CHAPTER III PRE-FEASIBILITY STUDY

3.1 HYDROLOGICAL ANALYSIS

3.1.1 WHAT IS HYDROLOGICAL ANALYSIS?

Hydrological data is vital for the proper planning and designing of small-hydro development projects. Historic river flow characteristics of such as mean annual flow, low flow, flood flows, and flow duration statistics are required to evaluate a potential hydropower site. Daily flow records are used for estimating the hydro electric potential of the site. Peak flow records are used for planning and designing of facilities to safely bypass flood flows.

In the Northern Laos area, it is highly likely that there are only small amounts of data available on the rivers being investigated, and in some cases none. In this case, if records are available for other similar adjacent rivers, these can be used to estimate river flow characteristics for the proposed sites.

In hydropower planning, “Hydrology” is applied to mainly:

(i) Evaluation of river flow characteristics in terms of seasonal variation,

(ii) Prediction of river flows in terms of seasonal, yearly and monthly variations,

(iii) Evaluation of drought discharges of the river,

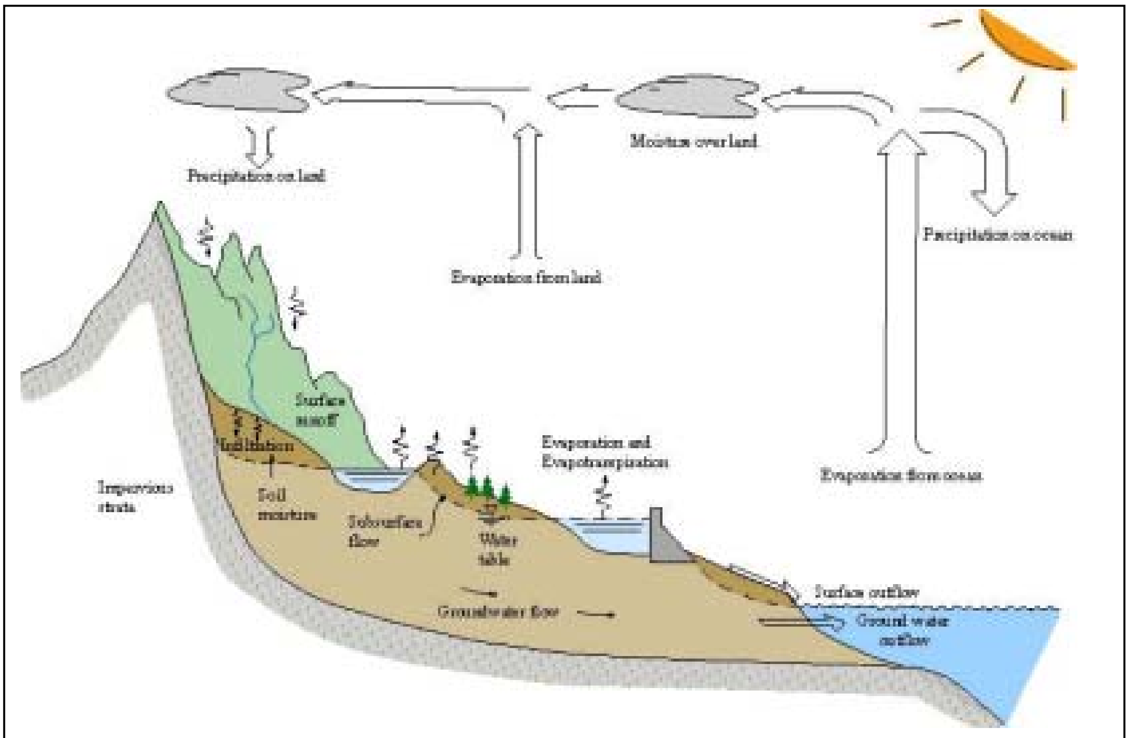
(iv) Relationship between rainfall and river runoff, and

(v) Estimation of flood flows at sites.

The extent of the hydrological analysis shall be determined after considering the amount and quality of the existing data and available information.

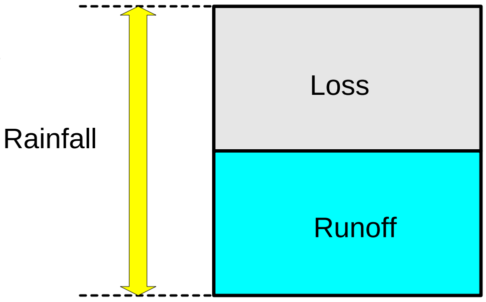
3.1.2 HYDROLOGICAL CYCLE AND RUNOFF COEFFICIENT

Figure in the next page shows an example of the hydrological cycle. The cycle has no beginning or end, and its many processes occur continuously. As shown schematically in this figure, Water evaporates from the ocean and the land surface become part of the atmosphere; The water vapor is transported and lifted into the atmosphere until it condenses and precipitates on the land or the ocean; The precipitated water may be intercepted by vegetation, or become a land flow over the ground surface, infiltrate the ground, flow through the soil as a subsurface flow, and discharge into streams as surface runoff. Much of the intercepted water and surface runoff returns to the atmosphere through evaporation. The infiltrated water may percolate deeper to recharge groundwater, later emerge in springs or seeping into streams to form surface runoff, and finally flow out to the sea or evaporate into the atmosphere as the hydrological cycle continues.



Hydrological Cycle

Some of the precipitated water evaporates and transpires, and some flows underground. The hydrological cycle is expressed in terms of annual balance:

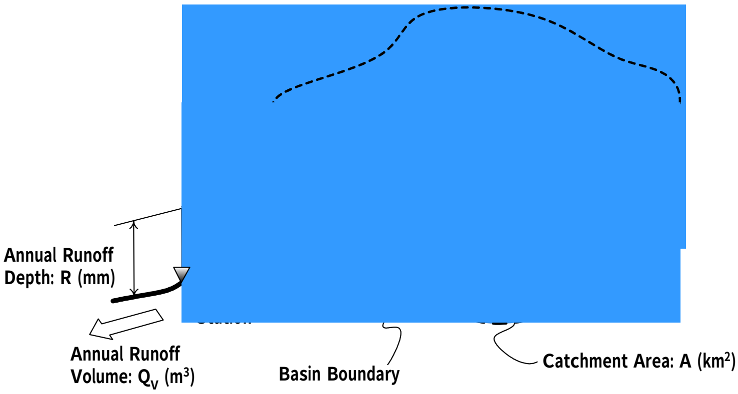


Annual Runoff = Annual Rainfall – Loss

Loss = Evapotranspiration + Subsurface Flow

The precipitated water is reduced by a loss of rainfall seeping into the ground and not recovered later in the form of subsurface flow. Evapotranspiration is the process by which water moves from the soil to the atmosphere. It comprises evaporation from the land or water surface, and transpiration from vegetation. Potential evapotranspiration can be estimated from record of pan evaporation measured at climatological stations and a conversion factor is applied to adjust for vegetation cover. A great deal of water evaporates if the air is dry and the sky is clear. Wind also increases evaporation as well as the length of the day and the air temperature. In practice, runoffs and losses are often expressed in terms of depth per year, so called the annual runoff depth in mm.

Annual Runoff Depth (mm) = Annual Rainfall (mm) – Loss (mm)



$$R = \frac{Q_V}{A \times 10^6} \text{ (m)}$$

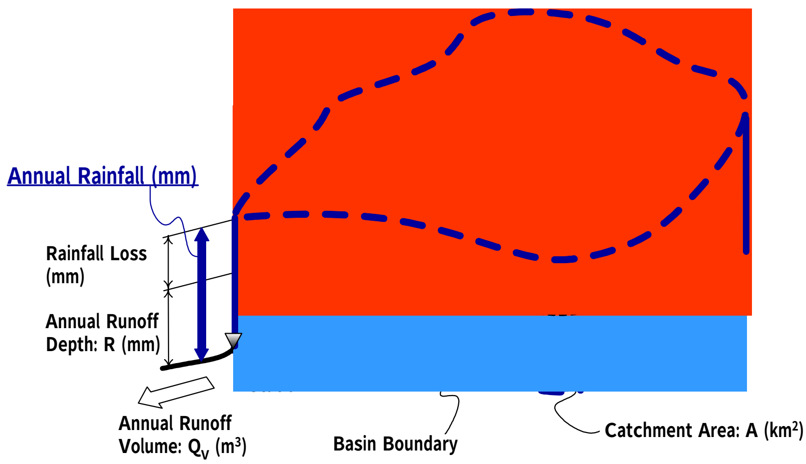
$$\textbf{Annual Runoff Volume (Qv in m}^3\textbf{/year)} = \sum_{i=1}^{i=365} Qi \ \textbf{x 60 (sec) x 60 (min) x 24 (hours)}$$

The annual runoff depth is computed by dividing the annual runoff volume by the catchment area at the gauge location as follows:

Annual Runoff Depth (Qr in mm) = Qv (m^3) / Catchment Area (km^2) x 10^{-3}

$$\textbf{Runoff Coefficient} = \frac{Qv}{Qr}$$

An inappropriate process of the conversion from the river water level records to the runoff records by means of the discharge rating curve might cause several defects in the resultant flow duration curve preparation. In order to avoid such possibility, the converted discharge data can be examined by means of cross-checking on the relationship between the annual mean rainfall over its watershed at the gauge location and its annual runoff depth. The difference between the annual mean rainfall and the annual runoff depth is so-called the evapotranspiration loss or the annual rainfall loss as schematically shown below.

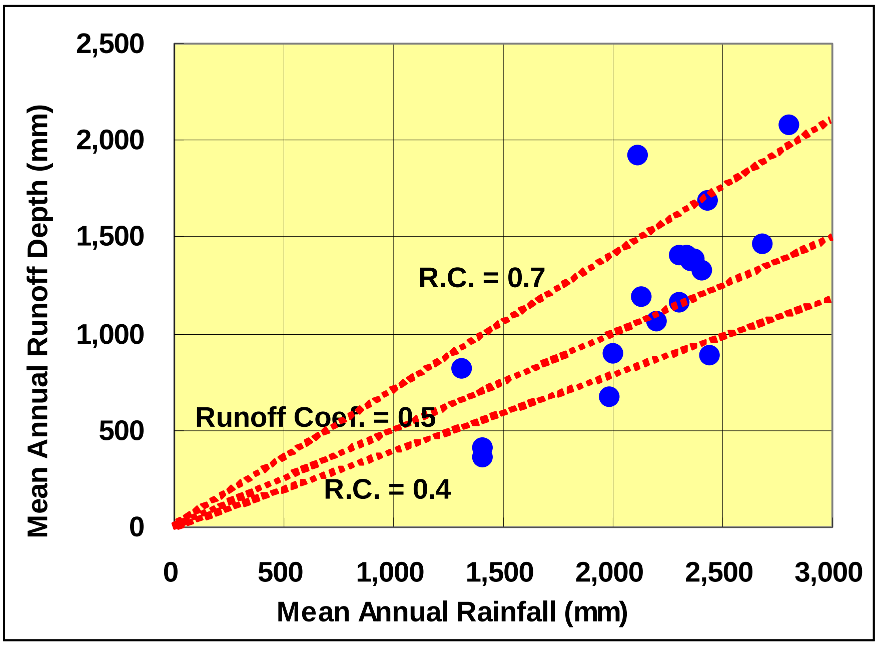


Reference: Runoff Coefficients in River Basins in Lao PDR

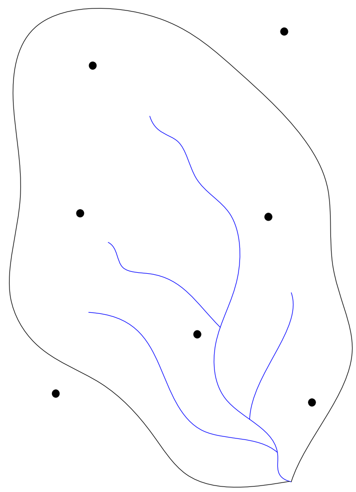
The relationship between the mean annual runoff at the river flow measurement station and the mean annual rainfall of the catchment area has been analyzed for several major rivers in Lao PDR undertaken by the Power System Planning in the Ministry of Industry and Handicraft in 1997. Most of the selected rivers locate in the northern region, only one station from the central Lao (Nam Theun at Ban Signo) and one from the southern Lao (Nam Sekong at Attapeu) are included. The relationship is summarized below.

River Basin	Station	Area (km2)	Mean Annual Rainfall (mm) ①	Mean Annual Runoff		Runoff Coefficient (=②/①)
				(m3/s)	(mm) ②	
Ou	Muong Ngoy	20,184	1,985	433.8	678	0.34
Suang	Ban Sibounhom	5,842	1,308	151.8	819	0.63
Khan	Ban Pak bak	7,049	1,408	80.0	358	0.25
	Ban Mixay	7,321	1,405	95.9	413	0.29
Ngum	Ban Naluang	4,756	2,000	135.8	900	0.45
	Damsite	8,372	2,306	309.6	1,166	0.51
	Ban Thalat	13,600	2,350	592.0	1,373	0.58
	Ban Pak Kanhoung	14,147	2,339	631.2	1,407	0.60
	Thangon	15,362	2,303	683.6	1,403	0.61
	Van Vieng	875	2,803	57.7	2,080	0.74
	Ban Hin Heup	4,860	2,429	261.0	1,694	0.70
	Muong Kasi	420	2,438	11.9	894	0.37
Nhiep	Muong Mai	4,367	2,409	184.5	1,332	0.55
Sane	Muong Borikhane	2,156	2,679	100.1	1,464	0.55
Theun	Ban Signo	3,505	2,113	213.9	1,925	0.91
	Kham Keut	7,726	2,133	291.2	1,189	0.56
	Phon Si	14,142	2,201	477.3	1,064	0.48
Sekong	Attopeu	9,696	2,371	426.0	1,386	0.58

The relationship is shown below. As seen, the runoff coefficient varies from 0.4 to 0.7.



3.1.3 RAINFALL ANALYSIS

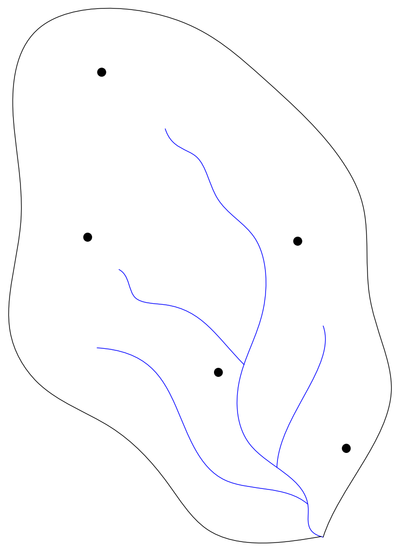


For estimation of the runoff coefficient, the annual basin mean rainfall shall be estimated. In Practice, there are three (3) methods of determining the basin mean rainfall: i) arithmetic-mean method; ii) Thiessen method; and iii) isohyetal method.

Suppose that there is a river basin which comprises the catchment area of 350 km^2 and there are five rainfall stations within the basin area and two rainfall stations close to the basin. The observed rainfall in each station is shown on the right.

(1) Arithmetic-mean Method

The arithmetic-mean method is the simplest method that involves averaging the rainfall depths recorded at a number of gauges as shown below. This method is satisfactory if the gauges are uniformly distributed over the area and the individual gauge measurements does not vary greatly from the mean.



$$\overline{P} = \frac{1}{N}\sum_{n=1}^{N} P_n$$

where, P : Basin Average Rainfall (mm)

N : Number of Rainfall Station

Pn : Observed Rainfall on each Station (mm)

Station	Observed Rainfall(mm)
P_2	220
P_3	250
P_4	120
P_5	130
P_7	120
Total	**840**

Basin Average Rainfall = 840 / 5 = 168 mm

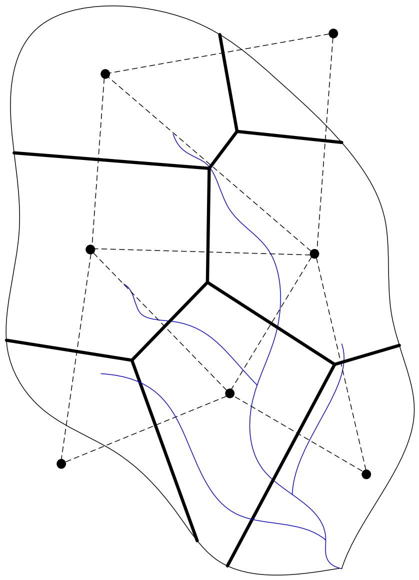
(2) Thiessen Method:

If some gauges are considered more representative for the area in question than others, the relative weights may be assigned to the gauges in computing the aerial average. The Thiessen method assumes that at any points in the watershed the rainfall is the same as that at the nearest gauge so the depth recorded at a given gauge is applied to a distance halfway to the next station in any direction. The relative weights for each gauge are determined from the corresponding areas of application in Thiessen polygon network, the boundaries of the polygons being formed by the perpendicular bisectors of the lines joining adjacent gauges. If there are N gauges and the area within the watershed assigned to each is A_n, and P_n is the rainfall recorded at the gauge, the areal average precipitation for the watershed is:

$$\overline{P} = \frac{1}{A}\sum_{n=1}^{N} A_n P_n$$

where, A; the watershed area $A = \sum_{n=1}^{N} A_n$

The Thiessen method is generally more accurate than the arithmetic-mean method, but it is inflexible, because a new Thiessen network must be constructed each time there is a change in the gauge network, such as when data is missing from one of the gauges. Also, the Thiessen method does not directly account for orographic influences on rainfall.



Station	Observed Rainfall (mm)	Area (km^2)	Weighted Rainfall (mm)
P_1	370	10	3,700
P_2	220	60	13,200
P_3	250	60	15,000
P_4	120	70	8,400
P_5	130	65	8,450
P_6	30	30	900
P_7	120	55	6,600
Total	**1,240**	**350**	**56,250**

Basin Average Rainfall = 56,250 / 350 = 160.7 mm

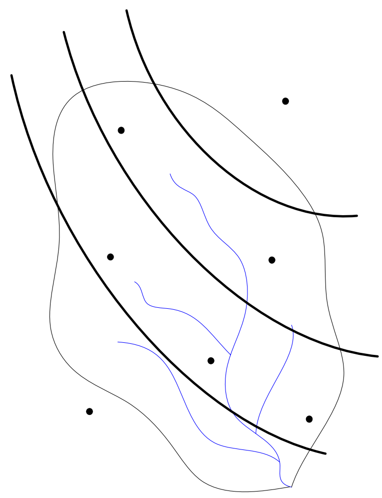
(3) Isohyet Method:

The isohyetal method overcomes some of these difficulties by constructing isohyets, using observed depths at rain gauges and interpolation between adjacent gauges. Where there is a dense network of rain gauges, isohyetal maps can be constructed using computer programs for the automated contouring. Once the isohyetal map is created, the area A_n between each pair of isohyets within the watershed is measured and multiplied by the average P_n of the rainfall depths of the two boundary isohyets, to compute the areal precipitation by the equation below:

$$\overline{P} = \frac{1}{A}\sum_{n=1}^{N} A_n\left(\frac{P_{n-1}+P_n}{2}\right)$$

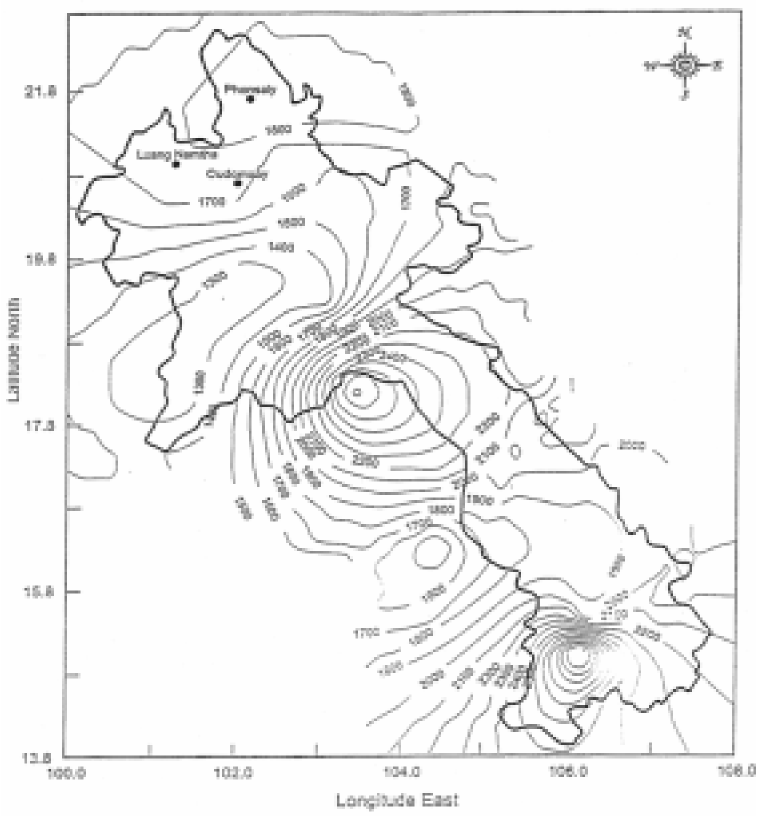
Isohyets Line (mm)	Average Rainfall (mm)	Area enclosed (km^2)	Rainfall Volume
-	60*	90	5,400
100	-	-	-
-	150	135	20,250
200	-	-	-
-	250	110	27,500
300	-	-	-
-	320*	15	4,800
-	-	-	-
Total	**780**	**350**	**57,950**

*Estimated



Basin Average Rainfall = 57,950 / 350 = 165.6 mm

The isohyetal map of average annual rainfall in Lao PDR which is prepared by Department of Meteorology and Hydrology is given below:



Average Annual Rainfall

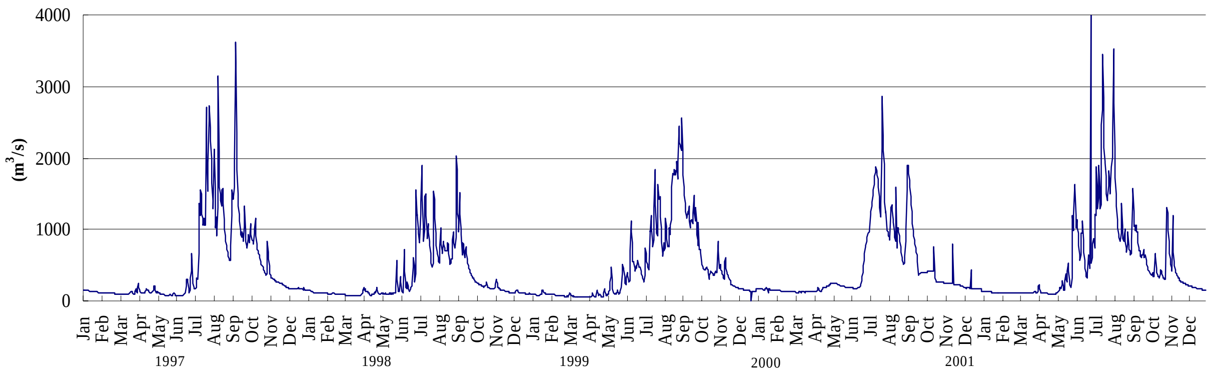
Source: Water Resources Guide Book of Lao P.D.R, Vol.1, Sep.2002, DMH

3.1.4 HYDROGRAPH AND FLOW DURATION CURVE

River flow varies from season to season and from year to year. There are two ways of expressing this; the annual flow hydrograph and the flow duration curve. Both of these are drawn up from the observed daily discharge records over many years.

(1) Hydrograph:

The hydrograph below shows a temporal pattern of the historical river flows elow is an example of the daily discharge hydrograph and daily discharge table guy station in the Nam Ou river.



Daily Discharge of Station: Ngoy, Nam Ou River (1997-2001)

Table Daily Discharge Table at Hinheup Station, Nam Lik River

Year : 1991 Unit : m^3/s

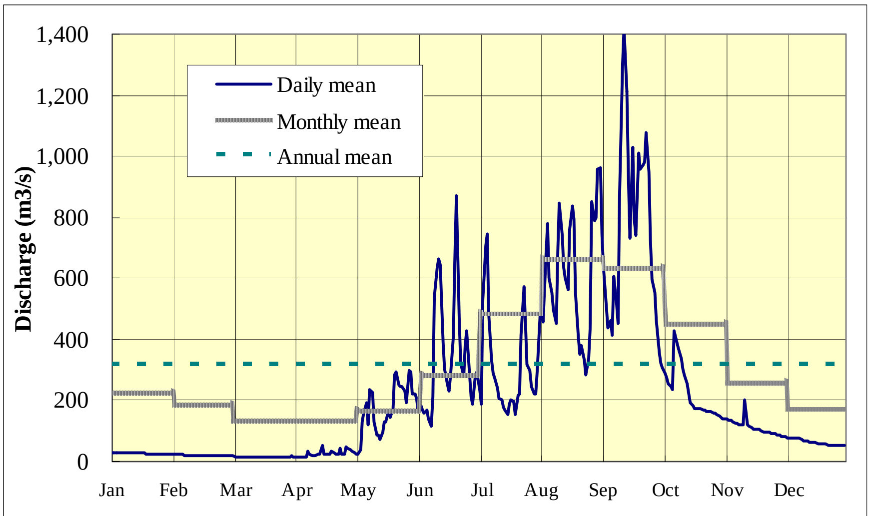
Date	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
1	229.0	215.0	158.0	134.0	127.0	181.0	372.0	367.0	625.0	557.0	411.0	205.0
2	231.0	215.0	154.0	134.0	129.0	151.0	392.0	609.0	575.0	616.0	398.0	205.0
3	231.0	215.0	150.0	132.0	130.0	190.0	403.0	i46,00	581.0	570.0	393.0	206.0
4	229.0	215.0	145.0	131.0	132.0	204.0	402.0	540.0	649.0	649.0	386.0	206.0
5	231.0	215.0	142.0	130.0	158.0	208.0	383.0	561.0	608.0	454.0	387.0	206.0
6	231.0	213.0	139.0	132.0	145.0	300.0	507.0	621.0	600.0	452.0	387.0	184.0
7	229.0	211.0	137.0	135.0	137.0	307.0	386.0	744.0	542.0	409.0	387.0	186.0
8	229.0	209.0	142.0	135.0	130.0	325.0	356.0	891.0	590.0	393.0	339.0	88.0
9	228.0	206.0	143.0	135.0	176.0	353.0	345.0	842.0	543.0	385.0	222.0	89.0
10	228.0	206.0	145.0	136.0	180.0	338.0	345.0	635.0	779.0	417.0	223.0	90.0
11	228.0	203.0	135.0	131.0	161.0	311.0	387.0	611.0	705.0	420.0	226.0	191.0
12	227.0	199.0	124.0	131.0	137.0	229.0	460.0	539.0	632.0	422.0	228.0	193.0
13	226.0	196.0	127.0	135.0	155.0	280.0	463.0	534.0	553.0	425.0	231.0	194.0
14	227.0	95.0	128.0	135.0	150.0	236.0	452.0	889.0	536.0	428.0	232.0	194.0
15	224.0	194.0	129.0	135.0	151.0	200.0	461.0	638.0	603.0	433.0	214.0	170.0
16	226.0	190.0	130.0	134.0	151.0	190.0	879.0	638.0	664.0	452.0	209.0	172.0
17	223.0	186.0	131.0	134.0	180.0	239.0	907.0	568.0	715.0	425.0	209.0	173.0
18	223.0	185.0	131.0	134.0	173.0	265.0	674.0	554.0	989.0	458.0	210.0	173.0
19	223.0	184.0	135.0	131.0	204.0	266.0	536.0	664.0	959.0	482.0	211.0	174.0
20	223.0	181.0	132.0	131.0	195.0	284.0	503.0	526.0	816.0	502.0	213.0	175.0
21	223.0	179.0	129.0	134.0	196.0	268.0	494.0	587.0	741.0	254.0	214.0	175.0
22	222.0	176.0	130.0	138.0	168.0	315.0	481.0	554.0	746.0	240.0	215.0	176.0
23	222.0	174.0	131.0	151.0	150.0	262.0	493.0	500.0	769.0	261.0	217.0	178.0
24	220.0	170.0	132.0	154.0	138.0	242.0	470.0	539.0	590.0	393.0	218.0	178.0
25	220.0	168.0	134.0	149.0	150.0	289.0	516.0	816.0	526.0	497.0	219.0	179.0
26	220.0	167.0	132.0	134.0	194.0	277.0	564.0	1120.0	502.0	479.0	195.0	180.0
27	220.0	164.0	134.0	129.0	239.0	285.0	525.0	1010.0	487.0	507.0	196.0	180.0
28	227.0	162.0	146.0	135.0	116.0	603.0	554.0	830.0	460.0	510.0	199.0	168.0
29	224.0		116.0	138.0	307.0	467.0	463.0	706.0	514.0	513.0	201.0	163.0
30	222.0		135.0	129.0	227.0	424.0	427.0	602.0	523.0	481.0	205.0	159.0
31	220.0		136.0		208.0		399.0	630.0		482.0		159.0
Mean	225.4	189.0	135.9	135.2	167.5	283.0	483.8	662.2	637.4	450.5	259.8	173.2
Max.	231.0	215.0	158.0	154.0	307.0	603.0	907.0	1120.0	989.0	649.0	411.0	206.0
Mim.	220.0	95.0	116.0	129.0	116.0	151.0	345.0	367.0	460.0	240.0	195.0	88.0

As given below, averaging of the river flow is usually made from the daily discharge data to compute the monthly mean discharge, annual mean discharge, mean monthly discharge and mean annual discharge.

Year	Monthly Mean Discharge (m^3/s)												Annual Mean
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
1991	225.4	189.0	135.9	135.2	167.5	283.0	483.8	662.2	637.4	450.5	259.8	173.2	**316.9**
1992	98.1	77.6	80.2	76.6	110.8	174.3	323.1	341.1	364.4	202.5	113.1	92.6	**171.2**
1993	45.5	37.7	25.7	19.8	61.1	250.8	589.7	430.8	431.9	203.5	106.6	76.9	**190.0**
1994	103.2	97.1	100.6	96.5	199.9	350.4	538.6	692.2	696.9	356.7	194.9	172.4	**300.0**
1995	52.3	42.2	33.2	32.2	56.4	176.8	604.9	1164.1	748.3	194.4	102.5	39.1	**270.5**
1996	25.8	23.9	29.7	37.9	46.1	119.7	229.5	620.7	478.5	181.5	128.2	60.3	**165.1**
1997	42.0	31.7	25.8	28.4	57.8	89.8	723.8	461.2	945.1	202.1	87.4	47.4	**228.5**
1998	25.3	15.2	8.4	19.6	23.6	106.3	318.1	366.2	298.1	104.6	54.0	31.1	**114.2**
1999	27.1	20.3	15.8	25.4	160.5	339.1	304.5	588.2	780.2	231.7	113.7	64.1	**222.5**
2000	40.8	32.0	16.9	12.5	164.9	496.1	448.4	630.8	727.8	210.0	105.7	59.6	**245.5**
2001	43.3	36.6	55.4	30.7	100.3	318.5	519.8	963.3	669.6	255.1	136.8	89.7	**268.3**
2002	83.0	62.6	52.8	46.7	195.1	503.0	469.6	785.1	505.2	245.4	204.0	111.6	**272.0**
Mean Monthly	**67.6**	**55.5**	**48.4**	**46.8**	**112.0**	**267.3**	**462.8**	**642.1**	**607.0**	**236.5**	**133.9**	**84.8**	**230.4**

Mean Annual

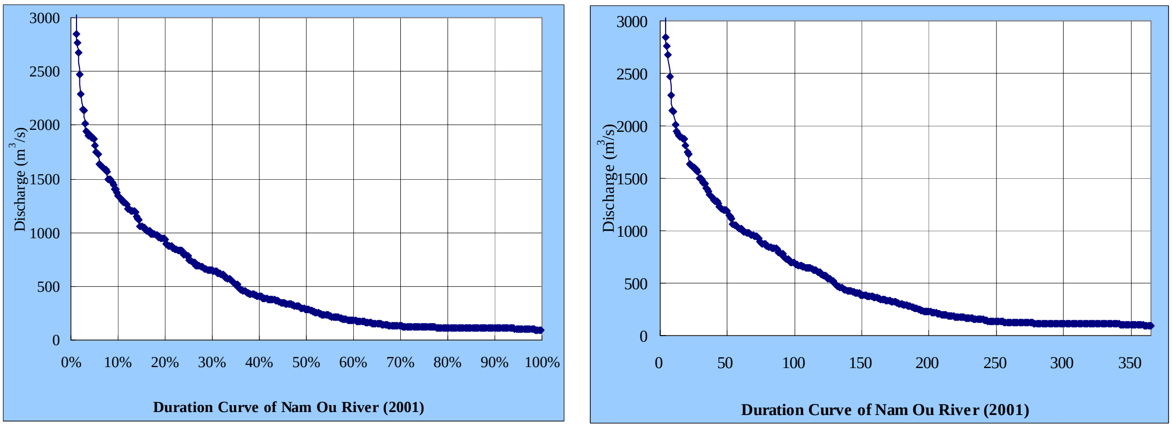
The relationship among the daily mean, monthly mean and annual mean discharges is schematically shown below.



Annual and Monthly Mean Discharge of Nam Lik River, 1991

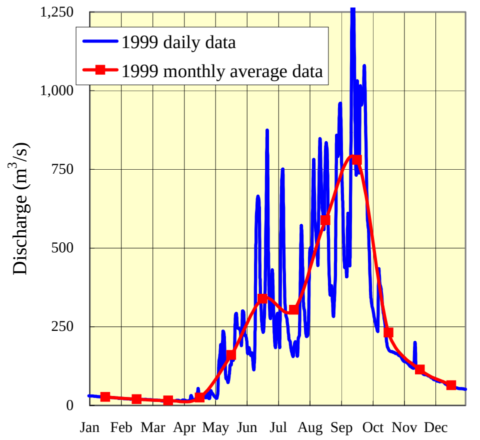
(2) Flow Duration Curve:

When the river flow records in a specific period (usually a year) are arranged in the descending order and plotted, the graph is called a flow duration curve. The flow duration curve is a plot of river flows against the number of days when the flow is equaled or exceeded in the given period. The ordinate is usually expressed in terms of m^3/sec. The abscissa covers either full year or can be expressed in terms of days or proportion (percentage) of the complete period. Below is an example of flow duration curves on different abscissas.

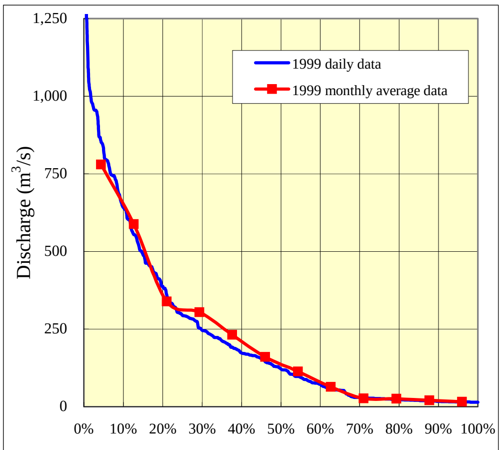


Comparison of Flow Duration Curves on Different Abscissas

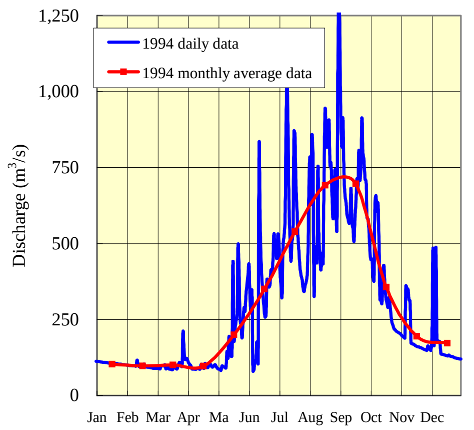
The flow duration curve of the observed flow characteristics for the given site shall be drawn a daily basis. The flow duration curves developed from the monthly flow data tend to overestimate flow values less than those obtained from the daily data, and thus are likely to be less reliable. Figure below shows a comparison of the duration curves drawn on the daily and monthly basis for the discharge of the Nam Lik River.



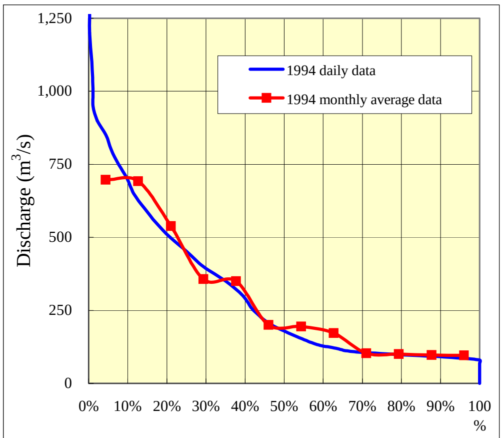
Comparison of Daily Data and Monthly Average Data of Hydrograph in the Normal Year, Nam Lik, 1999



Comparison of Daily Data and Monthly Average Data of Duration Curve of Normal Year, Nam Lik River, 1999



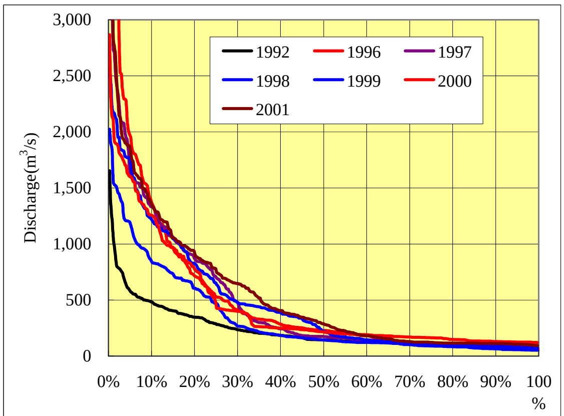
Comparison of Daily Data and Monthly Average Data of Hydrograph in the Wet Year (1994, Nam Lik)



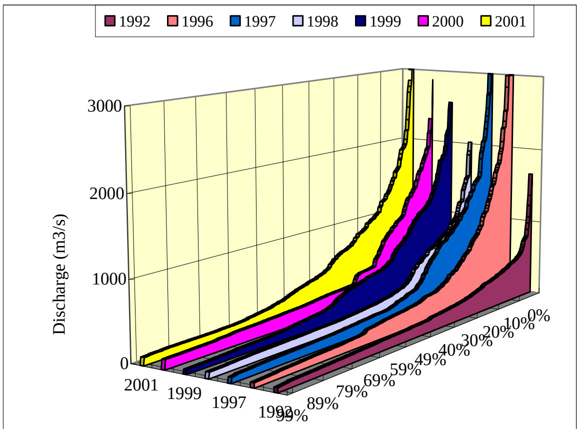
Comparison of Daily Data and Monthly Average Data of Duration Curve the Wet Year (1994, Nam Lik)

Comparison of Flow Duration Curves on Daily and Monthly Basis

When a flow duration curve for the given site is prepared from the data of many years, the curves represent the average quantity of river water available at the site. The flow duration curve is therefore very useful for a regional assessment of the small-hydro potential, that is, determining the install capacity and average annual energy production (detailed in Subsection 3.2.10). Figures below give a comparison of flow duration curves.



Duration curve of Nam Ou River (1992, 1996-2001)



Duration Curve of Nam Ou River (1992, 1996-2001)

The shape of the flow duration curve provides useful qualitative information about hydrology of the river. The curve with a steep slope indicates a “flashy” river or one which has high surface runoffs whereas a curve with a flat slope suggests the presence of surface or groundwater storage within its watershed. The area under the flow duration curve in the graph represents the total mean annual discharge. Large flows which occur during floods could not be utilized economically for small-hydro generation. Thus, large flows of the flow duration curve with low exceedance values is relatively not important.

3.1.5 WET, DRY AND NORMAL YEARS

As shown in the flow duration curves above in different years, the river flow varies from year to year. As a result, the annual runoff volume of the river varies year to year. The following table shows a comparison of the estimated annual runoff depth (see Subsection 3.1.2) at M. Ngoy station of the Nam Ou River.

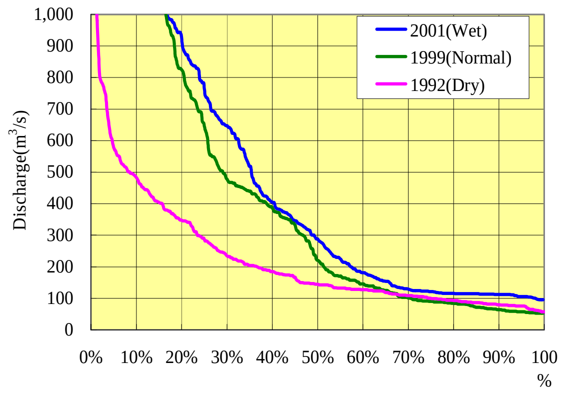
Average Runoff Vlume of M. Ngoy, Nam Ou River

CA= 19,698 km^2

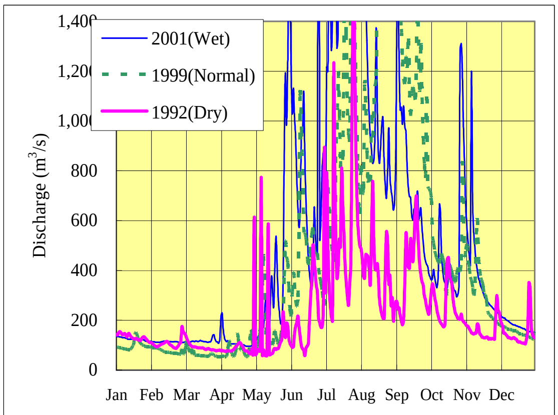
Year	Ave. Discharge (m^3/s)	Annual Volume (million m^3)	Runoff Depth (m)	
1991				
1992	225.5	7,111	**0.361**	Dry Year
1993				
1994				
1995				
1996	553.1	17,443	0.886	Wet Year
1997	475.0	14,980	0.760	
1998	329.1	10,378	0.527	
1999	461.5	14,554	**0.739**	Normal Year
2000	444.9	14,030	0.712	Normal Year
2001	553.1	17,443	**0.886**	Wet Year
2002				
Total Average	**434.6**	**13,706**	**0.696**	

As seen, there is a great variation of the annual runoff depth, and it varies 0.361 m in 1992 to 0.886 m in both years of 1996 and 2001, and the average depth is 0.696 m.

Although the annual basin mean rainfall in each year is not available, there might be more annual rainfall in the Nam Ou river basin in both 1996 and 2001(called hydrologically a “wet year”), and less rainfall in 1992 (a “dry year”), comparing those in 1999 and 2000 (a “normal year”). A comparison of the flow duration curve and hydrograph, and the estimated flow duration table for these specific hydrological years above are shown below.



Duration curve of Nam Lik (1992, 1996-2001)



Discharge Comparison of Wet and Dry Year (Nam Ou)

Durațiaron and Runoff in Middle, Wet, and Dry Year

Duration	Day	Runoff (m^3/s)		
%		1999(Normal)	2001 (Wet)	1992(Dry)
1%	2	2565.0	4197.0	1653.6
5%	18	1770.2	1872.0	585.7
10%	37	1232.1	1372.1	486.1
20%	73	826.0	931.9	348.3
30%	110	483.0	647.5	238.4
40%	146	389.6	405.7	185.2
50%	183	220.2	288.2	144.7
60%	219	146.3	180.9	127.2
70%	256	101.2	129.4	108.7
80%	292	84.3	115.8	94.2
85%	310	71.6	114.6	86.4
90%	329	64.3	112.3	80.3
92%	336	60.1	112.3	78.8
95%	347	57.3	105.3	75.8
96%	350	55.9	105.3	74.3
97%	354	54.6	104.2	65.6
98%	358	54.6	100.8	62.8
99%	361	53.2	95.4	60.0
100%	365	53.2	95.4	57.2

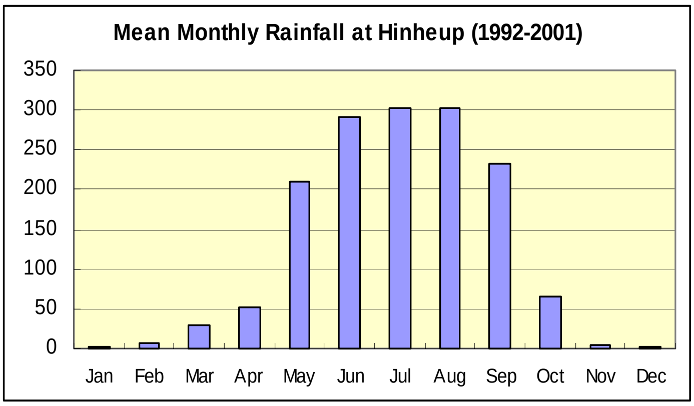
As estimated above, 95% of the Nam Ou river discharge in the normal year is 57.3 m3/s. It means that in the normal year discharge of the river discharge is available (secured) in 347 days (365 x 0.95 = 347) throughout the year.

In Laos, the wet season begins usually in April or May and ends in October. Table below shows an example of the monthly rainfall distribution in 1990-2001 at Hinheup in Vientiane Province. The mean monthly distribution in 1990-2001 at Hinheup is illustrated below.

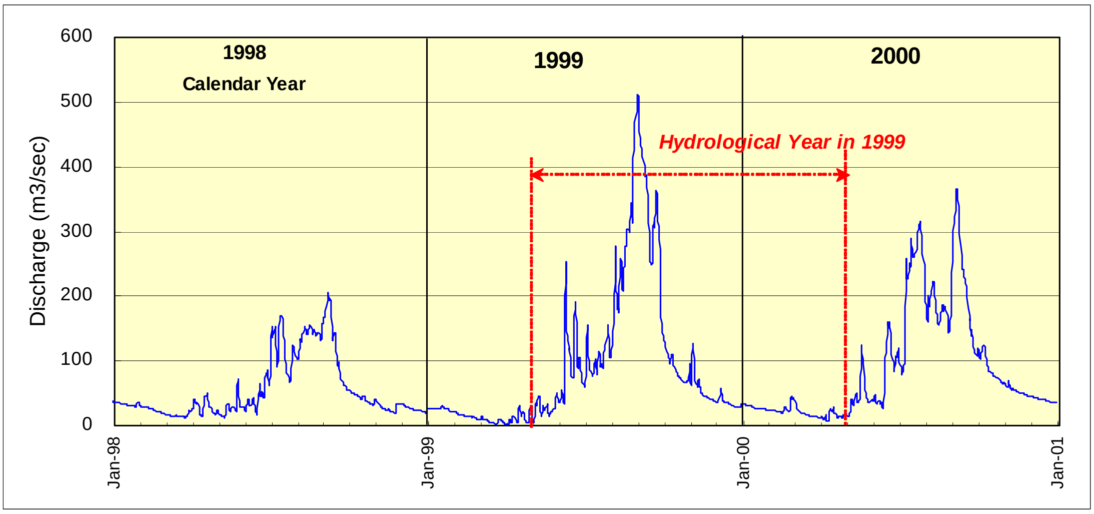
Monthly Rainfall (Station : Hinheup in Vientiane Province)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
1990	0.0	12.9	89.2	4.0	304.8	999.4	513.9	196.4	237.7	69.0	12.5	0.0	2,440
1991	2.3	0.0	23.5	4.3	175.9	304.7	400.6	301.2	280.2	79.7	0.0	1.6	1,574
1992	26.4	28.7	0.0	0.5	101.6	131.0	250.6	285.4	252.3	2.8	0.0	31.3	1,111
1993	0.0	3.0	8.2	63.5	164.2	257.8	316.6	201.3	157.1	33.0	0.0	0.0	1,205
1994	0.0	0.0	74.5	69.8	363.6	243.7	186.0	345.1	258.0	100.9	1.2	0.0	1,643
1995	2.3	0.0	12.5	92.5	60.9	266.8	484.7	462.4	140.0	47.3	3.1	0.0	1,573
1996	0.0	14.6	42.2	112.4	91.9	219.1	159.8	299.4	227.9	85.8	37.6	0.0	1,291
1997	1.9	0.0	2.1	63.6	86.4	117.4	501.8	288.9	208.6	67.4	0.0	0.0	1,338
1998	0.0	0.5	0.5	26.0	156.3	247.5	259.8	370.4	167.6	65.1	1.2	0.0	1,295
1999	0.0	0.0	17.1	59.8	361.7	218.9	136.3	259.3	266.7	5.2	0.0	5.3	1,330
2000	0.0	13.1	12.5	120.8	323.4	326.0	155.1	271.5	308.8	69.5	4.6	0.0	1,605
2001	0.0	0.0	80.2	18.6	320.9	175.9	254.8	340.7	294.0	168.8	6.0	1.6	1,662
Mean	**2.7**	**6.1**	**30.2**	**53.0**	**209.3**	**292.4**	**301.7**	**301.8**	**233.2**	**66.2**	**5.5**	**3.3**	**1,505**

As a result of commencement of the wet season, the river flow gradually rises usually around in May, although the actual hydrological behavior (the beginning of wet season) may vary from year to year and from location to location.



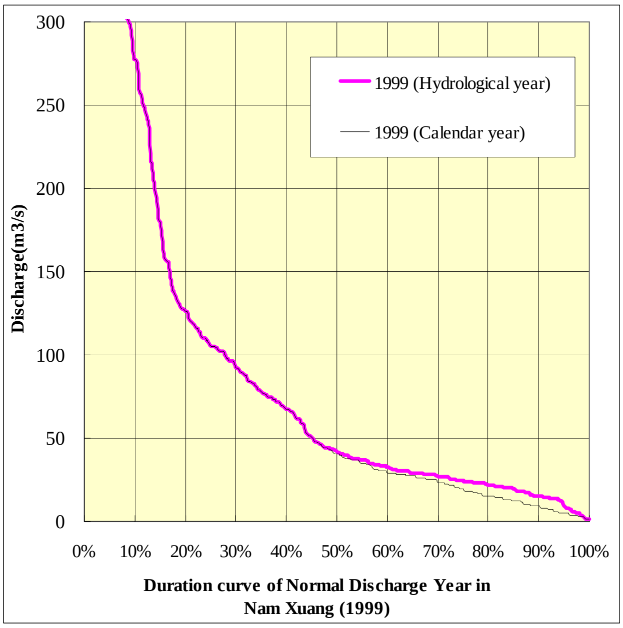
From the hydrological point of view, the duration curve for small-hydro planning shall be made preferably based on the hydrological year (one year from the beginning of the wet season to the end of the dry season) instead of the calendar year (from January to December). Figure below shows an illustration of the relationship the calendar year and hydrological year on the daily discharge hydrograph at the Sieao station on the Nam Xuang river.



Source: JICA Study Team

Relationship between Hydrological Year and Calendar Year

As shown above, it is considered that the hydrological year in 1999 starts in May 1999 and ends in April 2000. The duration curves are constructed for the calendar year and hydrological year both in 1999 for comparison. Figure below shows the duration curves. As shown, the low flows of 70-100% discharge of the hydrological year is larger than those of the calendar year, while higher flows more than the 50% discharge are almost the same. This is because that the smaller dry season flows in March and April in 1999 is much affected by the less wet season flows in 1988, when it is assessed hydrologically the dry year. It is also assessed that both the years of 1999 and 2000 are categorized as the normal year.

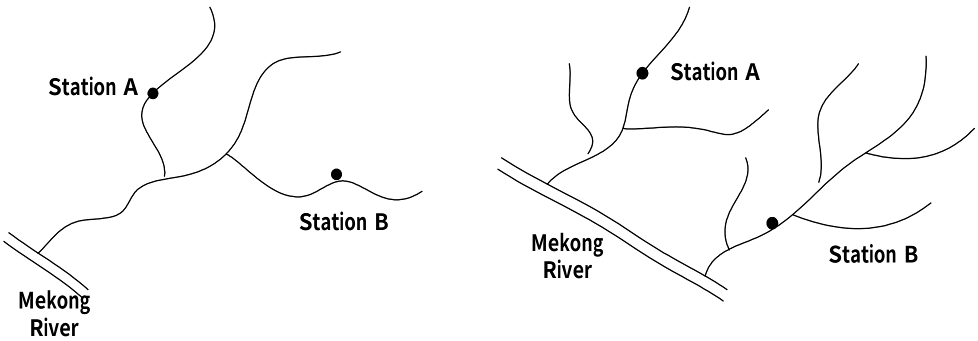


Source: JICA Study Team

Comparison of Duration Curves based on Hydrological Year and Calendar Year

3.1.6 INFILLING OF MISSING DISCHARGE DATA

If discharge record at some water level (discharge) gauging station has data missing therein, it shall be supplemented based on the linear regression method with neighboring gauging station where the basin characteristics are similar to those at the station in question. If there are more than two stations in neighboring catchments, the correlation analysis shall be made for each gauge. Then the supplemental stream gauges shall be selected in terms of highest correlation coefficient.

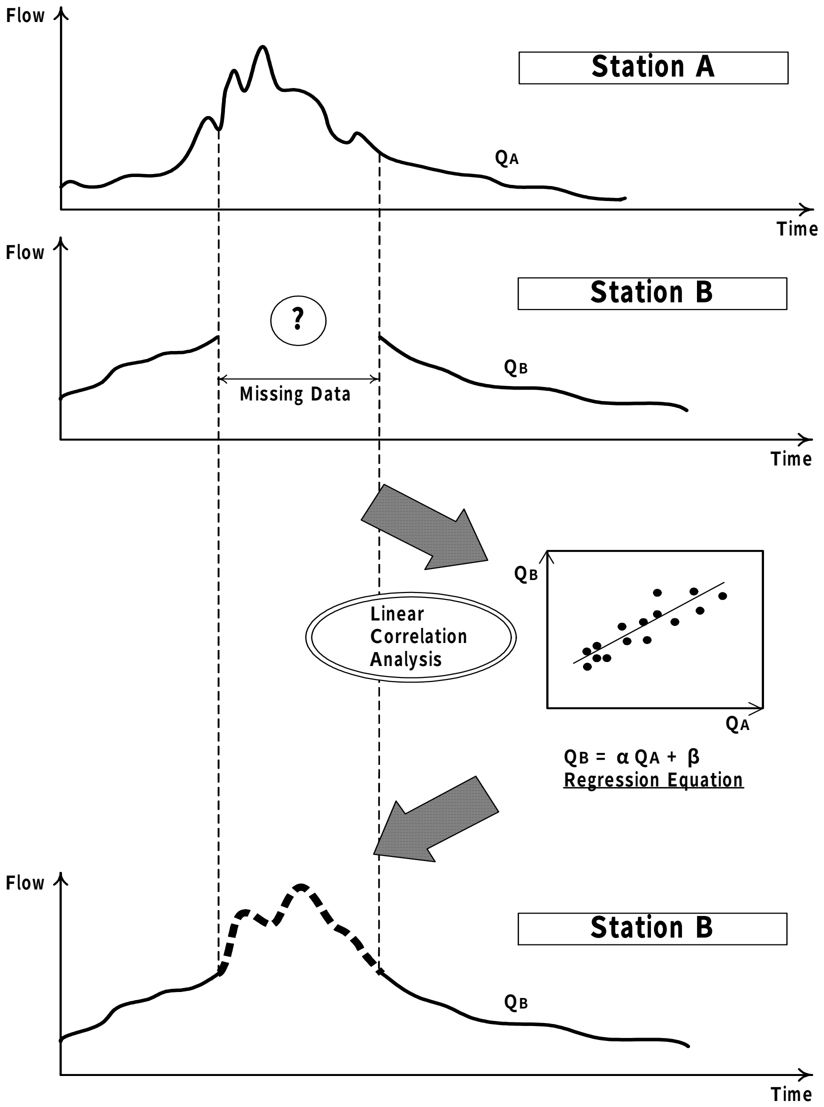


The procedure is schematically shown below. Equations of correlation coefficient and coefficients for linear regression are given as follows:

$$r = \frac{\sum_{i=1}^{n}(x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum_{i=1}^{n}(x_i - \bar{x})^2 \times \sum_{i=1}^{n}(y_i - \bar{y})^2}}$$

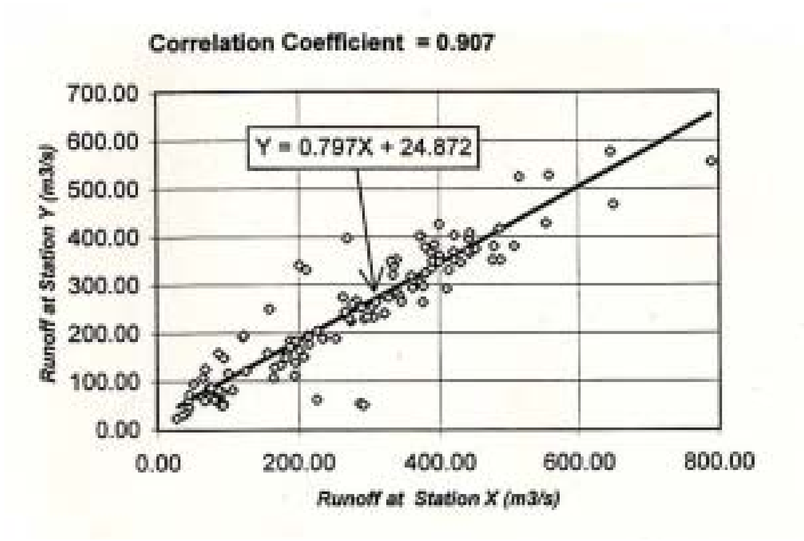
$$y = a + bx$$

$$\begin{cases} b = \dfrac{\sum_{i=1}^{n}(x_i - \overline{x})(y_i - \overline{y})}{\sum_{i=1}^{n}(x_i - \overline{x})^2} \\ a = \overline{y} - b\overline{x} \end{cases}$$



Infilling of Missing Data by Regression Method

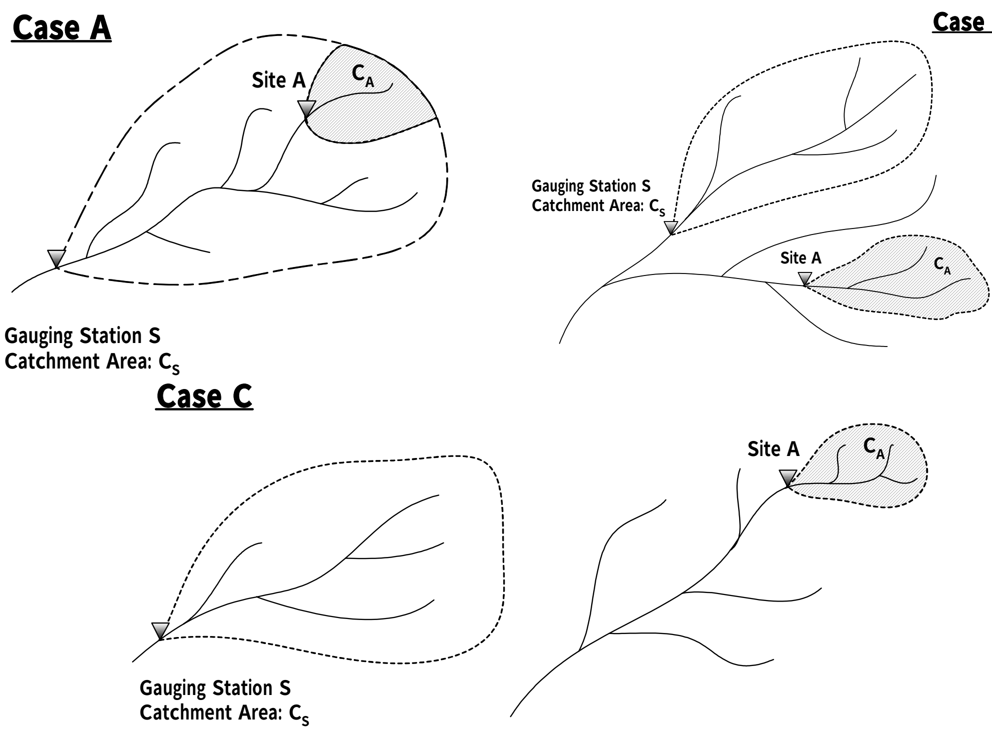
Examples of the linear regression analysis together with correlation coefficient are presented below:



3.1.7 ESTIMATION OF RUNOFF AT THE SITE

(1) General

The river discharge at a given site (say, proposed intake site for small-hydro scheme) shall be estimated applying the observed discharge data in the normal year at the selected gauging station. If the data includes some period with missing data, it shall be supplemented by means of the regression method as previously introduced in the subsection 3.1.6. The conceivable location of the site and gauging station is shown below:



In practice, following methods can be recommended for estimating the river discharge at the site.

(i) by use of Catchment Area Ratio

(ii) by use of Ratio of Catchment Area Ration and Annual Basin Mean Rainfall

(iii) by use of Flow Correlation

(iv) by use of Specific Discharge in the Dry Season

Examples of respective methods illustrated in the next pages in the form of an exercise for the discharge estimation.

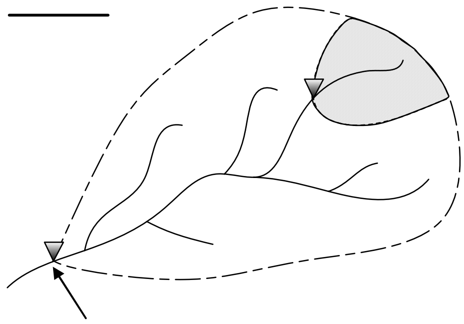
In the Master Plan Study on the Small-hydro in Northern Laos, the river discharge and its duration curve at the proposed sites were estimated applying the method (ii) above because of no availability of discharge data at the sites. Further, for confirmation of the dry season discharge (low flow of the 80 to 95% discharge) at the site, field discharge measurement was conducted by the current meter method (see subsection 2.3.2) in November to December 2004.

New Gauge Station on Nam Ngum River installed by JICA

New Gauge Station on Nam Ngum River installed by JICA

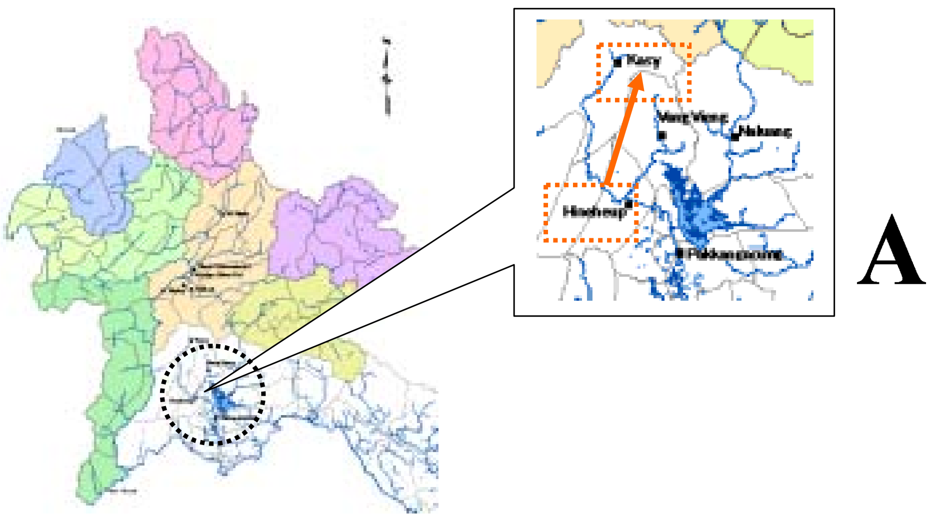
New Gauge Station on Nam Ngum River installed by JICA

(2) By use of Catchment Area Ratio



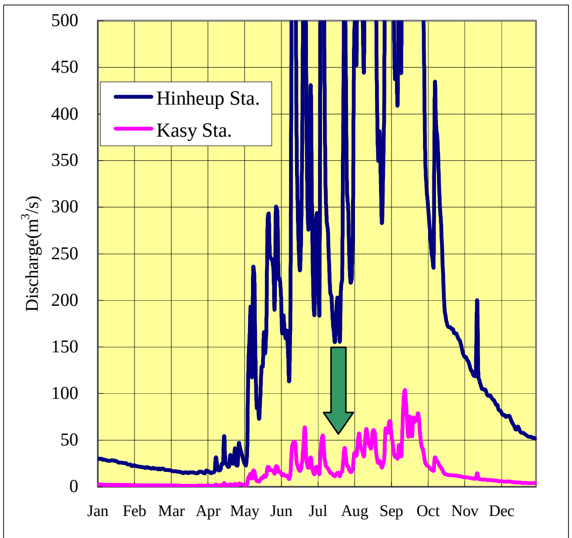
$$Q_A = Q_s \times \frac{C_A}{C_s} = \frac{Q_s}{C_s} \times C_A$$

Specific Discharge

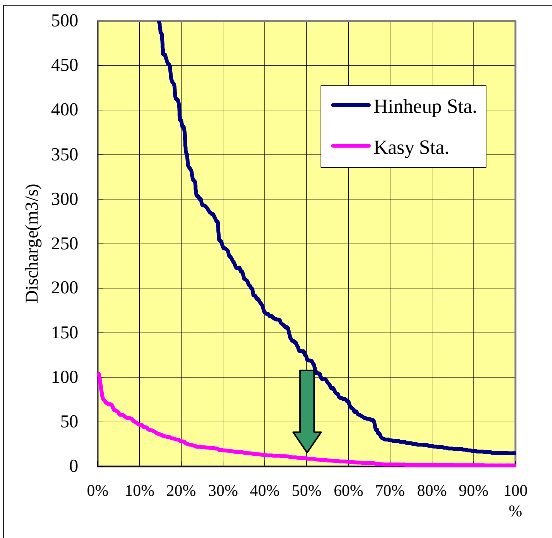


Catchment Area of Hinheup C_S= **5,115** **m^2** **0.073118**
Catchment Area of Kasy C_A= **374** **m^2**

$$Q_A = Q_s \times \frac{374}{5115} = 0.0731 Q_s$$

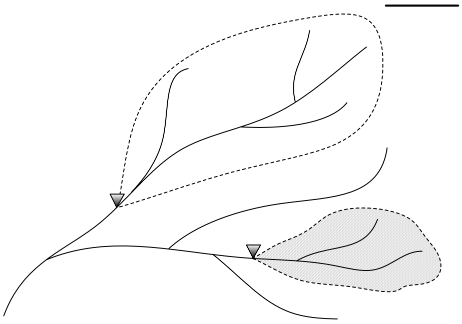


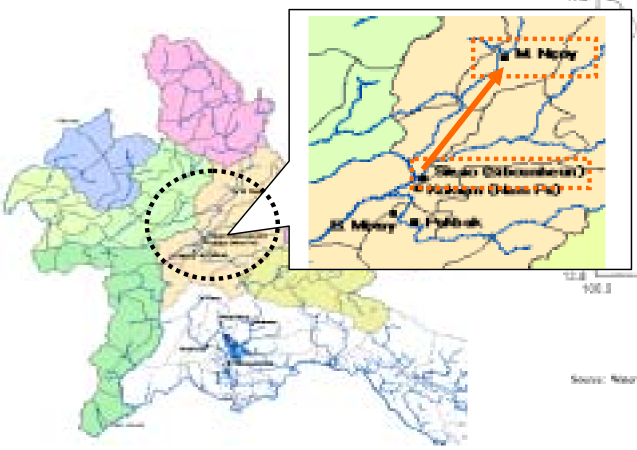
Comparison of Hydropraph of Hinheup and Kasy Station

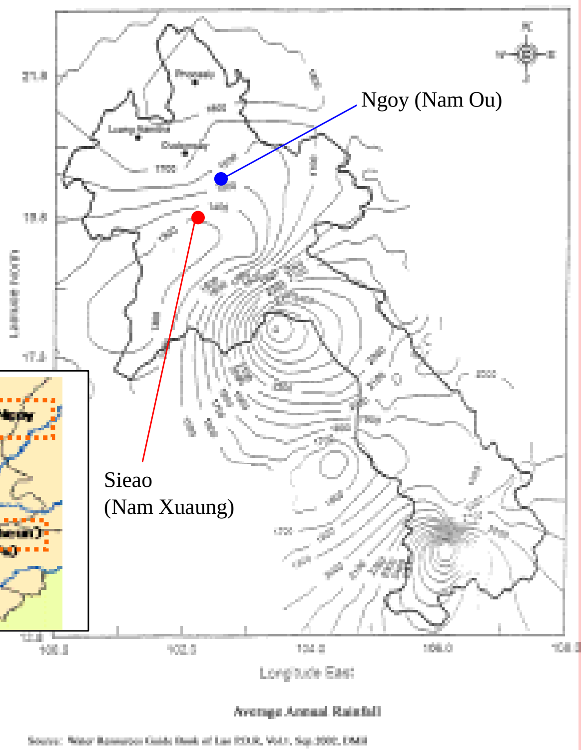


Comparison of Duration Curves of Hinheup and Kasy Station

(3) By use of Ratio of Catchment Area and Annual Basin Mean Rainfall

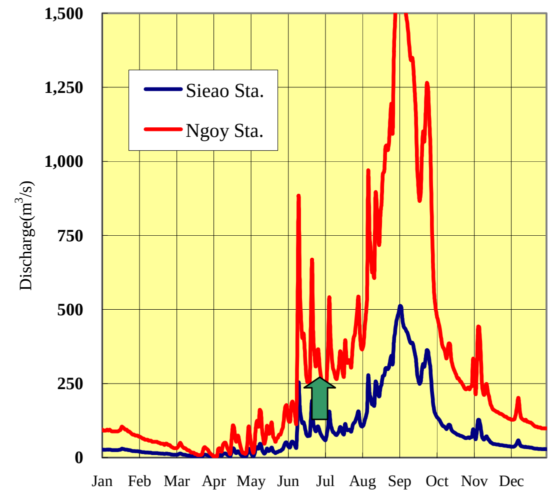




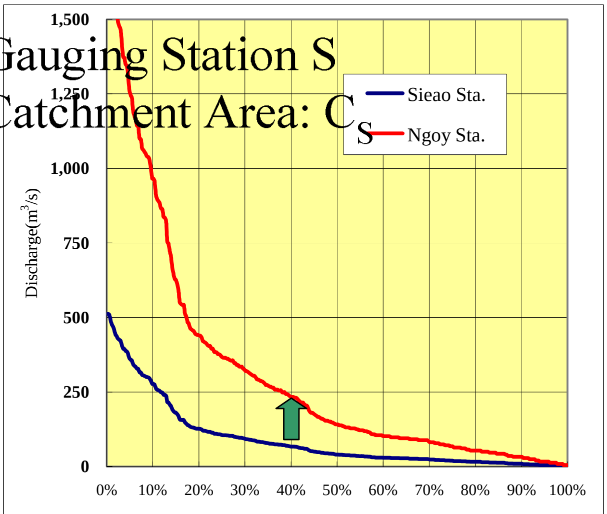


	Flow Data (m³/s)	Catchment Area (km²)	Mean Rainfall (mm)
Cauging Station S (Sieao)		6,503	1350
Site A (Ngoy)	?	19,698	1550

$$Q_A = Q_s \times \frac{C_A}{C_s} \times \frac{R_A}{R_s}$$



Comparison of Hydropraph of Sieao and Ngoy Station

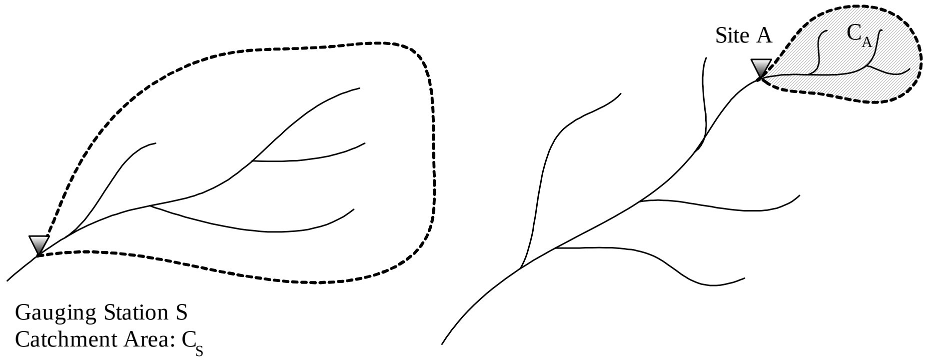


Comparison of Duration Curves of Sieao and Ngoy Station

S

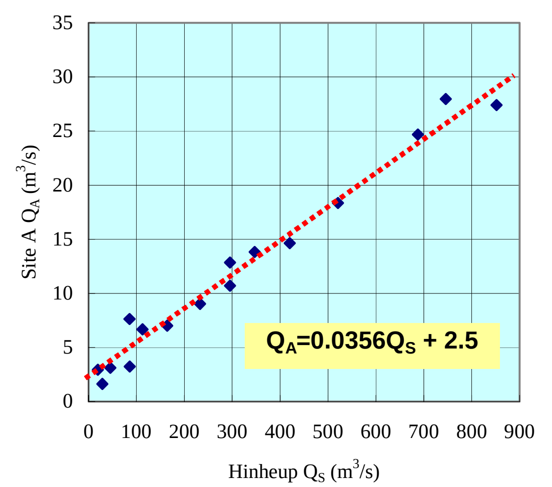
(4) By use of Ratio of Flow Correlation

Case C

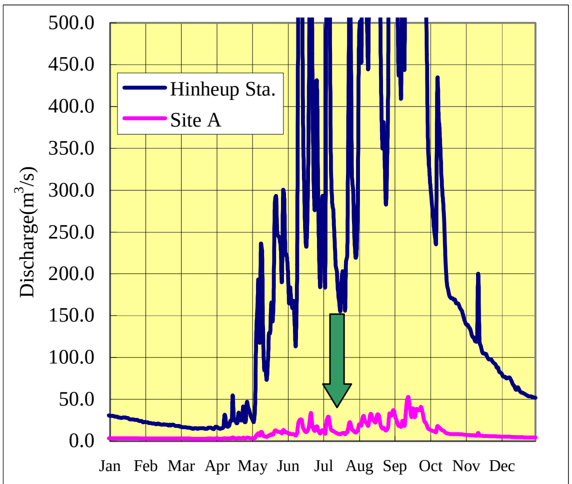


Discharge Measurement Data

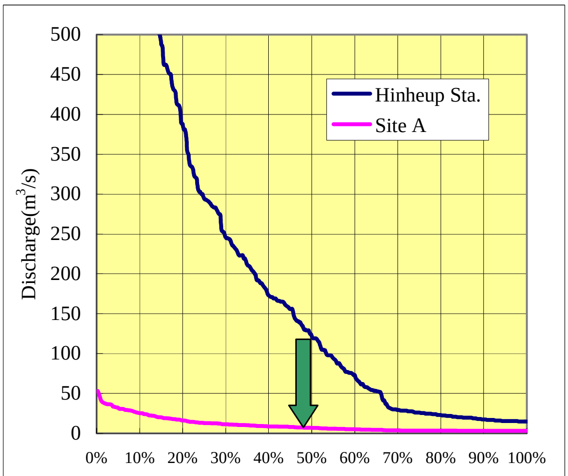
	Hinheup Q_S (m^3/s)	Site A Q_A (m^3/s)
1998/1/14	28.4	1.63
1998/1/24	85.4	7.63
1998/2/8	521	18.35
1998/2/22	19.5	2.95
1998/3/29	45.4	3.12
1998/4/18	420	14.63
1998/5/14	687.7	24.68
1998/5/30	295	12.84
1998/6/16	233	9.02
1998/7/7	746	27.96
1998/8/28	852	27.4
1998/10/2	347	13.82
1998/10/24	295	10.7
1998/11/19	164	7.02
1998/12/22	86.2	3.23
1998/12/29	112.6	6.68



Comparison of Discharge Data



Comparison of Hydropraph of Hinheup and Site A (Method C)



Comparison of Duration Curves of Hinheup and SiteA (Method C)

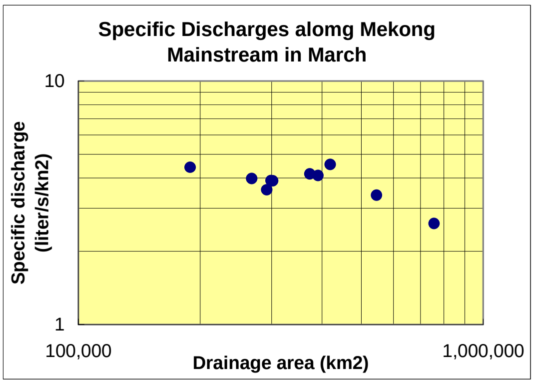
This method is applicable on the condition that several on-site discharge measurement data is available for the site of interest.

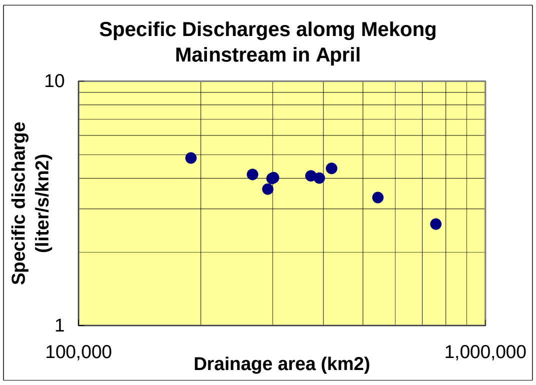
(5) By use of Specific Discharge in the Dry Season

Specific discharge (SD) means the discharge per km^2 expressed as follows:

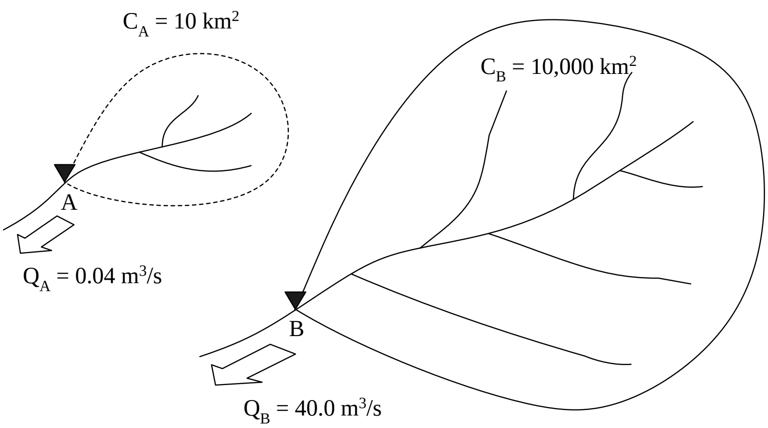
Specific Discharge ($m^3/s/km^2$) = Discharge (m^3/s) / Catchment Area (km^2)

Below is the distribution of the estimated specific discharges in March and April in the dry season along the Mekong mainstream.





As shown above, the specific discharges in both March and April are relatively very small in the range of 2 to 5 liter/sec/km^2 (= 0.002 to o.005 $m^3/sec/km^2$). The illustration below shows the relationship between the river discharges from the small and large catchment areas.



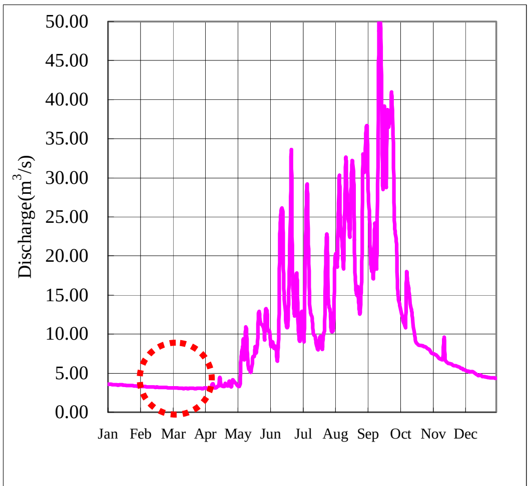
Specific Discharge

$$SD_A = \frac{0.04}{10} = \frac{40}{10} = 4 \text{ (liter/sec/km}^2\text{)}$$

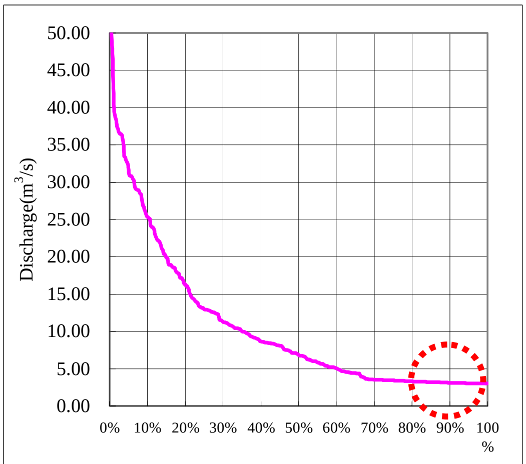
$$SD_B = \frac{40}{10{,}000} = \frac{40 \times 1{,}000}{10{,}000} = 4 \text{ (liter/sec/km}^2\text{)}$$

In addition to the above, specific discharges in the dry season in major rivers in Lao PDR are available. Discharge measurements were carried out on major Mekong tributaries in 1998, 1999 and 2001 by JICA Experts in collaboration with Department of Meteorology and Hydrology, Ministry of Agriculture and Forestry (Water Resources Guide Book of Lao PDR, Volume I Main Report, 2002).

This approach by use of specific discharges in the dry season is so called "smallest flow approach" and only estimates the low flow in the dry season (however, it is noted that not so definitive as to give a specific percent discharge, e.g. 95% dependable discharge). The expected plot of the estimated discharge is marked as given below.



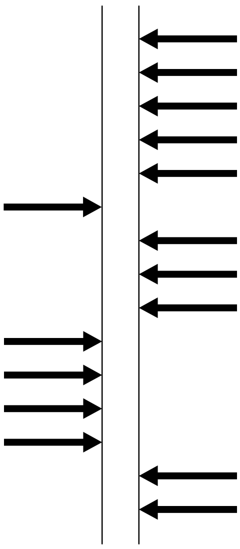
Estimated Hydropraph of Site A



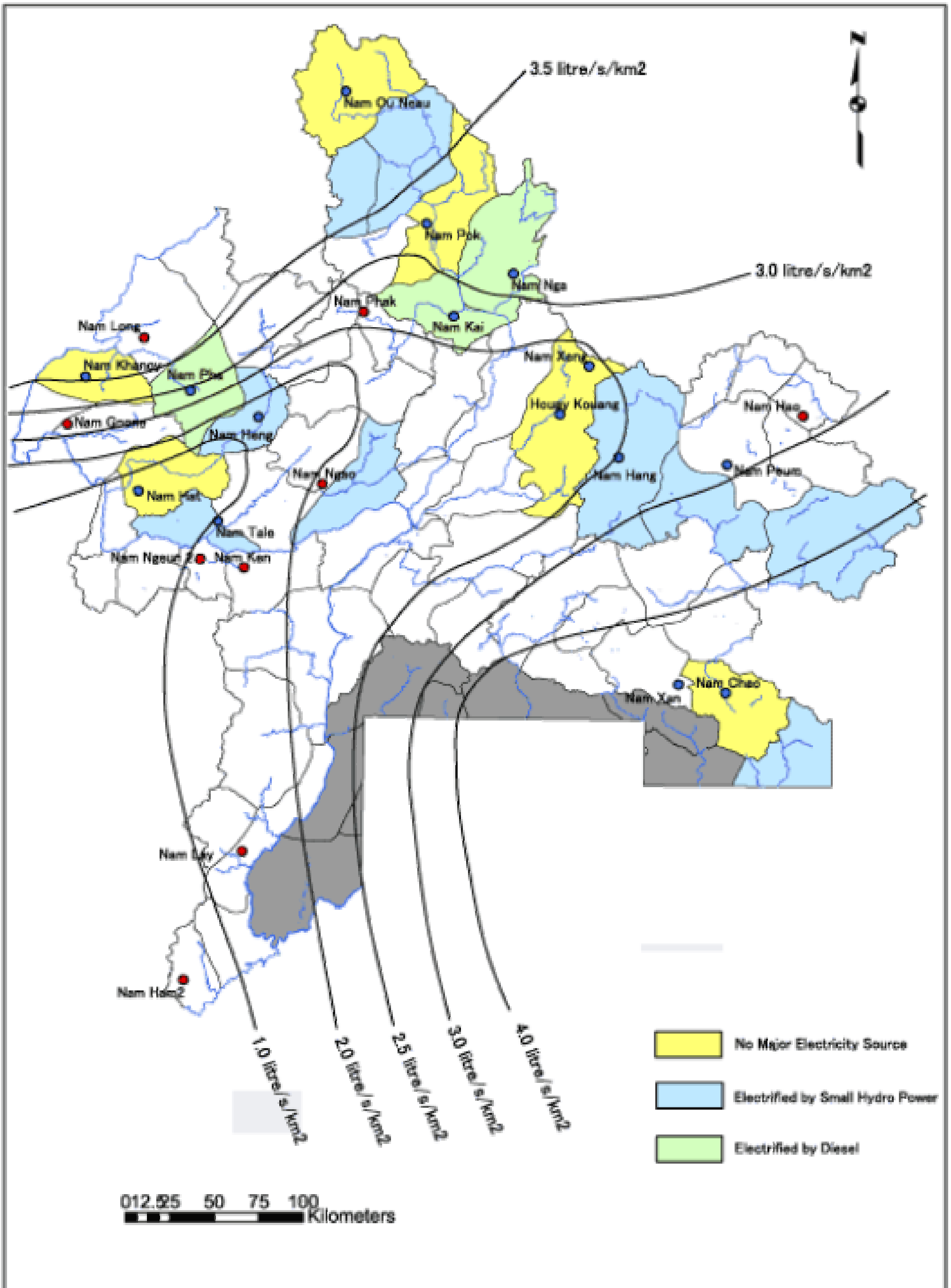
Estimated of Duration Curve of Site A

The smallest flow approach might be applied to any proposed small-hydro projects where it is possible to say that the smallest flow in the stream (in the driest part of the year) is always going to be sufficient to meet the requirements on power demand.

Discharge measurements were intensively carried out on major Mekong tributaries by JICA Experts in collaboration of Department of Meteorology and Hydrology, Ministry of Agriculture and Forestry in 1988. The measured low discharges in northern Laos in the dry season 1998 are summarized below.



Using these discharge measurement data, a regional map of the dry season specific discharges was prepared under the Master Plan Study. This map may be applied to estimate the regional smallest discharges in the northern Laos. It is noted, however, that the regional discharge suggested herein would be of preliminary nature with some margin for error. Of course it is of great importance to visit the objective river during the dry season (preferably the smallest flow time of the year) and to conduct discharge measurements.



SPECIFIC DISCHARGE IN DRY SEASON AT NORTHERN LAOS

Photos below show the Mekong River and its major tributary rivers in the dry season.

Mekong River in Dry Season in Vientiane

Nam Tha River in Nale

Mekong River in Dry Season in Luangphrabang

Mekong River at junction of Nam Ou River in Pak Ou

Nam Ou River

3.1.8 FLOOD ANALYSIS

Flood peak water level (height) should be estimated at the proposed powerhouse location. Thus, the site shall be selected with full confidence that frequent flooding (submergence) of powerhouse would not occur. In this respect, the regional flood study shall provide useful information. However, very little information on regional floods was available in the northern Laos. Under the Master Plan Study, estimation of regional floods was made by means of the empirical Creager's flood curve method as described below. This method might be applicable to estimate design floods in the regional areas where no flood data is available.

The Creager's equation is given by the following formula:

$$\mathbf{Q_q = 46 \times C \times A^{a-1}}$$

$$\mathbf{a = 0.894 \times A^{-0.048}}$$

where, Q_q : Specific peak discharge ($ft^3/sec/mile^2$)
C : Creager's coefficient
A : Catchment area ($mile^2$)

The unit conversions for feet and mile as follows:

1 ft^3 = 0.02832 m^3
1 km^2 = 0.3861 $mile^2$

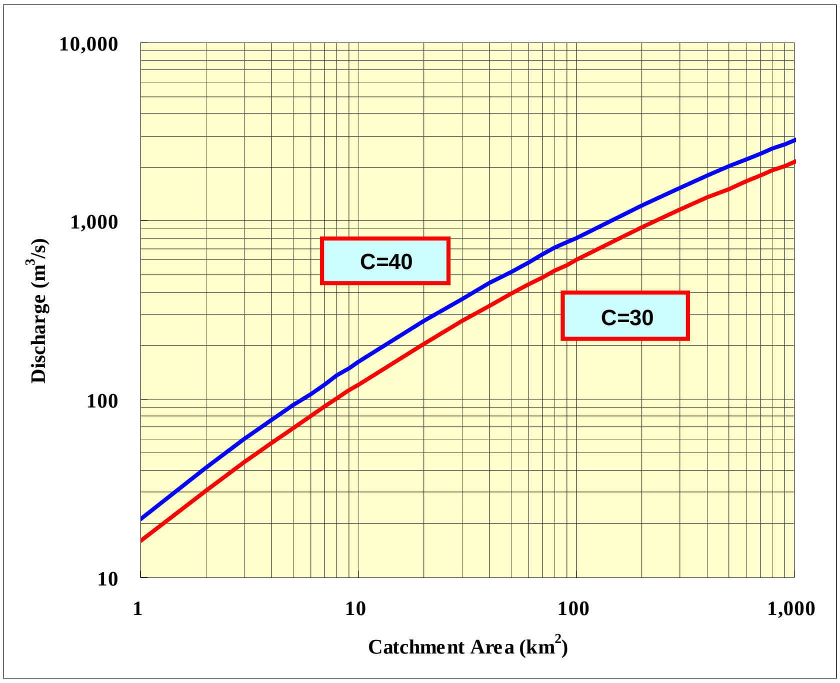
Therefore the Creager's equation is further expressed by the following formula:

$$\mathbf{Q = (46 \times 0.02832) \times C \times (0.3861 \times A)^{a-1}}$$

$$\mathbf{a = 0.894 \times (0.3861 \times A)^{-0.048}}$$

where, Q : Peak discharge (m^3/sec)
C : Creager's coefficient
A : Catchment area (km^2)

It is generally accepted that the probable 50 to 100-year peak floods (peak flood magnitude with return period of 50 to 100 years) are normally and empirically plotted around the flood curves of Creager’s coefficient of 30 to 40. The regional peak flood curves of Creager’s coefficients of 30 and 40 are presented below. Under the Master Plan Study, curves of the coefficient C=40 for the 100-year and C=30 for the 50-year are conservatively recommended. By use of this curve, the design flood peak discharges in any arbitrary schemes would be predicted.



Source: JICA Study Team

Creager's Curves

The flood stage (water level) for the estimated design flood discharge from the regional peak curve above is computed assuming an uniform flow in stream. Manning's equation is applicable as follows.

$$\boldsymbol{Q = A \times V_m}$$

$$Vm = \frac{1}{n} R^{2/3} I^{1/2}$$

where, Q : Discharge (m^3/s)

A : Flow area (m^2)

V_m : Mean flow velocity (m/s)

n : Roughness coefficient

R : Hydraulic radius (m)

I : River gradient

The required river geometry above (river cross section, river gradient, channel condition, etc.) shall be obtained from the site visit and topographical map. There are usually no field data to estimate the roughness coefficient above. The roughness coefficient highly depends upon the site condition usually in the range of 0.030 (grass or rock on the gravel bed) to 0.060 (gravel bed, large boulders).

Under the study on Hydropower Development Plan For The Lao PDR conducted in 1998, the flood peak (design flood) curves were developed based on the frequency analysis of annual flood peak flow on major rivers (Huai Bang Sai, Se Champhone, Nam Lik, Nam Suong, Nam Khan, Se Bang Fai, Nam Ngum, Se Bang Hieng, etc.) in Laos. The developed formulas for probable flood discharge are as flows:

$$Q_{100} = 35.7 \text{ x } A^{0.65}$$

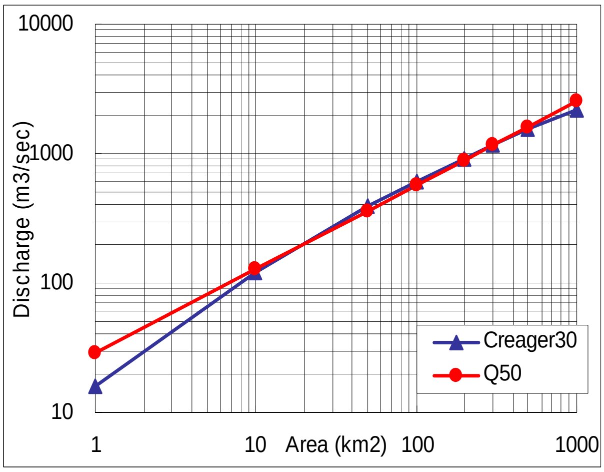
$$Q_{50} = 28.48 \text{ x } A^{0.65}$$

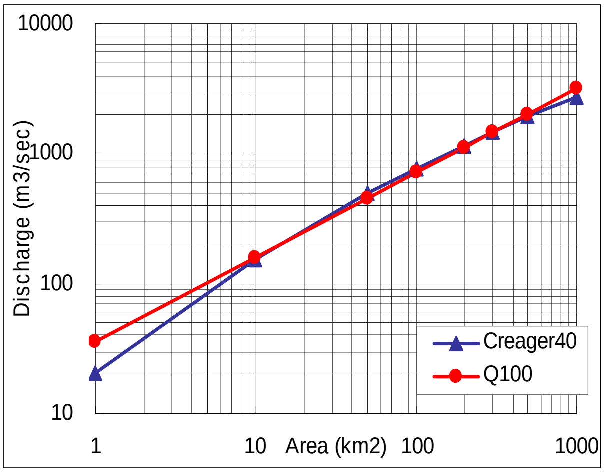
where, Q_{100} : 100-year flood discharge (m^3/sec)

Q_{50} : 50-year flood discharge (m^3/sec)

A : Catchment area (km^2)

It is however noted that the above formulas shall be applicable to the catchment area less than 2,000 km^2. Figures below illustrate a comparison of the curves drawn by the above formula with the Creager's curves. As seen, curves of the Q_{100} and Q_{50} almost agree with those of the coefficients of C=40 and 30 respectively. For the catchment area more than 10 km^2, both of the estimated 100-year and 50-year floods by the empirical Creager's curve are likely to be lower than those by the formula above.





Source: JICA Study Team

Comparison of Flood Curves in Laos to Creager's Curves

Design Floods in Lao PDR

As introduced in Section 1.4, the Lao Electric Power Technical Standards was established by MIH/DOE on February 12, 2004 under the technical cooperation between the Governments of Lao PDR and Japan. This Standards prescribes the fundamental requirements for power facilities and technical contents that should satisfy the fundamental requirements.

Article 17 of the Standards provides the Inflow Design Flood for dams as quoted below.

Article 17 Inflow Design Flood

1. Inflow design flood shall be set as follows, according to the dam classification specified in Paragraph 2.

Table 17-1 Inflow design flood

Dam Classification	Inflow design flood
High	Probable maximum flood (PMF)
Significant	Between PMF and annual exceedance probability 1/1,000
Low	Between PMF and annual exceedance probability 1/100

2. Each dam shall be classified in terms of the reasonably foreseeable consequences of failure. Consideration of potential damage shall not be confirmed to conditions existing at the time of construction. Probable future development in the downstream flood plain shall be evaluated in estimating damages and hazards to human life that would result from failure of the dam.

Table 17-2 Dam classification

Dam Classification	Loss of life	Impact on economy, society and environment
High	Large increase in loss expected	Excessive increase in economic, social and/or environmental impact
Significant	Some increase in loss expected	Substantial increase in economic, social and/or environmental impact
Low	No increase in loss expected	Low increase in economic, social and/or environmental impact