APPENDIX II

CONSTRUCTION MATERIAL

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CHAPTER 1 INTRODUCTION

1.1 Scope of Investigation

Project of Mukoh hydropower generation, located in the Mukoh River which is the upstream of the Tekalit River belonging to the southern tributary of the Rajang River, has a concrete gravity dam with a powerhouse just behind the dam.

Construction materials were investigated upon the concrete aggregates for the main materials of the dam and powerhouse.

The field investigation was carried out to examine both the river bed deposits which are scattered in the Mukoh and Tekalit rivers and the quarry around the proposed dam site.

First investigation was performed in order to select the borrow areas, and to estimate the collectable volume for the concrete aggregates.

The samples for the laboratory tests were obtained from test pits which were digged in the proposed borrow areas.

The laboratory tests were carried out to obtain the characteristics of the samples and to judge whether or not they were suitable for the concrete aggregates. The tests were entrusted to the Geotechique East Malaysia Sdn. Bhd in Kuching through SESCO.

1.2 Prospective Material Sources

The concrete volume of the Mukoh project is approximately 20,000 m^3 which is the sum of the dam, the powerhouse, ets., so that the volume of sand and gravel requires approximately 26,000m^3 as the concrete aggregates.

The investigation was carried out to select the river bed deposits which had sufficiently collectable volume for the concrete aggregates and to obtain the samples for the laboratory tests.

The Mukoh River is a mountain stream with a width of only 20m to 30 m and rapid. It has few river bed deposits. The deposits contain many big cobbles and boulders with a grain size of 30 cm to 100 cm and few sand and gravel.

The Tekalit River, which is about 15 km downstream from the proposed dam site, has many areas with river bed deposits and the maximum grain of the deposits is about 20cm. But the deposit volume of each area is not so much.

Consequently, the total volume of the collectable aggregates, which are obtained from each river bed around the dam site, is insufficient for the required volume, so that a quarry is proposed on the left bank close downstream of the damsite whose rock type is sandstone. In this case, crushed rock and sand are adopted as the concrete aggregates.

Rock type around the dam site consists of mainly shale and partly sandstone.

The field investigation and sampling for the laboratory test were carried out around the middle of June, 1987.

1.3 Laboratory Tests

The laboratory tests were carried out to obtain characteristics of the samples which were collected at the river bed deposits and the outcrops of the proposed quarry site, in order to judge whether or not the samples were suitable and usable for the concrete aggregates.

Moreover, the laboratory tests were carried out in regard to drilled cores to obtain the characteristics and compressive strength.

The samples were transported from the river bed deposits and the proposed quarry site to the Kuching city for the laboratory tests.

The test pitting, the sampling and the laboratory tests were performed under the supervision of the SESCO expert based on the technical assistance of the JICA team.

Table II-1 shows the items and the quantities of the material investigation.

CHAPTER 2 CONCRETE AGGREGATES

2.1 Field Investigation

Investigation of the river bed deposits was carried out between about 3 km upstream and 35 km downstream area from the damsite along the Mukoh and Tekalit rivers.

The sampling areas were selected on condition that it had more than 500 m^3 of the volume in a deposit and the maximum grain size was less than 20 cm.

As a result of the investigation, six (6) candidates of the sampling areas were selected out.

Samplings were carried out at one test pit in each deposit and samples for the laboratory test were collected as to sand and gravel whose maximum grain size was less than 80 mm.

Investigation of quarry site was carried out to sample the outcrops of sandstone on the left bank downstream from the dam site.

The samples were sealed up in 30 kg vinyl bags and transported to Kuching for the tests.

Locations, volume, maximum grain size and weight of the samples are shown in Fig. II-1 and Table II-2.

2.2 Laboratory Tests

With regard to the samples of six (6) areas of the river bed deposits, the laboratory tests of the following items were carried out:

1) Sieve analysis of sand and gravel,
2) Specific gravity and absorption of sand and gravel,
3) Organic impurities of sand, and
4) Scratch hardness of soft particles of gravel.

Furthermore, the following tests were carried out as to samples of three (3) areas which have relatively much volume of the river bed deposits out of the six (6) areas:

5) Soundness of sand and gravel,
6) Abrasion of gravel, and
7) Unit weight of sand and gravel.

With regard to the crushed rock which was sampled at the quarry, the following tests were carried out:

8) Specific gravity and absortion of gravel,
9) Scratch hardness for soft particles of gravel,
10) Soundness of gravel, and
11) Abrasion of gravel.

As to four (4) samples of the drilled cores, the following tests were carried out:

12) Unconfined compression, and
13) Specific gravity and absorption.

ASTM standards 1986 were applied as the technical specifications of each test.

Table II-1 shows the items and the quantities, and Table II-3 and Table II-4 show the results of the tests.

Furthermore, the evaluation for the test results is mentioned in the following section 2.3.

2.3 Evaluation for the Test Results

2.3.1 River bed deposits of the Mukoh River (TMK-6)

1) The river bed deposits around the damsite are not suitable for the concrete aggregates judging from the original grain size distribution; the maximum grain size of about 50 cm.

   Since the maximum grain size less than 100 mm is generally used for concrete aggragates of dam, it is necessary to take away the big grain size of gravel as well as cobbles and boulders.

   The total volume of the deposits around the damsite is about 3,000 m^3, however, the available volume of sand and gravel for the concrete aggregates is less than a half of the total volume and so the sum of the available volume is insufficient for the required volume.

2) Gravels of the Mukoh River contain a pretty soft stones and light stones and so these qualities are light specific gravity, high absorption rate, high percentages of soft stones, high abrasion rate and high soundness rate. Therefore, these gravels are unsuitable for the concrete aggregates.

   The qualities of the sand are in high absorption rate and high soundness rate.

   The test results were obtained from only one sample, so in future, it is necessary to review the field investigation and laboratory test by other smaples, when the sand and gravel of the Mukoh River are used concrete aggregates.

2.3.2 River bed deposits of the Tekalit River (TMK-1,2,3,4,5)

1) Although the gravels contain a few soft stone, the abrasion rate is not so high that these gravels are usable for the concrete aggregates without any problem.

2) The maximum grain size of the river bed deposits is about 20 cm, which is smaller than that of the Mukoh River. These deposits contain the big grain size, more than 30% of which exceed 10cm.

   The total volume of the deposits is about 6,800 m^3 in the river stretch of 20 km where the field investigation was carried out, but the usable volume for the concrete aggregates is about 4,700 m^3.

   Therefore, the collectable volume is insufficient for the required volume of the concrete aggregates, about 26,000 m^3.

   Moreover, it is difficult and uneconomical to trasport the concrete aggregates for this project because of no road along the river in this area and a long hauling distance between the sampling area and the dam site.

2.3.3 Crushed rock sample of the proposed quarry (TMK-7)

The laboratory test was carried out in order to obtain the property of the crushed rock sample which is sandstone.

As shown in Table II-3, this sample has sufficiently usable characteristics for the concrete aggregates.

The proposed quarry site is suitable, since it has a plenty of volume required for the concrete aggregates and a short hauling distance. However, additional laboratory tests will be conducted for confirming the quality of quarry rock.

CHAPTER 3 CONCLUSIONS AND RECOMMENDATIONS

1) The volume of the river bed deposits

The volume of the deposits in the Mukoh and Tekalit rivers is insufficient for the required volume of the concrete aggregates.

The transportation of them is difficult and uneconomical, because of not accessible road to the deposit areas along the river in spite of the far distance from dam site.

2) The proposed quarry site

Although the proposed quarry site is suitable, the further detail investigation of this site is required to confirm the quality of the rock and the collectable volume for the concrete aggregates.

3) The quality of the sand and gravel

The rock type of the sand and gravel in the Mukoh and Tekalit rivers is mainly shale and sandstone, and the shale has tendencies of light specific gravity, big absorption, soft stone and weak resistance abrasion.

Consequently, in use of these aggregates, it is required to consider the design of the concrete structure sufficiently.

Table II-1 Quantity of Material On Investigation

Work Item	Quantity
1. Field investigation	
a. Test pitting	7
b. Sampling	7
2. Laboratory test	
2.1 River deposits	
a. Sieve analysis (ASTM C136)	6
b. Specific gravity and absorption (ASTM C128 & C127)	6 (Sand) 7 (Gravel)
c. Organic impurities of sand (ASTM C40)	6
d. Scratch hardness of soft particulars in gravel (ASTM C235)	7
e. Soundness (ASTM C 88)	3 (Sand) 4 (Gravel)
f. Abrasion of gravel (ASTM C131 & C535)	4
g. Unit weight (ASTM C29)	4 (Sand) 4 (Gravel)
2.2 Drilled core sample	
a. Unconfined compression (ASTM D2938)	4
b. Specific gravity and absorption (ASTM C127)	4

Table II-2 Places of Test Pitting and Sampling

Sampling No.	Distance from dam site	Volume of river deposit (m^3)	Maximum size of particules (cm)	Sampling weight (kg)
TMK-1	15 km downstream (left bank)	600 (400)	10 - 20	90
TMK-2	22 km downstream (right bank)	2,000 (1,500)	10 - 20	180
TMK-3	25 km downstream (right bank)	1,200 (800)	10 - 20	180
TMK-4	27 km downstream (left bank)	1,500 (1,000)	10 - 20	90
TMK-5	32 km downstream (right bank)	1,500 (1,000)	10 - 20	90
TMK-6	2.5 km upstream (right bank)	3,000 (1,500)	30 - 50	180
	Total Volume	9,800 (6,200)		
TMK-7 (Rock samples from quarry)	left bank of dam site			50

Notes: 1; Figures in parantheses show the estimated volume of grain size under 10 cm.

2; Rock type of TMK-1 to TMK-6 are shale and sandstone and that of TMK-7 is sandstone.

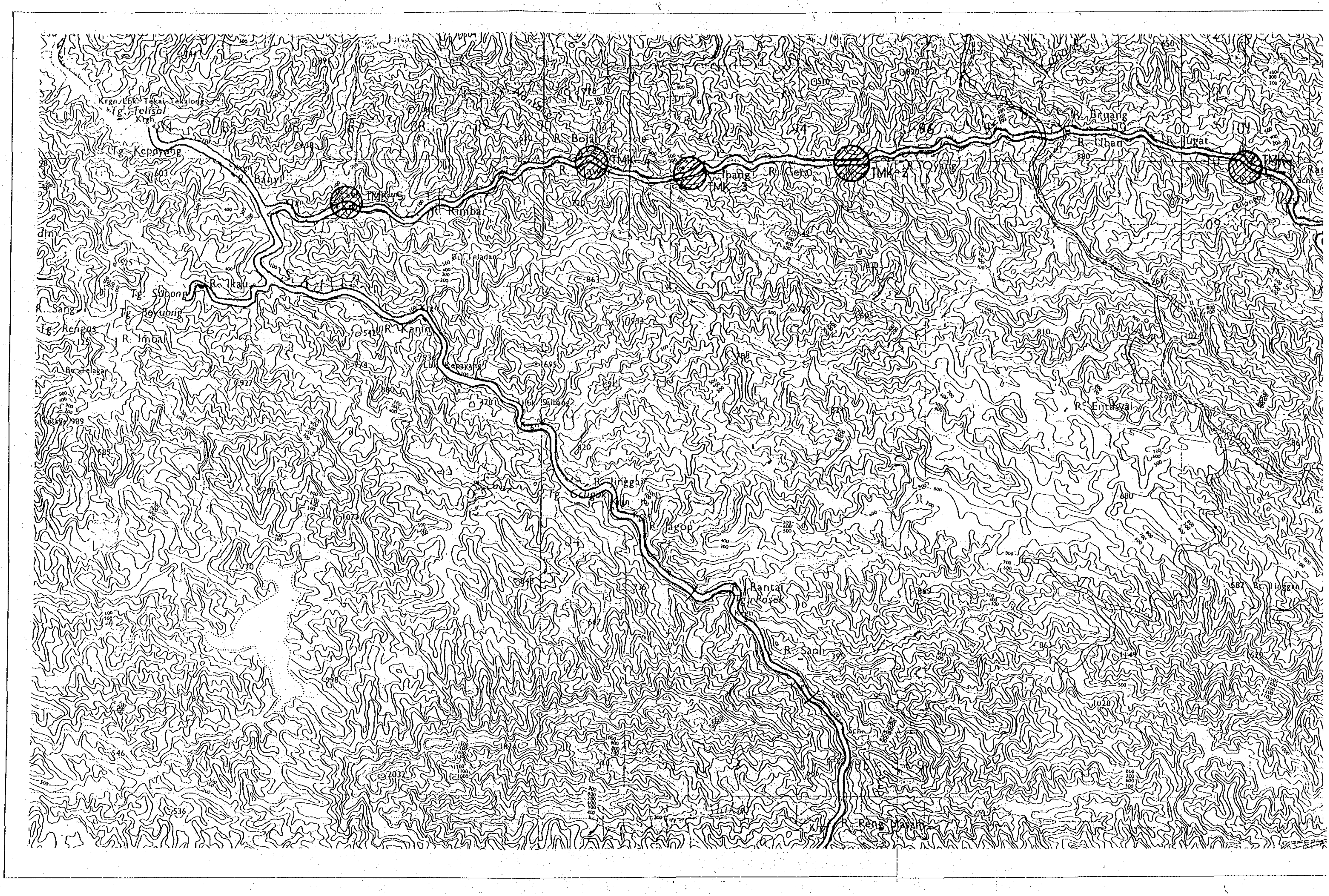
Table II-3 Summary Results of Laboratory Tests

Item of tests	Places			Values generally accepted
	Mukoh River (TNK-6)	Tekalit River (TMK-1 - 5)	Quarry (TMK-7)	
a. Fineness Modulus of gravel (F.M)	8.29	8.00	-	6.5 - 9.0
sand (F.M)	2.95	3.10	-	2.3 - 3.5
b. Specific gravity of gravel	2.484	2.529	2.500	2.5 - 2.7
sand	2.602	2.516	-	2.5 - 2.7
c. Absorption of gravel (%)	3.53	1.34	2.49	less than 3.0
sand (%)	4.02	1.35	-	less than 3.0
d. Organic impurities of sand	passed	passed	-	
e. Scratch hardness of gravel (%)	38.1	7.8	2.4	less than 5.0
f. Soundness of gravel (%)	15.3	6.4	1.9	less than 12.0
sand (%)	16.6	8.1	-	less than 10.0
g. Abrasion of gravel (%)	35.4	24.1	25.1	less than 40.0
h. Unit weight of gravel (t/m^3)	1.759	1.775	-	1.5 - 1.9
sand (t/m^3)	1.761	1.590	-	1.4 - 1.8

Table II-4 Results of Laboratory Test

Place and Sample No.	mm 75 (%)	mm 63 (%)	mm 50 (%)	mm 37.5 (%)	mm 19.0 (%)	mm 9.5 (%)	mm 4.75 (%)	mm 2.36 (%)	mm 1.18 (%)	mm 0.60 (%)	mm 0.30 (%)	mm 0.15 (%)	mm 0.075 (%)	Fineness Modulus (F.M.)	Specific gravity (SSD)	Absorp-tion (%)	Organic Impurities	Scratch Hardness (%)	Soundness (%)	Abrasion (%)	Unit Weight (t/m³)
River bed deposit	Sieve Analysis (Percentage Passing)																				
Coarse	100	95	85	71	40	17	0							7.72	2.492	1.99	-	8.1	-	-	1.744
TMK-1 Fine							100	64	45	31	10	3	0	3.47	2.505	1.19	Passed	-	-	-	1.735
Original	100	96	88	77	52	33	20	13	0	6	2	1	0	6.87	-	-	-	-	-	-	-
Coarse	100	91	75	59	32	14	0							7.95	2.535	1.74	-	10.4	7.2	-	1.791
TMK-2 Fine							100	77	62	50	13	3	0	2.95	2.521	1.09	Not Passed	-	8.0	-	1.518
Original	100	92	79	66	43	28	17	13	11	7	3	1	0	7.09	-	-	-	-	-	23.6	-
Coarse	100	95	69	47	25	11	0							8.17	2.533	1.02	-	93	5.6	-	1.791
TMK-3 Fine							100	84	62	43	12	2	0	2.97	2.499	2.04	Passed	-	8.2	-	1.518
Original	100	97	75	58	41	30	22	18	13	9	2	0	0	7.07	-	-	-	-	-	24.5	-
Coarse	100	95	80	58	31	14	0							7.97	2.535	0.99	-	6.8	-	-	-
TMK-4 Fine							100	76	50	34	10	4	0	3.26	2.570	1.00	Passed	-	-	-	-
Original	100	96	84	67	46	32	21	17	11	7	2	1	0	6.96	-	-	-	-	-	-	-
Coarse	100	87	69	51	21	7	0							8.21	2.550	0.96	-	4.3	-	-	-
TMK-5 Fine							100	88	73	44	8	2	0	2.85	2.486	1.44	Not Passed	-	-	-	-
Original	100	89	74	60	35	23	17	15	12	7	1	0	0	7.30	-	-	-	-	-	-	-
Coarse	100	85	65	44	19	8	0							8.29	2.484	3.53	-	38.1	15.3	1.759	
TMK-6 Fine							100	79	62	42	18	4	0	2.95	2.602	4.02	Passed	-	16.6	-	1.761
Original	100	88	71	53	33	24	17	13	10	7	3	1	0	7.39	-	-	-	-	-	35.4	-
	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
TMK-7 (Crushed Rock)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2.50	2.49	-	2.4	1.9	25.1	-
	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Drilled Core	Condition of Sample Cores: Depth (m)	Ground Water	Rock Type	Diameter (cm)	Hights (cm)	Specific gravity (SSD)	Absorp-tion (%)	Compressive Strength (Kg/cm²)	Remarks
BMK-1A	5.55 - 5.75	Saturated	Shale	5.4	10.2	2.590	0.74	345.48	
BMK-1C	12.70 - 12.95	Saturated	Shale	5.4	10.4	2.620	0.40	323.86	
BMK-2A	10.70 - 10.95	Saturated	Shale	5.4	9.8	2.760	0.83	214.34	
BMK-2B	11.60 - 11.85	Saturated	Shale	5.4	9.9	2.710	2.87	214.34	



Tg. Telisai
Tg. Kepayang
R. Rimbai
R. Bojan
TMK 4
TMK 3
R. Gerai
TMK 2
R. Bruang
R. Ubau
R. Jugat
Bt. Teladan
R. Ikau
R. Sang
Tg. Rengas
R. Imbai
R. Kanin
R. Entawai
R. Jagop
R. Rantai
R. Saoh

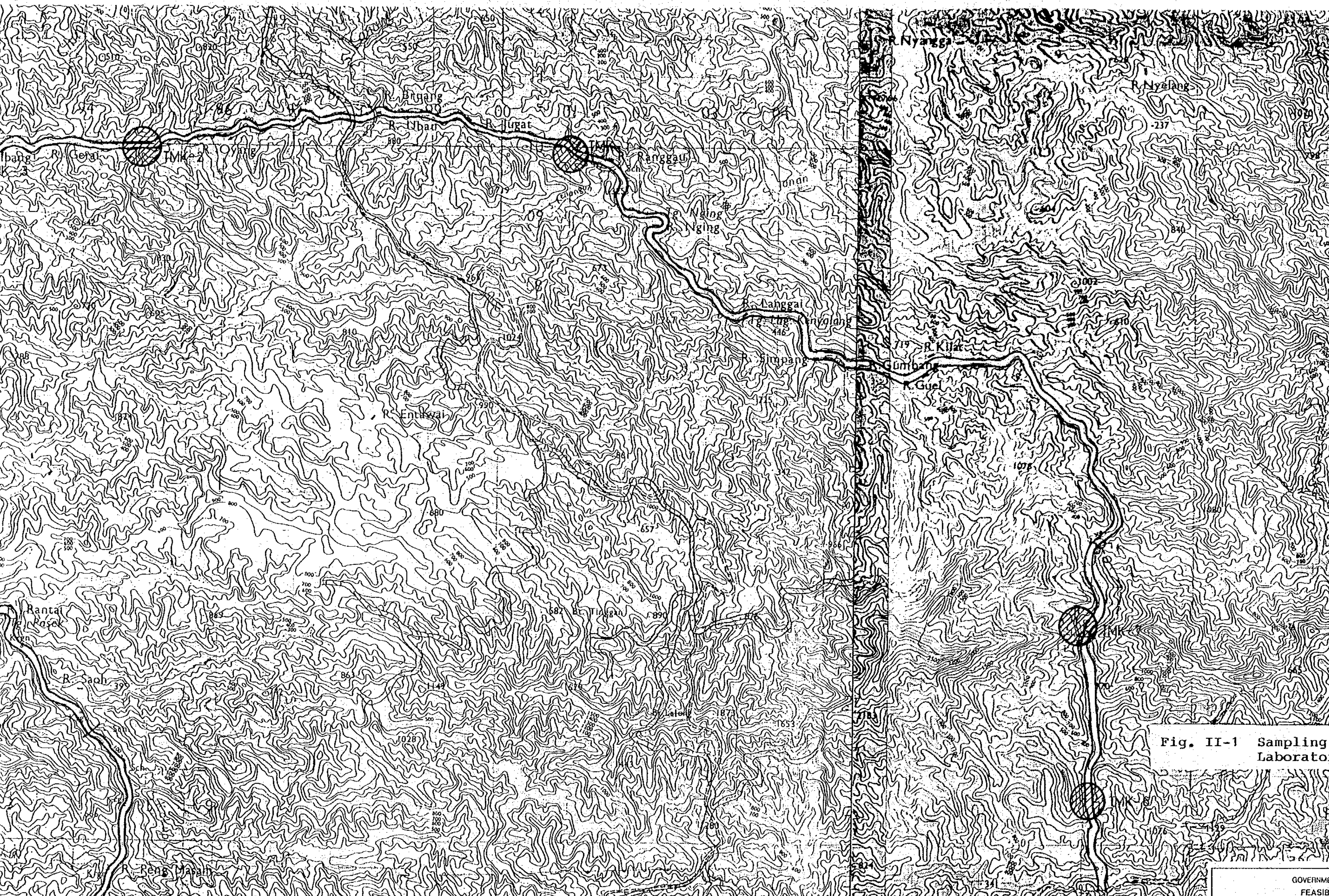


Fig. II-1 Sampling Locations for Laboratory Test

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APPENDIX III

HYDROLOGY

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CHAPTER 1. GENERAL

The preliminary meteo-hydrological assessment on identified potential sites was carried out from August 1986 to November 1986, followed by the meteo-hydrological investigation for the feasibility study of Mukoh hydroelectric power project.

The objectives of meteo-hydrological investigation are enumerated below:

- To collect and review meteo-hydrological data in and around the Mukoh River basin,
- To establish new water level and rainfall gauging stations in the vicinity of the Mukoh project site, and to develop the rating curve at the new water level gauging station site,
- To determine the long-term discharge at the intake site of Mukoh,
- To determine the flood discharge and volume for several return periods at intake site,
- To estimate the rate of sediment transportation at the intake site, and
- To clarify water quality of the Mukoh River.

CHAPTER 2. METEOROLOGY

2.1 Climatology

2.1.1 Whole Sarawak

The climate of Sarawak is classified into the tropical rain forest zone characterized by high moisture throughout the year. The northeast monsoon generally begins in the middle of October and lasts until the middle of April, while the southwest monsoon prevails from the middle of April to the middle of October. Prevailing patterns of monsoons are illustrated in Figure III-1.

Since the southwest monsoon is generally less vigourous than the northeast one, the rainy season of Sarawak coincides with the period of northeast monsoon. The southwestern part of Sarawak having the distinct rainy and dry seasons is well affected by the northeast monsoon, while the northeastern part, especially in the vicinity of state boundary between Sabah and Sarawak, has no distinctive rainy and dry seasons owing to rainfall brought by the southwest monsoon.

Meteorological data have been recorded for relatively longer period at four (4) stations under the control of Malaysian Meteorological Service (hereinafter called MMS). The location and altitude of the stations are summarized in Table III-1.

The daily mean temperature is invariable at about 26 C throughout the year, and the variation of temperature depends upon the diurnal change. Mean, maximum and minimum temperatures recorded at each station are shown in Figure III-2. The mean relative humidity is also almost constant in a range from 85 per cent to 87 per cent as shown in Figure III-3, although a slight seasonal change can be seen.

Mean sunshine hour is 5.7 hours per day on an arithmetic average of the stations. It corresponds to annual sunshine hours of 2,080 hours. A mean monthly pattern of sunshine hour is shown in Figure III-4.

Maximum surface wind speed of 31.8 m/sec was recorded at Kuching aerodrome on September 1964. The mean surface wind velocity has been recorded in a range from 0.9 m/sec to 1.3 m/sec. Maximum surface wind speed recorded in each month is shown in Figure III-5.

2.1.2 Project site

There is no meteorological gauging station in the vicinity of the project site. Evaporation data have however been recorded at the Kapit rainfall gauging station. The data shows that the monthly mean evaporation amount varies in a range from 148.3 mm in October to 121.1 mm in February as shown in Figure III-6. The annual mean evaporation amount is estimated at 1,652 mm.

2.2 Rainfall

2.2.1 Whole Sarawak

The Sarawak Hydrological Year Book 1981-1982 published by DID in 1986 contains the daily rainfall records at 136 rainfall gauging stations. Annual rainfall depth at the selected stations having relatively long recording period is enumerated in Table III-2. The isohyetal map of annual mean rainfall depth is illustrated in Figure III-7.

Mean annual rainfall depth over Sarawak is estimated at about 3,700 mm for the past 20 years. The wettest year is 1970 with annual rainfall depth of 4,310 mm, and the rainfall depth of 3,272 mm was recorded in 1972 which is the driest year. The variation of annual rainfall depth at three (3) representative stations; that is, Kuching station for southwest part, Kapit station for middle part and Ukong station for northeast part, is shown in Figure III-8.

The distribution of mean monthly rainfall given in Figures III-9 to III-20 shows that there is a distinctive rainy season from October through February in Divisions I to IV, VI and VII, while in the Division V the monthly rainfall is evenly distributed all the year round.

2.2.2 Project site

Among 136 rainfall stations, Nanga Bangkit rainfall station is the nearest station to the Mukoh project site. The location map of rainfall gauging network around the project site is shown in Figure III-21.

The data show the mean annual rainfall depth of 4,038 mm at the project site by applying the correlation analysis for monthly rainfall depths of Nanga Bangkit and Kapit recorded for 31 years from 1956 to 1986 as given in Table III-3. The correlation coefficient is estimated at 0.702.

The wettest year is 1966 with annual rainfall depth of 5,233 mm, and the driest year is 1972 with the depth of 2,408 mm. Especially, the rainfall depth from July to August in 1972 was 84.6 mm which corresponds to the draught with the recurrence interval of more than 100 years.

The dry season is defined for the period from June to August. The monthly rainfall depth reduces down to 237.2 mm in July while the wettest month is defined as December with the rainfall depth of 432.9 mm. Monthly mean, maximum and minimum rainfall depths in each month are illustrated in Figure III-22.

CHAPTER 3. HYDROLOGY

3.1 Low Flow Analysis

3.1.1 General

Run-of-river type schemes are generally elaborated on the basis of daily discharge records for a decade. The daily discharge records at the intake site, however, cover only the period of a few months. In the Study, the daily discharge data are generated for six (6) years by applying the tank model method calibrated at Kpg. Git and Buan Bidi water level gauging stations in Division I.

The flow duration curve at the intake site is used to determine the development scale of run-of-river scheme. The flow duration curve is a figure to express daily discharges against their excess rates by arranging the daily discharge data in the numerical descending order.

3.1.2 Tank model

Tank model is a widely practiced method to estimate long-term discharge data from rainfall data. Tank model is normally composed of three (3) or four (4) tanks connected subsequently to each other by their bottom outlets. Each tank has side holes, which contribute directly to the outflow of the river. The basic equation for outflow computation is below:

$$
\begin{aligned}
Qn &= 0 && (Xn < H1) \\
Qn &= A1\ (Xn - H1) && (H1 < Xn < H2) \quad \text{(Eq.III.1)} \\
Qn &= A2\ (Xn - H2) + A1\ (Xn - H1) && (H2 < Xn)
\end{aligned}
$$

$$Zn = b\ Xn \qquad \text{(Eq.III.2)}$$

$$Xn' = Xn - Qn - Zn - En \qquad \text{(Eq.III.3)}$$

$$Xn{+}1 = Xn' + In + 1 \qquad \text{(Eq.III.4)}$$

where,
- Xn : storage depth of n-th day
- Qn : outflow from side holes of n-th day
- Zn : outflow from bottom hole of n-th day
- En : evaporation rate at n-th day
- Xn' : storage depth at the end of n-th day
- In+1 : inflow at (n+1)th day
- A1,A2 : coefficient of side holes
- H1,H2 : depth of side holes
- b : coefficient of bottom hole

3.1.3 Coefficient of tank model

Tank model is assumed to consist of four (4) tanks and the coefficients of holes are calibrated on the basis of the discharge data at Kpg. Git and Buan Bidi water level gauging stations having a catchment area as small as 440 km^2 and 217 km^2 respectively, and the rainfall data in and around their catchments. The location maps of the stations are shown in Figure III-23.

Taking the available period and continuity of the rainfall record and the location of rainfall gauge into consideration, the Krokong rainfall station is selected for Buan Bidi, and Segu Bunuk, Kpg. Embahn and Padawan are selected for Kpg. Git. The average basin rainfall for the latter is estimated by the Thiessen's method. The period of simulation is seven (7) years from 1978 to 1984 for the former and two (2) years from 1977 to 1978 for the latter.

Through the trial and error method, the best fitting between the observed and estimated discharges is elaborated for both stations. The rating curves at both stations are not reliable for high discharge because of lackness of discharge measurements during high discharge and overtopping at riverbanks, so that the best fitness is tried weighing on low flow. Figures III-24 and III-25 show the results of calibration for Kpg. Git, while Figures III-26 and III-27 depict the results for Buan Bidi.

In order to apply the above results to the project site, the coefficient for the bottom hole of lowest tank is adjusted in proportion to their catchments as shown in Figure III-28. The coefficient of 0.0016 is adopted for tank model at the intake site.

3.1.4 Flow duration curve at intake site

Since no rainfall gauging station is located in the basin of Mukoh River, the rainfall data at Nanga Bangkit, which is the nearest station to the the intake site among 136 rainfall gauging stations over Sarawak, is applied to the analysis using tank model.

The rainfall data at the Nanga Bangkit station are recorded for the period from 1964 to 1986 with missing ones. Since the continuous daily rainfall data throughout the year are required to apply tank model, the daily rainfall data for six (6) years, namely, 1972, 1974, 1975, 1984 to 1986, are adopted. The generated daily discharge data for six (6) years are given in Tables III-4 to III-9.

The flow duration curves at the intake site are obtained for six (6) years by arranging the generated daily discharge data in the numerical descending order, which are shown in Figure III-30.

3.1.5 Long-term daily mean discharge

An average flow duration curve on a weighted average is obtained by assuming that the annual rainfall depth at the Kapit station is normally distributed as shown in Figure III-29.

The weight for each year is calculated as the ratio of representative area for each year to the whole area of 1.0. Then, the flow duration curve is adopted as a weighted average as shown in Figure III-30. The long-term daily mean discharge is also calculated by applying the weight on normal distribution curve to the daily mean discharge for each year. The long-term mean daily discharge is estimated at 19.1 m^3/sec at the intake site.

The adopted flow duration curve at the intake site is compared with that of representative gauging stations having relatively small catchment area as shown in Figure III-31.

3.2 High Flow Analysis

3.2.1 Rainfall analysis

(1) Frequency analysis

Frequency analysis of rainfall depth at the Nanga Bangkit station is made for various durations and return periods. Probable rainfall with the recurrence intervals of 2, 5, 10, 20, 50, 100 and 200 years are analysed for the rainfall duration of 1, 2, 3, and 5 days.

Three (3) methods, (i) Gumbel, (ii) Iwai and (iii) Log Pearson Type III, are applied to verify the fitness to the plotting position of recorded data. The results of frequency analysis for rainfall depth are given in Table III-10.

The above results do not show significant difference in their values estimated with three (3) methods. Therefore, the results of Gumbel method which is adopted by DID in their publications are applied to the further study.

(2) Conversion factor to average basin rainfall

The average basin rainfall generally tends to decrease with the increase of catchment area. Although the development of depth-area-duration curve for each storm is required to estimate the conversion factor of point rainfall to average basin rainfall, the lack of sufficient data in the Mukoh River basin prevents the derivation of conversion factor by the statistical procedure. The conversion factor is recommended by DID in his publications as shown in Figure III-32 and is applied to estimate the average basin rainfall for the site. The conversion factor of 0.93 is adopted for the site.

(3) Depth duration analysis

No hourly rainfall data has been recorded at the Nanga Bangkit station. Thus, the heavy rainfall data which is recorded at Kuching aerodrome are adopted to estimate the distribution of hourly rainfall.

The four (4) heavy rainfall data are adopted in the study as given in Table III-11.

The above data show that the heavy rainfall occurs for the duration within 24 hours and has such characteristic that about 80 per cent of 24-hour rainfall concentrates in 15 hours after rainfall starts. These torrential showers are usually observed from evening to early morning.

The average hourly rainfall distribution pattern as shown in Figure III-33 is obtained as an arithmetic mean of the above four (4) heavy rainfalls. The ratio of every 3-hour rainfall depth to 1-day rainfall depth is estimated as given in Table III-12.

(4) Design rainfall

Probable flood hydrographs at Batang Ai Hydro-electric Power Project having catchment area of 1,200 km^2 are referred for estimating the duration of design rainfall.

According to the said project, the probable flood hydrographs for various recurrence interval of 2, 10, 20, 50, 100 and 200 years were estimated on the basis of the five (5) flood hydrographs observed at the dam site. The duration of direct runoff for various probable floods is roughly estimated at about 30 hours which correspond to the duration of heavy rainfall within 24 hours. This suggests that an assumption of 24-hour rainstorm would be prudential for Mukoh with a small catchment.

The design rainfall depth at the site is, therefore, developed for the duration of 24 hours by the following equation:

$$R_{24} = C_f \times R_f \quad \text{(Eq.III.5)}$$

where, R_{24} : design rainfall depth for the duration of 24-hour (mm)

C_f : conversion factor of point rainfall to average basin rainfall (= 0.93)

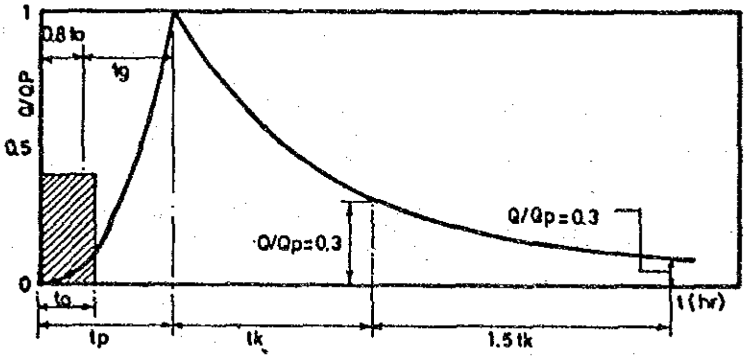
R_f : 1-day probable point rainfall depth (mm).

Design rainfall at the catchment of Mukoh site is divided into eight (8) by every three (3) hours on the basis of aforementioned depth duration analyses. The design rainfall is given in Table III-13.

3.2.2 Flood analysis

(1) Derivation of unitgraph

A unitgraph at the project site is developed by the Nakayasu's synthetic unit hydrograph method. The unitgraph is derived by the following procedures:



(i) Lag time of peak discharge

$$tg = 0.5 + 0.058L \quad (L<15\ km) \quad \text{(Eq.III.6)}$$
$$tg = 0.21 \times L\ exp(0.7) \quad (L>15\ km) \quad \text{(Eq.III.7)}$$

where, tg : lag time of peak discharge (hr)
L : river channel length (km)

$$tk = 0.47\ (\ A\ L\ )\ exp(0.25) \quad \text{(Eq.III.8)}$$

where, tk : recession time period from the time of peak discharge to 30 per cent of peak discharge (hr)
A : catchment area (km^2)

(ii) Time of concentration

$$tp = T1 = 0.8to + tg \quad \text{(Eq.III.9)}$$
$$t1 = T2 = tp + tk \quad \text{(Eq.III.10)}$$
$$t2 = T3 = tp + tk + 1.5tk \quad \text{(Eq.III.11)}$$

(iii) Peak discharge

$$Qp = A\ Ro\ /\ [\ 3.6\ (0.3\ tp + tk)\ ] \quad \text{(Eq.III.12)}$$

where, Qp : peak discharge (m^3/sec)
Ro : unit effective rainfall (mm)

(iv) Unitgraph

- Rising limb

$$Qr = (\ t\ /\ tp\ )\ exp(2.4) \quad (\ 0<t<tp\ ) \quad \text{(Eq.III.13)}$$

- Recession limb

$$Qr = 0.3\ exp[(t-tp)/tk] \quad (\ T1<t<T2\ ) \quad \text{(Eq.III.14)}$$

$$Qr = 0.3 \times 0.3 \exp[(t-T2)/1.5tk]$$
$$(T2<t<T3) \; . \; (Eq.III.15)$$

$$Qr = 0.3 \times 0.3 \times 0.3 \exp[(t-T3)/2tk]$$
$$(t>T3) \; .... \; (Eq.III.16)$$

The values required to obtain a unit hydrograph are the catchment area of 292 km^2 and the river length of 25.0 km.

(2) Loss rate

Initial rainfall loss is disregarded by assuming that the whole basin is saturated by antecedent rainfall, resulting in the estimate of a conservative side. While the retention loss rate after the saturation is assumed to be constant at 2.5 mm per hour.

The rate of 2.5 mm per hour as retention loss is estimated on the basis of other hydroelectric projects in Sarawak and Peninsula Malaysia as enumerated in Table III-14.

The retention loss rate generally tends to increase with the increase of catchment area. Therefore, the minimum retention loss rate of 2.5 mm per hour is adopted in view that most of the potential sites in the Study are located in the steep-sloped mountainous area with relatively small catchment and that future logging activities will lead to reduce its retention loss rate.

(3) Probable Flood Hydrograph

Probable flood hydrographs are calculated under the following conditions:

(1) A unitgraph is obtained by the Nakayasu's synthetic unit hydrograph method.

(2) Design hyetographs of 24-hour duration for various return periods are applied to synthesize the hydrographs.

(3) Retention loss rate of 2.5 mm per hour is subtracted from the design hyetograph to estimate rainfall excess.

(4) Base flow is assumed to be equivalent to the annual average discharge.

The probable flood hydrographs at the intake site are shown in Figure III-34. The peak discharges, flood volumes and their specific discharges are summarized in Table III-15.

(4) Rating curve at the powerhouse site

The rating curve at the powerhouse site is established by the Manning's formula; that is,

$$Q = n^{-1.0} A R^{0.667} I^{0.5} \quad \text{(Eq.III-17)}$$

where, Q : discharge (m^3/sec)
n : Manning's roughness coefficient (= 0.050)
A : flow area (m^2)
R : hydraulic depth (m)
I : water surface gradient.

The water surface gradient of 1 to 100 is estimated by using the maps on the scale of 1 to 50,000. The rating curve established is shown in Figure III-35.

The powerhouse is proposed to locate at immediately downstream of the intake site. The flood water level at the powerhouse site is estimated at El.77.900m for the 200-year probable flood.

3.3 Sedimentation and Water Quality

3.3.1 Sedimentation

Measurements on sedimentation were carried out five (5) times from June 24 to June 29, 1987. However, such data are still insufficient for the derivation of relationship between discharge and sediment volume.

The sediment volume at the intake site is estimeted on the basis of the surface denudation rate taking the study results of Batang Ai and Bakun Hydroelectric Projects into consideration.

The denudation rates for the above projects are 1.0 mm per annum for the former and 0.5 mm per annum for the latter. Those correspond to annual sediment deposit volume of 1.25 million m^3 and 7.60 million m^3, respectively.

The denudation rate of 1.0 mm per annum is adopted for the intake site, namely, the annual sediment volume flowing through the intake is estimated at 0.29 million m^3.

3.3.2 Water quality

River water sampling was simultaneously carried out with discharge measurements. The results of water quality test are given in Table III-16.

3.4 Right of Way in Water Use

There is no habitant in the Mukoh River basin upstream from the Mukoh site. Uppermost location of longhouse along the Mukoh River is about 2.0 km downstream from the proposed tailrace site.

Since all the logging activities in the basin are carried out through logging roads which traverses the mountain ridge, the Mukoh River is not used for the transport of logged timber.

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Table III - 1 List of Meteorological Gauging Station

No	Name of Station	Location Latitude	Location Longitude	Altitude (a.m.s.l.)	Recording period
1	Kuching aerodrome	01 29'N	110 20'E	21.7	1954-1986
2	Sibu aerodrome	02 20'N	111 50'E	7.5	1968-1986
3	Bintulu aerodrome	03 12'N	113 02'E	3.1	1968-1986
4	Miri aerodrome	04 20'N	113 59'E	17.0	1968-1986

Table III - 2 Annual Rainfall Depth at Representative Stations

(Unit:mm)

Year	Rainfall Gauging Station		
	Kuching	Kapit	Ukong
1950	3,951		
1951	3,873		
1952	4,404		
1953	4,220		
1954	3,884		
1955	4,677		
1956	3,529	3,405	
1957	3,861	3,004	
1958	3,722	3,000	
1959	3,553	3,808	
1960	3,872	4,025	
1961	4,160	4,022	
1962	4,516	3,237	
1963	4,909	3,767	4,402
1964	4,792	3,535	4,374
1965	3,329	3,659	4,362
1966	3,696	4,529	3,804
1967	3,654	3,630	4,201
1968	4,441	3,706	5,150
1969	4,277	3,672	3,729
1970	4,262	4,714	3,592
1971	4,988	4,353	3,609
1972	3,099	3,178	3,801
1973	4,521	4,571	4,327
1974	3,325	3,479	4,395
1975	4,520	3,574	4,022
1976	3,770	3,151	3,268
1977	5,296	2,870	3,549
1978	4,236	3,558	3,533
1979	4,365	3,901	3,839
1980	4,651	4,633	4,519
1981	3,869	3,224	3,668
1982	3,327	4,473	3,252
1983	4,118	4,021	3,616
1984	4,488	4,170	4,469
1985	3,772	3,500	3,424
1986	4,264	3.530	3,122
Maximum	5,296	4,714	5,150
Minimum	3,099	2,870	3,122
Average	4,104	3,739	3,903

Table No. III - 3 Monthly Rainfall Depth at Nanga Bangkit

(Unit : mm)

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL
1956	378.5	353.2	336.9	194.8	394.3	394.1	288.7	288.7	262.3	419.3	207.5	264.8	3783.1
1957	242.6	224.3	339.1	297.7	486.0	312.7	263.1	127.1	239.2	334.0	224.8	398.6	3489.2
1958	275.1	177.2	398.6	162.0	281.0	363.4	133.6	331.4	345.4	410.0	336.7	271.5	3486.0
1959	527.6	384.3	277.5	354.4	308.4	380.8	198.1	256.5	305.3	488.7	322.0	312.2	4115.7
1960	525.9	329.8	192.9	419.2	348.8	335.8	266.1	217.7	419.9	413.8	338.9	429.0	4237.8
1961	375.2	648.4	498.0	331.1	252.4	245.2	242.4	250.4	379.7	227.7	391.7	393.5	4235.6
1962	372.0	351.5	408.2	360.0	292.4	259.6	202.2	248.9	237.3	402.3	241.1	284.2	3659.7
1963	529.5	428.1	420.0	272.2	330.3	238.9	235.5	227.5	258.4	318.7	310.4	482.6	4052.1
1964	364.2	406.0	380.8	371.0	238.1	317.3	433.2	221.3	591.6	241.1	504.2	277.4	4346.2
1965	292.5	253.5	313.4	247.2	279.7	283.0	161.7	352.7	311.3	356.1	333.2	809.5	3993.8
1966	759.0	511.6	492.5	386.8	352.6	433.6	180.3	447.8	407.4	277.4	508.8	475.5	5233.3
1967	542.8	334.5	290.3	324.1	550.7	278.4	317.8	226.7	302.0	485.1	514.1	497.3	4663.9
1968	248.3	247.1	655.1	360.1	222.4	323.1	243.8	231.0	277.6	443.5	418.1	493.6	4163.8
1969	294.0	328.4	414.0	269.4	455.9	179.8	280.9	366.1	254.0	431.0	261.1	419.0	3953.7
1970	471.2	316.0	414.0	334.4	339.4	161.0	307.3	6.6	451.4	469.9	375.1	522.9	4169.2
1971	437.9	387.3	358.1	281.0	265.2	332.2	127.8	634.7	357.4	351.5	838.7	989.8	5361.6
1972	258.8	372.6	88.9	165.4	236.7	216.2	6.6	78.0	310.9	146.3	291.1	236.5	2408.0
1973	350.7	180.8	452.1	373.4	357.9	358.1	285.2	345.9	512.8	299.5	334.8	469.6	4320.8
1974	199.1	202.2	169.2	255.3	207.3	137.9	240.5	292.1	554.2	481.6	178.1	181.9	3099.4
1975	381.3	299.0	347.7	315.5	487.9	189.2	269.2	349.8	352.6	255.8	213.6	441.5	3903.1
1976	213.1	243.1	133.4	382.0	116.8	149.4	200.2	323.9	114.3	340.9	345.9	326.6	2889.6
1977	292.4	388.4	374.9	258.2	252.7	204.7	188.2	183.8	275.1	304.8	339.7	327.6	3390.3
1978	366.1	309.2	435.0	315.8	456.3	201.7	248.0	225.6	326.5	325.0	303.1	382.9	3895.2
1979	321.3	339.3	354.6	279.5	248.0	392.1	305.9	243.5	445.0	319.5	516.1	222.3	3987.2
1980	269.3	217.2	215.0	624.0	340.1	325.0	300.8	153.9	332.0	627.0	546.5	531.6	4482.4
1981	460.0	154.8	195.3	238.6	107.0	286.5	156.0	110.3	148.5	452.0	455.2	442.0	3206.2
1982	492.6	363.5	347.0	312.5	428.8	228.1	162.8	202.1	208.7	297.8	245.8	369.7	3659.5
1983	396.2	235.5	222.6	287.6	322.1	253.1	292.0	90.9	834.0	585.5	279.4	846.0	4644.7
1984	617.0	700.5	467.5	516.0	235.0	412.5	394.0	183.5	137.1	367.0	233.0	436.5	4699.6
1985	340.0	461.9	592.5	255.2	328.5	157.5	258.3	290.0	350.0	460.5	487.5	519.0	4500.9
1986	785.5	219.8	802.5	458.5	340.0	568.5	162.5	193.5	295.5	405.5	536.0	365.5	5133.3
AVE.	399.3	334.5	367.3	322.7	318.2	287.7	237.2	248.5	341.9	378.7	368.8	432.9	4037.6

Table No. III - 4 Generated Daily Discharge at Intake Site in 1972

(Unit : cms)

DAY	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1	20.3	10.2	8.4	4.7	4.4	4.4	5.9	3.0	2.8	28.9	3.6	5.8
2	16.3	8.0	7.9	4.7	6.3	4.4	5.5	2.9	39.0	17.4	3.6	5.7
3	10.5	7.9	7.4	4.7	4.5	4.3	5.1	2.9	24.4	8.2	3.6	5.7
4	7.9	7.7	7.0	4.7	4.5	4.3	4.7	2.8	19.2	5.0	3.6	5.5
5	7.7	7.3	6.6	4.7	4.6	4.3	4.4	2.8	12.4	4.8	3.5	5.5
6	7.5	6.9	6.2	4.7	4.7	4.3	4.1	2.8	25.0	4.6	3.5	5.4
7	7.1	6.8	6.2	4.6	5.1	4.3	3.9	2.7	101.2	4.2	3.5	5.4
8	6.9	6.9	6.1	4.6	23.6	4.2	3.9	2.7	33.3	3.8	3.5	5.4
9	6.7	6.8	6.0	4.6	12.5	4.2	3.9	2.6	22.2	3.7	3.6	5.4
10	6.6	8.0	5.6	4.6	52.1	4.1	3.8	2.6	13.2	3.6	6.1	5.3
11	6.4	8.1	5.3	4.6	29.6	4.1	3.8	2.5	7.4	3.6	21.6	5.3
12	6.0	8.2	5.2	4.6	16.1	4.0	3.8	2.5	5.7	3.5	11.1	19.4
13	5.7	11.2	5.1	4.5	8.8	4.0	3.7	2.5	5.5	3.2	6.5	10.5
14	5.6	35.7	5.1	4.5	8.7	4.0	3.7	2.4	5.3	2.8	6.7	7.2
15	5.3	32.3	5.1	4.5	9.9	4.0	3.6	2.4	5.2	2.8	14.1	5.6
16	5.0	30.3	5.1	8.8	8.4	3.9	3.6	2.3	5.1	21.3	9.4	6.0
17	4.8	20.6	5.1	6.2	6.8	3.9	3.6	2.3	4.9	18.9	9.5	10.5
18	4.8	61.9	5.0	5.9	6.7	3.9	3.5	2.3	4.4	14.7	17.1	10.0
19	5.0	92.7	5.0	70.1	6.4	3.9	3.5	2.2	4.0	9.1	51.1	9.2
20	6.6	142.7	5.0	24.4	6.0	19.9	3.4	2.2	3.6	5.5	34.5	7.1
21	74.5	45.1	4.9	13.1	5.6	68.3	3.4	2.1	3.5	4.1	18.5	5.9
22	23.3	41.5	4.9	7.3	10.3	79.6	3.4	2.1	3.4	4.0	12.9	5.7
23	13.0	24.1	5.3	6.1	6.6	29.0	3.3	2.1	3.2	3.7	8.2	5.6
24	21.2	17.0	4.9	6.0	5.8	15.4	3.3	2.1	2.9	3.5	6.2	6.7
25	17.1	12.1	4.8	6.0	6.1	7.6	3.2	2.1	2.6	3.5	6.7	10.0
26	16.8	10.2	4.8	5.8	5.9	7.7	3.2	3.8	2.6	3.5	6.6	16.7
27	27.6	9.9	4.8	5.5	5.8	9.0	3.1	17.8	6.6	3.6	9.9	9.3
28	26.6	9.4	4.8	5.1	5.7	7.5	3.1	8.2	22.4	3.7	7.9	6.8
29	15.4	8.9	4.8	4.8	5.3	6.3	3.1	4.4	33.6	3.7	6.1	5.9
30	27.0		4.9	4.5	5.0	6.2	3.1	2.9	42.9	3.7	5.9	5.8
31	15.7		4.7		4.6		3.0	2.8		3.6		5.8
Average	13.9	24.1	5.5	8.3	9.6	11.2	3.8	3.3	15.6	6.8	10.3	7.4

ANNUAL AVERAGE = 9.9 cms

Table No. III - 5 Generated Daily Discharge at Intake Site in 1974

(Unit : cms)

DAY	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1	7.0	5.7	18.5	16.1	6.8	4.4	4.2	5.6	6.0	8.3	11.8	6.0
2	6.9	5.7	12.5	10.2	6.6	4.3	3.9	10.2	5.9	8.2	11.3	5.8
3	32.5	5.5	9.7	9.4	6.3	4.3	13.5	22.6	5.8	11.0	12.4	5.5
4	27.0	5.4	7.3	7.3	6.1	4.3	6.8	32.4	5.7	9.1	10.8	5.5
5	18.8	5.3	7.0	6.2	5.8	4.3	5.2	17.4	46.0	68.5	52.3	5.5
6	11.3	5.0	6.9	9.7	5.4	4.3	4.5	30.2	125.6	93.8	23.0	5.5
7	8.3	5.0	6.7	8.8	5.3	4.3	4.6	16.5	127.1	32.9	39.1	5.5
8	7.6	5.0	6.4	7.2	5.0	4.3	4.6	32.2	175.0	18.9	22.9	5.5
9	7.6	5.0	6.0	6.3	5.7	4.3	4.5	17.7	51.5	10.7	13.7	5.4
10	7.4	5.0	5.7	6.2	5.1	4.2	4.3	10.2	28.4	34.3	12.1	5.4
11	7.2	4.9	5.3	5.9	5.1	4.2	4.0	7.4	34.9	19.7	10.1	5.4
12	6.9	4.7	5.0	10.5	5.2	4.2	3.9	18.6	26.5	12.4	9.8	5.4
13	6.7	4.7	4.7	13.5	18.4	4.2	6.3	10.9	19.6	9.3	9.5	5.3
14	6.6	4.7	4.6	11.0	10.0	4.1	4.0	8.6	22.5	14.3	9.0	5.3
15	11.8	7.1	4.6	9.2	7.2	4.1	4.1	7.3	18.9	19.1	8.5	5.3
16	8.9	6.1	4.6	6.9	106.8	4.0	4.5	7.1	20.8	17.0	8.0	5.2
17	7.4	5.1	4.5	6.3	28.6	4.0	5.9	6.9	16.2	12.0	7.9	5.2
18	6.8	5.1	4.5	6.2	15.7	4.0	6.0	6.8	12.0	11.2	7.7	5.2
19	6.7	5.1	4.5	5.8	8.5	16.6	4.6	6.7	11.7	10.1	7.3	5.2
20	6.4	5.1	4.4	5.7	6.9	8.3	4.6	6.5	9.6	9.0	7.2	5.1
21	9.6	8.4	4.4	5.6	6.7	6.0	11.0	6.1	9.1	18.0	7.1	5.1
22	8.7	7.0	4.4	5.7	6.4	4.5	11.2	5.6	40.9	12.0	7.0	5.1
23	7.7	18.2	4.4	5.7	9.4	4.4	55.0	5.6	24.5	9.7	6.8	5.3
24	6.6	12.1	4.3	5.6	6.5	4.4	21.2	5.5	17.0	22.7	6.4	5.3
25	6.6	8.9	4.3	5.6	6.4	12.0	11.2	13.5	11.4	13.7	6.4	5.4
26	6.7	17.4	4.3	45.9	6.3	6.8	9.0	8.2	9.0	30.2	6.4	5.5
27	6.7	10.0	4.3	61.7	6.0	5.2	6.7	6.3	8.8	17.6	6.4	14.7
28	6.5	9.0	4.3	24.4	5.6	4.9	6.1	6.6	8.7	34.5	6.4	8.9
29	6.4		12.7	13.2	5.3	4.8	6.0	6.7	8.6	96.5	6.3	6.9
30	6.2		120.4	7.6	4.9	4.5	5.9	6.3	8.5	33.1	6.1	7.3
31	6.1		30.6		4.6		5.7	6.0		19.5		19.6
Average	9.3	7.0	10.7	11.6	10.9	5.3	8.2	11.6	30.5	23.8	12.0	6.4

ANNUAL AVERAGE = 12.3 cms