season.
3.12	Sanitation	B	B	Sanitation of workers during construction work needs to be properly managed.
3.13	Hazards (Risk)	B	-	No hazards is expected.

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As a result of IESE study, it is concluded that environmental and social impact of the NN1 expansion project are basically not significant. Negative impacts can be avoided or mitigated by conventional construction management with proper instruction and operation with mitigation plans.

On the other hand, continuous impact that may affect to natural and social environment is expected due to larger daily water level fluctuation at the downstream of the Nam Ngum River. This is due to the change of operation pattern in NN1 power station after the expansion work. In the off-peak time, downstream river water level is reduced and increased during peak-time.

The concept of the water level fluctuation in the dry season is illustrated below.

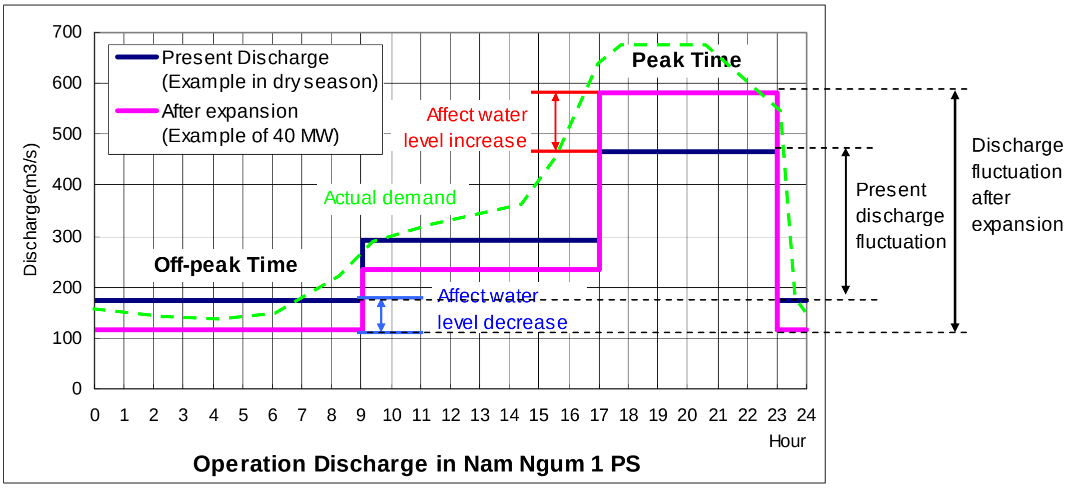

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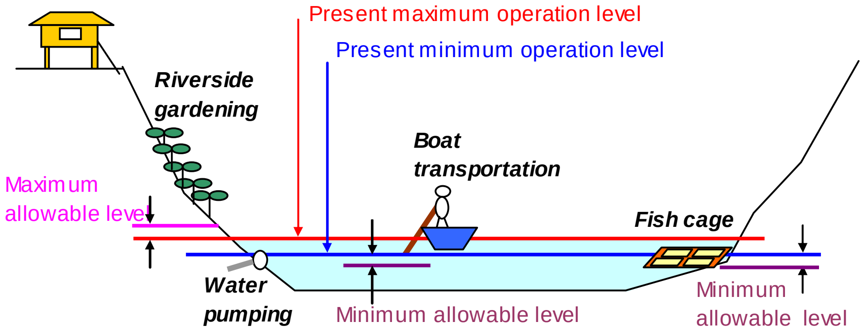
Figure 6.3.1 Concept of Expansion plan and Discharge from Nam Ngum 1 Power Station

Downstream discharge fluctuation comes from the change of output and generation discharge at the NN1. River side gardening is possibly affected from water level increase during peak time. Meanwhile, boat transportation and fishery may be affected by water level decrease during off-peak time. Irrigation and river water pumping may also be affected by the water level decrease. If pump intake is located lower than the decreased water level in a dry season, a problem on water supply is caused.

This water level fluctuation occurs only in the dry season. The expansion project gives no affect to downstream in the rainy season. This is because plenty of water is available in the rainy season and there is no need to save water during off-peak time. In the rainy season, NN1 discharge will be stable at maximum operation discharge.

The concept is shown in the figure below. It needs to confirm both maximum and minimum allowable river water level at peak and off-peak time, respectively, during dry season, considering usage of river water of people living at downstream. The interview survey and hydrological assessment conducted in IESE study made clear the allowable water level fluctuation.



Needs to find:
- Allowable water level increase for riverside gardening
  (Compared to maximum discharge from power station)
- Allowable water level decrease for fish pond, boat, and pumping
  (Compared to minimum discharge from power station)

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Figure 6.3.2 Affect of Water Level Fluctuation in Dry Season to Downstream People

Minimum NN1 output at off-peak time should be determined considering minimum requirement of river maintenance flow. It needs to determine minimum discharge of NN1 and minimum requirement of water level considering the affect of downstream residents. The result of the IESE survey is referred to determine how to set the off-peak minimum operation output of NN1 after the expansion.

Meanwhile, owing to other hydropower development plan such as Nam Lik 1/2 which is under construction, the seasonal water flow will be favorably regulated than the current status. Flood will be mitigated to some extent and some amount of dry season discharge will be increased at the time when NN1 expansion is completed. IESE evaluated the impact considering this condition.

The summary of anticipated negative and positive environmental and social impacts is shown in the tables below. The tables include the impact during construction and operation stages. Project closure is not assumed in this project since it serves as a national backbone infrastructure.

Table 6.3.2 Possible Negative Impact

Category	Type	Possible Negative Impact	Stage
Social Environment	Social infrastructure	Labors coming from outside may affect. Security of nearby villages and sanitation of workers during construction work may have adverse impact if proper management is not held.	Construction
	Water usage	In dry season, irrigation and water use at downstream of NN1 will be affected if off-peak output is zero or only with single 18 MW unit. To confirm minimum river maintenance flow required by downstream society, at least single 40 MW unit should be operated during off-peak time. It needs to monitor the Nam Lik flow at the same time. In addition, rapid water level increase during off-peak to peak time shift may affect downstream safety of people.	Operation
	Sanitation	Sanitation of workers during construction phase may affect to water quality or health condition of surrounding areas. The expected scale of amount of workers is approx. 400 and not quite large.	Construction
Natural Environment	Water pollution	It is expected that temporary water pollution occurs due to concrete mixing, aggregate collection and washing, and excavation works during construction. The affect is temporary and small but should be minimized.	Construction

Category	Type	Possible Negative Impact	Stage
	Hydrological Situation	In dry season, river discharge will increase during peak generation hours and decrease during off-peak hours. For 40 MW expansion, maximum output during peak time does not affect to downstream. However, water decrease will affect to downstream if zero operation or smallest operation with single 18 MW unit is conducted during off-teak time. The condition is also affected by discharge amount of the Nam Lik River.	Operation
	Landscape	Additional powerhouse slightly changes appearance of the NN1. If optional work of river bed excavation is conducted to obtain additional head and energy output, downstream scenery is also slightly changed but this is not significant.	Cosntruction

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Table 6.3.3 Possible Positive Impact

Category	Type	Possible Positive Impact	Stage
Social Environment	Local Economy	Employment will be created by the construction works.	Construction
Natural Environment	Global warming	It will have positive impact due to utilization of spilled water for additional energy of 56 GWh due to expansion, which can save fossil fuel in the grid in Thailand owing to the reduction of power import from Thailand.	Operation

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Number of household and population affected by the expansion project is shown in the table below.

Table 6.3.4 Category and Number of the Affected

	Category	Amount	Remarks	Source
1)	Population of Nam Ngum River basin	69,559	Indirectly affected people	NNRB Profile, 2009,. WREA
2)	Riverside < 1km villages downstream < 50 km of NN1	24	Villages in affected area	GIS database, 2007, NGD
3)	Riverside < 1km households downstream < 50 km of NN1	5,800	Households in affected area	NN1 Expansion IEE Socio-economic Interview Survey
4)	Riverside < 1km population downstream < 50 km of NN1	30,347	Population in affected area	Ditto
5)	Nos of river water general users of 4)	28,648	Affected people	Ditto
6)	Nos of boat transporter users of 4)	11,714	Affected people	Ditto
7)	Nos of gardening household of 3)	2,285	Affected households	Ditto
8)	Nos of fishery household of 3)	400	Affected households	Ditto
9)	Nos of commercial fish cage hh of 3)	64	Affected households	Ditto
10)	Nos of irrigation pumping station	15	Affected infrastructure	Ditto
11)	Area of irrigation in dry season (ha)	1,035	Affected infrastructure	Ditto

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In terms of watershed of NN1, population of the NNRB of about 70,000 can be regarded as the indirectly affected. Meanwhile, upstream of NN1 is not directly affected by this project, since there is no necessity for reservoir creation or enlargement, land acquisition, or forestry cutting. However, their activity related to shifting cultivation and deforestation of watershed residents may lead to deterioration of regulation capacity of watershed forest, which may affect the reservoir condition of NN1 in the future. These are not the effects of the expansion project to the environment but the environmental condition that gives affects to the project.

Meanwhile, possible directly affected people is the riverside residents using river water of the Nam Ngum River at the downstream of NN1, since the river water level fluctuation will become larger than present due to enhanced peak operation in dry seasons after the expansion work.

The IESE survey defined the affected areas as the location within 1 km from the Nam Ngum river bank and within 50 km downstream of NN1 as shown in Figure 6.2.8. The possible affected people are the dwellers living in this area. The Survey Team firstly identified those villages using GIS village database of 2007 obtained from National Geographic Center. Then, the Survey Team conducted socio-economic survey for the riverside affected area to identify possible impact of NN1 expansion project. It was found that the affected area consists of 24 villages, 5,800 households, and population of 30,347 as of June 2009.

The Survey Team explained about the expansion project and possible environmental impacts of water level fluctuation to village authorities consisting of village chiefs, women's union, labor union, youths, and so on. As a result, all villages agreed to promote the expansion project.

As a whole, impact during construction stage is temporary and can be mitigated through conventional measurement of general hydropower construction. However, downstream water level fluctuation affect to downstream residents lasts as long as operation is conducted. Accordingly, the impact is assessed with hydrological analysis for dry season.

6.3.2 DETAILED STUDY OF ENVIRONMENTAL AND SOCIAL IMPACT

(1) Downstream Water Level Fluctuation

Boat transportation and fishing is affected by the water level decrease. Riverside gardening is affected by water level increase. It needs to convert discharge of NN1 to water level at downstream when the affect of discharge change of NN1 is assessed.

For this conversion, H-Q curve (relation of water level and discharge) can be used if hydrological data already exists at a certain location. The Survey Team applied the H-Q curve of the existing gauging station at Pakkagnoung, located at 15 km downstream of NN1.

First, downstream affect was assessed for independent discharge fluctuation of NN1 after expansion, without considering tributary or remaining catchment. The peak discharge from NN1 is increased from 465 m^3/s to 582 m^3/s after 40 MW expansion. This difference of discharge corresponds to 0.45 m water level difference when H-Q curve at Pakkagnoung is applied. That is, 40 MW expansion will increase water level at 0.45 m at 15 km downstream in the peak time. Meanwhile, off-peak operation will have two options, i.e., single operation with 40 MW unit or 18 MW unit, while current off-peak operation is held at least 58 MW. When this discharge decrease is converted to water level decrease with the same way, water level is decreased at 0.33 m for 40 MW single operation and 0.76 m for 18 MW single operation.

To assess if above water level change is acceptable to downstream people, the Survey Team conducted the interview survey to downstream dwellers. This enabled to grasp the water level change that downstream dwellers feels they are affected. By this result, the Survey Team analyzed the correlation of NN1 discharge fluctuation affect and water level that downstream dwellers judges to affect.

From 24 villages at the downstream of NN1, 94 households were selected at random who are located at riverside and use the river for income activity such as fishery and riverside gardening. Figure below shows affecting water levels and its number of the riverside households confirmed in socio-economic survey.

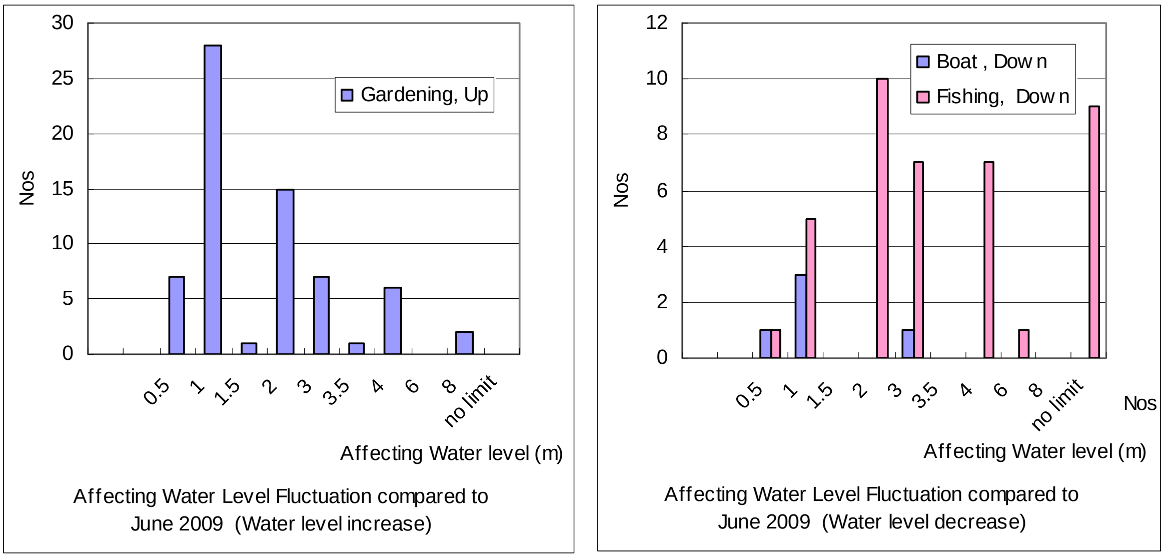

Figure 6.3.3 Affecting Water Level Fluctuation to Downstream Residents

From the figures above, it can be said that 0.5-1.0 m is the minimum water fluctuation level affecting both the increase and decrease of downstream residents. This is however a preliminary figure.

Actually, water level fluctuates every day not only by NN1 discharge but also by rainfall and flow from tributary rivers and remaining catchment. In addition, the riverside households are located at various locations along the downstream river. Water level change due to NN1 discharge change differs depending on river cross section of each household location. Considering these aspects, affects of discharge change of NN1 was assessed in detail.

The Survey Team conducted hourly water level measurement at three gauging station, namely, Thalat, Sensaveng, and Pakkagnoung, during the period including during the interview survey. The raw data is included in Appendix C-5 in the Datafile. The interviewed riverside households are spread to various locations within downstream, 50 km from NN1. Water level fluctuation affects due to discharge change varies depending on locations and river cross sections. Accordingly, water level that affects residents is converted to water level at Pakkagnoung located 15 km downstream from NN1. Subsequently, the water level at Pakkagnoung is converted to discharge using H-Q curve of Pakkagnoung. The method of conversion is as follows:

1) Select the nearest gauging station from the location of interview
2) Obtain statistical correlation of water level of gauging station at 1) and water level at Pakkagnoung

3) Using correlation of 2), calculate converted value of water level at Pakkagnoung

4) Calculate discharge using water level of 3) at Pakkagnoung using H-Q curve.

Figure below shows the discharge value at Pakkagnoung, converted from affected water level of riverside residents, and percentage of affected households due to the value. H-Q curve shown in **Figure 6.2.3** is used for the conversion.

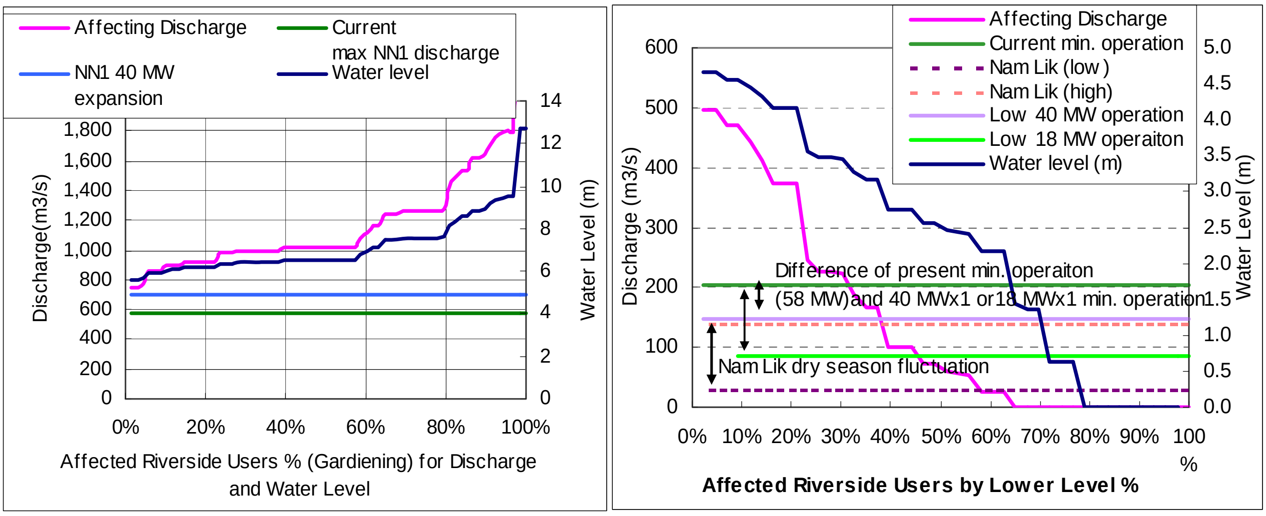

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Figure 6.3.4 Affecting Discharge and Water Level for Increase and Decrease

Vertical axis in the above figure is the percentage of affected households in all interviewed households against the discharge shown in the left vertical axis. Above left figure is for water level increase while right figure is for water level decrease.

For example in the left figure above, 40% of households are affected if discharge at Pakkagnoung becomes more than 1000 m^3/s. In the same figure, 40 MW expansion with total rated discharge at 582 m^3/s will not affect the riverside residents. However, additional discharge from Nam Lik needs to be considered. In the dry season, Nam Lik discharge varies from 29 m^3/s (driest discharge in 10 years possibility) to 137 m^3/s (maximum monthly average in 10 years). Affects may occur depends on the natural flow from Nam Lik. However, even if maximum monthly average discharge at 137 m^3/s comes from the Nam Lik, the downstream affect will be only less than 5% of residents. It can be said that peak operation with 40 MW expansion will not affect riverside residents due to water level increase.

Meanwhile, affect of water level decrease affect is more complex. Above right figure shows the affected number of riverside residents in off-peak operation when minimum operation becomes lower than current condition at off-peak time. After expansion, off-peak water level will decrease since off-peak discharge is shifted to peak operation. Two possible discharges considered to be changed from current 58 MW (174.1 m^3/s) to 40 MW single operation (117.1 m^3/s) or to 18MW single operation (57 m^3/s). In addition, inflow from the Nam Lik has to be considered. For the Nam Lik, minimum dry season discharge is assumed to be 29.1 m^3/s (90% dependable discharge) and the maximum is assumed at 136.7 m^3/s (maximum monthly average in 10 years).

The assumed condition for water level decrease is summarized as follows:

- Current off-peak time operation (Base Condition): 58 MW (40 + 18 MW) with 174.1 m^3/s
- Off-peak operation Case- 40MW: single 40 MW operation with 117.1 m^3/s
- Off-peak operation Case -18 MW: single 18 MW operation with 57 m^3/s
- Nam Lik discharge- low side (driest discharge of 10 years possibility): 29.1 m^3/s
- Nam Lik discharge - high side (maximum monthly average in 10 years dry season): 136.7 m^3/s

At present, minimum operation of NN1 is conducted with at least 58 MW (174.1 m^3/s). When minimum dry season discharge of the Nam Lik, 29.1 m^3/s is added, downstream discharge will be 203.2 m^3/s. The right figure above shows that 33% of households are already affected by this default discharge level at present. If off-peak Case-40 MW is conducted, affected household percentage will become 38% and for Case-18 MW, increased to 45%.

Meanwhile, discharge of the Nam Lik can vary from 29.1 to 136.7 m^3/s, which is larger than the difference between Base Case (174.1 m^3/s) and Case 40 MW (174.1-117.1=57 m^3/s). It can be said that the Nam Lik flow affects more the downstream condition. When considering the fluctuation due to independent NN1 off-peak operation reduction, the difference will be about 0.3-0.4 m for Case-40 MW and 0.7 m for Case-18 MW (details will be described later). According to interviews, affecting water level decrease starts from 0.5 m. Thus, single operation with 40 MW is considered to be the acceptable level. However, it is recommended that Case-18 MW should be avoided if discharge from the Nam Lik can not cover the balance of discharge reduction. It means downstream affect can be avoided when NN1 adjusts off-peak generation discharge according to Nam Lik flow condition.

After construction of the Nam Lik 1/2 scheduled in 2011, the river will be more regulated than present due to regulating functions of the dam of Nam Lik 1/2. The average dry season discharge from Nam Lik 1/2 in April is planned to be increased from 16.5 m^3/s to 42.7 m^3/s according to the feasibility study of Nam Lik 1. This will mitigate the flow condition in the dry season at the downstream.

The above analysis is only based on the assumption if the river cross section topology of interviewed households is the same as that of Pakkagnoung Station. Actually, from downstream to NN1, there are various river cross sections, and correlation of water level and discharge may vary as per site conditions. Accordingly, non-uniform flow analysis was conducted to confirm water level at various locations from 10 km downstream from NN1 to upstream reaching NN1, where the affect is considered to be the largest. This analysis uses the solving potential energy equation of continuation using the Newton Method of numerical analysis.

In order to conduct the calculation, cross-section surveys were conducted at 25 locations in the above area. The section interval is 500 m downstream starting from 10 km from NN1. Figure below shows the cross sections from NN1 direct downstream (CR1) to 10 km downstream (CR5). CR1 to CR8 are locations of upstream of the confluence of the Nam Ngum and the Nam Lik. CR12 to CR25 are at locations after the confluence.

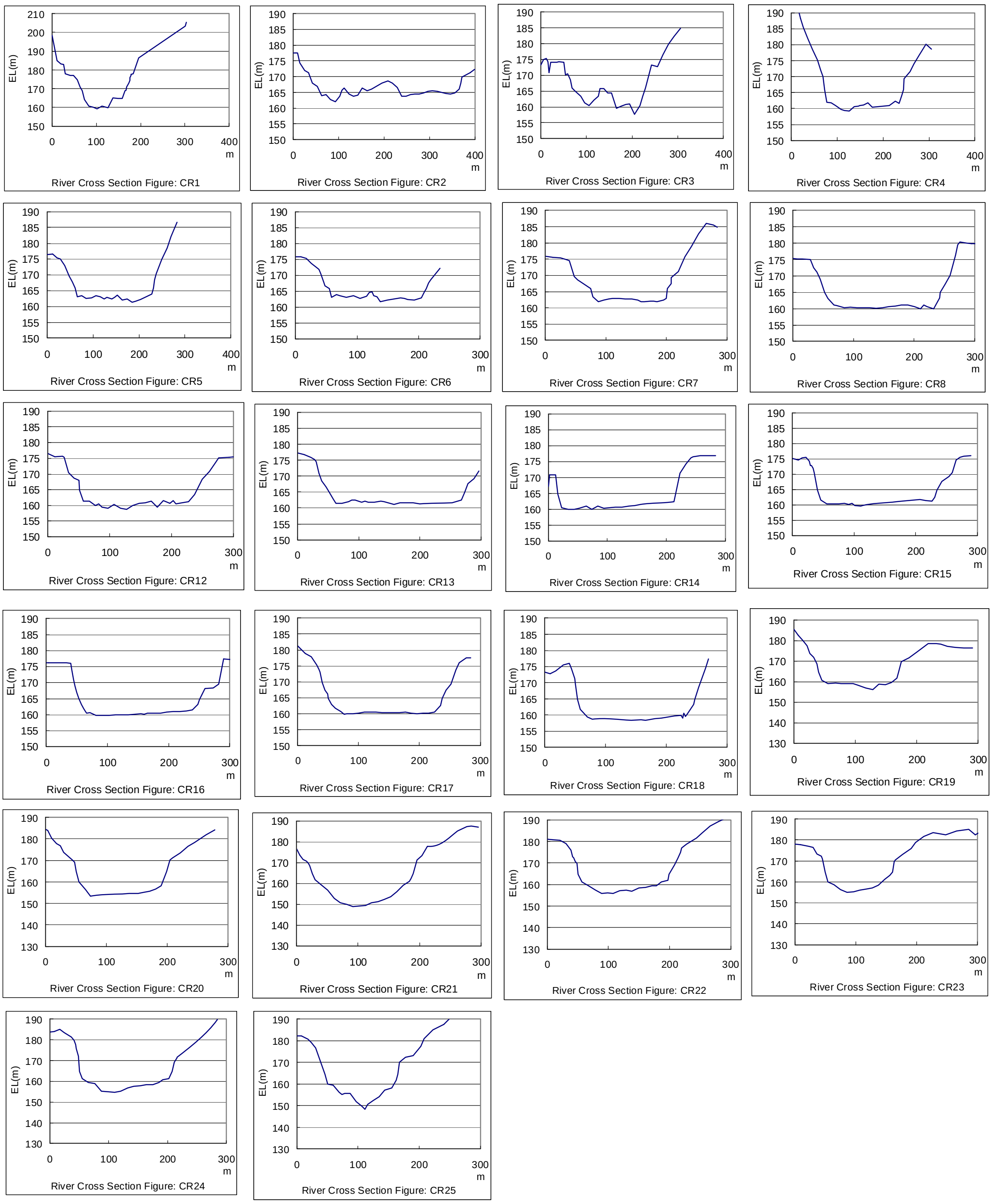

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Figure 6.3.5 Cross Section of the Nam Ngum River from Dam Site (CR1) to 10 km Downstream (CR25)

After the confluence with the Nam Lik, the following discharges are considered as: (i) the discharge of the Nam Lik at Hinheup gauging station, (ii) discharge from remaining catchments at Thalat (from Hinheup to confluence), and (iii) discharge from NN1. For the case of water level increase, 136.7 m^3/s maximum monthly average dry season discharge during 10 years is considered as the discharge of the Nam Lik. For water level decrease, 29.05 m^3/s, 90% dependable discharge is applied. This means that the worst flow conditions during dry seasons are applied to water level increase and decrease respectively.

For peak time, the case is set with a discharge of 40 MW expansion plan and compared with other alternative plans such as 60 MW, 80 MW, and 120 MW. For off-peak operation, Case-18 MW and Case-40 MW are considered for calculation. The cases are summarized in the table below.

Table 6.3.5 Case Pattern and Discharge Condition

Description	Hinheup	NN1	Thalath	Total Q	WL at Pkk	CR25 level
	Q m3/s	Q m3/s	Q m3/s	Q m3/s	EL. m	EL. m
Catchmetn area (km2)	5030		348.6			
Present condition (June 06 2009)	226.1	306.6	15.7	**532.7**	4.800	**164.650**
For water level increase in dry season						
Base case current max. operation	136.7	465.3	9.5	602.00	**5.059**	**164.909**
Highest case +120 MW exp.	136.7	816.3	9.5	953.00	**6.245**	**166.095**
High case +80 MW exp.	136.7	699.3	9.5	836.00	**5.869**	**165.719**
High case + 60 MW exp.	136.7	640.8	9.5	777.50	**5.675**	**165.525**
High case + 40 MW exp. (195MW)	136.7	582.3	9.5	719.00	**5.475**	**165.325**
For water level decrease in dry season						
Base 58 MW current off-peak	29.05	174.1	2.0	203.15	**3.354**	**163.204**
Base 80 MW current off-peak	29.05	234.2	2.0	263.25	**3.657**	**163.507**
Lowest case 18 MW single	29.05	57	2.0	86.05	**2.655**	**162.505**
Lowest case 40 MW single	29.05	117.1	2.0	146.15	**3.038**	**162.888**
Low case + 40 MW exp. (195MW)	29.05	582.3	2.0	611.35	**5.093**	**164.943**

* Rainy season is not assumed since peak operation is not held and water fluctuation will not affect.

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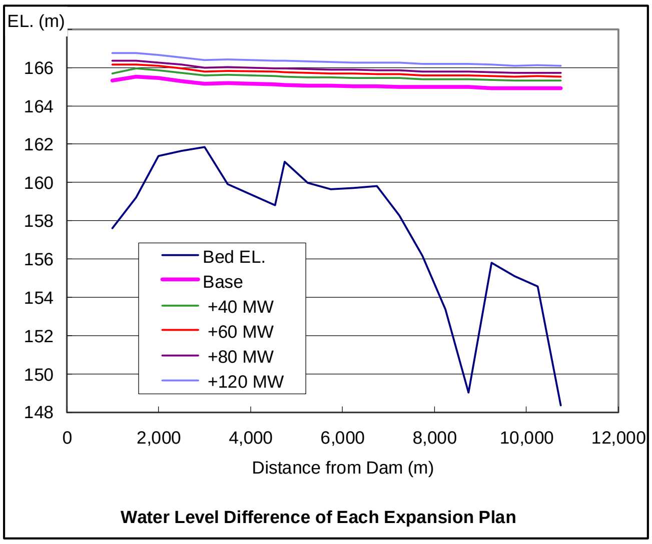
The following figure is the result of non-uniform flow calculation from 10 km downstream NN1 to reach NN1 dam site, for peak time water level increase at 40 MW final plan and 60 MW, 80 MW, and 120 MW alternative plans.



Unit (m)			Increase from Base Level (m)			
Distance	Bed EL.	Base WL	+40 MW	+60 MW	+80 MW	+120 MW
10,740	148.35	164.91	0.42	0.62	0.81	1.19
10,240	154.57	164.92	0.42	0.62	0.82	1.20
9,740	155.09	164.92	0.42	0.62	0.81	1.19
9,240	155.81	164.94	0.42	0.63	0.83	1.21
8,740	149.03	164.97	0.43	0.64	0.84	1.23
8,240	153.35	164.98	0.43	0.64	0.84	1.23
7,740	156.17	164.97	0.43	0.63	0.83	1.22
7,240	158.29	165.00	0.44	0.64	0.85	1.24
6,740	159.81	165.01	0.44	0.65	0.85	1.24
6,240	159.73	165.03	0.44	0.65	0.85	1.25
5,740	159.65	165.05	0.44	0.65	0.85	1.25
5,240	159.97	165.07	0.44	0.65	0.86	1.26
4,740	161.09	165.10	0.44	0.65	0.86	1.25
4,530	158.81	165.13	0.44	0.65	0.84	1.24
3,500	159.92	165.17	0.44	0.65	0.85	1.25
3,000	161.84	165.16	0.44	0.65	0.84	1.23
2,500	161.66	165.30	0.43	0.64	0.84	1.24
2,000	161.38	165.45	0.43	0.63	0.83	1.22
1,500	159.20	165.53	0.43	0.64	0.83	1.23
1,000	157.62	165.33	0.36	0.83	1.03	1.42

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Figure 6.3.6 Result of Non-uniform Flow Calculation: Output Increase at Peak Time

The result shows that the water level difference between each case and base condition is almost the same along the 10 km analyzed section. It was also confirmed that water level difference in each case is almost the same as that of at Pakkagnoung. It can be concluded that 0.4-0.5 m increase is shown in case of peak 40 MW increase (195 MW output in total), which gives no problem at the downstream.

Result of off-peak time is shown in the figure below.

Unit (m)		Decrease from Base 58 MW (m)		
Distance from DS	Bed EL.	Sigle 18 MW	Single 40 MW	*Full 195 MW - single 40 MW*
10,740	148.35	-0.70	-0.32	*2.06*
10,240	154.57	-0.70	-0.32	*2.07*
9,740	155.09	-0.70	-0.32	*2.06*
9,240	155.81	-0.70	-0.32	*2.08*
8,740	149.03	-0.71	-0.32	*2.11*
8,240	153.35	-0.71	-0.32	*2.11*
7,740	156.17	-0.71	-0.32	*2.11*
7,240	158.29	-0.72	-0.32	*2.13*
6,740	159.81	-0.72	-0.33	*2.14*
6,240	159.73	-0.72	-0.33	*2.15*
5,740	159.65	-0.73	-0.33	*2.16*
5,240	159.97	-0.73	-0.33	*2.17*
4,740	161.09	-0.74	-0.34	*2.18*
4,530	158.81	-0.92	-0.36	*2.25*
3,500	159.92	-0.93	-0.36	*2.27*
3,000	161.84	-0.93	-0.36	*2.26*
2,500	161.66	-0.65	-0.44	*2.37*

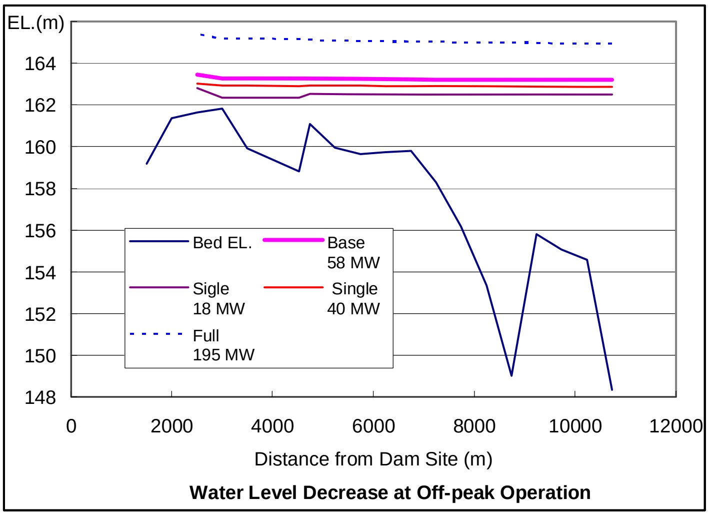

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Figure 6.3.7 Result of Non-uniform Flow Calculation: Output Decrease at Off-Peak Time

For off-peak time, water level decrease for Case-40 MW is 0.3-0.4 m which would be within acceptable level to downstream people. However, Case-18MW with decrease of 0.7-0.9 m is possibly affects some activities in the area. As mentioned above, the condition is dependent on the discharge amount of the Nam Lik.

Accordingly, the basic operation rule is formulated in the Preparatory Survey with the assumption that off-peak operation is held with a minimum of single 40 MW unit.

Meanwhile, water level change at the time of operation transition from off-peak time to peak time also needs consideration. Figure above also indicates water level difference between off-peak and peak time. When off-peak time is shifted to peak time, and 40 MW is increased to maximum operation at 195 MW, water level at downstream will suddenly increase to 2.0-2.3 m within a few minutes. This is expected early morning or afternoon before evening peak time. Although the speed of water level increase rate will become moderate at downstream, this rapid water level increase may induce accident of downstream river uses. This would be a problem of safety to downstream riverside residents. Meanwhile, as for the shift from peak to off-peak time at midnight, it would not be a problem since rapid water level decrease does not affect safety. However, precaution remains necessary.

At the present operation of shifting from off-peak to peak time, 80 MW (2 x 40 MW units) opening at one time is already conducted. Accordingly, it is considered that 80 MW increase from off-peak to peak time is not a problem. However, larger increase at one time more than the present level should be avoided. When large output increase is required, step-wise increase by 80 MW at maximum has to be kept, and additional output increase should be conducted after 30 minutes or 1 hour to reach the maximum operation at 195 MW. It is necessary to set operation rule accordingly. In addition, precaution should be explained to for downstream people regarding the peak time water level which will be increased at about 0.4-0.5 m than before. This explanation should be given during a public consultation to be held before commissioning. In addition, warning sign board should be installed at every location of river water use to inform the residents about this matter. In detailed design stage, it is recommended to study the requirement of automatic warning system.

(2) Irrigation

The Survey Team conducted irrigation survey located downstream of NN1 to confirm if water level decrease in off-peak hours in dry season will not affect the existing irrigation water intake. There are 14 irrigation intakes within 50 km downstream of NN1 in Keo Oudom, Viengkham, and Thoulakhom District. The intake pump is usually installed at 1.3 m above from river bed. According to the confirmation with the Provincial Agriculture Department, water level has been kept at least 2 m at the downstream irrigation location, even at the worst case of ten years possibility. Accordingly, irrigation pumps have margins of at least 0.7 m from water surface. Thus, water level decrease at 0.5 m during the off-peak generation with single 40 MW units is considered not to affect the irrigation pumping. The details of irrigation survey result is included in Appendix C-6 of the Datafile.

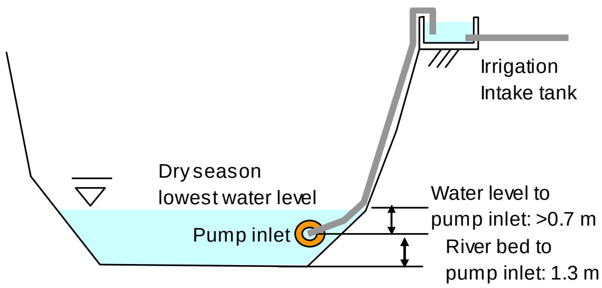

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Figure 6.3.8 Conceptual Figure of Irrigation Pump and River Cross Section

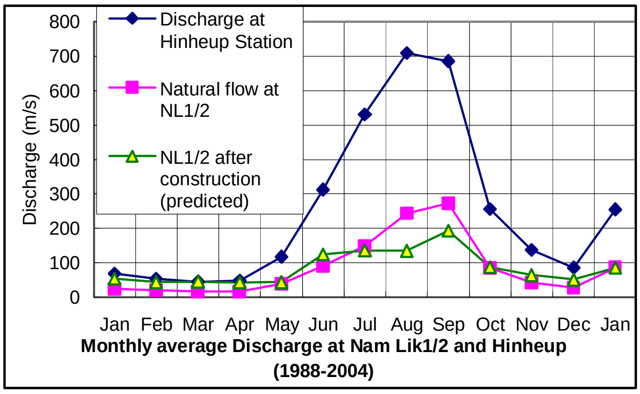
According to ”NNRBDSP Component 1, Nam Ngum River Basin Profile, 2009”, the total capacity of irrigation pump at the downstream of the Nam Ngum River is 32.8 m^3/s and the future maximum total pump capacity planned up to the year 2027 is 74 m^3/s. Since the discharge from single 40 MW is 117 m^3/s, corresponding operation in the dry season is sufficient to cover the downstream irrigation requirement.

(3) Affect of the Nam Lik River and Nam Lik 1/2

As was described above, flow from the Nam Lik River will affect the downstream water level condition. The construction of reservoir of Nam Lik 1/2 will improve the river condition of downstream, that is, water in dry season will be increased and water in dry season will be decreased. In the above off-peak water level assessment, flow from the Nam Lik is assumed to be available at least 90% dependable discharge (29.1 m^3/s). It is necessary that Nam Lik 1/2 provides maintenance flow so that the Nam Lik discharge becomes larger than above.

Figure below shows the change in flow before and after the construction of Nam Lik 1/2.

Month	Discharge at Hinheup Station	Natural flow at NL1/2	NL1/2 after construction	NL1/2 after-before
Jan	67.8	23.9	53.5	29.6
Feb	53.6	19.3	43.5	24.2
Mar	44.6	16.3	44.7	28.4
Apr	48.2	16.5	42.7	26.2
May	117.2	37.1	43.0	5.9
Jun	312.5	89.9	123.7	33.8
Jul	530.8	147.6	135.5	-12.1
Aug	709.9	243.7	134.3	-109.4
Sep	685.8	271.9	192.7	-79.2
Oct	255.3	84.3	87.0	2.7
Nov	136.5	41.6	63.4	21.8
Dec	85.1	26.5	50.3	23.8
Jan	254.8	85.2	84.6	-0.6



Source: Feasibility Study of Nam Lik 1 Vol.1 Engineering Report, 2008

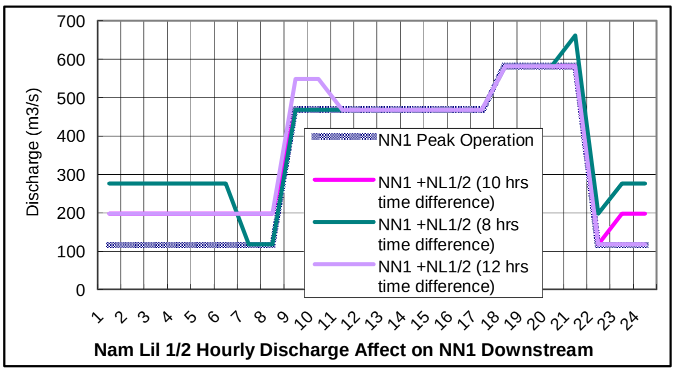
Figure 6.3.9 Monthly Average Discharge of Hinheup and Nam Lik 1/2 before and after Construction of Nam Lik 1/2

About 6 to 30 m^3/s is expected to be increased in the dry season after the construction of Nam Lik 1/2, which brings better condition to downstream. However, it is also necessary to consider daily operation pattern of Nam Lik 1/2 with 100 MW capacity. The operation rule of the Nam Lik 1/2 is not clear at present. In dry season, Nam Lik 1/2 is considered to have a peak generation at 30 MW with 80 m^3/s for 10 hours, judging from its salient features in the feasibility report. The hourly discharge fluctuation due to its peak generation will also affect to downstream water level. If the peak time of Nam Lik 1/2 is the same with NN1, it seems that water level fluctuations of both power stations are overlapped and affect of downstream areas becomes larger. Meanwhile, the distance from Nam Lik 1/2 to the confluence is about 89 km. There will be time difference between the peak discharge of Nam Lik 1/2 and NN1 when flow from Nam Lik 1/2 reaches to the confluence to the Nam Ngum River.

Using uniform-flow calculation, the Survey Team assessed the flow velocity and time for Nam Lik 1/2 to reach the confluence. The condition and result of the calculation are shown in the table below.

Condition for uniform flow calculation	Discharge of NL1/2	Average slope	Peak operation at NL1/2	Distance from NL1/2
	80 m3/s	I=1/1800	10 hr	89 km

Manning coeff.	Velocity	Velocity	Time to confluence		Difference
-	m/s	km/hr	hrs	day	hrs
0.03	0.69	2.47	36.0	1.50	12.04
0.0275	0.72	2.61	34.1	1.42	10.15
0.025	0.77	2.76	32.2	1.34	8.23



unit: m3/s

Hr	NN1 Peak Operatio	NN1 +NL1/2 (8 hrs time difference)	NN1 +NL1/2 (10 hrs time difference)	NN1 +NL1/2 (12 hrs time difference)
1	117	277	197	197
2	117	277	197	197
3	117	277	197	197
4	117	277	197	197
5	117	277	197	197
6	117	277	197	197
7	117	117	197	197
8	117	117	197	197
9	468	468	468	548
10	468	468	468	548
11	468	468	468	468
12	468	468	468	468
13	468	468	468	468
14	468	468	468	468
15	468	468	468	468
16	468	468	468	468
17	468	468	468	468
18	582	582	582	582
19	582	582	582	582
20	582	582	582	582
21	582	662	582	582
22	117	197	117	117
23	117	277	197	117
24	117	277	197	117

Prepared by JICA Survey Team

Figure 6.3.10 Peak Discharge Affect from Nam Lik 1/2

The peak time at the confluence difference between NN1 and Nam Lik 1/2 will be about 8 to 12 hours, varies depending on the Manning coefficient, which is determined based on surface condition of river bed. Assuming the peak time of Nam Lik 1/2 is 10 hours from 13:00 to 22:00, the peak discharge of Nam Lik 1/2 comes almost at the off-peak hours of NN1. This is a favorable condition for downstream, since peak flow from Nam Lik 1/2 can cover water level decrease of NN1 off-peak. Even if the peak is overlapped as the worst case, the increase from the current 155 MW NN1 peak operation is about 0.7 m, which is considered to be acceptable to most river side households. Actually, the water level increase due to Nam Lik 1/2 peak operation will be moderated at the confluence and at downstream due to the distance between confluence and Nam Lik 1/2. Moreover, the actual increase will be delayed than above assumption. Accordingly, affect of overlapped increase will be smaller than said assumption.

Above assessment is conducted only based on the assumed Nam Lik 1/2 peak operation pattern. Actual operation pattern however could be different. When starting the operation of NN1 expansion, it is necessary to confirm the daily operation pattern of Nam Lik 1/2 and assess downstream water level condition. In addition, maintenance flow from Nam Lik 1/2 is required so that flow from the Nam Lik is more than 90% dependable discharge that the Survey Team used in its assumption as the worst case. EdL should request adjusting the peak operation pattern of Nam Lik 1/2 and provide maintenance flow if necessary. These are required to ensure that downstream of the Nam Ngum River is not affected.

6.3.3 ENVIRONMENTAL AFFECT COMPARISON OF ALTERNATIVE PLANS

In the feasibility study conducted in 1995 by IDA, eight alternative plans were proposed for the expansion plan. In early 2009, the Survey Team arranged 12 alternative plans. These alternative plans consist of several outputs, i.e., 40, 60, 80, and 120 MW plans. Subsequently, the Survey Team selected 40 MW as the most prospective plan. The amount of water discharged from NN1 expansion is shown in the table below.

Table 6.3.6 Concept of Expansion plan and Discharge from Nam Ngum 1 Power Station

Unit	Rated output (MW)	Rated Discharge (m^3/s)	Total Output (MW)	Total Rated Discharge (m^3/s)
Unit 1 and 2	18.3 x 2	57 x 2	156.6	465.3
Unit 3, 4, and 5	40.0 x 3	117.1 x 3		
Unit 6 for expansion (alternatives will be determined later)	(Option A1, A4-1, D2-1) 40 x 1 = 40MW	117	196.6	582.3
	(Option A2, A4-2, A4-4, D2-2) 60 x 1 = 60 MW	175.5	216.6	640.8
	(Option B2-1, D2-3) 40 x 2 =80 MW	234	236.6	699.3
	(Option B2-2 and B2-4) 60 x 2 = 120 MW	351	276.6	816.3

Prepared by JICA Survey Team

The environmental affect expected in each alternative plan is summarized in the following table.

Table 6.3.7 Advantage, Disadvantage and Environmental Impact of Alternative Plans

Plan	Advantage	Disadvantage	Environmental Impact
A1 (40MW)	Intake coffer construction is easy. Overall layout is compact. Headloss in waterway is least.	Land space is narrow. Access way to existing transformers is blocked during intake construction.	Affect to downstream can be mitigated in by selecting off-peak operation output. Conventiona mitigation measurement is sufficient for construction.
A2 (60MW)	Intake coffer construction is easy. Overall layout is compact. Less headloss.	Land space is very narrow. Spillway wall foundation requires special slope stabilization. Existing building width is not enough. Existing carne is not usable. Roof of unit-5 bay requires replacement. Unit-5 is not operable during replacement.	Gardening of few riverside households may be affected due to water level fluctuation. Conventional mitigation measurement is sufficient for construction.
A4-1 A4-3 (40MW)	Land space is sufficient. Intake coffer construction is easy. Tailrace outlet of A4-3 is apart from existing tailbay.	Existing Nam Leuk GIS S/S has to be relocated. Construction of tailrace outlet of A4-1 disturbs operation of existing units 1&2. Existing crane is not usable. Locating switchyard on roof is not allowed due to lack of safety distance below existing 115kV lines	Affect to downstream can be mitigated in by selecting off-peak operation output. Conventional mitigation measurement is sufficient for construction.
A4-2 A4-4 (60MW)	Land space is sufficient. Intake coffer construction is easy. Tailrace outlet pf A4-4 is apart from existing tailbay.	Construction of tailrace outlet of A4-2 disturbs operation of existing units 1&2. Existing crane is not usable. Locating switchyard on roof is not allowed due to lack of safety distance below existing 115kV lines passing over the roof.	Gardening of few riverside households may be affected due to water level fluctuation. Conventional mitigation measurement is sufficient for construction.
B2-1 (80MW) B2-2 (120MW)	Land space is sufficient. Intake coffer construction is easy. New powerhouse is independent from existing powerhouse .	Existing Nam Leuk GIS S/S has to be relocated. Tunnel waterways are long and require steel lining in full length. 120MW case needs new 54 km long	Several riverside households may be affected. For 120 MW, water level increase in peak time will be more than 1m, which may require compensation.
D2-1 (40MW) D2-2 (60MW) D2-3 (80MW) D2-4 (120MW)	No obstructive structure in expansion area. Up to 80MW, generated power is transmitted through existing T/L via exiting switchyard.	Intake tower is independent in deep reservoir (>30 m deep). Construction of tower without lowering WL is very difficult. 120MW case needs new 54 km long transmission line.	Several riverside households may be affected. For 120 MW, water level increase in peak time will be more than 1m, which may require compensation. Construction scale is large and EMP needs mitigation for especially for tunneling work.

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For the 40 MW plan, it is considered that there is no significant affect downstream. Conventional mitigation measures are sufficient for construction. For 80 and 120 MW expansion alternative scale, daily water level fluctuation at down stream becomes more than 1 m, which may need compensation for riverside gardening. In addition, large scale alternative plans require additional transmission lines, which needs another IESE study to assess the impacts. Furthermore, larger scale may change JICA's category from B to A, which requires EISA.

The following table shows the requirement of expected compensation of each expansion scale and cost estimates of compensation.

Table 6.3.8 Cost for Compensation of Alternative Plans

Cost for Compensation (40 MW) US$

Item	Unit price	Unit qty (ha)	Qty (hh)	Unit	Coeff.	Amount	Per hh
Fish cage	10,000	0	64	ha-hh	0	0	0
Gardening	6,000	0.6	2285	ha-hh	0	0	0
TOTAL						0	

Cost for Compensation (60 MW) US$

Item	Unit price	Unit qty (ha)	Qty (hh)	Unit	Coeff.	Amount	Per hh
Fish cage	10,000	0.25	64	ha-hh	0	0	0
Gardening	6,000	0.6	2285	ha-hh	0.1	822,600	360
TOTAL						822,600	

Cost for Compensation (80 MW) US$

Item	Unit price	Unit qty (ha)	Qty (hh)	Unit	Coeff.	Amount	Per hh
Fish cage	10,000	0.25	64	ha-hh	0.1	16,000	250
Gardening	6,000	0.6	2285	ha-hh	0.15	1,233,900	540
TOTAL						1,249,900	

Cost for Compensation (120 MW) US$

Item	Unit price	Unit qty (ha)	Qty (hh)	Unit	Coeff.	Amount	Per hh
Fish cage	10,000	0.25	64	ha-hh	0.15	24,000	375
Gardening	6,000	0.6	2285	ha-hh	0.2	1,645,200	720
TOTAL						1,669,200	

* Quantity (household) was assumed from interview of 24 villages' percentage engaged for the category.

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The Survey Team selected A4 plan of 40 MW as the final optimum plan in the second field survey. The A1 plan has the least cost and least environmental impact among all plans.

For the comparison of with/without the project, the assumptions on advantages and disadvantages were assessed.

In case the expansion project is not implemented, the affect due to construction works and downstream water level fluctuation during operation can be avoided. However, electricity has to be imported from Thailand for peak hour use, additional 56 GWh will not be obtained, and thermal power needs to be applied as an alternative energy source.

Table 6.3.9 Advantage and Disadvantage for the Case without Expansion Project

Advantage	Disadvantage
- No downstream affect will be seen. The condition is the same as present. - No construction will be held and temporary impact due to construction will be avoided. - Project cost at about US$60 will be saved.	- No expansion will be held, and Lao PDR must import expensive energy at peak power in dry season from Thailand, which will be a burden of foreign currency balance of nation. EdL needs to cover the cost which may deprive other development opportunity for poverty reduction such as rural electrification. - No additional annual power output, namely 56 GWh, will not be obtained. - Thermal power in Thailand will be used for peak power import to Lao PDR, which releases CO_2.

Prepared by JICA Survey Team

6.3.4 ENVIRONMENTAL AND SOCIAL MANAGEMENT PLAN (ESMP)

(1) Requirement of ESMP

The Survey Team prepared ESMP as a component of IESE. For the expansion project, required environmental management items are set as follows:

(i) Anti-pollution measure: air quality, water quality, material collection, waste management, soil contamination, noise and vibration, and management of abandoned site;

(ii) Natural environment: topography and geology; and

(iii) Social environment: living, hygienic condition, and landscape.

The key matter for social management plan is to provide information about dry season water level fluctuation and provide warning sign to riverside residents. Especially, the following mitigation measures shall be conducted to avoid social effects:

- At off-peak time, NN1 operation shall be held with at least 40 MW single unit. Zero operation is not allowed since maintenance flow is required. Single operation with 18 MW is possible only if the Nam Lik discharge is sufficient, more than 117.1 m^3/s[4].
- If dry season peak water level increase of Nam Lik 1/2 overlaps with that of NN1 in dry season at the downstream of the confluence, NN1 should request to the project owner of Nam Lik 1/2 to modify peak operation time of Nam Lik 1/2 so that overlapped downstream water level increase can be avoided. In addition, maintenance flow from Nam Lik 1/2 is required so that flow from the Nam Lik is more than 90% dependable discharge.
- Hourly data of downstream water level and discharge of NN1 power station and the Nam Lik River shall be monitored during detailed design and in the first half year of the operation.
- When shifting from off-peak to peak operation, step-wise increase by 80 MW at maximum has to be kept. Additional output increase should be conducted after 30 minutes or 1 hour to reach the maximum operation. Operation rule should be set accordingly.
- Warning sign board about rapid water level increase at riverside shall be provided where people have activities such as fishery, washing, pumping, gardening, and swimming before the completion of the construction. Requirement of warning system should be studied in detailed design stage.

Main item for environmental management plan is mitigation of temporary pollution to air and water during construction. At the basic design stage, the Survey Team conducted the following environmental and social consideration for construction works:

- Prevention of reservoir water pollution: for the construction work of dam piercing, temporary closure made of steel forepole is applied at the intake side of the dam to prevent water quality deterioration due to excavation work. The expansion project applies temporary closure of rectangular shape which is simple and convenient to install.

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[4] When assuming the worst case of 10 years possibility, discharge at 29.1 m^3/s can be added to discharge from NN1. Then, discharge of Base Condition (present) becomes 203.2 m^3/s, Case-40MW is 146.2 m^3/s, and Case-18MW is 86.1 m3/s. Accordingly, 203.2-86.1=117.1m^3/s is needed for the Nam Lik when single 18 MW is operated.

- Minimizing change of land surface: construction material will be collected not from quarry site but from existing collection site from the Nam Lik River, which is considered to cause lesser impacts. The required area for working yard, office, and construction camp is limited to about 2 ha at left bank of downstream of the dam, which can minimize change of land surface.

The expected raw materials to be used in the expansion works include cement, sand and gravel, timber, and water. The rough quantity estimate is as follows:

- Concrete: 16,000 to 30,000 m^3
- Sand and gravel including waste: 20,000 to 38,000 m^3
- Cement: 6,000 to 10,000 ton
- Timber and water: ad libitum
- Insulation oil: 7.6 kl/single phase x 3 phases = 22.8 kL
- Steel forepole for temporary closure: about 900 ton
- Steel for Intake, gate, and penstock, pipe: about 450 ton

The above amount is considerably small considering output scale compared to general new hydropower projects of the same output.

The rough amount of construction waste is estimated as follows:

- Demolished concrete from dam and buildings: 1,200 m^3
- Excavation for penstock and additional power station: 75,000 m^3
- Back-fill required for site: 15,000 m^3

The following table summarizes the environmental and social management and mitigation plans. These will be implemented by the engineer, environmental specialist, and hydrologist who will be employed in the detailed design and construction supervision stage, as well as contractors, and staffs of NN1 powerhouse.

Table 6.3.10 Environmental Management and Mitigation Plan

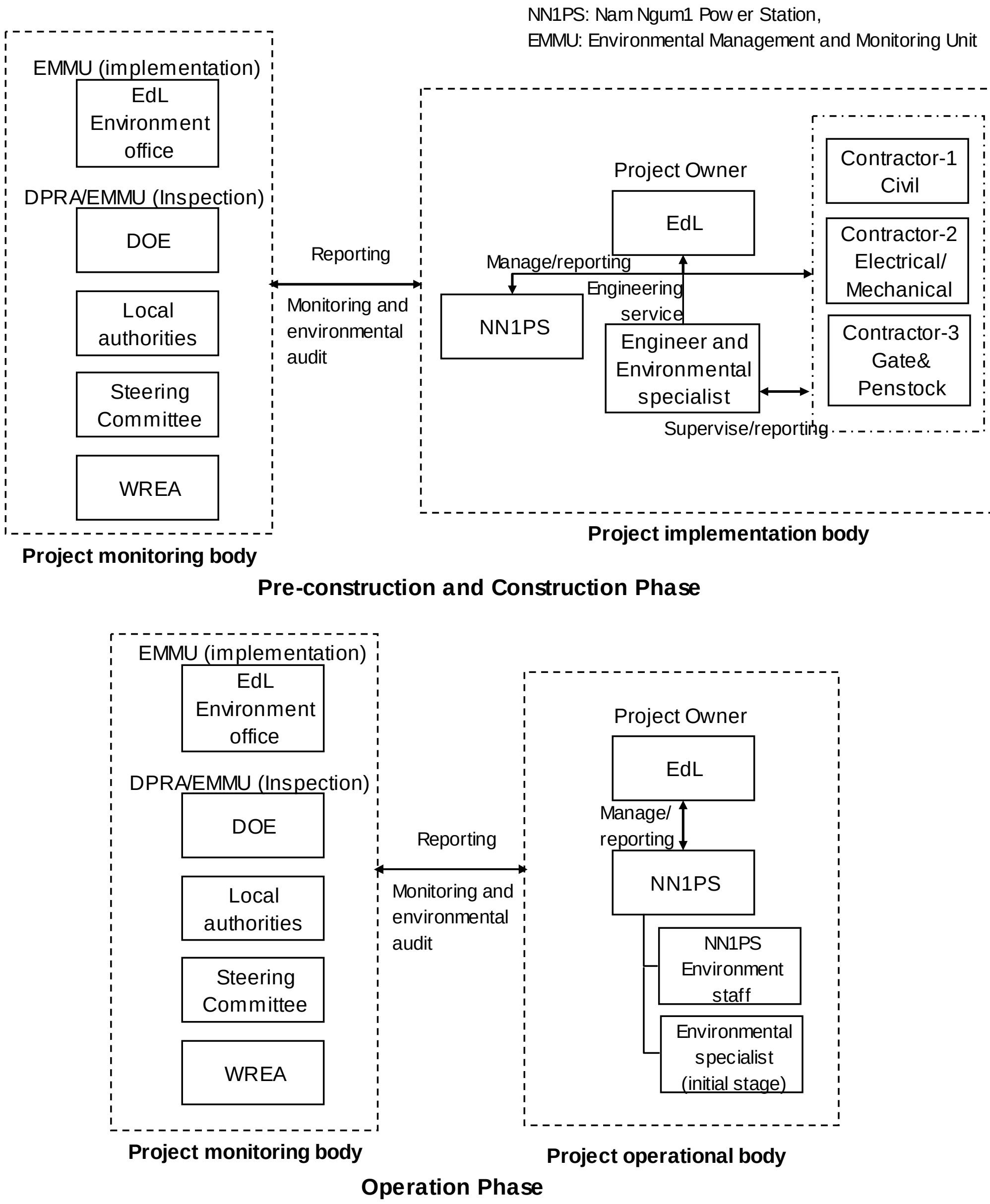
Description	Environmental Impact	Mitigation Plan	Responsibility
1. Study Stage (conducted in IESE)			
Environmental permits	-	Environmental Clearance Certificate must be obtained before starting construction.	EdL
Explanations to the Public	-	Village consultation to all downstream 24 villages were held during survey. Public Consultation was held on 16 June 09 and consensus was obtained for project implementation.	EdL and consultants
2. Construction Stage			
2.1 Anti-pollution measures			
Air quality	Dust increase on earth road during dry season	- Sprinkle water to control dust - Minimize travel distance	Contractor
	Increase of emission	- Regular checking of engine and exhaust of machinery, and its recording and reporting	Contractor
	Dust increase during aggregate collection	- Respiratory protection for workers at site	Contractor
Water quality	Increase of suspended soil, particular matter, and DO	- Regular water sampling and quality analysis at downstream of construction site. In case not acceptable level, find reason and trap waste water.	NN1PS/Engineer
Waste	Production of large amount of demolished concrete and excavated soil	- Dispose of materials to approved area so as no to disturb scenery and not to contaminate water.	Contractor
Soil contamination	Leakage of insulation oil and machinery oil possibly affects.	- Capture insulation oils in barrel and use oil proof sheet to avoid any leakage.	Contractor
Noise and vibration	Not significant since site is apart from villages, but access road is affected.	- Instructuction to driver to comply speed limit. - Check proper material loading and unloading. - To use silnecer and muffler for equipment.	Contractor
Management of abandoned sites	Site	- Site rehabilitation with topsoil recovery, reshaping, revegetation, and remediation with site clean up work - Stabilization of waste disposal area	Contractor
2.2 Natural Environment			
Subsidence	Not expected	-	-
Odor	Not expected	-	-
Sediment	Not expected	-	-
Protected areas	Not expected	-	-
Ecosystem	Not expected	-	-
Topography and geology	Collapse of cut stone and deterioration of mud stone foundation may happen.	- Prevention with rock support and prompt concrete work in construction.	Engineer
2.3 Social Environment			
Resettlement and compensation	Not expected	-	-
Sanitation	Camping of construction worker s health problem and disease may happen.	- Provision of proper sanitation with septic facilities. - Prohibition of untreated human waste to enter any watercourse.	Contractor
Heritage	Not expected	-	-
Living and livelihood	Provision of employment opportunity (positive)	-Source workforce from qualified locals and orient workers on desirable working relationship with skill enhancement and employment program.	Contractor
Landscape	If optional work of removing downstream rock shelves conducted, minor scenery is changed.	- Provision of explanation to villagers and tourists for the meaning that the work is enhancing energy, which can reduce CO2 and benefit to global environment.	Engineer/NN1PS
Ethnic minorities and indigenous peoples	Not expected	-	-
3. Operation Phase			
Hydrology/ Social and economic environment, public safety	Water level decrease during off-peak time, depending on Nam Lik flow in dry season.	- Daily monitoring downstream water level including the Nam Lik. Avoid zero or single 18 MW operation for off-peak hours to keep downstream water level. - Precaution to downstream communities for rapid increased/decrease of river water level with sign board and public consultation. Keep present output increase rate and conduct gradual opening output as possible.	NN1PS
	Water level increase during peak operation, depending on Nam Lik flow in dry season.		NN1PS
	Rapid water level increase from off-peak to peak time.		NN1PS
4. Monitoring and Audit			
Environmental audits	-	Undertake third party monitoring audits	WREA,
Environmental monitoring	-	Monitoring by EMMU for compliance of ESMP and ECC.	NN1PS, EMMU

NN1PS: Nam Ngum 1 Power Station. ECC: Environmental Compliance Certificate.

Prepard by JICA Survey Team

(2) Framework of ESMP

The figure below shows institutional framework at construction and operation stages. The Project Owner EdL will employ the engineer and environmental specialist for construction supervision. NN1 will assign a section for social relations so that general people can make a contact if any environmental and social issue occurs.



Prepared by JICA Survey Team

Figure 6.3.11 Environmental Management Frameworks

The Steering Committee includes provincial, district, and local authorities, and consists of the following organizations:

(1) Department of Electricity
(2) Provincial Water Resources and Environmental Office
(3) District's Water Resources and Environmental Office
(4) Provincial Agriculture and Forestry Office

(5) District Agriculture and Forestry Office
(6) Village administrative authorities.

The management arrangement and its roles are summarized in the table below.

Table 6.3.11 Management Arrangements for ESMP of Expansion Project

Item	Management Body	Role	Remarks
1. Project Owner	EdL	Overall project management Project financing	
2. Project Management	Nam Ngum1 PS , the Engineer, and environmental specialist	Expansion project management at site, implementation of ESMP	The Engineer will be selected before construction.
3. Project Contractors	To be determined	Works stipulated in a contract of the expansion project	
4. Environment Management Personnel			
Project's EMO	NN1 PS environment staff and Head of Environmental Office, EdL	Environmental monitoring during implementation of expansion project	
DOE EMMU	Social and Environmental Management Division, DOE	Environmental monitoring and inspection for expansion project	
WREA	Head of Division for Energy Sector, ESIAD	Guidance for environmental administration according to Decree, guideline, and standard.	
Contractor's environmental staff	To be assigned from contractor	Compliance of environmental management during works at site	
5. Environmental Advisory Panel	--		Not proposed since the impact is not significant.
6. Consultative committees	Steering Committee	Third party's monitoring, consolidation of local opinion during construction and operation, and recommendation to project	Compose of DoE, NN1PS, Provincial and district WREA and MoAF, and village authorities

Prepared by JICA Survey Team

(3) Contractor's Environmental Management Plan (CEMP)

Three contract packages are being proposed for the construction work of the expansion project: (i) civil works, (ii) hydraulic works, and (iii) electrical and mechanical works. These may be reviewed based on contract scale. CEMP shall be provided to all contractors' bid documents for works on the projects. All ESMP requirements, that are the responsibility of contractors, shall be included in the contract documents. The requirements are set out in CEMP. DOE and WREA shall approve all CEMP and monitor its implementation.

For the compliance of environmental requirements, contractors shall appoint an environmental and safeguard officer. Said officer shall be qualified in environmental and safety matters and familiar with the type of works being performed. His assignment shall be full-time and include initiation of measures for the ESMP, protection of health, and prevention of accidents. He should also oversee all environmental and safety regulations. Contractors shall hold regular meetings on environment and safety at least once every month with the engineer and environmental specialist. Contractors shall be responsible for all environmental, safety and health controls and shall submit a written program to the engineer for approval of the environmental and safety methodology. Requirement for CEMP is summarized in the table below.

Table 6.3.12 CEMP Requirement

Category	Description
Public morality	Contractors shall pay attention to the public morality of his staff and workers both on and off the site. In the interests of good community relations, contractors and his personnel shall be circumspect in their dealings with people residing near site and take steps to minimize any disturbance to them. Contractors shall arbitrate any dispute arising between his personnel and persons in the neighborhood of the construction works.
Safety	Contactor shall take all necessary precautions against risk of loss of life or of injury to any person employed in the works, to employees of the project owner, the engineer, or to visitors having good and sufficient reasons to be about the works. Contractors shall furthermore take all necessary precautions against damage to the property of others located at or adjacent to the site. Contractors shall make arrangements to transport, store, and handle explosives and fuels in a safe manner for protecting the public in accordance with the laws and security regulations in Lao PDR. Contractors shall obtain all necessary licenses and shall pay all charges in respect of the same as may be necessary for the purpose of moving, storing, and handling explosives and fuels, and shall make all applications and obtain approvals for the same from relevant authorities of the Government of Lao PDR.
Sanitary and Hygiene Arrangement	Contractors shall keep the site in a clean sanitary condition. Contractors shall construct and maintain at the site temporary toilet facilities complete with adequate toilets bowls, urinals and hand basins, collection tanks, sewage treatment systems and absorption trenches, for all of his personnel. Contractors shall instruct his personnel to use only these toilet facilities. The location of these facilities and their construction shall be as approved by the engineer and the project owner. Sewage from temporary facilities shall be disposed of in a hygienic manner as approved. If contractors adopt untreated water supply system of the work sites, he shall make suitable arrangements for an adequate supply of treated drinking water to be made available for his personnel at the work sites. Contractors shall remove all rubbish and shall provide an adequate number of covered garbage bins and containers placed at convenient points around his camp yards and work sites. Contractors shall institute and maintain a regular garbage collection and disposal system, utilizing a covered vehicle for collection and transport of garbage to the place of disposal. Garbage shall be disposed by burning, burial or other means approved by the engineer and the project owner.
Air, Water, and Soil Conservation	All precautions shall be taken by contractors to prevent the air, surface water and underground water, from any kind of pollution within and adjacent to the construction site. Precautions shall also be paid to soil erosion from any lands used or occupied by contractors for the purpose of temporary works and of the bed or banks of any river and the deposition of excavated or eroded material in any river that may result from the execution of works. Contractors shall carry out proper measures to reduce dust nuisance resulting from his operations. Measures shall include, but not be limited to, installation of dust suppression units on his equipment, watering down of excavated material during loading operations, provision of respiratory protection such as musk for workers, and use of water tanks and sprinkler to public roads, material collection areas, and disposal areas. All soil conservation measures shall be carried out at the earliest possible time to ensure that required protection is established most effectively during the progress of works.
Tree Preservation	Due precautions shall be taken by contractors and those workers to protect trees and shrubs as far as is practical in and adjacent to work sites. Trees shall not be cut down or removed without the approval and contractors shall prepare necessary application for approval of tree cut.
Waster Material	Construction waste such as demolished concrete and excavated soil shall be kept spoil bank approved by the engineer. No materials from required excavations shall be removed from the site without written approval of the engineer.
Noise Control	Contractors shall carry out work without unreasonable noise. Compressors used on the site work shall be silenced either by using full silenced models fitted with effective exhaust silences and properly lined and sealed acoustic covers to all the design of the manufacturers of the compressor or by the use of effective acoustic screens to enclosure the noise source. Pneumatic percussion tools used on the site shall be fitted with silencers or other equipment shall be maintained in good and efficient working order.

Prepared by JICA Survey Team

(4) Environmental Monitoring Plan

Based on above description, environmental and social monitoring plan is set as shown in the table below with corresponding responsible party and frequency of implementation.

Table 6.3.13 Environmental and Social Monitoring Plan

Description	Mitigation Plan	Responsibility	Monitoring	Frequency
1. Study Stage (conducted in IEE)				
Environmental permits	Environmental Clearance Certificate must be obtained before construction.	EdL	-	Done
Explanations to the Public	Explanation to all downstream 24 villages were held during survey. Public Consultation was held on 16 June 09 and consensus was obtained for project implementation.	EdL and consultants	-	Done
2. Construction Stage				
2.1 Anti-pollution measures				
Air quality	- Sprinkle water to control dust - Minimize travel distance	Contractor	Contractor	Daily
	- Regular checking of engine and exhaust of machinery, and its recording and reporting	Contractor	Enineer	Monthly
	- Respiratory protection for workers at site	Contractor	Enineer	Daily
Water quality	- Regular water sampling and quality analysis at downstream of construction site. In case not acceptable level, find reason and trap waste water.	NN1PS/Engineer	EdL	Monthly
Waste	- Dispose of materials to approved area so as no to disturb scenery and not to contaminate water.	Contractor	Enineer	Weekly
Soil contamination	- Capture insulation oils in barrel and use oil proof sheet to avoid any leakage.	Contractor	Enineer	Weekly
Noise and vibration	- Instructuction to driver to comply speed limit. - Check proper material loading and unloading. - To use silnecer and muffler for equipment.	Contractor	Enineer	Weekly
Management of abandoned sites	- Site rehabilitation with topsoil recovery, reshaping, revegetation, and remediation with site clean up work - Stabilization of waste disposal area	Contractor	Enineer	At finishing stage
2.2 Natural Environment				
Topography and geology	- Prevention with rock support and prompt concrete work in construction.	Engineer	EdL	Before construciton
2.3 Social Environment				
Sanitation	- Provision of proper sanitation with septic facilities. - Prohibition of untreated human waste to enter any watercourse.	Contractor	Enineer	Weekly
Living and livelihood, safety	-Source workforce from qualified locals and orient workers on desirable working relationship with skill enhancement and employment program.	Contractor	Enineer	Work commence ment
Landscape	- Provision of explanation to villagers and tourists for the meaning that the work is enhancing energy, which can reduce CO2 and benefit to global environment.	Engineer/NN1PS	EdL	At finishing stage
3. Operation Phase				
Hydrology/ Social and economic environment, public safety	- Daily monitoring downstream water level including the Nam Lik. Avoid zero or single 18 MW operation for off-peak hours to keep downstream water level.	NN1PS	EdL	Every day
	- Precaution to downstream communities for rapid increased/decrease of river water level with sign board and public consultation. Keep present output increase rate and conduct gradual opening output as possible.	NN1PS	EdL	Every day
4. Monitoring and Audit				
Environmental audits	Undertake third party monitoring audits	WREA,	-	1year after construction
Environmental monitoring	Monitoring by EMMU for compliance of ESMP and ECC.	NN1PS, EMMU	WREA, Steering Committee	Quartely

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For the environmental monitoring, the following monitoring items are necessary in the project.

- Ambient monitoring: Water quality and hourly water level measurement at the Nam Lik River and the Nam Ngum River shall be conducted by the project owner and environmental specialist
- Validation monitoring and Effectiveness monitoring: Engineers and environmental specialist shall prepare Quarterly Report with specifying impact items if the impact is already predicted or not and if the measurements are effective in ESMP.
- Compliance monitoring: to ensure that the ESMP is being implemented as required and that the appropriate regulatory requirements, standards, etc., have been met. Environmental Auditing shall be conducted by Steering Committee and WREA.

To demonstrate the compliance with the environmental management, the contractors will maintain daily records of his mitigation implementation during the construction phase. The EMMU for implementation, namely, Environmental Office of EdL, shall carryout monitoring works. The engineer and environmental specialists will prepare Quarterly Monitoring Reports during construction phase. After the approval by the project owner of NN1 power station, EMMU for implementation will review the report with those conducting the site survey. Then, Quarterly Monitoring Report shall be submitted to EMMU for inspection, namely, Social and Environmental Management Division of DOE. EMMU for inspection shall give advice for corrective action according to the Quarterly Report. Said report shall also be distributed to WREA and Steering Committee for their comments and suggestions. The EMMU for implementation and environmental specialist shall compile the Final Environmental Monitoring Report of the construction phase within three months of the construction completion and submit to EdL, DOE, WREA, and Steering Committee. The project shall pass the report to stakeholders to get feed backs. The designated Environmental Specialist shall provide database of environmental management works such as water level record to Project Owner for future use.

For environmental auditing, WREA shall conduct it and prepare an environmental audit report of the project after one year of the operation start of the expansion project. The environmental audit report includes a final assessment of the degree to which the project satisfied as part of the proposed environmental requirements, the effectiveness of mitigation measures and institutional development and whether any unanticipated effects occurred as a result of the project activities.

(5) Cost and Schedule of ESMP

The cost for environmental management is shown in the table below. This will be included in the overall project cost as an environmental management cost.

Table 6.3.14 Cost Estimation for Environmental Management

Description	Unit price	Qty	Unit	Amount
Detailed Design				
Environmental Specialist (international)	20,000	1	P/M	20,000
Hydrologist	4,000	2	P/M	8,000
Miscellaneous expenses	14,000	1	L.S.	14,000
Subtotal				***42,000***
Construction				
Environmental Specialist (international)	20,000	3	P/M	60,000
Environmental specialist (local)	4,000	18	P/M	72,000
Water quality Analysis	2,000	18	set	36,000
Governmental monitoring cost	1,200	12	times	14,400
Miscellaneous expenses	91,200	1	L.S.	91,200
Subtotal				***273,600***
Operation				
Environmental Specialist	4,000	3	P/M	12,000
Hydrologist	4,000	2	P/M	8,000
Governmental monitoring cost	1,200	4	times	4,800
Environmental audit cost	5,000	1	time	5,000
Miscellaneous expenses	14900	1	L.S.	14,900
Subtotal				***44,700***
TOTAL				**360,300**

* Compensation is not included Unit:US$

* Miscellaneous expenses includes transportation, communication, reporting, etc.

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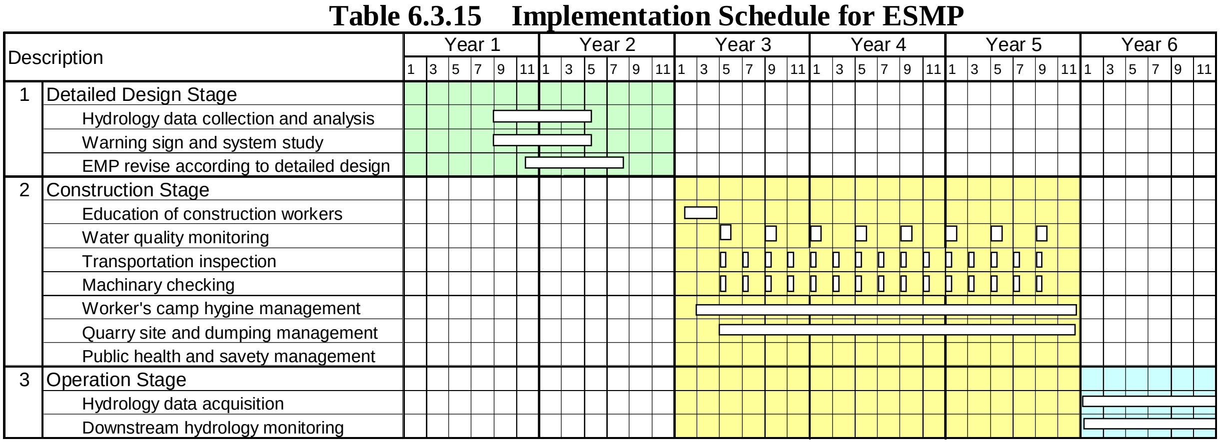
As shown in Table 6.3.14, the costs of detailed design and construction stages (in total US$0.32 million) will be covered under the construction cost with a loan component once the loan has materialized. However, cost of operation stage (US$45,000) has to be covered by the Project Owner.

The implementation schedule of ESMP is shown in the table below. The ESMP will be conducted during detailed design stage and construction period. Furthermore, it is necessary to continue one year after the onset of operation. The schedule is tentative and might change according to the funding schedule.

Table 6.3.15 Implementation Schedule for ESMP



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6.3.5 PUBLIC CONSULTATION

Village Consultation was conducted from 29 May to 5 June during the village socio interview survey in all 24 downstream riverside villages within 50 km from NN1. Public Consultation was conducted on 16 July 2009 at conference hall of NN1 power station with participants representing local authorities, village heads, officials of district and provincial organizations, WREA, and EdL officers. Project component and possible impacts and effects were explained to participants who expressed clear understanding of the project. Basic consensus towards the construction of NN1 expansion project was obtained by participants. The minutes of the public consultation is attached in Appendix C.

The summary of the result of village consultation is as follows:

(1) Affecting water level increase for riverside gardening and affecting water level decrease for boat transportation, fish pond, gage fisheries and water pumping;

It was explained that the water level fluctuation is considered to be affected during the dry season for downstream households. It was confirmed that they would have almost no adverse impacts to the economic status within a fluctuation range at 0.5 m, while none of the riverside cultivators complained that they will be affected of such increase.

(2) Requirement for resettlement and compensation

Villagers confirmed that the allowable water level increase is 0.5 m at peak time. When the water level decreases to 0.6 m at off peak, small number of families would be affected. This include those engaged in boat transportation and fisheries as their allowable water level is 0.5 m. However they will all waive for the project to proceed.

(3) Overall opinion of the downstream people to the project

All village authorities and household heads interviewed agreed with the Government's plan for NN1 hydropower station expansion as it would be the main potential sources of income for the country. They all opted to waive for any resettlement and compensation since the main impact of water level change will not at all affect their assets and impacts are much smaller compare to natural disaster.

The comments and feed-backs from the participants of the concluded Public Consultation are summarized as follows:

1) Comments from village authority: Village authorities agreed with the presentation of the IESE team on the information regarding initial environmental and social impacts, and measures to address the issues. They gave further instruction to organizations concerned such as concerned units of the province, district and authority at the village level. They must take responsibility in educating people in order to make those who are likely to be affected from the project understand more with the aim to achieve overall national interest, otherwise misunderstanding such as fear of impact on flood, which is not related to the expansion project, may occur.

2) Comment and advise from WREA for the plan of environmental management that IESE team:

- further attention should be given to the long term impact that may arise from the development of the project
- allocation of funding in detail should be presented that will be used in the work of environmental and social management as well as monitoring from each relevant sector that should be done sufficiently.
- attention should be given to the stage of working with locality especially the participation of the people as well as community who may be affected from the expansion project.

3) Comments from other participants such as the village head and provincial authority:

- we ask the Project Owner as well as IESE team to pay close attention to the mitigation measures and monitoring and do it carefully and clearly in order to make the project runs smoothly, without any or reduce and minimize possible negative impacts to the locality either on environment or society and those mitigating measures must be included in the agreement with the contractor and make it easier to monitor.

Those comments have already been incorporated in this IESE report and ESMP.

As the future Public Involvement requirement during pre-construction stage, EdL, NN1 power station and the engineer shall hold Public Consultation meetings. The required contents for the pubic consultation are as follows:

- Public awareness for detailed construction works
- Information provision about detailed assessment of downstream water level change
- Warning and information provision about water level acute change at the shift of peak and off-peak time

In addition, it is necessary to allocate and assign personnel in charge of social issues during construction and operation so that the general public can contact them for any complaints and issues.

6.4 CO_2 EMISSION REDUCTION BY THE EXPANSION PROJECT

Generally, CO_2 emission from hydropower is much lower than thermal power. The emission factor of hydropower is 5 g/kWh while that of thermal power using petroleum is 188 g/kWh[5]. Accordingly, there is no substantial impact of global warming owing to the expansion project. Thus, the project has positive impacts on global warming.

NN1 hydropower expansion project aims to enhance hydropower and there is little emission greenhouse gas during project operation. In the construction stage, some amount of CO_2 will be emitted from the following activities:

- Diesel oil consumption during transportation of materials
- Diesel oil consumption during application of heavy construction machinery

In addition, methane leakage is considered in general hydropower due to anaerobic fermentation by submergence of organic material in reservoir. The expansion project does not have this aspect, since the reservoir was created in 1969 and no additional reservoir is created in this expansion project.

5 Dam Handbook (Dam Binran) using material of Ministry of the Environment, Japan, 1995

The Project could possibly apply for Clean Development Mechanism (CDM), since the expansion is for hydropower of renewable energy. The methodology of ACM0002 (Version 07), "Consolidated baseline methodology for connected electricity generation from renewable sources", in effect in December 2007, could be possibly adapted for CDM application of the expansion project. Although EdL grid is supplied mainly by hydropower, the methodology can be applied when EdL grid is considered to be combined with EGAT grid in Thailand. The increase of the energy output in NN1 can substitute the energy for thermal power and save the use of fossil fuel in Thailand.

After the development of Nam Ngum 2 (NN2), inflow of NN1 will be seasonally regulated for the sake of NN2 dam. This enables NN1 to utilize more water than before since spilled water in rainy season from Nam Ngum 1 reservoir will be able to be utilized after NN2 construction. Moreover, when 40 MW is expanded, the expansion enables additional power utilization of spilled water at NN1. This additional energy due to 40 MW expansion can be considered to be the emission reduction of CO_2 by a substitution of energy from thermal power in Thailand.

However, the main objective of the expansion project is to shift the energy from off-peak to peak time. Thus, above additional energy output is considered to be a minor component. Of the estimated 1,120 GWh total annual output of 40 MW expansion plan, only 56 GWh can be considered to correspond as additional output as shown in the table below. This is only a small fraction of general new hydropower.

The Survey Team calculated emission coefficient and emission reduction of CO_2 using the methodology described in "Study on Policy for Project Formulation of Countermeasure of Climate Change in Electricity and Energy Sector, August 2008, JICA" (JICA method). The Survey Team used the base data of Thailand, and not of Lao PDR, since increased energy of NN1 expansion is considered to substitute the energy of Thailand EGAT grid. Although the emission factor of EGAT Grid is calculated to be 0.56 ton-CO_2/MWh in, the emission factor calculated applied in above method was 0.706 ton-CO_2/MWh. This is because JICA method considers substituting from the most expensive energy source first. According to IEA database in 2006, power source of EGAT grid is natural gas at 68%, coal at 18%, and petroleum is at 6%. CDM methodology applies weighted average of the energy source component. Meanwhile, JICA method substitutes petroleum first, which is the most expensive energy source and has high emission coefficient (0.708 for petroleum, higher than 0.414 for natural gas). In the JICA method, this substitution is possible up to 5% of all energy used in the grid. The substitution due to expansion project is less than the amount. Accordingly, emission coefficient of petroleum was applied to all energy substitution in the JICA method. This is larger than that of grid average emission coefficient. The calculation is shown in the table below.

Table 6.4.1 Amount of Emission Reduction by NN1 Expansion Project

Country: Lao PDR (Calculation is based on data in Thailand)

Project effect:	56,000	MWh/year
Conversion factor:	3600	kJ/kWh
	41.868	TJ/ktoe
	10	Tcal/ktoe
	860	kcal/kWh
	3.667	t-CO2 / t-C

Description	Energy output		Electricity Input	Thermal Efficiency	Carbon Content	Fraction Factor	Emission coefficient	
	GWh	Ratio	ktoe	%	tC/TJ		kg-CO2/kWh	
Petroleum	8,521	6%	1965	37%	20.0	0.990	**0.708**	**0.556**
Gas	94,026	68%	18972	43%	15.3	0.995	**0.474**	
Coal	24,927	18%	4929	43%	26.8	0.980	**0.814**	
Other	11,268	8%	1626	60%				
Total	138,742	100%	27492	43%				
5% of Total	6,937	5%						

Description	Fuel cost	Constrain Priority	Installed Capacity	Load factor	Energy output	Reduction incapable	Reduction possible
			MW	%	MWh	MWh	MWh
Petroleum		1		0	8,521,000	6,937,100	1,583,900
Gas		2		0	94,026,000	6,937,100	87,088,900
Coal		3		0	24,927,000	6,937,100	17,989,900

Description	Reduction incapable	Reduction possible	Amount Reduction	Thermal Efficiency	Carbon Content	Fraction Factor	Fuel Reduction	Emission Reduction
	MWh	MWh	MWh	%	tC/TJ		ktoe	ton-CO2
Petroleum	6,937,100	1,583,900	56,000	37%	20.0	0.990	12.9	**39,650**
Gas	6,937,100	87,088,900	0	43%	15.3	0.995	0.0	**0**
Coal	6,937,100	17,989,900	0	43%	26.8	0.980	0.0	**0**
Total								**39,650**

			20	US$/ton-CO2
Project CO2 Emission:	0	ton-CO2/year		
Project Emission Reduction with grid coefficient:	31,135	ton-CO2/year	622,702	US$/year
Actual Project CO2 Reduction:	**39,650**	ton-CO2/year	793,001	US$/year

From the above calculation, when leakage is not considered, the emission reduction will be 39,650 ton-CO_2/year as per the JICA method. When grid average emission coefficient is used, emission reduction will be 31,135 ton-CO_2/year .When the price of Certified Emission Reduction (CER) is 20 US$/ton-$CO_2$, revenue of CER will be as shown in the table below.

Table 6.4.2 Emission Reduction and Revenue from CER

Method	JICA Method	EGAT Grid Average
CER Price	US$20/ton-$CO_2$	
Emission Reduction	39,650 ton-CO_2/year	31,135 ton-CO_2/year
Emission Coefficient	0.708 ton-CO_2/MWh	0.49 ton-CO_2/MWh
Revenue from CER	About 0.7 mil US$/year	About 0.5 mil US$

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When the expansion project is applied to CDM, the validation of baseline in monitoring of the expansion project would be difficult and require quite complicated procedure, different from new construction of hydropower projects. It needs to clearly segregate what portion of energy output is actually derived from the expansion project. Above annual output energy was calculated using the simulation of Implicit Stochastic Optimization method based on NN1 data for 30 years. The simulation result is well consistent with actual NN reservoir status. Said result could be used as baseline data in CDM. However, to use above simulation result as a baseline data, it needs to prepare PDD first, and see if it is approved in CDM board. Meanwhile, it is necessary that third party verify the result of simulation, and it is not clear if this is actually approved.

In addition, in the monitoring process, it needs to segregate annual increased energy amount of expansion project from the total energy output of NN1. Annual inflow condition varies over the years. It would need to monitor annual inflow of the Nan Ngum Reservoir after project commencement. Then, based on the discharge and water level data, it needs to compare the operation rule of “with 40 MW expansion” and “without expansion”, and compare energy output of with/without expansion project. Accordingly, it is necessary to clarify the amount of increased energy output enabled due to expansion project. This requires complicated hydrological simulation with data collection from NN2 and remaining catchment of the Nam Ngum 1 reservoir to distinguish the additional energy output. This shall be verified every year as a part of the monitoring process. This would be a considerable burden for the project proponent. In addition, it will need large amount of explanation and time for monitoring and verification.

Theoretically, it is considered possible to apply the expansion project to CDM. However, the actual procedure will be quite complicated. When considering the new hydropower with the same output as the expansion scale, CDM of new hydropower will have more simple process and larger CER revenue.