upper part. Of the two stations, the Limang G.S. is the only stream gauging station within the basin, but the discharge data available is rather poor in reliability for the following reasons. (i) Many gauging omissions are presented. (ii) Highly reliable discharge data cannot be obtained as the frequency of river discharge gauging for preparing the water-stage and discharge curves is low. (iii) The stream gauging function during flood time poses an elaborate on problem.

However, as the Stabat Stream Gauging Station is located some 78km downstream from the project site, and the rainfall and basin characteristics around the station are somewhat different from those of the upstream basin of the Wampu River, the construction of a stream gauging station within the project was considered. It was also decided that a rainfall observation station should be built at an appropriate point in the project area.

The stream gauging station and the rainfall observation station were built as follows.

Stream gauging station :	Teba Stream Gauging Station located on the lower part of the Teba River, a tributary of the Wampu River. (One automatic water level recorder and one current meter)
Rainfall station :	Rihtengah Raingage Station on the upstream of the Wampu River, near to the village of Rihtengah (one automatic rainfall recorder)

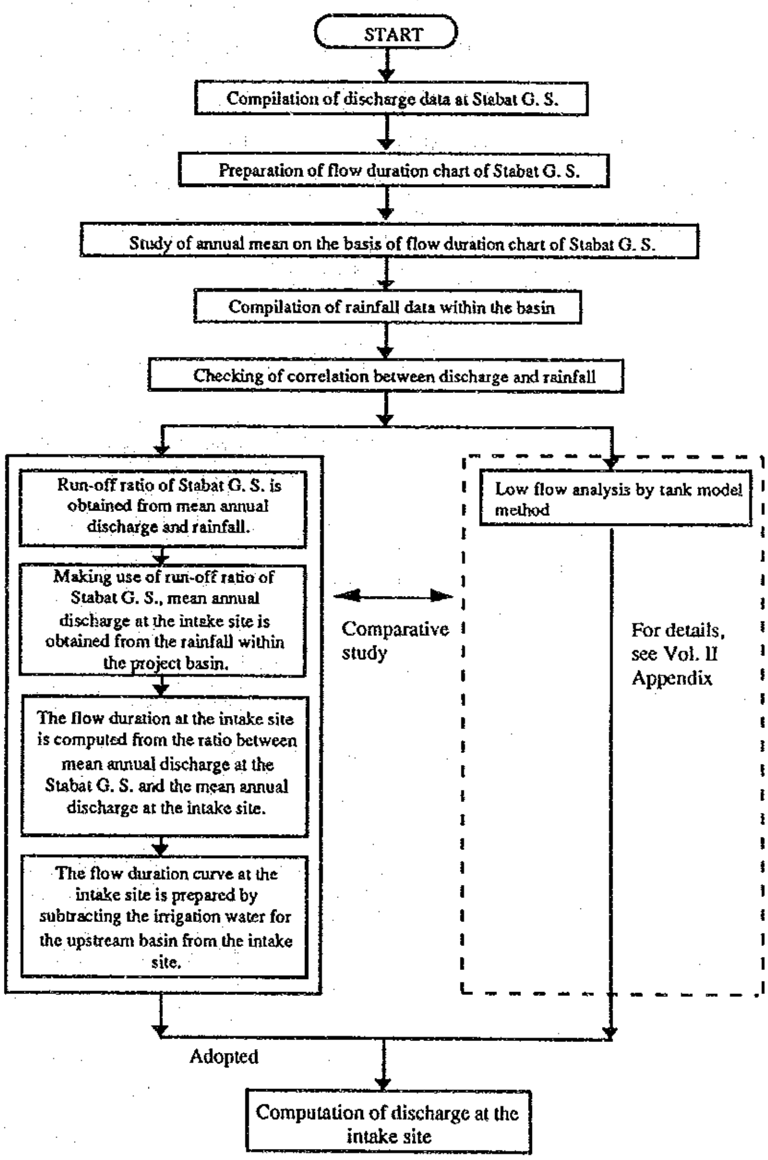
As a result of reconnaissance carried out in the initial stage of this feasibility study in February 1990, it was intended to set up a stream gauging station at the Kaperas site just downstream the junction of the Wampu River and Teba River, its tributary, but PLN was already planned a stream gauging station at this site. Therefore, after consultation with PLN it was set up at the above stated site.

3.2.6 Estimation of Discharge at Project Site

As stated in the preceding section "3.2.5 River Discharge," the only stream gauging station available for this project is the Stabat Stream Gauging Station. Although it is considered that the basin characteristics at that station are different from those of the project site because it is located in a plain at a distance of 50km or more from Kaperas, it is the only gauging station on the Wampu River that has been in operation for sufficiently long period and where reliable discharge data can be obtained. Also, rainfall observation stations are situated along the Wampu River, including the project area, and therefore rainfall data is available.

Because of the distance between the project site and the stream gauging site and because the rainfall situation at the two sites cannot be deemed identical, the discharge at the project site was estimated by "the catchment area ratio conversion weighted to include rainfall method." The rainfall depth of the catchment was obtained by means of the isohyetal method. This method follows the procedures in (1) to (5) of this section, and the flow duration of the project site resulting from the computation in given in Table 3-3 to Table 3-5. The study flow is given below.

Also, as a result of low flow analysis using the tank model method for reference, the rainfall and discharge are obviously correlated, so it is considered that "catchment area ratio conversion weighted to include rainfall method" as stated above can be applied to this area. Incidentally, the computation of the discharge at this site by the tank model method cannot be adopted because of insufficient data. Low water analysis using the tank model method is described in Vol. II Appendix.



(1) Selection of the representative mean year by flow duration

When the mean year of the flow duration is obtained on the basis of the discharge data for the recent 10 years (1979 to 1988) at the Stabat Stream Gauging Station, it can be seen that the year 1983 is the closest to the mean value, as shown in Vol. II Appendix Hydrology. 1983 was therefore selected as the representative mean year. If the mean value of daily discharges for the whole period is taken, the run-off characteristics resulting from the basin environment will be lost, but the adoption of the representative mean year offers the advantage of indicating the run-off characteristics. The data for the latest 10 years also takes into consideration run-off changes resulting from the development of the basin.

(2) Rainfall of the representative mean year in the project basin

The rainfall depth for 1983, the representative mean year, was obtained as below. The isohyetal map was prepared on the basis of the rainfall data in and around the basin. Then the divided areas of the basin surrounded by the neighboring isohyetal lines were measured by the planimeter and the mean annual rainfall depth was calculated using equation given below. This is a rational method since the topography, wind directions and elevation are taken into consideration (Refer to Table 3-2 and Fig. 3-4).

$$\overline{R} = \sum_{i=1}^{n} \frac{R_i + R_{i+1}}{2} \bullet \frac{a_i}{A}$$

where $\overline{R}$: mean annual rainfall depth (mm)

R_i, R_{i+1} : values of neighboring isohyetal lines (mm)

A : total basin area of the selected position (km^2)

ai : divided areas between isohyetal lines in the total area of the basin (km^2)

The results of computations of the mean annual rainfalls at the Stabat, Kaperas and Limang site using the above method are as given below.

Names of surveyed points in the basin	Basin area (km^2)	Mean annual rainfall (mm)
Stabat (78km downstream of Limang)	3,870	2,476
Kaperas (28km downstream of Limang)	1,570	1,893
Limang (Intake Dam Site)	959	1,499

(3) Computation of rainfall run-off ratio on the Wampu River

Computation of the mean annual discharge and the rainfall run-off ratio at Stabat on the Wampu River gives the result given below.

$$q = \frac{86.4 \times 365 \times Q}{A} = \frac{86.4 \times 365 \times 203.63}{3,870} = 1,659 \text{ (mm)}$$

where
q : annual run-off depth (mm)
A : drainage area (km^2)
Q : mean daily discharge (m^3/s)

Run-off ratio at Stabat:

$$f = \frac{q}{\bar{R}} = \frac{1,659}{2,476} = 0.670$$

where
f : run-off ratio
$\bar{R}$: mean annual rainfall depth (mm)
q : annual run-off depth (mm)

The above run-off ratio of 0.670 is a value smaller than the mean evapotranspiration rate since the mean evapotranspiration of the basin is 1,294mm and the difference between the mean annual rainfall depth and the run-off is 817mm. This is considered attributable to the inclusion of the run-off amount, which forms the base flow, in the run-off amount computed on the basis of the mean annual discharge.

(4) Discharge at Limang site (W/AA Intake Site: Basin Area of 959km^2)

When the run-off depth and the mean annual discharge at the Limang site are obtained on the basis of the run-off ratio at the Stabat site on the Wampu River, the result given below is obtained.

Run-off depth:

$$qi = \bar{R}i \cdot f = 1,499 \times 0.67 = 1004.25 \text{ (mm)}$$

where
qi : annual run-off depth at the Limang site
$\bar{R}i$: mean annual rainfall depth at the Limang site
f : Run-off coefficient

Mean annual discharge:

$$\bar{Q}i = \frac{qi \cdot Ai}{365 \text{ (day)} \cdot 86.4 \text{ (sec)}} = \frac{1004.25 \times 959}{31,535} = 30.54 \text{ (m}^3\text{/s)}$$

where $\bar{Q}$: mean annual discharge at Limang (m^3/sec)
qi : annual run-off depth at Limang (mm)
Ai : basin area at Limang (km^2)

In the case of the discharge at Limang when computed from the discharge at Stabat, the computation if based solely on the ratio of basin areas would not be appropriate as the rainfall depths are not identical. Conversion should be made under the equation given below, which takes the rainfall depth and the run-off rate into consideration.

$$Ql = Qs \cdot Kl \cdot \frac{Al}{As}$$

$$Kl \frac{Al}{As} = \frac{Ql}{Qs}$$

$$Kl = \frac{QlAs}{QsAl}$$

$$Kl = \frac{30.54 \times 3,870}{203.65 \times 959} = 0.605$$

where Ql : discharge at Limang (m^3/sec)
Qs : discharge at Stabat (m^3/sec)
Kl : correction coefficient at Limang
As : basin area at Stabat (km^2)
Al : basin area at Limang (km^2)

The discharge at the Stabat site was converted into the discharge at the Limang site by means of the above equations. The discharge of $4.1m^3/sec$, taken as irrigation water in the Limang basin was subtracted, Table 3-6 (1) results.

(5) Discharge at Kaperas site (Basin Area: $1,570km^2$)

When the discharge at Kaperas site was computed as in the preceding section (4), the following procedures were taken:

Run-off depth:

$$qd = Rd \cdot f = 1,893 \times 0.67 = 1,268.07 \text{ (mm)}$$

Mean annual discharge:

$$\bar{Q}d = \frac{qd \cdot Ad}{365 \text{ (day)} \cdot 86.4 \text{ (sec)}} = \frac{1,268.07 \times 1,570}{31,536} = 63.13 \text{ (m}^3\text{/s)}$$

Mean annual discharge:

$$Qd = Qs \cdot Kd \cdot \frac{Ad}{As}$$

$$Kd\frac{Ad}{As} = \frac{Qd}{Qs}$$

$$Kd = \frac{QdAs}{QsAd}$$

$$= \frac{63.13 \times 3{,}870}{203.65 \times 1{,}570} = 0.764$$

where
Q_d : dam site discharge (m^3/s)
Q_s discharge at Stabat (m^3/s)
K_d : dam site correcting coefficient
A_s : basin area at Stabat (km^2)
A_d : basin area at dam site (km^2)

The mean annual discharge at the Stabat station was converted into Kaperas site discharge by means of the above equations, and when the irrigation water of $4.1m^3/sec$ regularly taken in the upstream area is subtracted, Kaperas site discharge is obtained as shown in Table 3-6 (5). The inflow and discharge mass-curves at the Kaperas dam site are shown in Vol. II Appendix.

(6) Computation results

As stated above, "the method by catchment area ratio conversion weighted to include rainfall (isohyetal line map method)" was adopted for computation of the discharge at the dam site. Shown below are the computation results at the Stabat site and the Limang site (W/AA intake dam site). The results of the analysis by the Tank Model method as performed at the Stabat site are shown in the table for reference (refer to the Appendix Vol. II for details).

Stabat site (catchment area = $3{,}450km^2$)

Calculation method Calculation result	Isohyetal map method (m^3/s)	Reference value (Tank model method) (m^3/s)	Correlation
Qmax	775.00	884.08	0.787 (computed by tank model method)
Qmin	88.60	83.14	
Qmean	203.63	224.37	
High stream flow	235.00	293.34	
Normal stream flow	165.00	181.09	
Low stream flow	124.00	122.25	
Drought discharge	96.40	88.42	

As for the computed results for the Stabat site, given in the above table, the discharge computed using the tank model method is a little larger in all cases. The correlation coefficient of 0.8 is reasonable. This is considered to be attributable to the fact that the discharge and rainfall data of the mean year (1983) were used in both methods. Accordingly, the result of computations for the Limang intake dam site using the isohyetal map method is considered usable for the present study, being based on reliable data.

Limang site (W/AA Intake Site: catchment area = 959km^2)

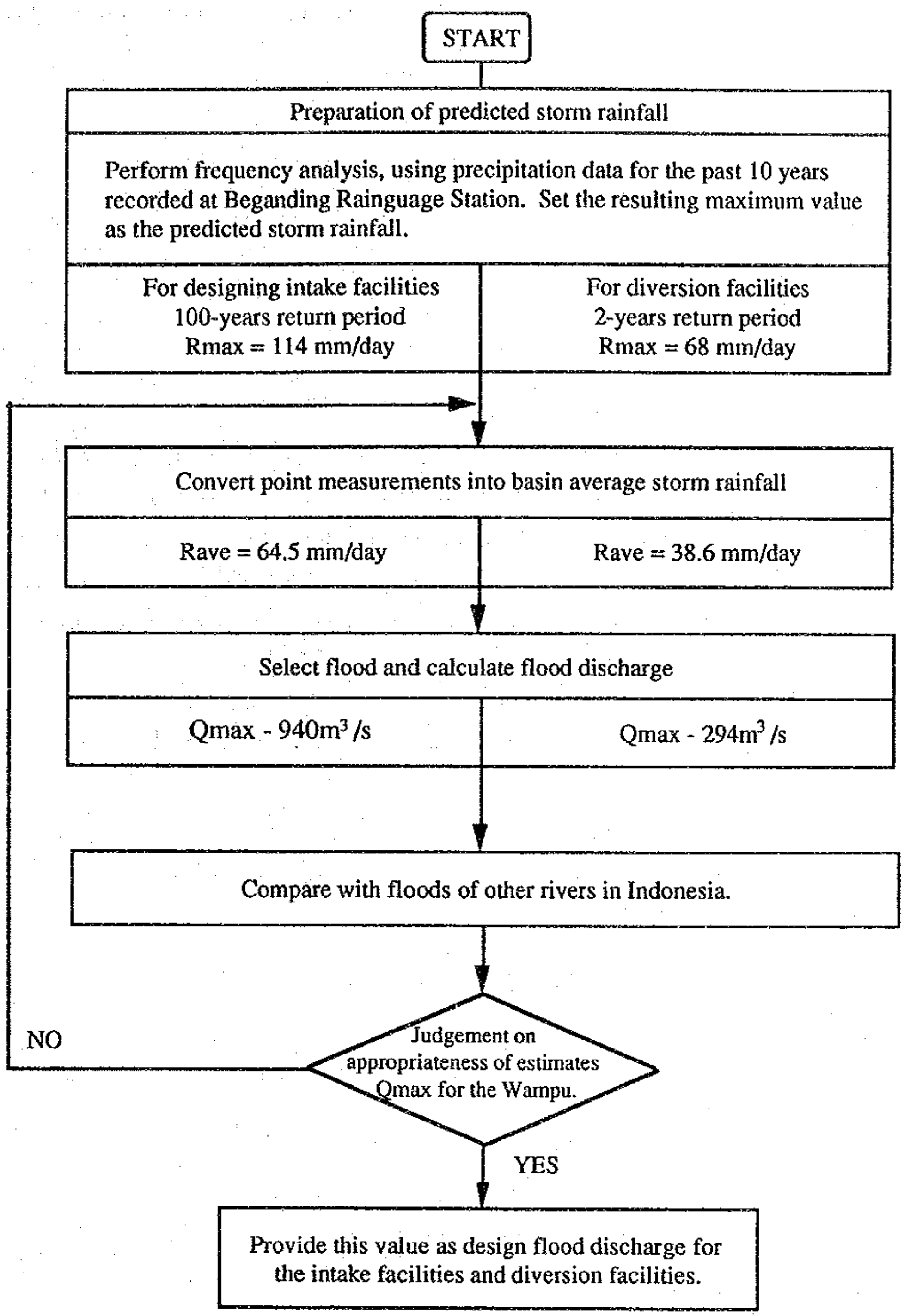
	Isohyetal map method
Qmax	108.13m^3/s
Qmin	9.97 "
Qmean	26.11 "
High stream flow	31.59 "
Normal stream flow	20.68 "
Low stream flow	14.43 "
Drought discharge	10.40 "

3.2.7 Flood (High Water Discharge)

Frequency analyses were undertaken from the rainfall storm data available in the basin and the probable rainfall was computed under the respective methods of Hazen, Thomas and Gumbel. Then, using the highest computed value, the probable flood discharge of the river is computed. In this analysis the storage function method was used. In the computation the storage volume given as the function of outflow will accurately grasp the non-uniformity of flood discharge in time and execute non-linear analysis (10 representative floods are selected from the available flood data).

The flood estimating procedures for the project site are shown in the following flow chart.

Flood Analysis Flow Chart



(1) Average storm rainfall in basin for use in flood flow calculation

The following table shows results of probable daily rainfall (maximum daily rainfall): For details, see Vol. II Hydrology.

(mm)

Probable rainfall \ Calculation formula	Hazen	Thomas	Gumbel	Note
100-year return period	100	100	114	For intake dam facilities
2 year return period	67.6	67.6	68	For diversion facilities

The maximum daily rainfall of 114 mm/day and 68 mm/day were obtained for the intake dam and diversion facilities at Limang site, respectively from the Gumbel formula (the largest value in the above table). Because these maximum daily rainfall values were obtained based solely on the data from Beganding Raingauge Station, the average rainfall data in the catchment is needed for use in flood calculation. This average rainfall can be calculated in the following manner:

(a) Hazen's formula (Engineering Hydrology by R.S. Varshney, USA)

$$i = \frac{1.13\,I}{A^{0.13}}$$

where i : average rainfall (mm/day)

I : maximum rainfall (mm/day)

A : catchment area (km^2)

Consequently, the average catchment rainfall for use in flood calculation can be obtained as follows:

Site	Facilities	Catchment area (A) (km^2)	Max. daily rainfall (I) based on results of probability calculation (mm/day)	Average rainfall (i) accoding to Hazen's formula (mm/day)
LIMANG	Intake dam	959	114	$i = \frac{1.13 \times 114}{959^{0.13}} = 52.7$
	Diversion	959	68	$i = \frac{1.13 \times 68}{959^{0.13}} = 31.5$

(b) Calculation by Horton's formula*

$$\frac{\overline{P}}{Po} = e^{-k\left(\frac{A}{2.5899}\right)^{n}}$$

where $\overline{P}$: average rainfall (mm)

Po : maximum rainfall (mm)

A : catchment area (km^2)

K, n : see table

Items in formula		Application area	By Miami Conservancy District (U.S.A.) Northern storm	Southern storm
Horton's formula* (U.S.A)	K		0.0883	0.112
	n		0.24	0.23
Conversion to Wampu Limang site	A (km^2)		959	959
	$e^{-k\left(\frac{A}{2.5899}\right)^{n}}$		0.694	0.646
Estimated average rainfall at Wampu Limang site	$e^{-k\left(\frac{A}{2.5899}\right)^{n}}$		Average : $\frac{0.694 + 0.613}{2} = 0.670$	
	$\overline{P} = Po\, e^{-k\left(\frac{A}{2.5899}\right)^{n}}$ (mm/day)	For intake facilities ($P_0 = 114$)	$114 \times 0.670 = 76.4$	
		For diversion facilities ($P_0 = 68$)	$68 \times 0.670 = 45.6$	

* Horton R.E, Discussion on Distribution of Intense Rainfall, Trans, ASCE, Vol. 87, pp. 578-585

(c) Average catchment rainfall for use in flood calculation

Based on the above calculation results, the average catchment rainfall (daily) for flood calculation is obtained as the average of the results by both Hazen's formula and Horton's.

Site	Probable rainfall	Point rainfall	Conversion to average rainfall: Hazen's formula	Horton's formula	Average rainfall in catchment area
LIMANG	100-year return period for intake facilities	114	52.7	76.4	$\frac{52.7+76.4}{2} = 64.5$ (57% for 114)
	2-year return period for diversion facilities	68	31.5	45.6	$\frac{31.5+45.6}{2} = 38.6$ (57% for 68)

(2) Estimation of flood discharge by storage function method

(a) Theoretical formula and input data

This method estimates the flood discharge of a river from rainfall. The computer application is suited for calculation of flood discharge in complex river systems.

Storage function is a formula for calculation of the discharge of a catchment area and flood discharge of a river channel by combining the following formulas:

An exponential function of storage volume S from Manning's formula and its discharge volume Q

$S = KQ^P$ (kinetic equation).. 1

and continuous equations for the catchment area and river channel

(for catchment area)

$$\frac{1}{3.6} f_1 r_{ave} A - Q = \frac{ds_{l1}}{dt} \quad \cdots\cdots 2$$

(for river channel)

$$f_2 \bullet I - Q = \frac{ds_{l2}}{dt} \quad \cdots\cdots 3$$

where

K•P : coefficient for catchment area and river channel
f_1 : inflow coefficient for catchment area and river channel
f_2 : inflow coefficient for river channel
r_{ave} : average catchment rainfall (mm/hr)
A : catchment area
Q : direct catchment discharge or river channel terminal discharge
I : channel inflow group
s_{l1} : apparent catchment storage
s_{l2} : apparent catchment storage
t : time

(i) Storage function K and P

As an empirical formula to obtain the storage function (K•p) for the catchment area, the following formula was used:

$$K = 43.4 \bullet C \bullet L^{1/3} \bullet i^{-1/3}$$

where C : 0.12 (for a natural catchment area)
L : main river channel, to be set as 70 km
i : gradient of main river channel, to be set as 1/100

hence:

$$K = 43.4 \times 0.12 \times 70^{0.33} \times 0.01^{-0.33} = 97$$

For safety sake, K = 72 which is equal to 75% of the above value was adopted.

P is given as indicated below.

	Flat land	Hilly area	Wampu site (hilly area) x 0.7
P	1.0	0.5	0.35

(ii) Lag time in catchment area, Tl

$$Tl = 0.047 \bullet L - 0.56 \text{ (hr)}$$

where L : total length of river channel in catchmet area (Limang = 70km)

hence:

$$Tl = 0.047 \times 70 - 0.56$$
$$= 2.7 \text{ hr} \rightarrow 3.0$$

(iii) r_{ave} = 64.5 mm/day for intake facilities and 38.6 mm/day for diversion facilities

(3) Results of calculation of design flood

The following table shows the results of calculation by the storage function method, using storm rainfall data representing 10 floods from the existing flood data:

Facilities \ Case	PLANNED FLOOD DISCHARGE (m^3/sec)										
	Flood wave 1	Flood wave 2	Flood wave 3	Flood wave 4	Flood wave 5	Flood wave 6	Flood wave 7	**Flood wave 8**	Flood wave 9	Flood wave 10	Remarks
For intake facilities LIMANG	181.80	182.03	189.49	197.25	305.50	771.68	332.43	**935.23**	243.96	194.11	100-year return period
For diversion facilities	46.25	46.28	47.05	47.83	76.63	227.23	90.05	**293.65**	591.15	49.00	2-year return period
Rainfall data	(1980. 6.19)	(1981. 5.10)	(1981. 10.21)	(1982. 8.23 ~ 8.24)	(1982. 11.11 ~ 11.13)	(1982. 12.29 ~ 12.31)	(1983. 11.25 ~ 11.27)	**(1984. 1.20 ~ 1.25)**	(1984. 3.28 ~ 3.30)	(1984. 9.15 ~ 9.16)	–

As will be noted from this table, a rainfall pattern "Flood wave 8" (January 20 to 25, 1984) from among the 10 cases of flood results in the greatest flood discharge. When this particular rainfall pattern occurred, 2 hours continuous rainfall resulted in 50 to 80mm of rain.

The following table shows the design flood discharge:

Design Flood Discharge

	Site	Design flood discharge (m^3/sec)	Probable flood
Limang C.A 959km^2	For intake facilities	940	100-year return period
	For diversion facilities	300	2-year return period

The reliability of the derived design flood discharge is difficult to determine because river discharge data for the upper river drainage basin is extremely limited. It is therefore impossible to verify the design flood discharges.

As a possible verification the design discharge calculated for this site was compared with maximum flood discharges on rivers in various parts of Indonesia using the Creager's equation.

The maximum flood discharge of Indonesian rivers is expressed as the coefficient of drainage basin in the range of between C = 10 to 30 in Creager's equation. In comparison, C = 13.3 was obtained for the Limang site of Wampu river. Thus, it is clear that this value is well within the range of the maximum flood discharge of Indonesian rivers. Further, as Fig. 3-8 shows, the design flood at Limang site virtually falls within the group of rivers in Sumatra. Consequently, it is believed that the design maximum flood discharge for the intake dam site is a reliable value.

3.2.8 Sedimentation and Water Quality

The sediment load at the intake dam site was estimated using two methods: "results of measurement at the Limang Stream Gauging Station" and "estimation from some formulas." Water quality was investigated in the upstream and downstream parts of the project area (Limang, Kaperas, and Teba).

(1) Estimation of sediment load

(a) Actual values measured at Limang G.S

The existing data on the suspended load measured at the Limang Stream Gauging Station during the period of 1981 to 1984 and the result of measurement during the period of this study (Sept. 1991 to Feb. 1992) are given in Table 3-6. Sediment load is estimated from this suspended load in the following manner.

For suspended load, the largest value of 479 mg/ℓ in Table 3-6 is used to be conservative. Where the mean inflow to the intake dam is 30 m^3/s and sediment density is a general value 1.6 t/m^3, then qs, suspended sediment load per year is,

$$qs = 479 \times 10^{-6} \times 30.0 \times 86{,}400 \times 365/1.6 = 283{,}200 \ m^3/year$$

Assuming the bed load is 50% of the suspended sediment load, the annual sediment volume (suspended load + bed load) Qsl is estimated to be,

$$Qsl = 1.5 \times qs = 424{,}800 \ m^3/year$$

Since the catchment area of the intake dam site is 959km^2, the specific sedimentation Qs is,

$$Qs = Qsl/959 = 424{,}800/959 = 443 \ m^3/km^2/year$$

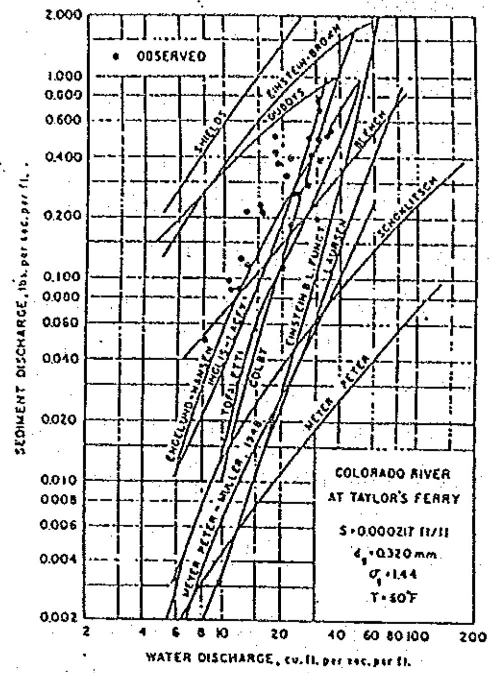
(b) Estimation from some formulas

As factors affecting the sediment load are numerous and highly complex, accurate estimation of the sediment load is theoretically difficult, but various methods and formulas have been reported as practical means of roughly estimating such sediment loads.

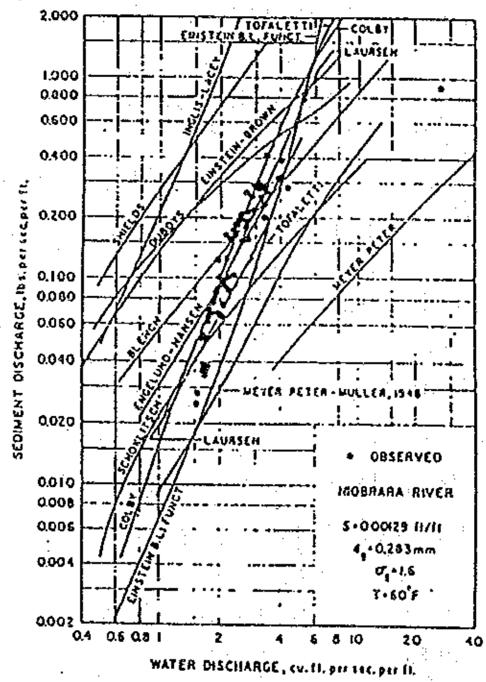
Of the above, when looking into the relations between the measured values and each formula on the two rivers shown in the figure below, the surveyed data on the sediment loads of the two rivers were found to be very close to the values given in the Colby formula (in the Sediments Engineering (pp.190 to 191) of

ASCE's Manual and Reports on Engineering Practices). The sediment load at the Limang site will be obtained as follows using a figure based on the Colby formula.

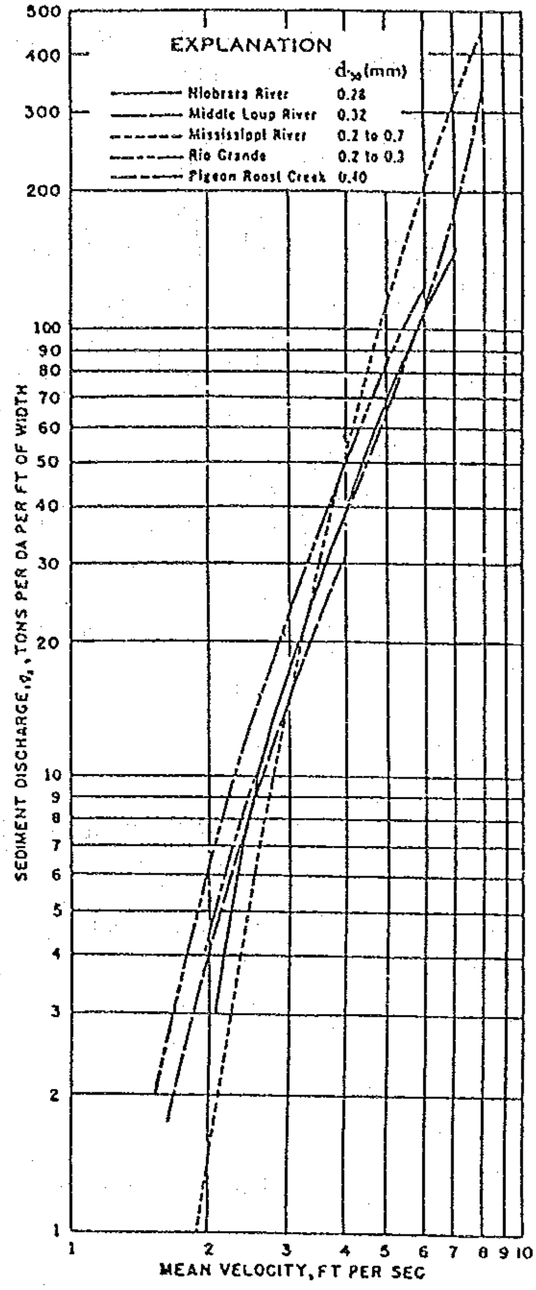
The sediment load at the Kaperas dam site in the Wampu hydroelectric power project area will be obtained as hereunder using the Colby system diagram.



Sediment Discharge as Function of Water Discharge for Colorado River at Taylor's Ferry Obtained from Observation and Calculations by Several Formulas



Sediment Discharge as Function of Water Discharge for Nlobrara River near Cody, Neb., Obtained from Observations and Calculations by Several Formulas.



Relationship between Observed Discharge of Sands and Mean Velocity for Five Sand-Bed Streams at Average Temperatures of about 60° F; Colby (1964b)

The dam site catchment area is $959km^2$, the river width is taken as 17m, the river depth is taken as 1.5m and the mean annual discharge Q is taken as $30m^3/sec$.

Therefore:

$$V = \frac{Q}{A} = \frac{30}{17\times2} = 0.88 \text{ m/s} = 3.281 \times 0.88 = 2.89 \text{ fps}$$

From the Colby formula given above, qs = 18 ton/day/ft of width can be read out as the sediment discharge.

When this is converted into the metric system,

$$\begin{aligned} qs &= 18 \times 0.972/\text{day}/0.3048\text{m of width} = 57.4 \text{ ton/day/m of width} \\ &= 57.4 \times 17 = 976 \text{ ton/day} \end{aligned}$$

If the unit volume-weight of sediment is considered as 1.6 t/m^3

$$qs = (976/1.6) = 610 \text{ m}^3/\text{day}$$

Accordingly, the annual sediment load per km^2 (specific sediment load) can be computed as follows.

$$Qs = \frac{610 \times 365}{959} = 232 \text{ m}^3/\text{yr/km}^2$$

(c) Adoption of design sedimentation

From the amount of suspended load, the sedimentation obtained in (a) above is 443 $m^3/km^2/year$ and the specific sedimentation obtained from (b) is 232 $m^3/km^2/year$. In this study, 500 m^3/km^2 year was adopted to be conservative as the design sedimentation.

(2) Water quality

Although water quality was observed from various aspects during the period of this study (Sept. 1991 to Feb. 1992), those impurities in water that may affect the concrete structures are as follows:

- pH value (hydrogen ion density)

At the Kaperas site located downstream the project area, it is 6.8 in average and it is 6.9 in average the Limang site located upstream the project area. pH values of 6.8 to 6.9 are less than 7 and not abnormally acidic though they are within the acidic range, so the water with such pH value can be used for concrete mixing.

- Sulfate

  It is a little larger in the upstream as 25 mg/ℓ at the Kaperas site, 27.5 mg/ℓ at the Tebah site in the downstream and 33.8 mg/ℓ at the Limang site in the upstream. Either value is far less than the tolerable density of 10,000 mg/ℓ for concrete mixing water, so there is no problem.

- As for other values such as color, turbidity, etc. necessary for placing concrete, it has been found from the results of the tests that they are complying with the water quality standard.

Table 3-1 Annual Mean Rainfall of Wampu Basin in 1953 ~ 1989

No.	Station Name	1953 ~ 1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	Mean	n
1	BPP Selesai	–	–	–	–	–	–	–	–	3339	2903	2500	2879	3433	2727	2896	4230	3105	213	3144.6	9
2	Kota Gadung	–	2187	1543	1554	1478	1400	1260	1365	1154	967	1479	1393	1748	1561	1573	2113	1651	1334	1573.7	17
3	BPP Tiga Panah	–	–	–	–	–	–	139	155	1891	579	1906	1267	1944	1469	1490	2104	1629	1299	1255.2	12
4	Tiga Panah (Camat)	–	–	–	–	–	–	–	–	–	–	–	–	1833	1557	1368	2080	2096	–	1786.4	5
5	Tiga Paucur	–	–	–	–	–	–	1204	1644	1169	2148	4326	1122	1848	1521	1598	2019	1792	1459	2047.7	13
6	BPP Sinabung	–	–	–	–	–	–	–	–	–	–	–	1100	1711	1729	1413	1995	2222	1188	1622.7	7
7	BPP Sumber Jaya	–	–	–	–	–	–	1263	1798	1900	1317	1637	1049	2111	754	1406	1279	1365	1211	1481.9	12
8	BPP Pancur Jaya Karc	–	–	–	–	–	–	–	–	–	–	–	904	1418	1447	1076	1685	1703	954	1405.7	7
9	Kaban Jahe	1934	1769	1678	1403	1830	1939	1619	1278	1593	1571	1773	1506	2407	1070	–	–	–	–	1811.8	14
10	Tanjung Pura	–	–	–	–	–	–	–	–	–	–	–	–	1126	1037	911	1544	945	–	1149.2	5
11	Besitang	–	–	–	1770	1675	1720	2150	2034	2213	867	1919	–	4423	1091	–	–	–	–	2221.9	10
12	Polonia		2391	2264	1923	1797	2034	2299	2131	2707	2049	2145	1951	2196	2329	2326	2394	2899	2960	2271.6	17
13	Bahorok	4697	4924	4749	3507	4284	3232	1758	1425	–	1251	944	1293	990	1075	–	–	–	–	3076.5	12
14	Timbang Langkt	–	–	–	–	1041	1520	1694	1451	1303	1246	–	1884	1862	1718	1195	–	2911	–	1948.6	11
15	Lau Balang	–	–	1154	1543	692	–	–	–	–	–	–	–	943	710	454	1884	–	–	1228.3	7
16	Tohgkoh	2759	3222	2173	2008	2397	2070	–	–	–	1299	2783	1915	–	–	–	–	–	–	2582.4	11
17	Situnggaling	–	1640	1093	914	1097	1292	1300	1980	1223	925	1854	1404	2076	2039	1454	2020		1550	1514.7	17
18	Batang Serangan	2686	3164	2149	3001	2997	2510	3300	2964	2865	3296	1470	2944	–	–	–	–	–	–	3010.1	30
19	Beduin	2501	3873	2941	4184	3673	3179	3434	2710	3523	3458	1603	2145	–	–	–	–	–	–	3016.9	30
20	Bultelang	1996	1943	1566	1722	1346	1544	2227	2240	3446	2338	2321	2301	2009	1832	1486	–	–	–	1941.4	30
21	Bungara	–	–	4166	4600	4301	3983	4367	3354	4151	3850	3569	3751	4494	4466	3847	5055	–	–	3756.4	30
22	Gohor Lama	2279	2085	1714	–	1678	–	2378	2092	–	–	–	–	–	–	–	–	–	–	2076.3	23
23	Kwala Begumit	1503	2305	1852	1760	1900	1525	1974	1652	2947	2153	1668	1749	1528	–	2720	–	–	–	1844.6	31
24	Kwala Bingei	–	–	–	–	1738	1914	2311	2081	1940	–	–	1921	–	1850	1803	1874	1416	–	1995.3	10
25	Kwala Besilam	2969	4884	1807	2330	1600	1442	1554	1560	1869	1866	1968	1661	1511	1832	1451	–	–	–	2340	32
26	Marike	4164	4556	3769	3749	3825	3384	4221	3641	3781	3782	4522	4026	3919	2111	4581	5255	2383	–	4081.5	35
27	Padang Brahrang	2518	2779	2862	3150	2275	2753	2619	–	–	–	–	–	3079	3066	3163	3452	–	–	2779.2	30
28	Sawit Seberang	1133	2652	1727	2787	2579	1861	1225	2309	2565	2473	1516	1730	–	–	–	–	–	–	2493.5	29
29	TG Keliling	–	1916	3402	4179	2755	3491	3381	2612	–	–	–	–	–	–	–	–	–	–	3804.3	24
30	Ginja Raja	1310	1918	1235	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1573.5	20
31	Turangi	2589	3529	2936	4542	4218	4105	4005	3009	3988	3632	3650	4086	3533	3307	3905	5154	–	–	3864.9	33
32	Blangkahan	2809	5562	4617	3136	3551	2780	3515	2780	4010	3611	2815	3160	1853	2806	3816	4239	4232	–	3545	33
33	Bukit Mas	1832	2553	1914	2306	2134	1852	1916	1280	–	–	–	–	–	–	–	–	–	–	2086.9	17
34	Rambutan	1105	2165	1625	1502	922	1410	1456	2023	2453	1365	1325	1156	1031	1101	1185	1436	1366	1263	1575.6	37
35	P Batu Karang (Payung)	–	–	–	–	–	–	1711	–	3530	3008	–	–	2734	–	–	–	–	–	3057.8	4
36	Munthe	–	–	–	–	–	–	1159	–	–	954	1944	1056	648	–	–	–	–	–	1167.1	5
37	Paya Lah Lah	–	–	–	–	–	–	928	1531	1793	788	902	1170	1705	–	–	–	–	–	1501.1	7
38	Simolap	–	–	–	–	–	–	1000	–	895	1304	1295	1364	1509	1742	1493	1644	1296	1300	1366.4	11
39	Beganding	–	–	–	–	–	–	1544	1331	991	1282	1769	1095	1363	574	1631				1287	9
	Σ																		Σn•Mean =	1724021.5	696

$$\text{Mean} = \frac{\Sigma n \cdot \text{Mean}}{\Sigma n} = \frac{1724021.5}{696} = 2477 \quad \text{Ave} = 2500\text{mm/year}$$

Table 3-2 Monthly Mean Rainfall of Wampu Basin in 1983 (Representative Year)

Unit: mm

No.		Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sept.	Oct.	Nov.	Dec.	Total
R1	BPP TIGA PANCH	9	20	67	83	90	92	159	59	187	269	119	113	1,267
R2	KABANJAHE	31	42	181	146	273	35	96	120	210	445	182	125	1,886
R3	TIGA PAUCUR	2	46	40	41	76	57	45	92	157	224	206	136	1,122
R4	BPP SINABUNG	53	34	80	82	47	25	66	37	176	158	206	136	1,100
R5	MARIKE	459	181	430	140	145	150	193	215	351	648	620	494	4,026
R6	TURANGI	209	28	430	92	424	167	314	310	352	791	510	459	4,086
R7	BUNGARA	259	93	353	197	338	258	328	264	321	558	430	352	3,751
R8	BLANGKAHAN	142	40	257	51	279	268	350	302	416	482	454	119	3,160
R9	BEKUING	42	0	245	0	213	220	173	128	312	294	267	251	2,145
R10	TIMBANG LANGKAT	64	10	71	53	208	245	138	154	389	213	222	117	1,884
R11	PORONIA	74	73	65	34	206	192	282	127	244	350	129	175	1,951
R12	BPP SELESAI	88	40	10	68	233	451	461	165	510	351	323	219	2,919
R13	KWALA BEGUMIT	119	0	59	15	186	258	212	107	222	130	329	112	1,749
R14	KWALA BINGEI	73	39	41	32	276	367	201	156	266	99	255	166	1,960
R15	SAWIT SEBERANG	52	0	77	23	155	190	205	216	388	150	180	94	1,730
R16	KWALA BESILAM	107	0	55	37	210	295	251	130	341	155	40	40	1,661
R17	MARIHAT	192	40	213	68	457	173	337	194	566	655	229	232	3,356
R18	DOLOK ULU	90	16	15	48	155	217	132	164	283	265	175	139	1,699
R19	BPP SUMBER OATA	21	52	65	87	24	34	52	111	142	129	154	178	1,049

Table 3-3 Flow Duration at Stabat G.S (C.A = 3870 km^2)

Q_{35} = 351.00 m^3/S
Q_{95} = 235.00
Q_{185} = 165.00
Q_{275} = 124.00
Q_{355} = 96.40

DY = Day
QD =Discharge (m^3/S)

DY	QD	DY	QD
5	666.00	190	160.00
10	522.00	195	158.00
15	447.00	200	155.00
20	422.00	205	151.00
25	393.00	210	148.00
30	376.00	215	147.00
35	351.00	220	144.00
40	343.00	225	143.00
45	336.00	230	140.00
50	317.00	235	138.00
55	304.00	240	136.00
60	298.00	245	134.00
65	287.00	250	133.00
70	281.00	255	130.00
75	270.00	260	129.00
80	263.00	265	126.00
85	254.00	270	125.00
90	245.00	275	124.00
95	235.00	280	122.00
100	228.00	285	121.00
105	224.00	290	120.00
110	222.00	295	118.00
115	218.00	300	118.00
120	214.00	305	116.00
125	210.00	310	113.00
130	205.00	315	111.00
135	201.00	320	110.00
140	198.00	325	108.00
145	195.00	330	106.00
150	189.00	335	103.00
155	184.00	340	102.00
160	178.00	345	99.80
165	177.00	350	98.00
170	174.00	355	96.40
175	172.00	360	94.80
180	169.00	365	88.60
185	165.00		

Table 3-4 Flow Duration at Limang Site (C.A = 959 km^2)

Q_1: (Q_{35}) = 48.37 m^3/S
Q_2: (Q_{95}) = 31.59 m^3/S
Q_3: (Q_{185}) = 20.68 m^3/S
Q_4: (Q_{275}) = 14.43 m^3/S
Q_5: (Q_{355}) = 10.40 m^3/S

DY = Day
QD = Discharge (m^3/S)
F1 = Water Utilization Factor
F2 = River Water Factor

DY	QD	F1	F2
5	81.08	0.319	0.991
10	69.43	0.369	0.982
20	57.78	0.436	0.965
35	48.37	0.506	0.938
40	46.13	0.526	0.929
60	39.31	0.594	0.894
80	34.48	0.650	0.859
95	31.59	0.688	0.832
100	30.73	0.700	0.824
120	27.66	0.744	0.788
140	25.07	0.784	0.753
160	22.83	0.821	0.718
180	20.85	0.855	0.683
185	20.68	0.858	0.679
200	19.45	0.879	0.655
220	17.95	0.904	0.621
240	16.57	0.927	0.588
260	15.31	0.947	0.555
275	14.43	0.960	0.531
280	14.14	0.964	0.522
300	13.06	0.978	0.489
320	12.04	0.989	0.456
340	11.08	0.997	0.423
355	10.40	0.999	0.398
365	9.97	1.000	0.382

Table 3-5 Flow Duration at Kaperas Site (C.A = 1570 km^2)

Q_1: (Q_{35}) = 104.71 m^3/S
Q_2: (Q_{95}) = 68.75 m^3/S
Q_3: (Q_{185}) = 47.05 m^3/S
Q_4: (Q_{275}) = 34.34 m^3/S
Q_5: (Q_{355}) = 25.78 m^3/S

DY = Day
QD = Discharge (m^3/S)
F1 = Water Utilization Factor
F2 = River Water Factor

DY	QD	F1	F2
5	171.95	0.337	0.992
10	147.87	0.388	0.984
20	123.79	0.456	0.967
35	104.35	0.527	0.943
40	99.71	0.547	0.935
60	85.62	0.615	0.902
80	75.63	0.671	0.869
95	69.66	0.708	0.845
100	67.88	0.719	0.837
120	61.54	0.762	0.804
140	56.19	0.801	0.772
160	51.55	0.836	0.739
180	47.46	0.868	0.706
185	47.11	0.871	0.703
200	44.57	0.891	0.680
220	41.46	0.914	0.650
240	38.63	0.935	0.619
260	36.02	0.953	0.589
275	34.19	0.965	0.566
280	33.60	0.969	0.558
300	31.36	0.981	0.527
320	29.25	0.991	0.497
340	27.28	0.997	0.466
355	25.87	1.000	0.443
365	24.97	1.000	0.428

Table 3-6 Existing Irrigation Facilities

Ordering Number	Name of Irrigation	Total Estimated Available Area (ha)	Irrigated Rice Field (ha)
2	Munte	800	432
3	Singgamanik	275	244
7	Bungabaru	140	100
9	Parakacih Laukapur	135	111
13	Payund Batukarang	950	841
14	Tanjung Merawa	250	198
15	Tanjung	250	192
16	Singarang-Garang	70	55
17	Beganding	80	76
18	Jandimeriah Paritcinah	260	178
19	Sukatendel	100	92
20	Kelupang	200	52
26	Suka	460	249
27	Sukanalu	202	190
28	Singakutambelin	150	132
30	Kandibata	100	73
31	Pertumbuken	100	68
32	Badigulen Bulanjahe	165	159
	Total	4687	3442

Assumption : Normal water requirement 1.2 litter/sec/ha

1.2×4687 ha = 5624.4 l/sec $\rightarrow$ 5.6 m^3/S
1.2×3442 ha = 4130.4 l/sec $\rightarrow$ 4.1 m^3/S

Table 3-7 Measurement of Suspended Load at Limang Gauging Station

Date	Suspended Load per 1 litter (mg/l)	Date	Suspended Load per 1 litter (mg/l)
Dec. 1982	163	Sep. 1991	276 *
Feb. 1982	106	Oct. 1991	479 *
Apr. 1982	123	Nov. 1991	388 *
May 1982	251	Dec. 1991	416 *
Mar. 1983	288	Jan. 1992	311 *
Aug. 1983	19	Feb. 1992	320 *
Dec. 1983	224		
Apr. 1984	71		

Note: The data of * were obtained in this feasibility study.

3.3 Topographic Maps

Existing maps covering the study area for the project are available in 1:500,000, 1:250,000, 1:50,000 and other scales. These topographical maps were used in drafting the basic plan for the study area.

In this investigation, to make the detailed plans, larger scale maps were prepared including 1:10,000 using aerial photogrammetry and covering areas along the Wampu River, and 1:500 topographic maps and longitudinal sectional survey maps of each site for the main structures. These maps are compiled in Vol. II Appendix.

Aerial Photogrammetry

- Aerial photogrammetry
  Scale : 1:10,000   Flight line with a total extension of 145km.
- Control point survey
  National triangulation points : 9 points (T-2427, 2474, 2475, 2515, 2519, 2520, 2522, 1619, 2620)
  Newly installed bench mark : 11 points (WP1~WP2, Traverse survey:80km, Levelling survey: 105.1km)
- Aerial triangulation

Flight Line	Photo No.	No. of models
1	8~23	13
2	2~29	27
3	2~29	18
4	6~12	6

- Mapping
  Mapping scale : 1:10,000   Mapping area : 360km^2 Contour interval : 5.0m
- Production of original drawings
  Dimensions : 100cm x 70cm (10km x 7km)   No. of sheets : 8 sheets

Ground Survey

• Plane-table survey (Scale : 1:500, Contour interval : 2m)	
Intake dam site : 16ha (4ha × 4 sites)	Head tank : 5ha (1ha × 5 sites)
Powerhouse : 3 ha (1ha × 3 sites)	Dam site : 30ha (1 site)
• Profile levelling (Scale : 1:500)	
Intake dam site : 4.8km (300m × 4 line × 4 sites)	
Penstock : 7.5km (2,500m × 3 sites)	Dam site : 6.4km (800m × 8 line)
• Cross sectioning (Scale 1:500)	
Intake dam site : 1.6km (400m × 4 line)	Dam site : 1km (1,000m × 1 line)

3.4 Geology

This section discusses the regional geology, site geology, engineering geology and the field operations for geological investigation performed in this feasibility study.

The surface geological mapping (scale 1/10,000) indicates that the lower scheme damsite is located in the Late Permian limestone, and that it has a number of solution channels and cavities. The important point to note is the potential leakage from the storage through limestone caverns; consequently, particular attention was paid to the detailed geological investigations on the lower damsite.

3.4.1 Geological Investigation

The items of geological investigation performed in this feasibility study are as follows:

a. Geological mapping,
b. Core drilling, 25 spots and 1,610.5m length in total,
c. Standard penetration tests in the drillholes,
d. Permeability tests in the drillholes at the dam and intake sites,
e. Seismic prospecting, 30 lines and 1,727m total length,
f. Test pitting,
g. Laboratory rock tests,
h. Laboratory soil tests, and
i. Concrete aggregate tests.

(1) Geological mapping

Geological mapping to a scale of 1:10,000 in the project area and to a scale of 1:500 for the damsite, intake site and powerhouse sites. The photogrammetric maps on a scale of 1:10,000 were used for base maps.

(2) Drilling

Core drilling was undertaken at the intake sites, lower damsite, power station sites, and quarry & borrow sites.

Twenty-five (25) locations with a total length of 1,610.5m were core drilled.

The drilling quantity at the respective sites is indicated in Table 3-8 together with the results of permeability and standard penetration tests carried out in the drillholes. The location is shown in Fig. 3-13.

The drilling logs were prepared by PT. Kwarsa Hexagon. All the drilling cores were examined for rock type, rock grade, weathering condition, etc., and the results including those of the quarry and borrow sites are attached in Volume IV Appendix Geology.

(3) Permeability test

The permeability of the dam foundation bedrock constitutes an important item affecting the stability of the dam.

Under this study, the permeability test was carried out based on the Lugeon test widely adopted as a damsite permeability test method executed by using drillholes. According to the Lugeon test, water is pressure-injected in to a specific length (called a stage) in a drillhole, and a Lugeon value (Lu) is obtained from the relationship between the pressure and the amount of injected water. It is a measure of the permeability of the bedrock. The Lugeon value represents the amount of water injected per minute (lit/min.) per meter of test section at an injection pressure of 10 kgf/cm^2. Under this stage, the length was set at 5m.

When the test is performed while raising the injection pressure step by step, the amount of injection will sometimes increase rapidly at a certain injection pressure. This rapid increase arises when the fillings in cracks of bedrock are washed away due to the water pressure. This is phenomenon arises when the cracks in the bedrock are widened, and the pressure at this time is referred to as the critical pressure. The amount of injection at an injection pressure of 10 kgf/cm^2 is assumed as the Lugeon value but where the critical pressure is less than 10 kgf/cm^2, the Lugeon value is estimated from the "injection pressure (not higher than the critical pressure) and injection quantity curve (P-Q curve)".

The Lugeon value and coefficient of permeability are obtained form the following formulae:

Lugeon value

$$Lu = \frac{10 \cdot Q}{L \cdot H}$$

where Lu: Lugeon value (lit/min/m/10kgf/cm^2)
Q: Amount of injected water (lit/min)
L: Length of test section (m)
H: Injection water head (kgf/cm^2)

Coefficient of permeability

(Packer's method in the U.S. B.R. Earth Manual E-18)

$$k = \frac{q}{2\pi \cdot L \cdot H} \times \log \frac{L}{r_o}$$

where k: Coefficient of permeability (cm/sec)
q: Amount of injected water (cm^3)
L: Length of test section (cm)
H: Injection water head (cm)
ro: Radius of test hole (cm)

The number of stages and drillhole length for the permeability test carried out under this study are indicated in Table 3-8 and the test results are summarized in Table 3-9.

(4) Standard penetration test

The standard penetration test (SPT) was carried out to clarify the distribution and properties of overburden, weathered residual soils, highly weathered rock and other soils. The standard penetration test value is expressed by the number of blows (N value) required for penetration of the Raymond sampler by 30cm into soil, and the value can be correlated with the design value of the bearing capacity of ground, and other properties.

The field measurement is carried out according to the following procedures:

- When drilling has reached a specified test depth, drillhole bottom cuttings are removed.

- The Raymond sampler connected to the drill rod was inserted into and lowered to the bottom of the hole.

- After attaching a locking block to the rod, a 63.5kgf weight is dropped by 75cm, and the number of blows per 10cm, 10cm and 10cm of penetration is recorded.

- Then, the number of blows required for a penetration of 30cm is recorded as the N value.

The No. of the standard penetration tests including length of drillholes carried out under the study is indicated in Table 3-8, and the results of the standard penetration tests are indicated in Table 3-10.

(5) Seismic-refraction survey

Seismic refraction surveying was carried out by field operation in June and July 1991.

Arrangement of Traverse

The seismic refraction survey was carried out for the purpose of clarifying the outline of geological conditions at the intake and lower damsite, penstock routes, power station sites, and quarry and borrow sites. The profiles of this seismic-refraction survey were arranged in straight line unless there was a particular problem. Moreover, the directions and locations of the profiles were determined taking into account the locations of proposed structures, drilling and so forth. The seismic survey was carried out along thirty (30) profiles with a total length of 1,727m. The details of seismic-refraction survey and arrangement of the profiles are indicated respectively in Table 3-11 and Fig. 3-13.

Field Work

After arranging the shot points and detectors along the traverse, measurement was carried out based on split measurement. In principle, one plotting (distance) was set at 110m based on the number of detector channels and interval of receiving point (5m).

Prior to starting measurement, profile levelling was carried out, and the receiving point pegs were set at a horizontal distance interval of 5m along the traverse.

To exactly clarify the conditions of deep portions adjacent to both end of traverse, remote blasting was performed.

Interpretation

The first arrival time of primary wave (P-wave) was read from recording paper by the accuracy of 1/1,000 second, and plotted on the time-distance graph. By analyzing the time-distance curve, the geological conditions were divided into several strata (velocity layers) with different P-wave velocities, and a seismic profile was obtained.

The analyzed seismic profiles are attached in Volume IV Appendices Geology and Construction Material.

(6) Laboratory test of rock

In order to determine the properties of the various rock types in the project area, the laboratory tests were carried out on specimens taken from drilled cores. The test results are summarized in Table 3-12.

3.4.2 Regional Topography and Geology

(1) Topography

In terms of topography and geology, the Sumatra Island is an island belonging to the Great Sunda Mountain System. The Great Sunda Mountain System is one of the great volcanic belts in the earth extending over 7,000km from the Banda Sea in Eastern Indonesia through the Lesser Sunda Islands, Bali Island, Java Island, Sumatra Island, Andaman and Nicobar Islands, and further to Burma (Myanmar). The Sumatra Island is a long island extending in the northwest and southeast direction with a length of 1,650km, a width of 100 to 200km in the northern part and 350km in the southern part.

Topographically, the Sumatra Island indicates a comparatively simple structure and is essentially divided into two parts, namely, the west and east coast areas by the Barisan Ranges, a backbone range in the longitudinal direction or northwestern and southeastern direction on the slightly to the west side of the center of the island.

The geological structure of the Sumatra Island is characterized by a depression zone called the median Semangko rift zone ranging on the peak of the Barisan geanticline comprising the Barisan Range. The median Semangko rift zone is featured by the Semanko Fault or Great Sumatra Fault belonging to the Sumatra fault system, and extends over 1,650km from Banda Aceh at the northern edge to Toruk Semanko at the southern edge of the island. Macroscopically, this fault system can be traced back by the linear topography of long and narrow valleys, depression zone of volcano, lakes and other linear topography extending in northwest - southeast direction. This right handed lateral fault system is still observed to be extensively active to date.

The project site is located on the upper reaches of the Wampu River that flows through northwestern portion of the Province of North Sumatra. The site is located 70km southwest of Medan, the capital city of Province of North Sumatra.

With its head in the mountainous area of Sinabung volcano and Lake Toba, the Wampu River gathers numerous tributaries as it advances westwards through the Kabanjahe Plateau about 1,000m above sea level. In the vicinity of Kampung Limang it changes course to north, descends in the mountainous area about 30km and flows through the plain to the Strait of Malacca. In the project area, the Wampu River cuts a deep gorge. The gorge is an extremely youthful, V-shaped valley, which is being vigorously deepened.

In accordance with "the Geology of the Medan Quadrangle, Sumatra," by the Geological Research and Development Center, 1982, the project site and surrounding area is physiographically diverse, but may be subdivided into the four (4) units (from northeast to southwest) as follows (see also Fig. 3-13).

- The East Coast Foothills,
- The Berastagi Highland,
- The Kabanjahe Plateau, and
- The Eastern Barisan Range.

a. The East Coast Foothills

The East Coast Foothills rise above the Eastern Lowland, which lie in the lower course of the Wampu River and extend to the north of Binjai, to the northwest of the Wampu River. They are low (<EL.150m), structurally controlled, forested hills trending NW-SE.

b. The Berastagi Highlands

The Berastagi Highlands form a 10-15km broad forested range, mainly of volcanic origin. They extend east from the Wampu River gorge to Berastagi.

Summits often exceed 1,500m, then swing southeastwards where they lose height and width. The highest peaks being the cone of Sinabun (2,451m) and the volcanic complex of Sibayak (2,212m). Drainage is radial off individual peaks and generally related to primary volcanic landforms. Streams tend not to merge, and the lower northern slopes in particular occupy many deeply cut valleys. Canyons are developed in the softer tuffs. Karst topography is formed over Permian limestones on the east of the Wampu River.

c. The Kabanjahe Plateau

The Kabanjahe Plateau is a deforested, depositional plateau created over previous mountainous relief by massive tuff flows from the Toba volcano. It slopes gently westwards, decreasing in elevation from 1,300m in the east to 600m in the west. The Plateau is surrounded by high mountains and gradually pinches out westwards and northwestwards into two narrow tuff-filled valleys that originally funneled the tuff flow through the Berastagi mountains. Tuff flow gradients are much steeper in the mountains. Drainage is generally as a consequence closely spaced. Deep narrow canyons and hummocky surface relief are characteristic land forms.

d. The Eastern Barisan Range

This rugged, densely forested terrain is underlain by resistant pre-Tertiary metawackes (Bohorok Formation). It rises abruptly from the East Coast Foothills and is bounded 25km to the west by the Alas-Reunum Depression. Valleys are narrow and precipitous within the Range. Summits frequently exceed 2,000m. Drainage is dendritic on the gross scale.

(2) General geology

The project area is geologically composed of the pre-Tertiary, Tertiary and Quartanary sediments.

The pre-Tertiary rocks are Permo-Carboniferous in age and divided into the Bohorok Formation and Batumilmil Limestone Formation. The Bohorok Formation of Late Carboniferous to Early Permian age is lithologically composed mainly of massive and non-bedded metawackes, slates, quartzose metaarenites, metasiltstones, metaconglomerates, etc., and occupy the Eastern Barisan Range.

The Batumilmil Limestone Formation of Late Permian age is particularly represented by fossiliferous reefal limestone, gray calcilutites and lenses of chert along the eastern flank of the Barisans, and rests unconformably upon the Bohorok Formation.

The Tertiary rocks are composed of the Jambo Aye Group of Late to Early Miocene age and unconformably cover the pre-Tertiary rocks. The group in the area is divided into the Butar, Bruksah and Bampo Formations. The Butar Formation is exposed in the southern part of the project area and consists mainly of interbedded shales and sandstones, minor oil shale horizons overlying mainly rippled gray mudstones and basal graded sandstone sequence with minor interbeds of conglomerate and mudstone. The Bruksah and Bampo Formations are exposed in the northern part of the area, and the Bampo Formation conformably overlies the Bruksah Formation. The Bruksah Formation consists mainly of gray calcareouse siltstone with sandstone and conglomerate interbeds. The Bampo Formation consists mainly of black shales in the area.

The Quarternary sediments are divided into Toba tuffs and alluvial deposits.

Toba tuffs of Pleistocene age are presumed to have been delivered from the Toba volcano to the south. Soon afterwards there occurred a cataclysmic eruption, leading to very rapid accumulation of up to 500m of partially welded pumiceouse rhyodacitic tuffs.

The alluvial deposits are composed of colluvium, that is talus deposits on the mountain slopes, and fluvial deposits. The fluvial deposits include of unconsolidated clay, silt, sand, gravel and boulders that are found in the floor of river valleys.

3.4.3 Site Geology

According to "the Geology of the Medan Quadrangle, Sumatra (Scale: 1/250,000), 1982," prepared by the Geological Research and Development Center of Indonesia, the project area, that is, the intake site, waterway route, power plant and other sites, geologically consists mainly of the pre-Tertiary rocks, Tertiary rocks and Toba tuffs. These are covered by recent deposits called overburden. The geologic map of the project site is copied in Fig. 3-14, reduced from a scale of 1/10,000.

Sediments in the project area are divided into nine (9) stratigraphic units. The stratigraphy of the project area is indicated in Table 3-13. The respective units are explained below successively from the older ones.

Metawackes (Bohorok fmn.)

This unit is the lowest stratigraphic unit in the project area and has the largest exposure in the area. This unit is presumably Late Carboniferous to Early Permian in age, and converted into metasedimentary rocks. This unit is represented by massive non-bedded joined metawackes with subordinate dark skates.

When fresh, the rock belongs to "Strong Rock or Very Strong Rock" as estimated from geological hammer tests.

Limestones (Batumilmil fmn.)

This limestone unit is distributed widely on the right bank of the Wampu River and the lower damsite, as well as the exposures on the steep precipices of Mt. Batumilmil and Mt. B. Batucerrain. The unit consists mainly of fossiliferous reefal limestone and gray calicilutites with chart lenses. The unit is presumably late Permian in age and rests unconformably upon the metawackes.

The rocks are massive and hard when fresh. Because of the calcium carbonate content, limestones are soluble and permeable, and then generally give rise to dry landscapes. The aerial photographs show Karst topographic feature on Mt. Batumilmil and Mt. B. Batucerrain in a small scale. A number of solution channels and cavities were also recognized in the field.

Sandstones (Butar fmn.)

The sandstones unit is distributed widely in the southern part of the area, and is the lowest stratigraphic unit of the Butar Formation. The unit is presumably Late Oligocene to Early Miocene in age, and consists mainly of medium- to coarse-grained quartz sandstones. It trends west-northwest and dips 10 to 25°S. Rocks are massive and hard when fresh.

Conglomerate (Butar fmn.)

This unit is restricted in distribution and is exposed on the road 1.3km north of Ujundeleng. The unit is interbedded stratum in the alternating beds of sandstones and shales. It consists of pebbles cemented together with reddish silt (may be tuff) and intercalated with shale beds. Rocks are massive and hard when fresh.

Sandstones and shales alts. (Butar fmn.)

This unit is distributed from Ujungdeleng to Richtengah on the left bank of Wampu River and is the upper part of the Butar Formation. It consists mainly of the alternating beds of sandstones and shales, dominated by dark colored shales. The unit trends northwest and dips 45 to 55°SW. Rocks are massive and relatively hard.

Gray siltstones (Bruksah fmn.)

This unit is distributed in the northern part of the area, and is the Bruksah Formation of Late Oligocene in age. It consists mainly of gray calcareous siltstone with micaceous sandstones and basal conglomerates. The unit trends east-west and dips gently north. Rocks are massive and relatively hard.

Black mudstones (Bampo fmn.)

This unit distributed in the northern part of the area and is the Bampo Formation of Late Oligocene to Early Miocene in age. It consists mainly of Black mudstones. The unit trends east-west and dips gently north. Rocks are massive and relatively hard.

Toba tuffs

This unit consists mainly of non-bedded pumiceouse rhyodacitic tuff with partially welded and columnar jointed. Toba tuff is distributed widely in the northern and southern part of the project area, and tuff flows have filled the pre-volcanic valleys in the Eastern Barisan Ranges. The tuffs are loose and soft except for welded tuff.

Overburden

The bedrock covering materials, including alluvial deposits, talus deposits, weathered residuals and surface soil, are distributed covering the foundation bedrock mentioned above. Riverbed deposits are found sporadically in the floor of valleys with a small scale. It consists of unconsolidated gravel, sand, silt and clay.

3.4.4 Engineering Geology

From the preliminary and detailed surveys carried out in this feasibility study, the study team proposed the most promising three alternatives run-of-river type W/AA, W/A and W/C in the upstream basin (See Chapter 5 in detail).

In this section geological evaluation for the above alternative schemes in the upstream basin are explained and the other schemes proposed in the Interim Report (October 1991) are explained in Vol. IV Appendices Geology and Construction Materials.

This section also presents the geological evaluation for the reservoir scheme in the downstream basin which was found to be not feasible, in particular geologically. Limestone was found at the damsite with potential for large problems with permeability, making construction of a reservoir very difficult and expensive. The geological data related to this matter are shown in Vol. IV Appendix Geology and Construction Materials.

Drilling and seismic-refraction surveys were performed at the respective sites. Standard Penetration Tests (SPT) were made to obtain soil characteristics in the vertical holes, and Permeability Tests (Lugeon Test) were made in the holes at the intake damsite and the lower dam site in the downstream basin.

(1) Intake dam site (Wampu upstream development)

a. Intake dam site W/AA

Intake Site W/AA is located close to Limang. Topographically, the site is located in the Kabanjahe Plateau, and the plateau is almost covered with a cornfield and a grove of candlenut (kemiri) near the site.

The width of L. Biang (Wampu River) is about 20m at the intake damsite. The slope is 30 to 35° on the left bank and 15 to 20° on the right bank. The relative height is about 25 to 30m from the riverbed to the heights of the plateau. The river flows relatively gently in a broad valley at the upstream near the site, but is changes into a deep narrow gorge and swiftly flowing river downstream of the dam site.

Geology at the site is Toba tuff, and river terrace deposits covered by talus deposits. Toba tuff of the foundation rock is a massive non-bedded pumiceouse welded rhyodacitic tuff, and is well-exposed along both banks of the river. The river terrace deposits consist of unconsolidated sand and gravel, and remain isolated by on the both banks in a small scale. The talus deposits cover the river terrace deposits on the left bank of the river at the site, and consist mainly of loose sandy silt.

The site was investigated by surface geological mapping, core drilling of two (2) drillholes (BUD-121 & -122; 20m × 2 holes) and seismic-refraction survey of two (2) traverses (SU-1 & -2; 330m & 660m). The results are as indicated by the geological profile in Fig. 3-15, and summarized as described below:

- The welded tuff constituting the bed rock is massive and non-bedded; and classified as Weak rock: laboratory tests gave values for uniaxial compressive strength of 115-175 kgf/cm^2. The tuff will not cause any problem in view of the strength as a foundation rock for a low dam.

- From the result of drilling, seismic-refraction survey and surface geological mapping, no large scale fault, fracture zone or other geological hazard were observed at the intake dam site.

- As a result of seismic-refraction survey SU-1 & SU-2, the foundations were divided into the following four (4) layers from the ground surface: 0.3-0.4 km/s (No.1 velocity layer), 0.5-0.6 km/s (No.2 velocity layer), 1.0 km/s (No.3 velocity layer), and 2.5 km/s (No.4 velocity layer). Of these, No. 4 velocity layer (2.5 km/s) corresponds to the fresh welded tuff of the foundation rock. No. 1 velocity layer belongs to the top soil, talus deposits, weathered residual soil or complete weathered tuff rock; No. 2 velocity layer (0.5-0.6 km/s) belongs to the river terrace deposits or completely weathered tuff rock; and No.3 velocity layer (1.0 km/s) belongs to the highly weathered tuff rock. No.1, No.2 and No.3 velocity layers are distributed roughly in parallel with the ground surface slope on the right bank of the river; on the other hand, they are distributed almost horizontal on the left bank.

- Permeability tests on the bedrock gave values of 5-35 Lu.
  It should be concluded, from the results shown above, that the intake damsite has no serious geological problems for a low dam.

b. Intake dam site W/A

The intake damsite is located near Negerijahe and just downstream of the confluence of L. Biang (Wampu river) and its tributary L. Mbelin. The river width is about 10m at this intake damsite. At the site, the river cuts a deep gorge, and is an extremely youthful, V-shaped, valley. The relative height of the bluff is about 50m. The slopes of both banks are extremely steep; with slope angle of 90-45°. The welded tuff is well-exposed continuously on the bluff of the both banks of the river. The hillside has been burnt off and deforested.

The site consists of massive non-bedded welded pumiceous rhyodacitic tuff erupted from Toba Volcano.

The site was investigated by surface geological mapping, core drilling of one (1) drillhole (BUD-123; 55m) and seismic-refraction survey of one (1) traverse (SU-3; 550m). The results are as indicated by the geological profile in Fig. 3-16, and summarized as described below:

- The welded tuff consisting the bed rock is massive non-bedded and jointed; and classified as Weak Rock : laboratory tests gave values for uniaxial compressive strength of 144 kgf/cm^2. The tuff will not cause any problem in view of the strength as a foundation rock of a low dam.

- From a result of drilling, seismic-refraction survey and surface geological mapping, no large scale fault, fracture zone or other geological hazard were observed at the intake dam site.

- As a result of seismic-refraction survey SU-3, the foundations were divided into the following four (4) layers from the ground surface: 0.3-0.5 km/s (No.1 velocity layer); 0.6-0.75 km/s (No.2 velocity layer), 1.0-1.2 km/s (No.3 velocity layer); and 2.6 km/s (No.4 velocity layer). Of these, No.4 velocity layer (2.6 km/s) corresponds to the fresh welded tuff of the foundation rock. In general, No.1 velocity layer (0.3-0.5 km/s) belongs to the top soil, weathered residual soil or completely weathered tuff rock; No.2 velocity layer (0.6-0.75 km/s) belongs to the highly weathered tuff rock; and No.3 velocity layer (1.0-1.2 km) also belongs to the highly weathered tuff rock, respectively. No.1, No.2 and No.3 velocity layers are distributed roughly parallel with the ground surface slope on the both banks.

- Permeability tests in BUD-123 gave values of 5-35 Lu.

- The welded tuff forms quite level and smooth land surfaces. After erosion, step and tread topography, and quite deep gorges developed at the project site. As the gorges were cut deeper, the wall of the valley was relaxed by block disintegration that was controlled by discontinuities in the rock mass. Consequently, at the upper part of the valley wall the rocks were broken by vertical to near vertical joints spaced at from 1 to 10m, and which shows progressive opening and toppling. For any cut slope, it is important to consider what rock fall or block movement may occur.

It should be concluded, from the results shown above, that the intake damsite has no serious geological problem for a low dam, except for the stability of cut slopes.

c. Intake dam site W/C

The intake damsite is located near Ujungdeleng and about 4km downstream of the Intake dam site W/A. Topographically and geologically, the condition of intake damsite is similar to that of W/A. The width is about 10m at the intake damsite. At the site, the river cuts a deep gorge, and is an extremely youthful, V-shaped, valley; with slope angles of 90-45°. The relative height of the bluff is about 80m. The welded tuff is well-exposed continuously on the bluff of the both bank of the river. The hillside has been burnt off and deforested.

The site consists of massive non-bedded welded pumiceous rhyodacitic tuff erupted from Toba Volcano.

The site was investigated by surface geological mapping, core drilling of one (1) drillhole (BUD-124; 95m) and seismic-refraction survey by one (1) traverse (SU-4; 550m). The results are as indicated by the geological profile in Fig. 3-17, and summarized as described below:

- The welded tuff consisting the bed rock is massive non-bedded and jointed; and classified into Weak Rock: laboratory tests gave values for uniaxial compressive strength of 115-175 kgf/cm^2. The tuff will not cause any problem in view of the strength as a foundation rock of a low dam.

- From a result of drilling, seismic-refraction survey and surface geological mapping, no large scale fault, fracture zone or other geological hazard were observed at the intake site.

- As a result of seismic-refraction survey SU-4, the foundations were divided into the following four (4) layers from the ground surface: 0.3-0.4 km/s (No.1 velocity layer); 0.6-0.75 km/s (No.2 velocity layer); 1.0-1.15 km/s (No.3 velocity layer); and 1.94-2.10 km/s (No.4 velocity layer). Of these, No.4 velocity layer (1.94-2.10 km/s) corresponds to the fresh to slightly weathered welded tuff of the foundation rock. In general, No.1 velocity layer (0.3-0.4 km/s) belongs to the top soil, weathered residual soil or completely weathered tuff rock; No.2 velocity layer (0.4-0.75 km/s) belongs to the highly weathered tuff rock; and No.3 velocity layer (1.0-1.15 km/s) also belongs to the highly weathered tuff rock, respectively. No.1, No.2 and No.3 velocity layers are distributed roughly parallel with the ground surface slope on the both banks.

- Permeability test in BUD-124 gave values of 5-20 Lu.

- The welded tuff forms quite level and smooth land surfaces after erosion, step and tread topography, and quite deep gorges developed at the project site. As the gorges were cut deeper, the wall of valley was relaxed by block disintegration that was controlled by discontinuities in the rock mass. Consequently, at the upper part of the wall of valley, the rocks were broken by vertical to near vertical joints spaced at from 1 to 10m, and which shows progressive opening and toppling. For any cut slope, it is important to consider what rock fall or block movement that may occur.

It should be concluded, from the results shown above, that the intake damsite has no serious geological problem for a low dam, except for the stability of cut slope.

(2) Power station site and headtank W/AA, W/A & W/C (Wampu upstream development)

The site is located just upstream of the confluence of the Wampu River and its tributary Lau Kululuran. Topographically, the site is in the Eastern Barisan range. The Wampu River cuts a V-shaped valley and the slope of the penstock line route has a gradient of 30-35°.

The site consists of massive and non-bedded metawacke and slate of the Bohorok Formation of Late Carboniferous to Early Permian age; river terrace deposits and talus deposits.

The site was investigated by surface geological mapping, core drilling of three (3) drillholes (BUP-114, -115, -116 & -117; 40m, 40m, 30m & 20m, respectively), seismic-refraction survey of four (4) traverses; SU-8 (660m) along the penstock line route, SU-9 (330m), SU-10 (330m) and SU-11 (330m). The results are as indicated by the geological profile in Fig. 3-18, and summarized as described below:

- The metawacke and slate consisting the bedrock are massive and strong when fresh. The bedrock will not cause any problem in view of the strength as a foundation rock of a power station and anchor blocks of penstock.

- From a result of drilling, seismic-refraction survey and surface geological mapping, no large scale fault, fracture zone and other geological hazard were observed at this site.

- As a result of seismic-refraction survey, the foundations were divided into the following five (5) layers from the ground surface: 0.30-0.50 km/s (No.1 velocity layer); 0.60-0.93 km/s (No.2 velocity layer); 1.10-1.25 km/s (No.3 velocity layer); 2.70-3.00 km/s (No.4 velocity layer); and 3.85 km/s (No.5 velocity layer). Of these, No.5 velocity layer (3.85 km/s) corresponds to the fresh rock of the Pre-Tertiary sedimentary rocks; and No.4 velocity layer (2.70-3.00 km/s) corresponds to the slightly weathered rock of pre-Tertiary sedimentary rocks. In general, No.1 velocity layer (0.30-0.50 km/s) belongs to the top soil or weathered residual soil No.2 velocity layer (0.50-0.85 km/s) belongs to the completely weathered rock of pre-Tertiary rocks; and No.3 velocity layer (1.0-1.1 km/s) belongs to the highly weathered rock of pre-Tertiary rocks, respectively. No.1, No.2 and No.3 velocity layers are distributed roughly parallel with the ground surface slope along the penstock line route, and correlates well with the result of core drilling.

- Data from the drilling and seismic-refraction survey, as well as field evidence, indicate that the proposed penstock line, between headtank and power station site, is composed of metawacke and slate which are hard, massive, jointed and strong rock, and debris, residual weathered soil and completely weathered rocks are distributed with a thickness ranging from 5m to 10m.

- The proposed powerstation site is composed of slate and terrace deposits. The slate of the foundation rock is hard, strong and jointed, and covered with the terrace deposits to a depth of 8m. The terrace deposits is composed of loose sands and gravels.

(3) Headrace Tunnel W/AA, W/A and W/C (Wampu upstream development)

a. Headrace Tunnel W/AA

A non-pressure tunnel for headrace of W/AA is proposed on the right bank of the Wampu River. In general, the geological conditions for the headrace tunnel route of 18km long are very good with massive, hard and strong rock strata except for the upstream part of route. The upstream part of route consists of massive non-bedded welded pumiceous rhyodacitic tuff erupted from Toba volcano. The welded tuff is relatively soft and belongs "Weak Rock". The midstream part of route consists of alternating beds of sandstone and shale of the Butar Formation of Late Oligocene to Early Miocene age, and limestone of the Batumilmil Limestone Formation of Late Permian age. The downstream part of route consists of metawacke and slate of the Bohorok Formation of Late Carboniferous to Early Permian age.

b. Headrace Tunnel W/A

A non-pressure tunnel for headrace of W/A is proposed on the right bank of the Wampu River. In general, the geological conditions for headrace tunnel route of 16km long are very good with massive, hard and strong rock strata except for upstream part of route. The upstream part of route consists of massive non-bedded welded pumiceous rhyodacitic tuff erupted from Toba volcano. The welded tuff is relatively soft and belongs to "Weak Rock". The midstream part of route consists of alternating beds of sandstone and shale of the Butar Formation of Late Oligocene to Early Miocene age, and limestone of the Batumilmil Limestone Formation of Late Permian age. The downstream part of route consists of metawacke and slate of the Bohorok Formation of Late Carboniferous to Early Permian age.

c. Headrace Tunnel W/C

A non-pressure tunnel for headrace of W/C is proposed on the right bank of the Wampu River. In general, the geological conditions for headrace tunnel route of 11km long are very good with massive, hard and strong rock strata except for the upstream part of route. The upstream part of route consists of massive non-bedded welded pumiceous rhyodacitic tuff erupted from Toba volcano. The welded tuff is relatively soft and belongs to "Weak Rock". The midstream part of route consists of limestone of the Batumilmil Limestone Formation of Late Permian age. The downstream part of route consists of metawacke and slate of the Bohorok formation of Late Carboniferous to Early Permian age.

(4) Dam Site (Wampu downstream development)

The damsite is proposed immediately downstream of the confluence of the Wampu River and its tributary Lau Tebah at the beginning of the Feasibility Study. A rockfill type dam of 97m high is proposed for the lower Wampu scheme. The damsite is composed mainly of Late Permian limestone of the Batumilmil Limestone Formation, and the tuff flows from Toba volcano have filled pre-volcanic valley in the limestone. The river deposits are on the riverbed consisting of unconsolidated gravel, sand and clay with about 8m deep.

At the damsite, the width of Wampu River is about 60m. The slopes are 25 to 40° on the both banks up to 250m altitude. Above 250m altitude, the limestones are well-exposed on the both banks and form high ground with vertical cliffs in the damsite area.

In general, because of calcium carbonate content, limestones are soluble. The characteristics of limestone have two major effects at a damsite. The more important is the question of leakage from the storage. After the initial filling, the storage will drain through limestone caverns. The second, but somewhat lesser, problem associated with cavernously weathered limestone concerns the bearing capacity of the foundation rocks. Solution openings, whether rubble filled, have the effects of reducing the strength of rock mass.

The tuff also has same two major effects at a damsite. One is the question of leakage through the sub-volcanic sediments. If tuff flows are underlain by soft bedrock or unconsolidated and high permeable pre-volcanic river deposits, high water losses from a storage may occur. The second is the question of the bearing capacity of the tuff. At the damsite, the tuff come into extremely weak rock or firm to very stiff soils classification estimated from scratch and geological hammer tests. The strength and deformability of tuff will be very low.

As mentioned above, there are some critical geological problems on the lower damsite, particularly leakage from the storage through limestone cavern. The site therefore was investigated to know the geological conditions; particularly the distribution of Toba tuff, and the permeability of Toba tuff and limestone foundation, by surface geological mapping, core drilling of seven (7) holes (BDD-101, -102, -103, -104, -105, -106 and -107; 100m each), seismic-refraction survey of seven traverses; SD-1 (770m) along the dam axis, SD-2 (660m), SD-3 (660m), SD-4 (770m), SD-5 (550m), SD-6 (660m) and SD-7 (660m). The results are attached in Appendix IV Geology and Construction Materials, and summarized as follows:

- The damsite is located on the Late Permian Limestones, overlain by Pleistocene ash flow named Toba tuff which has filled pre-volcanic valley. As a result of drilling, the limestone is massive and hard when fresh, and fine white veins are well developed extremely closely, densely and irregularly. Toba tuff consists mainly of relatively soft tuff but partially hard welded tuff, and core recovery of the tuff was commonly very poor at this site. The tuff reaches to a depth of 60m from the ground surface of riverbed.

- Lugeon test was carried out in each bore holes. In general, the Lugeon tests on Toba tuff gave values of more than 30 Lu. The Lugeon tests on limestone gave values of less than 10 Lu, which were common, but of more than 50 Lu, encountered infrequently. Especially, the Lugeon tests carried out in BDD-107 which set on the left bank gave values of more than 50 Lu on most of test sections. Such high permeability is due to limestone caverns. Filling limestone cavern was found in the drilling BDD-107 at the depth from 91.0 to 97.5m. The water pressure test result shows that the injection water was sucked and the permeability was estimated more than 100 Lu at the section.

- Fast driven of the drilling and water loss that were indicated of limestone solution channel were observed frequently on its run.

- As a result of drilling of BDD-106 & BDD-107 set on the left bank, the ground water levels are below 100m from ground surface.

- Karst features such as swallow-holes, sinkholes, dry valleys, spring, limestone caverns with stalactite and stalagmite, and solution channels, which were recognized at the damsite area, are indicated of the underground movement of water that might be locally causing caves.

- As a result of seismic-refraction survey, the dam foundation were divided into following five (5) velocity layers: 0.3-0.5 km/s (No.1 velocity layer), 1.0-1.3 km/s (No.2 velocity layer), 0.73-1.23 km/s (No.3 velocity layer), 1.0-1.5 km/s (No.4 velocity layer), and 2.5-3.5 km/s (No.5 velocity layer). Among them, No.5 velocity layer (2.5-3.5 km/s) corresponds to the fresh limestone of the foundation rock; No.4 velocity layer (1.0-1.5 km/s) corresponds to the weathered limestone of the foundation rock; and No.3 velocity layer (0.73-1.23 km/s) corresponds to Toba tuff, respectively. In general, No.1 velocity layer (0.3-0.5 km/s) belongs to top soil or weathered residual soil; and No.2 velocity layer (1.0-1.5 km/s) belongs to river deposits. No.1 and No.2 velocity layers are distributed roughly parallel with the ground surface slope on the both banks, and No.2 velocity layer increase in its thickness from 5m to 30m below 250m altitude. The loud sound like bass dram resounded when the dynamite exploded for shooting in limestone. From such phenomenon it may be inferred that the limestone cavern and solution open crack echoed with the sound of shooting.

- Laboratory rock mechanics test by using limestone drill core gave values for uniaxial strength of 99.2-365.1 kgf/cm^2. Such strength loss for hard limestone is due to very strong development of fine white vein in this rock. Laboratory rock mechanics test by using drill core of welded Toba tuff gave values of 36.2-7.27 kgf/cm^2.

It was concluded from the above reason that the lower damsite might have the vital geological question about high permeability of the dam foundation, because; Toba tuff is pervious rock of 50 Lu or more and reaches to 60m from the riverbed; there are a number of limestone cavities and solution channels in the limestone foundation and the groundwater table is below 100m from ground surface on the left bank so they are indicated of underground movement of water that might be locally causing caves.

In a word, the serious loss of stored water can occur through limestone cavities, so the special consideration of remedial measures against leakage should be required.

As the remedial measures, grouting is generally used for foundation treatment, and it should be considered that the range of grouting is not only beneath the dam foundation but also the reservoir in which limestone is exposed. In addition to above mentioned, limestone cavities are distributed deeply in the limestone foundation, therefore, it should be emphasized that the cost of these measures will be extremely high and be uneconomical. Moreover, the underground solution channels are irregular in size, shape and distribution, and they are not easy and definitely found in advance of the beginning of the work, so the additional measures will be necessary after initial filling.

To sum up the above description and together with the results of Economic Feasibility Study reported in the Inception Report (October 1991), it can be judged that the constructing reservoir of dam was unfeasible because the lower dam scheme have the critical geological problem such as leakage from the storage, and the cost of these measures will be extremely high. Therefore, it has to be stressed that the scheme is not feasible from both economic and geologic point of view.

Note: In the Interim Report (October 1991), the Economic Feasibility was studied about the both cases of reservoir development scheme and regulating pondage on the Lower Wampu scheme, and the results clearly indicated that Benefit/Cost ratios of them were less than 1 (B/C<1), then either of them are not feasible from economic point of view.

3.4.5 Seismicity

The Indonesian Archipelago including Sumatra Island is located in the Circum-Pacific Orogenic zone (seismic zone), an area with high seismicity. As many as 500 earthquakes are recorded annually throughout Indonesia, including ten large scale ones. However, many of them are under the sea or deep earthquakes, and damaging earthquakes seldom occur.

On Sumatra Island, where the project site is located, the occurrence of large scale shallow earthquakes and intermediate earthquakes causing damages is limited roughly to the Semanko tectonic zone, which is a geological tectonic line constituting the axial zone of Sumatra Island and running throughout the Barisan Mountains, and the Indian Ocean side on the west side of the Semanko tectonic zone. Therefore, the project area, which is located on the east side of the Semanko tectonic zone, is in a relatively low seismicity area.

Since no earthquake observation facility has been installed so far in the project site area, it is impossible to directly analyze the effect of earthquakes upon the dam and other major structures. Therefore, the design seismic intensities were calculated by using statistical methods based on the existing earthquake data. The earthquake data had been obtained from the Meteorological and Geophysical Institute of Indonesia, Jakarta.

The available record of earthquakes in Sumatra covers the years since 1901. The present analysis, however, utilized only the records from 1951 to 1988, which have reliable descriptions on the approximate locations of the epicenters and magnitude of the earthquakes.

(1) Seismic intensity of past earthquakes

The seismic intensity at the project site as determined by the Japan Meteorological Agency (JMA) was obtained from the following formulas (Kawasumi, 1951) based upon the available earthquake data for the period from 1951 to 1988.

$$Ij = Mk - 0.00183\,(d-100) - 4.605 \log (d/100) \quad (d>100km)$$

$$Ij = Mk + 4.605 \log (Do/D) + sk\,(D-Do) \log e \quad (d<100km)$$

where Ij : JMA intensity scale at the project site
Mk : JMA intensity scale at a point 100km from the epicenter
d : Distance from the epicenter to the project site (km)
D : Distance from the hypocenter to the project site (km)
Do : Distance from the hypocenter to a point 100km from the epicenter (km)
k : Damping rate of S-wave (0.0192/km)

Meanwhile, the JMA seismic intensity scale at a point 100km from the epicenter is calculated from the following formula:

$$Mk = 2M - 9.7$$

where M : Magnitude

From the analysis, the number of felt earthquakes at the project site from 1951 to 1988 is estimated to be 38, and the highest seismic intensity in the past is II (Ij = 2.5, magnitude 7.0, epicentral distance 217km, on 20 June 1976).

The seismic intensity scales of felt earthquakes are shown in Table 3-14 and together with the respective earthquake data.

(2) Maximum ground acceleration according to past earthquakes

The maximum ground acceleration (a_0) at the foundation bedrock can be obtained applying hypocentral distance and magnitude by the following empirical formula of Kanai (Kanai, et al., 1966).

$$a_o = (1/T)\ 10^a$$
$$a = 0.61M - P\ \log D + Q$$
$$P = 1.66 + 3.60/D$$
$$Q = 0.167 - 1.83/D$$

where a_o : Acceleration at foundation bedrock (gal)
T : Predominant period of earthquake motion (s)
M : Magnitude
D : Hypocentral distance (km)

In addtion, the predominant period of earthquake motion was obtained from the relation chart of Seed (Seed et at., 1969) as indicated in overleaf.

From the above, the past maximum ground acceleration (a_o) obtained from Kanai's formula is 7.54 gal (magnitude 5.3 on 22 June 1976).

3) Recurrence analysis

The occurrence of earthquakes can be expressed by the recurrence process. The earthquake accelerations obtained from the empirical formula of Kanai are arranged successively from larger ones, and the probability values are obtained from plotting positions. The plotting position is given from the following formula:

$$Te = n/m$$

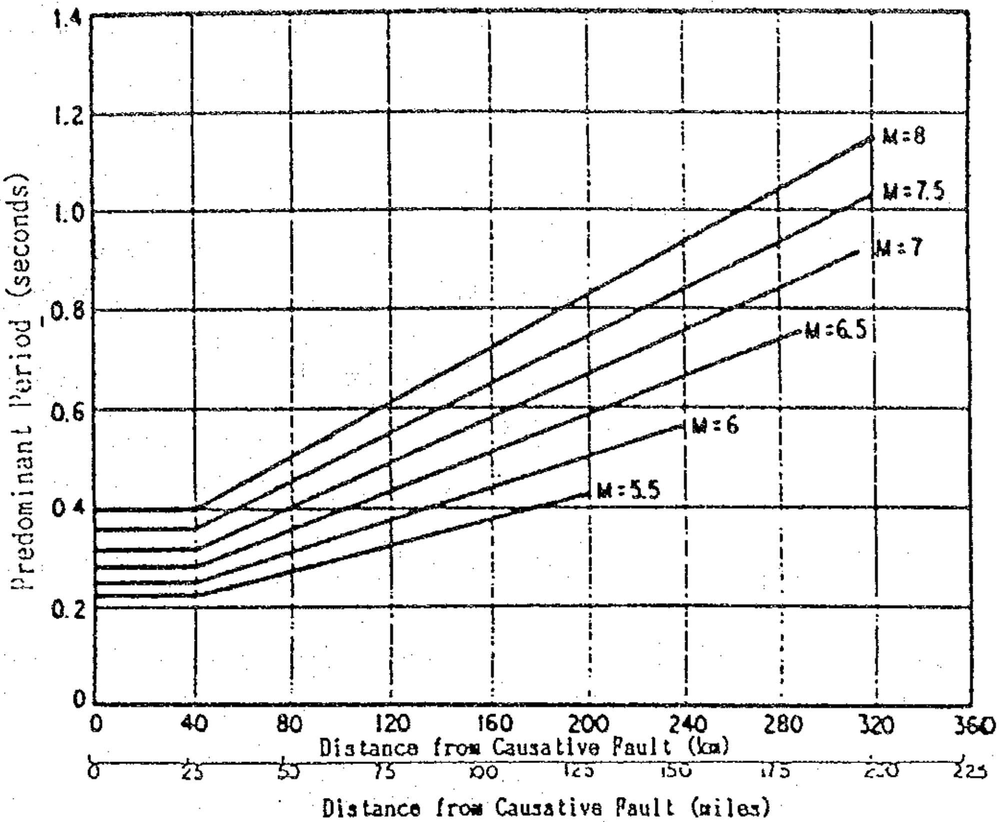
where Te : Recurrence period (time period)
n : Number of recorded years
m : Serial number of earthquakes from maximum value

The result of plotting the recurrence period (Te) and the respective maximum acceleration (a) logarithmically is presented in Fig. When this plot is approximated by the least square method (LSM) and moment method (MM), the relations between them are expressed as follows:

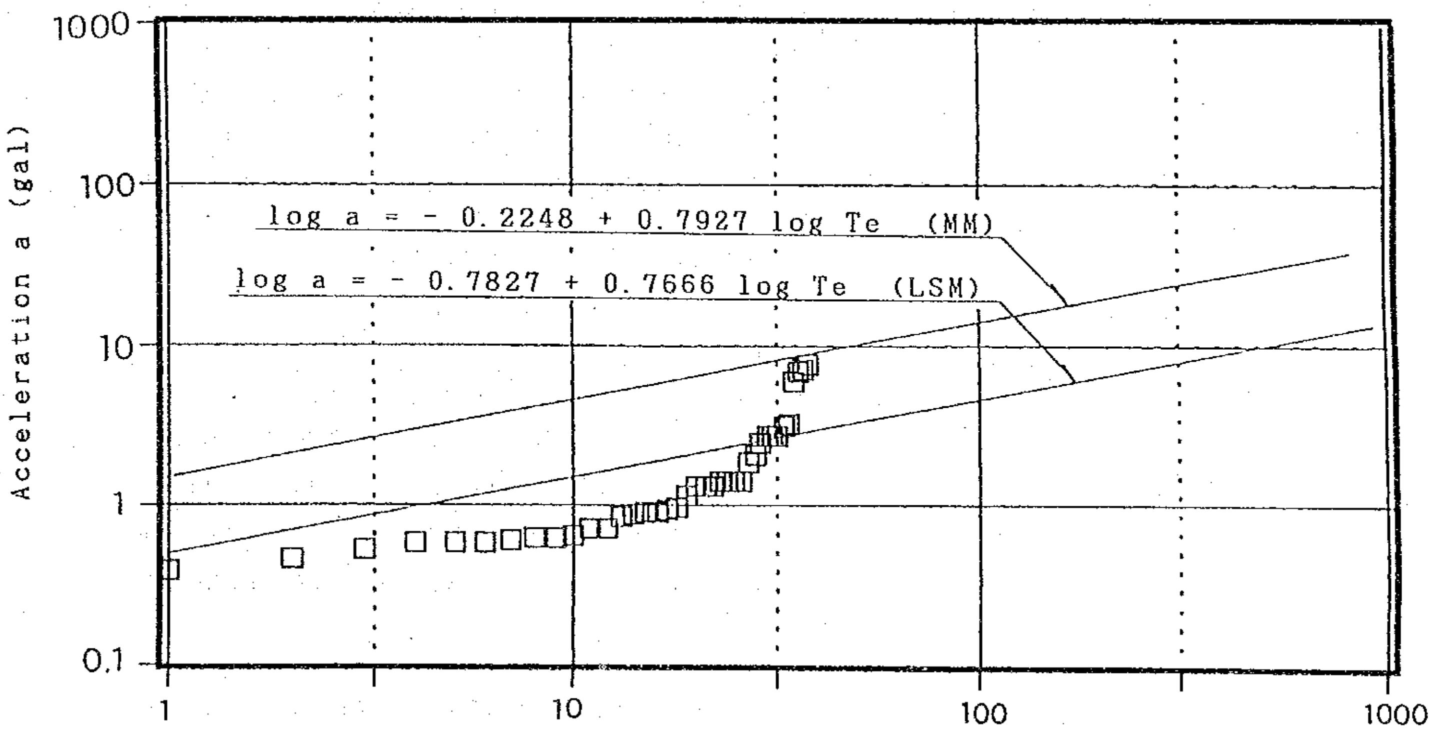
$$\log a = -0.7827 + 0.7666 \log Te \quad \text{(LSM)}$$

$$\log a = -0.2248 + 0.7927 \log Te \quad \text{(MM)}$$

From the above formulas, the respective probability values for the project site are calculated to be 5.63 gal (0.006g) for 100 year and 9.58 gal (0.010g) for 200 year return periods respectively from the least square method (LSM); or 22.94 gal (0.02g) for 100 year and 39.73 gal (0.04g) for 200 year return periods respectively from the moment method.



PREDOMINANT PERIODS FOR MAXIMUM ACCELERATION IN ROCK



RETURN PERIOD Te

3.5 Construction Materials

(1) General

The investigation for construction material was carried out for the purpose of selecting the sites for obtaining the dam body material and concrete aggregate. The items of the investigation carried out under this study are as follows:

a. Surface geological reconnaissance for selecting the quarry, borrow, and sand & gravel sites,

b. Drilling and standard penetration test,

c. Seismic-refraction survey at the selected quarry and borrow sites,

d. Test pitting at the sites proposed for obtaining dam body material and concrete aggregates,

e. Laboratory tests of soil material and concrete aggregates,

f. Laboratory tests of drilled cores.

The construction materials for the reservoir scheme in the downstream basin which was considered to be not feasible, therefore, are explained in Vol. IV Appendix Geology.

The sites for obtaining concrete aggregate were selected based on the results of surface geological reconnaissance. List of Test Pits is shown in Table 3-15. The results of the laboratory tests of soil material and concrete aggregates are summarized in Table 3-16 and 3-17, respectively.

(2) Concrete Aggregate

In and around the upper project site, the Wampu River cuts deep narrow gorges, and the river deposits occur in the small quantities. In addition, the river deposits are rich in light weight, porous, soft tuff boulders which are produced from the Kabanjahe Plateau. The Kabanjahe Plateau is created over previous mountainous relief by massive tuff flows from the Toba volcano. It can be judged that the river deposits are not suitable for concrete aggregate material.

The volcanic product from the Sinabun volcano was selected for concrete aggregate material of upper project site. It is made up largely of hard and tough andesite boulder, and distribute widely in the southern foot of the Sinabung volcano. The distribution area can be traced readily by large andesite boulder on the ground, and their area extent be estimated to be more than 5km square. The andesite boulders are hard and tough, and they are used for roadstone aggregate in the area, then they might meet the possibility of quantity and quality for concrete aggregate.

Five test pits (TGP-6, -7, -8, -9 & -10) were excavated at Susuk where roadstone has been mined in a shallow open pit. Susuk is located about 8km ENE of Limang intake site (W/AA). As a result of test pitting, the volcanic product of the Sinabun volcano consists of andesite gravel, sand, scoria and pumice, and they were deposited stratificationally with their thickness of several ten centimeters to a few meters. The andesite gravels were mainly of 3cm to 8cm in diameter, and the contents showed a wide scatter from a low of 10-20% to a high of 50-80%.

As a result of concrete aggregate test, test gave good values for soundness of less than 7%. The other hand, test gave relatively high values for abrasion of 45 to 55%, and for wash loss of 11 to 25%. Such high values may be caused by vesicular friable pumice or scoria contained in the volcanic product. Therefore it will be necessary to avoid to use all of volcanic product for concrete aggregate. Selective excavation, beneficiation, screening, etc. will be required to select hard tough andesite gravels, moreover, crushing or grinding andesite gravel will be necessary to produce the fine or coarse aggregate.

The headrace tunnel will path in massive hard Paleozoic rocks of metawacke, slate and limestone in the greater part of it expect in Tertiary rocks or Toba tuff. Mucks of fresh Paleozoic rocks are also usable for concrete aggregate by crushing or grinding them.

Table 3-8 LIST OF DRILLING

Drilling No.	LOCATION	LENGTH (m)	SPT (TIME)	WPT (TIME)	REMARKS
BDD 101	LOWER DAMSITE	100.0	4	17	
BDD 102	LOWER DAMSITE	100.0	6	12	
BDD 103	LOWER DAMSITE	100.0	2	17	
BDD 104	LOWER DAMSITE	100.0	0	19	Incl.
BDD 105	LOWER DAMSITE	100.0	4	19	
BDD 106	LOWER DAMSITE	100.0	7	19	
BDD 107	LOWER DAMSITE	100.0	1	19	
BDQ 108	QUARRY II	40.0	5	0	
BDQ 109	QUARRY I	45.5	14	0	
BUP 110	P/S III (W/D)	40.0	18	0	
BUP 111	P/S III (W/D)	40.0	16	0	
BUP 112	P/S III (W/D)	30.0	14	0	
BUP 113	P/S III (W/D)	20.0	2	0	
BUP 114	P/S II (W/AA, W/A or W/C)	40.0	7	0	
BUP 115	P/S II (W/AA, W/A or W/C)	40.0	15	0	
BUP 116	P/S II (W/AA, W/A or W/C)	30.0	8	0	
BUP 117	P/S II (W/AA, W/A or W/C)	20.0	5	0	
BUP 118	P/S I (W/E)	130.0	6	0	
BUP 119	P/S I (W/E)	40.0	17	0	
BUP 120	P/S I (W/E)	100.0	16	0	
BUD 121	INTAKE SITE I (W/AA)	20.0	5	3	
BUD 122	INTAKE SITE I (W/AA)	20.0	3	3	
BUD 123	INTAKE SITE II (W/A or W/E)	55.0	11	8	
BUD 124	INTAKE SITE III (W/C)	95.0	8	8	
BUD 125	INTAKE SITE IV (W/D)	105.0	17	8	
	TOTAL	1610.5	211	152	

Note: SPT; Standard Penetration Test
WPT: Water Pressure Test
Incl.; Inclined Hole

Table 3-9 SUMMARY OF WATER PRESSURE TEST (1)

Hole No.	Stage No.	Test Section GL- m		m	Section Length m	Lu	Remarks
BDD 101	1	5.00	-	11.00	6.00	86.1	
	2	10.00	-	15.00	5.00	12.5	
	3	15.00	-	20.00	5.00	25.8	
	4	20.00	-	24.40	4.40	56.8	
	5	25.00	-	30.00	5.00	52.6	
	6	30.00	-	35.00	5.00	35.2	
	7	35.00	-	40.00	5.00	6.5	
	8	40.00	-	45.00	5.00	7.5	
	9	45.00	-	50.00	5.00	10.9	
	10	53.50	-	55.25	1.75	70.1	
	11	55.25	-	60.00	4.75	18.9	
	12	60.00	-	65.00	5.00	24.6	
	13	65.00	-	70.00	5.00	12.5	
	14	70.00	-	75.00	5.00	4.7	
	15	75.00	-	80.00	5.00	12.5	
	16	80.00	-	85.00	5.00	20.6	
	17	85.00	-	90.00	5.00	16.0	
	18	90.00	-	95.00	5.00	15.9	
	19	95.00	-	100.00	5.00	15.2	
BDD 102	1	27.00	-	30.00	3.00	63.9	
	2	30.00	-	35.00	5.00	77.3	
	3	35.00	-	40.00	5.00	49.1	
	4	40.00	-	45.00	5.00	51.3	
	5	45.00	-	50.00	5.00	59.4	
	6	50.00	-	55.00	5.00	43.1	
	7	55.00	-	60.00	5.00	74.8	
	8	60.00	-	65.00	5.00	43.5	
	9	65.00	-	70.00	5.00	10.8	
	10	70.00	-	75.00	5.00	13.4	
	11	75.00	-	80.00	5.00	1.9	
	12	80.00	-	85.00	5.00	Cannot test	
	13	85.00	-	90.00	5.00	54.5	
	14	90.00	-	95.00	5.00	59.7	
	15	95.00	-	100.00	5.00	Cannot test	

Table 3-9 SUMMARY OF WATER PRESSURE TEST (2)

Hole No.	Stage No.	Test Section GL- m		m	Section Length m	Lu	Remarks
BDD 103	1	10.00	-	15.00	5.00	1.5	
	2	15.00	-	20.00	5.00	18.2	
	3	20.00	-	25.00	5.00	Cannot test	
	4	25.00	-	30.00	5.00	59.5	
	5	30.00	-	35.00	5.00	62.5	
	6	35.00	-	40.00	5.00	73.4	
	7	40.00	-	45.00	5.00	77.3	
	8	45.50	-	50.00	4.50	87.1	
	9	52.50	-	55.00	2.50	126.0	
	10	55.00	-	60.00	5.00	13.2	
	11	60.00	-	65.00	5.00	45.7	
	12	65.00	-	70.00	5.00	24.8	
	13	70.00	-	75.00	5.00	16.0	
	14	75.00	-	80.00	5.00	2.0	
	15	80.00	-	85.00	5.00	19.6	
	16	85.00	-	90.00	5.00	3.4	
	17	90.00	-	95.00	5.00	1.9	
	18	95.00	-	100.00	5.00	2.3	
BDD 104	1	7.50	-	10.00	2.50	88.8	
	2	10.50	-	15.00	4.50	23.4	
	3	15.00	-	20.00	5.00	21.9	
	4	20.00	-	25.00	5.00	19.3	
	5	25.00	-	30.00	5.00	57.0	
	6	30.00	-	35.00	5.00	52.8	
	7	35.00	-	40.00	5.00	33.5	
	8	40.00	-	45.00	5.00	35.8	
	9	45.00	-	50.00	5.00	66.5	
	10	50.00	-	55.00	5.00	38.2	
	11	55.00	-	60.00	5.00	36.5	
	12	60.00	-	65.00	5.00	73.5	
	13	65.00	-	70.00	5.00	21.8	
	14	70.00	-	75.00	5.00	13.0	
	15	75.00	-	80.00	5.00	1.4	
	16	80.00	-	85.00	5.00	2.0	
	17	85.00	-	90.00	5.00	2.8	
	18	90.00	-	95.00	5.00	2.7	
	19	95.00	-	100.00	5.00	2.2	

Table 3-9 SUMMARY OF WATER PRESSURE TEST (3)

Hole No.	Stage No.	Test Section GL- m		m	Section Length m	Lu	Remarks
BDD 105	1	5.00	-	10.00	5.00	7.9	
	2	10.00	-	15.00	5.00	6.2	
	3	15.00	-	20.00	5.00	8.1	
	4	20.50	-	25.00	4.50	11.6	
	5	27.00	-	30.00	3.00	17.0	
	6	30.00	-	35.00	5.00	2.5	
	7	35.00	-	40.00	5.00	0.5	
	8	40.00	-	45.00	5.00	33.3	
	9	45.00	-	50.00	5.00	20.0	
	10	50.00	-	55.00	5.00	56.9	
	11	55.00	-	60.00	5.00	52.5	
	12	60.00	-	65.00	5.00	12.8	
	13	65.00	-	70.00	5.00	20.7	
	14	70.00	-	75.00	5.00	16.8	
	15	75.00	-	80.00	5.00	27.1	
	16	80.00	-	85.00	5.00	4.8	
	17	85.00	-	90.00	5.00	7.5	
	18	90.00	-	95.00	5.00	7.7	
	19	95.00	-	100.00	5.00	27.7	
BDD 106	1	6.00	-	9.50	3.5	18.1	
	2	12.00	-	15.00	3.00	30.3	
	3	15.00	-	20.00	5.00	11.3	
	4	20.00	-	26.00	6.00	16.6	
	5	25.00	-	30.00	5.00	21.9	
	6	30.00	-	35.00	5.00	12.6	
	7	35.00	-	40.00	5.00	12.1	
	8	43.00	-	45.00	2.00	25.3	
	9	45.00	-	50.00	5.00	2.5	
	10	53.00	-	55.00	2.00	8.0	
	11	55.00	-	60.00	5.00	4.1	
	12	60.00	-	65.00	5.00	15.0	
	13	65.00	-	70.00	5.00	1.0	
	14	70.00	-	75.00	5.00	0.6	
	15	75.00	-	80.00	5.00	0.3	
	16	80.00	-	85.00	5.00	0.1	
	17	85.00	-	91.00	5.00	0.1	
	18	90.00	-	95.00	5.00	0.9	
	19	95.00	-	100.00	5.00	0.9	

Table 3-9 SUMMARY OF WATER PRESSURE TEST (4)

Hole No.	Stage No.	Test Section GL- m		m	Section Length m	Lu	Remarks
BDD 107	1	5.00	-	10.00	5.00	27.6	
	2	10.00	-	15.00	5.00	103.9	
	3	15.00	-	20.00	5.00	10.0	
	4	20.00	-	25.00	5.00	42.4	
	5	25.00	-	30.00	5.00	1.2	
	6	30.00	-	35.00	5.00	1.2	
	7	35.00	-	40.00	5.00	0.5	
	8	40.00	-	45.00	5.00	0.3	
	9	45.00	-	50.00	5.00	0.3	
	10	50.00	-	55.00	5.00	0.3	
	11	55.00	-	60.00	5.00	0.9	
	12	60.00	-	65.00	5.00	0.4	
	13	65.00	-	70.00	5.00	0.2	
	14	70.00	-	75.00	5.00	0.2	
	15	75.00	-	80.00	5.00	0.3	
	16	80.00	-	86.60	6.60	0.3	
	17	85.00	-	91.70	6.70	0.3	
	18	90.00	-	95.60	5.60	>100	
	19	98.00	-	100.00	2.00	0.7	
BUD 121	1	5.00	-	10.00	5.00	23.0	
	2	10.00	-	15.00	5.00	3.7	
	3	15.00	-	20.00	5.00	4.7	
BUD 122	1	7.00	-	10.00	3.00	32.0	
	2	10.00	-	15.00	5.00	16.0	
	3	15.00	-	20.00	5.00	35.8	
BUD 123	1	15.00	-	20.00	5.00	8.8	
	2	20.00	-	25.00	5.00	6.7	
	3	25.00	-	30.00	5.00	2.9	
	4	30.00	-	35.00	5.00	17.4	
	5	35.00	-	40.00	5.00	20.6	
	6	40.00	-	45.00	5.00	31.4	
	7	45.00	-	50.00	5.00	16.2	
	8	50.00	-	55.00	5.00	4.5	

Table 3-9 SUMMARY OF WATER PRESSURE TEST (5)

Hole No.	Stage No.	Test Section GL- m		m	Section Length m	Lu	Remarks
BUD 124	1	55.00	-	60.00	5.00	19.1	
	2	60.00	-	65.00	5.00	17.9	
	3	65.00	-	70.00	5.00	15.7	
	4	70.00	-	75.00	5.00	12.9	
	5	75.00	-	80.00	5.00	14.0	
	6	80.00	-	85.00	5.00	14.1	
	7	85.00	-	90.00	5.00	8.9	
	8	90.00	-	95.00	5.00	7.9	
BUD 125	1	69.00	-	70.00	1.00	64.2	
	2	70.00	-	75.00	5.00	13.5	
	3	75.00	-	80.00	5.00	12.6	
	4	80.00	-	85.00	5.00	11.1	
	5	85.00	-	90.00	5.00	11.0	
	6	90.00	-	95.00	5.00	11.9	
	7	95.00	-	100.00	5.00	11.7	
	8	100.00	-	105.00	5.00	11.4	

Table 3-10 SUMMARY OF STANDARD PENETRATION TEST (1)

Borehole No.	Depth (m) GL -			Number of blows N1	N2	N3	N4	N-value
BDD 101	0.00	-	0.35	3	15	23	50/5	>50
	1.00	-	1.03	50/3	-	-	-	>50
	2.00	-	2.02	50/2	-	-	-	>50
	3.00	-	3.03	50/3	-	-	-	>50
		-						
	6.00	-	6.02	50/2	-	-	-	>50
		-						
	15.00	-	15.02	50/2	-	-	-	>50
		-						
	23.00	-	23.02	50/2	-	-	-	>50
BDD 102	0.00	-	0.45	2	2	2	2	6
	5.00	-	5.45	2	4	6	8	18
	6.00	-	6.45	14	14	14	13	41
		-						
	8.00	-	8.18	15	50/8	-	-	>50
	9.00	-	9.12	10	50/2	-	-	>50
	10.00	-	10.05	50/5	-	-	-	>50
	11.00	-	11.04	50/4	-	-	-	>50
	12.00	-	12.05	50/5	-	-	-	>50
	13.00	-	13.07	50/7	-	-	-	>50
	14.00	-	14.05	50/5	-	-	-	>50
	15.00	-	15.13	27	30/3	-	-	>50
BDD 103	0.00	-	0.08	50/8	-	-	-	>50
	1.00	-	1.09	50/9	-	-	-	>50
BDD 105	0.00	-	0.45	0	1	1	1	3
	1.00	-	1.45	5	7	8	15	30
	2.00	-	2.45	7	9	11	17	37
	3.00	-	3.3	17	16	24	-	>50
BDD 106	0.00	-	0.45	1	1	1	11	13
	1.00	-	1.35	5	4	24	35/5	>50
	2.00	-	2.2	25	30	-	-	>50
	3.00	-	3.2	21	34	-	-	>50
	4.00	-	4.2	11	42	-	-	>50
	5.00	-	5.15	30	21/5	-	-	>50
	6.00	-	6.25	28	30/15	-	-	>50
	7.00	-	7.3	18	20	20	-	>50
	8.00	-	8.2	30	25	-	-	>50
BDD 107	0.00	-	0.08	30/8	-	-	-	>50

Table 3-10 SUMMARY OF STANDARD PENETRATION TEST (2)

Borehole No.	Depth (m) GL -			Number of blows N1	N2	N3	N4	N-value
BDQ 108	0.00	-	0.35	2	2	4	6	12
	1.00	-	1.45	4	5	7	7	19
	2.00	-	2.05	25/5	-	-	-	>50
	3.00	-	3	50/0	-	-	-	>50
	4.00	-	4	50/0	-	-	-	>50
	5.00	-	5	50/0	-	-	-	>50
BDQ 109	0.00	-	0.45	1	2	2	2	6
	1.00	-	1.45	2	2	3	3	8
	2.00	-	2.45	2	2	3	4	9
	3.00	-	3.45	1	1	2	3	6
	4.00	-	4.45	1	1	2	2	5
	5.00	-	5.45	2	2	4	4	10
	6.00	-	6.45	1	1	1	2	4
	7.00	-	7.45	1	1	1	1	3
	8.00	-	8.45	1	1	1	3	5
	9.00	-	9.45	0	0	0	0	0
	10.00	-	10.45	1	2	1	2	5
	11.00	-	11.45	1	1	1	1	3
	12.00	-	12.45	2	3	4	8	15
	13.00	-	13.4	10	12	30	52	>50
BUP 110	0.00	-	0.45	2	5	6	7	18
	1.00	-	1.45	5	6	8	9	23
	2.00	-	2.45	7	8	10	11	29
	3.00	-	3.45	6	8	11	9	28
	4.00	-	4.45	4	6	9	11	26
	5.00	-	5.45	6	8	10	12	30
	6.00	-	6.45	8	10	11	13	34
	7.00	-	7.45	7	9	11	12	32
	8.00	-	8.45	5	7	9	11	27
	9.00	-	9.45	4	5	8	9	22
	10.00	-	10.45	6	8	9	9	26
	11.00	-	11.45	5	7	9	10	26
	12.00	-	12.45	7	9	6	9	24
	13.00	-	13.45	5	7	9	8	24
	14.00	-	14.45	6	8	9	11	28
	15.00	-	15.45	15	17	17	19	>50
	16.00	-	16.45	16	18	19	11	48
	17.00	-	17.45	14	17	19	11	47

Table 3-10 SUMMARY OF STANDARD PENETRATION TEST (3)

Borehole No.	Depth (m) GL -	Number of blows N1	N2	N3	N4	N-value
BUP 111	0.00 - 0.45	6	11	12	12	35
	1.00 - 1.45	10	14	12	15	41
	2.00 - 2.45	10	16	18	18	>50
	3.00 - 3.45	12	12	14	16	42
	4.00 - 4.45	12	14	16	18	48
	5.00 - 5.45	11	14	16	19	49
	6.00 - 6.45	13	15	17	19	>50
	7.00 - 7.45	12	14	16	18	48
	8.00 - 8.45	11	14	14	19	47
	9.00 - 9.45	13	16	18	20	>50
	10.00 - 10.45	10	14	16	19	49
	11.00 - 11.45	19	15	18	20	>50
	12.00 - 12.45	10	12	15	17	44
	13.00 - 13.45	10	16	16	18	50
	14.00 - 14.45	9	17	19	31	>50
	15.00 - 15.45	10	14	16	18	48
	-					
	17.00 - 17.45	10	18	20	22	>50
	18.00 - 18.45	14	18	20	21	>50
BUP 112	0.00 - 0.45	4	5	5	9	19
	1.00 - 1.45	10	12	20	19	>50
	2.00 - 2.45	10	13	15	16	44
	3.00 - 3.45	15	20	22	22	>50
	4.00 - 4.45	10	13	10	17	40
	5.00 - 5.45	10	11	14	20	45
	6.00 - 6.45	13	10	11	15	36
	7.00 - 7.45	10	12	16	21	49
	8.00 - 8.45	7	10	12	15	37
	9.00 - 9.45	15	15	20	23	>50
	10.00 - 10.45	13	16	19	22	>50
	11.00 - 11.45	20	24	30	42	>50
	12.00 - 12.45	10	9	11	10	30
	13.00 - 13.45	10	8	9	42	>50
	-					
	15.00 - 15.45	14	15	17	20	>50
	-					
	19.00 - 19	50/0	-	-	-	>50
BUP 113	0.00 - 0.45	4	6	4	4	14
	1.00 - 1.04	60/4	-	-	-	>50
	-					
	8.05 - 8.5	9	25	20	20	>50
	-					
	10.85 - 11.35	11	20	23	25	>50

Table 3-10 SUMMARY OF STANDARD PENETRATION TEST (4)

Borehole No.	Depth (m) GL -			Number of blows N1	N2	N3	N4	N-value
BUP 114	0.00	-	0.45	1	2	4	6	12
	1.00	-	1.45	3	4	6	11	21
	2.00	-	2.45	1	9	14	19	42
	3.00	-	3.15	25	50/5	-	-	>50
	4.00	-	4.25	21	28	50/5	-	>50
	5.00	-	5.15	34	50/5	-	-	>50
	6.00	-	6	50/0	-	-	-	>50
	7.00	-	7	50/0	-	-	-	>50
	8.00	-	8.25	16	39	50/5	-	>50
	9.00	-	9.05	50/5	-	-	-	>50
	10.00	-	10	50/0	-	-	-	>50
	11.00	-	11	50/0	-	-	-	>50
	12.00	-	12	50/0	-	-	-	>50
	13.00	-	13	50/0	-	-	-	>50
	14.00	-	14	50/0	-	-	-	>50
BUP 115	0.00	-	0.45	1	2	2	3	7
	1.00	-	1.45	2	3	4	6	13
	2.00	-	2.45	6	8	9	11	28
	3.00	-	3.45	4	7	6	9	22
	4.00	-	4	50/0	-	-	-	>50
	5.00	-	5.45	7	8	9	14	31
	6.00	-	6.45	8	7	9	12	28
	7.00	-	7.45	9	8	10	13	31
	8.00	-	8.45	9	9	16	27	>50
	9.00	-	9.45	12	16	13	16	45
	10.00	-	10.45	16	14	27	41	>50
	11.00	-	11.45	13	15	18	28	>50
	12.00	-	12.1	13	50/0	-	-	>50
	13.00	-	13.35	20	18	36	50/5	>50
	14.00	-	14.05	50/5	-	-	-	>50
BUP 116	0.00	-	0.45	3	4	4	5	13
	1.00	-	1.45	10	11	18	19	48
	2.00	-	2.45	8	7	8	13	28
	3.00	-	3.45	7	13	19	21	->50
	4.00	-	4.45	14	12	16	15	43
	5.00	-	5.25	17	36	50/5	-	>50
	6.00	-	6.25	24	48	50/5	-	>50
	7.00	-	7.45	14	23	37	38	>50
	8.00	-	8.35	12	23	39	30/5	>50
		-						
	10.00	-	10.45	8	10	19	19	48
		-						
	12.00	-	12.25	21	33	50/5	-	>50
	13.00	-	13.35	18	10	28	50/5	>50
	14.00	-	14.45	16	18	43	39	>50
	15.00	-	15	50/0	-	-	-	>50
	16.00	-	16	50/0	-	-	-	>50

Table 3-10 SUMMARY OF STANDARD PENETRATION TEST (5)

Borehole No.	Depth (m) GL -	Number of blows N1	N2	N3	N4	N-value
BUP 117	0.00 - 0.45	1	1	2	2	5
	1.00 - 1.45	1	2	2	3	7
	2.00 - 2	50/0	-	-	-	>50
	3.00 - 3.03	50/3	-	-	-	>50
	4.00 - 4	50/0	-	-	-	>50
	-					
	7.00 - 7.03	50/5	-	-	-	>50
	-					
	9.00 - 9.03	50/3	-	-	-	>50
BUP 118	0.00 - 0.45	3	5	7	11	23
	1.00 - 1.45	4	5	8	10	23
	2.05 - 2.5	3	7	11	13	31
	3.00 - 3.45	5	14	13	15	42
	4.00 - 4.45	5	11	16	18	45
	5.00 - 5.05	15/5	-	-	-	>50
BUP 119	0.00 - 0.45	3	3	3	3/15	8
	1.00 - 1.45	1	1	1	2/15	4
	2.00 - 2.45	2	2	3	4/15	8
	3.00 - 3.45	2	2	2	4/15	7
	4.00 - 4.45	4	4	5	10/15	16
	5.00 - 5.45	3	4	5	10/15	16
	6.00 - 6.45	3	5	6	9/15	17
	7.00 - 7.45	2	4	6	10/15	17
	8.00 - 8.45	3	4	5	8/15	14
	9.00 - 9.45	4	5	5	10/15	17
	10.00 - 10.45	4	6	6	14/15	21
	11.00 - 11.45	5	5	6	13/15	18
	12.00 - 12.45	6	7	7	12/15	22
	13.00 - 13.45	5	8	8	15/15	26
	14.00 - 14.45	6	12	16	32/15	49
	15.00 - 15.4	10	15	20	25	>50
	16.00 - 16.05	50/5	-	-	-	>50

Table 3-10 SUMMARY OF STANDARD PENETRATION TEST (6)

Borehole No.	Depth (m) GL -			Number of blows N1	N2	N3	N4	N-value
BUP 120	0.00	-	0.45	4	3	3	5/15	9
	1.00	-	1.45	1	2	2	5/15	7
	2.00	-	2.45	1	3	2	5/15	8
	3.00	-	3.45	2	3	5	6/15	12
	4.00	-	4.45	2	4	3	5/15	10
	5.00	-	5.45	3	4	4	7/15	12
	6.00	-	6.45	2	5	6	9/15	17
	7.00	-	7.45	3	7	7	11/15	21
	8.00	-	8.45	2	8	6	9/15	20
	9.00	-	9.45	4	6	7	13/15	21
	10.00	-	10.45	7	8	7	15/15	25
	11.00	-	11.45	8	11	17	25/15	45
	12.00	-	12.45	10	12	18	28/15	49
	13.00	-	13.45	8	16	20	30/15	>50
	14.00	-	14.4	13	16	24	39	>50
	15.00	-	15.25	25	48	40/5	-	>50
BUD 121	0.00	-	0.21	1	1	10/1	-	>50
	1.00	-	1.06	16/6	-	-	-	>50
	2.00	-	2.02	20/2	-	-	-	>50
	3.00	-	3.01	13/1	-	-	-	>50
	4.00	-	4.02	20/2	-	-	-	>50
BUD 122	0.00	-	0.45	1	1	1	2	4
	1.00	-	1.45	1	2	2	3	7
	2.00	-	2.45	2	3	4	4	11
BUD 123	0.00	-	0.45	1	1	2	2	5
	1.00	-	1.45	1	1	1	2	4
	2.00	-	2.45	2	2	4	5	11
	3.00	-	3.45	5	6	7	8	21
	4.00	-	4.45	5	5	6	8	19
	5.00	-	5.45	6	7	10	10	27
	6.00	-	6.45	8	11	14	14	39
	7.00	-	7.45	7	10	12	15	37
	8.00	-	8.45	10	12	12	15	39
	9.00	-	9.45	10	13	14	16	43
	10.00	-	10.2	20	35	-	-	>50
BUD 124	0.00	-	0.45	2	2	4	5	11
	1.00	-	1.45	3	4	6	8	18
	2.00	-	2.45	4	4	4	5	13
	3.00	-	3.45	3	3	5	8	16
	4.00	-	4.45	4	4	7	6	17
	5.00	-	5.17	21	50/7	-	-	>50
	6.00	-	6.15	36	50/5	-	-	>50
	7.00	-	7.09	50/9	-	-	-	>50

Table 3-10 SUMMARY OF STANDARD PENETRATION TEST (7)

Borehole No.	Depth (m) GL -			Number of blows N1	N2	N3	N4	N-value
BUD 125	0.00	-	0.45	2	2	2	2	6
	1.00	-	1.45	2	1	1	1	3
	2.00	-	2.45	2	2	2	3	7
	3.00	-	3.45	2	1	1	2	4
	4.00	-	4.45	1	1	2	2	5
	5.00	-	5.45	2	2	2	3	7
	6.00	-	6.45	2	1	2	3	6
	7.00	-	7.45	2	3	3	2	8
	8.00	-	8.45	2	6	6	12	24
	9.00	-	9.45	2	3	4	7	14
	10.00	-	10.45	8	10	12	13	35
	11.00	-	11.45	12	20	29	52	>50
	12.00	-	12.45	10	12	12	16	40
	13.00	-	13.45	8	13	12	13	38
	14.00	-	14.3	25	33	56	-	>50
	15.00	-	15.1	59	-	-	-	>50
	16.00	-	16.07	50/7	-	-	-	>50

Table 3-11 LIST OF SEISMIC PROSPECTING

No.	Section No.	Location	Length (m)
1	SD - 1	Lower Damsite	770
2	SD - 2	Lower Damsite	660
3	SD - 3	Lower Damsite	660
4	SD - 4	Lower Damsite	770
5	SD - 5	Lower Damsite	550
6	SD - 6	Lower Damsite	660
7	SD - 7	Lower Damsite	660
8	SD - 8	Quarry I	1,540
9	SD - 9	Quarry I	330
10	SD - 10	Quarry I	330
11	SD - 11	Quarry I	550
12	SD - 12	Quarry II	880
13	SD - 13	Quarry II	440
14	SD - 14	Quarry II	440
15	SD - 15	Quarry II	550
16	SU - 1	Intake Site I (W/AA)	330
17	SU - 2	Intake Site I (W/AA)	660
18	SU - 3	Intake Site II (W/A or W/E)	550
19	SU - 4	Intake Site III (W/C)	550
20	SU - 5	P/S I (W/E)	990
21	SU - 6	P/S I (W/E)	550
22	SU - 7	Intake Site IV (W/D)	550
23	SU - 8	P/S II (W/AA, W/A or W/C)	660
24	SU - 9	P/S II (W/AA, W/A or W/C)	330
25	SU - 10	P/S II (W/AA, W/A or W/C)	330
26	SU - 11	P/S II (W/AA, W/A or W/C)	330
27	SU - 12	P/S III (W/D)	660
28	SU - 13	P/S III (W/D)	330
29	SU - 14	P/S III (W/D)	330
30	SU - 15	P/S III (W/D)	330
		Total	17,270

Table 3-12 Summary of Rock Mechanics Laboratory Test

Boring No.	Depth m	Rock Type m	Specific Gravity g/cm3	Absorption %	Porosity %	Compressive Strength kgf/cm²	Tensile Strength kgf/cm²	Sonic Velosity Vp m/sec	Sonic Velosity Vs m/sec	Soundness %
BDD-101	8.55 - 9.00	Ls	2.611	3.3	8.4	130.9	17.9	3,626	1,124	5.9
BDD-101	10.00 - 10.40	Ls	2.63	3.6	9.7	203.0	25.4	3,532	1,837	7.8
BDD-101	13.30 - 13.70	Ls	2.695	0.8	2.3	99.2	12.2	2,963	1,749	5.6
BDD-102	60.20 - 60.45	Ls	2.635	1.0	2.5	365.1	12.9	3,270	1,996	8.3
BDD-103	14.25 - 14.55	Tf	1.844	18.4	28.6	72.7	8.9	671	575	12.3
BDD-103	15.00 - 15.20	Tf	1.853	20.7	31.8	36.2	8.5	746	447	11.2
BDD-103	44.50 - 44.80	Ls	2.604	1.4	3.7	198.3	29.7	2,654	1,221	10.9
BDD-104	20.00 - 20.60	Tf	1.86	20.1	31.2	48.7	12.1	1,224	808	6.9
BDD-104	22.20 - 22.55	Tf	1.825	22.4	33.5	44.4	10.9	1,080	659	10.7
BDD-104	80.00 - 80.25	Ls	2.614	1.1	2.9	188.8	23.4	2,774	1,719	7.7
BDD-104	89.00 - 89.40	Ls	2.753	1.4	3.9	207.7	23.9	2,465	1,505	8.2
BDD-104	98.50 - 99.00	Ls	2.649	4.0	10.2	200.0	24.3	2,311	1,503	13.6
BDD-105	15.10 - 15.37	Tf	1.575	22.5	28.9	59.8	5.5	648	415	11.4
BDD-105	15.50 - 15.75	Tf	1.769	22.4	32.3	58.0	5.3	561	370	10.9
BDD-105	63.10 - 63.25	Ls	2.65	1.5	3.4	102.7	12.3	2,988	1,792	13.2
BDD-106	67.30 - 67.75	Ls	2.773	1.2	3.4	169.4	15.7	3,324	1,031	5.1
BDQ-108	29.75 - 29.95	Sl	2.658	1.2	3.2	103.4	12.2	1,978	1,246	9.7
BDQ-108	31.30 - 31.70	Sl	2.596	2.9	7.3	101.0	12.5	1,670	1,088	10.4
BDQ-109	35.30 - 35.70	Tf	1.897	17.7	28.5	46.8	9.8	1,450	464	8.5
BUP-113	16.00 - 16.40	Sl	2.641	1.1	2.8	249.2	28.9	3,179	1,907	13.7
BUP-113	18.00 - 18.35	Sl	2.615	1.5	3.8	474.7	22.0	3,484	1,359	14.7
BUP-115	33.70 - 34.00	Ss	2.677	0.5	1.4	117.0	14.2	2,450	1,495	8.6
BUP-115	34.10 - 34.60	Ss	2.408	6.7	15.0	126.3	16.0	2,356	1,367	5.1
BUP-116	25.00 - 25.40	Sl	2.593	3.4	8.6	58.0	9.3	2,127	1,361	13.3
BUP-118	37.20 - 37.53	TMs	2.723	0.7	1.9	76.6	16.3	2,384	1,348	7.9
BUP-118	54.00 - 54.30	TSs	2.585	1.8	4.5	31.5	11.8	2,092	1,255	8.5
BUP-118	102.65 - 103.00	TCg	2.623	1.3	3.4	31.0	9.6	1,756	1,159	12.7
BUP-119	22.00 - 22.71	Tf	1.863	16.5	26.4	40.9	6.1	1,464	672	9.3
BUP-119	33.00 - 33.40	Tf	1.872	20.2	31.5	61.1	7.8	1,659	979	8.1
BUP-120	53.10 - 53.40	Tf	2.086	6.3	12.4	175.1	20.7	1,588	1,033	6.8
BUP-120	62.00 - 62.35	Tf	2.049	8.5	16.0	140.1	15.5	1,705	1,109	4.0
BUP-120	88.00 - 88.40	Tf	2.256	3.3	7.2	119.3	10.6	2,241	1,258	10.9
BUD-121	9.45 - 10.00	Tf	1.877	16.6	26.7	115.8	16.1	989	514	5.0
BUD-121	14.00 - 14.30	Tf	1.872	20.3	31.6	156.7	16.4	957	622	6.6
BUD-122	12.00 - 12.30	Tf	1.755	27.1	37.5	136.3	7.1	1,268	607	8.8
BUD-123	25.00 - 25.40	Tf	1.982	16.2	27.7	144.1	6.6	1,359	774	9.8
BUD-123	46.00 - 46.50	Tf	2.199	6.8	14.1	289.9	21.7	1,541	755	8.4
BUD-123	52.00 - 52.45	Tf	1.546	8.1	11.6	190.3	24.7	1,891	964	8.4
BUD-124	25.00 - 25.40	Tf	1.895	19.2	30.5	49.9	8.5	1,077	700	11.7
BUD-124	37.00 - 37.55	Tf	2.061	10.1	18.8	45.3	8.1	1,418	695	7.3
BUD-124	64.00 - 64.30	Tf	2.2	7.3	15.0	208.3	22.3	1,891	1,118	7.1
BUD-124	73.10 - 73.50	Tf	2.223	6.1	12.8	172.9	19.4	1,709	974	6.9
BUD-124	93.00 - 93.50	Tf	2.344	2.0	4.5	152.7	17.4	2,088	1,168	7.5
BUD-125	24.60 - 25.00	Tf	1.89	16.5	26.7	30.9	5.9	1,439	734	7.9
BUD-125	39.00 - 39.60	Tf	2.03	11.0	20.2	351.6	21.7	1,708	529	3.3
BUD-125	59.00 - 59.40	Tf	2.05	9.5	17.8	344.2	24.9	1,388	737	9.8
BUD-125	97.00 - 97.40	Tf	2.237	4.1	8.9	356.9	27.5	2,071	1,139	16.0

Note : Tf; Toba tuff
TMs; Tertiary mudstone
TSs; Tertiary sandstone
TCg; Tertiary conglomerate
Ls; Limestone
Ss; Metawacke
Sl; Slate

Table 3-13 Stratigraphy of Project Site

Formation	Unit	Age	Major outcrops in the area	Lithology
	Riverbed deposits	Holocene	In the floor of rivers	Grabel, sand & clay (unconsolidated)
	Toba tuff	Pleistocene	In the south and north of area	Rhyodacitic tuffs pertially welded (soft and loose)
Bampo fmn.	Black mudstones	Late Oligocene • Early Miocene	In the north of area	Mainly composed of black mudstones (massive and weak to medium strong rock)
Bruksah fmn.	Grey siltstones	Late Oligocene		Mainly composed of grey calcareous siltstones with micaceouse sandstones & basal conglomerates (massive and weak to medium strong rock)
Butar fmn.	Sandstones & shales al.	Late Oligocene • Early Miocene	In the south of area	Alternating beds of sandstones and shales dominated by shales (massive and weak to medium strong rock)
	Conglomerate			Consists of pebbles cemented together reddish silt intercalated with shale beds
	Sandstones			Medium- to coarse-grained quartz sandstones
Batumilmil Limestone fmn.	Limestones	Late Permian	Lower damsite area & Mt. Batumilmil	Fossiliferous reefal limestones locally recrystallised grey calicilutites and chert lenses
Bohorok fmn.	Metawackes	Late Carboni-ferous • Early Permian	The middle part of area	Non-beded and massive jointed metawackes with subordinate dark slates

Table 3-14 List of Earthquakes for Wampu Project

No.	DATE Y M D	EPICENTER LAT.	LONG.	DEPTH km	M	DE km	DF km	Ij	Kanai's f. gal
1	19530707	1.000	100.000		6.3	306	306	0.3	1.41
2	19550517	6.600	94.000		7.5	608	608	0.8	3.15
3	19560402	2.000	97.000		6.5	185	185	1.9	6.86
4	19570220	2.000	97.000		6.3	185	185	1.5	3.11
5	19570311	1.500	97.300		6.4	208	208	1.4	2.72
6	19580207	3.500	96.500		6	197	197	0.8	1.85
7	19581229	2.500	99.000		5.5	110	110	1.1	2.05
8	19591012	2.000	98.500		6.3	128	128	2.4	2.74
9	19640403	3.900	96.600	51	6.1	201	207	0.9	1.41
10	19650419	1.800	98.500	55	5.5	150	160	0.4	0.71
11	19650520	1.900	99.200	42	5.5	173	178	0.1	0.60
12	19650719	3.000	97.100	33	5.2	127	131	0.2	0.63
13	19660119	3.400	97.500	33	4.9	87	93	0.1	0.65
14	19670412	5.300	97.300	55	6.1	263	269	0.3	0.62
15	19670728	2.100	98.000	32	5.1	117	121	0.2	0.53
16	19691217	2.900	98.600	52	4.9	47	70	0.3	1.16
17	19691217	2.800	98.000	42	5.1	44	61	0.9	1.44
18	19700803	2.600	98.000	38	5.9	64	74	2.3	5.86
19	19740214	2.500	99.000	34	5.6	110	115	1.3	2.69
20	19740227	1.300	97.700	33	5.9	211	213	0.4	0.71
21	19740317	1.300	98.600	61	5.7	206	215	0.1	1.32
22	19740719	3.500	98.300	33	4.8	42	54	0.4	1.31
23	19760222	3.200	99.000	180	5.6	85	199	1.5	0.58
24	19760620	3.400	96.300	33	7	217	219	2.5	7.09
25	19760621	3.400	96.400	32	5.8	206	208	0.3	1.42
26	19760622	3.400	98.200	33	5.3	31	45	1.6	7.54
27	19760907	2.700	99.200	175	5.1	117	210	0.2	0.39
28	19800401	4.030	97.560	41	5.6	125	132	1	2.45
29	19800502	3.390	98.110	56	4.7	33	65	0	0.99
30	19800722	2.630	99.130	163	5	113	199	0	0.90
31	19820224	4.370	97.760	52	5.4	148	157	0.2	0.95
32	19820307	3.730	97.420	124	5	113	168	0	0.58
33	19820803	2.860	97.490	58	5	88	105	0.3	0.85
34	19840529	3.570	97.140	71	5.8	131	149	1.3	0.90
35	19841117	0.200	98.030	33	6.3	325	327	0.1	0.58
36	19870425	2.260	99.020	33	5.9	129	134	1.5	1.33
37	19870428	2.020	99.060	29	5.7	153	156	0.8	0.88
38	19870517	3.000	97.150	61	5.1	121	136	0.1	0.47

Y : Year
M : Month
D : Date
M : Magnitude
DE : Distance from the epicentre
DF : Distance from the focus
Ij : Intensity in JMA (Japan Meteorological Agency) scale

Table 3-15 List of Test Pits

Location	No.	Remarks
Quarry & Borrow Site		
Q-I Site (Upper Site)	TPS-1, TPS-2, TPS-3, TPS-4	
Q-II Site)Lower Site)	TPS-5, TPS-6	
Sand & Gravel Pit		
Lau Tebah	TPG-1, TPG-2, TPG-3	
Wampu River	TPG-4, TPG-5	
Susuk	TPG-6, TPG-7, TPG-8, TPG-9, TPG-10	

Table 3-16 Summary of Soil Mechanics Laboratory Test

Test Pit No.	Depth	Location	Specific Gravity	% of Passing Sieve No.200	% of Clayey Material of 0.005 mm or under	Water Content	Consistency		Compaction Test		Permeability Test
							LL	PL	rd	Wopt	
	m			%		%	%	%	t/m3	%	cm/sec
TPS-1	0.55 - 1.05	Quarry I	2.56	77.97	25.53	41.71	40.07	31.42	1.173	44.80	4.489 x 10-5
TPS-1	3.35 - 3.85	Quarry I	2.67	60.46	24.28	34.95	41.25	31.29	1.349	33.60	1.390 x 10-4
TPS-2	0.65 - 1.15	Quarry I	2.51	48.77	28.67	19.18	-	-	1.253	22.80	2.300 x 10-4
TPS-2	3.45 - 3.95	Quarry I	2.53	43.21	16.26	22.95	-	-	1.245	8.40	4.795 x 10-4
TPS-3	0.55 - 0.95	Quarry I	2.51	32.03	17.70	22.39	-	-	1.282	11.40	4.981 x 10-4
TPS-3	3.25 - 3.75	Quarry I	2.53	63.22	16.44	18.19	-	-	1.455	10.40	3.620 x 10-4
TPS-4	0.40 - 0.90	Quarry I	2.57	72.46	22.65	28.76	43.74	32.59	1.253	38.85	4.070 x 10-5
TPS-4	3.35 - 3.85	Quarry I	2.66	53.27	30.17	38.73	44.77	33.69	1.343	34.20	-
TPS-5	0.65 - 1.15	Quarry II	2.63	93.25	24.85	23.92	-	-	1.388	31.20	1.529 x 10-5
TPS-5	3.15 - 3.65	Quarry II	2.72	57.28	27.67	26.97	-	-	1.291	11.80	-
TPS-6	0.35 - 0.85	Quarry II	2.65	69.91	29.58	38.68	58.63	45.10	1.273	37.80	1.458 x 10-5
TPS-6	2.85 - 3.35	Quarry II	2.94	67.76	21.89	44.87	61.20	46.67	1.404	33.60	8.855 x 10-5
TPS-7	0.15 - 0.65	Quarry II	2.57	54.46	23.51	13.19	48.88	31.22	1.337	34.00	4.087 x 10-6
TPS-7	2.05 - 2.55	Quarry II	2.76	51.86	19.09	17.94	50.16	32.05	1.549	26.60	7.944 x 10-5

Table 3-17 Summary of Concrete Aggregate Test

Test Pit No.	Location g/cm3	Specific Gravity Fine g/cm3	Specific Gravity Coarse %	Absorption Fine %	Absorption Coarse kg/m3	Unit Weight Fine kg/m3	Unit Weight Coarse %	Wash Loss Conte Fine %	Wash Loss Conte Coarse %	Clay Lump Fine %	Clay Lump Coarse %	F.M.	Passing No.200 %	Soundness %	Abrasion %	Organic Impurities Plate No.
TPG- 1	Lau Tebah	2.45	2.43	2.88	3.31	1562	1612	6.60	2.1	6.4	0.3	5.3	0.5	4.8	35.1	4
TPG- 2	Lau Tebah	2.54	2.47	2.04	2.97	1531	1501	17.80	1.7	1.7	0.1	5.9	1.2	6.1	33.7	5
TPG- 3	Lau Tebah	2.62	2.72	0.60	2.21	1626	1706	16.40	1.8	0.2	0.1	4.9	1.3	7	32.4	5
TPG- 4	S. Wampu	2.66	2.45	1.21	2.80	1647	1611	3.20	2.2	0.8	0.3	5.1	0.8	6.1	51.4	4
TPG- 5	S. Wampu	2.66	2.46	1.63	3.34	1564	1664	6.40	2.1	0.4	0.4	5.1	0.8	5.7	55.8	4
TPG- 6	Susuk	2.71	2.32	0.40	3.91	1320	1420	11.60	2.2	2.7	0.3	4.8	1.8	5.2	57.9	>5
TPG- 7	Susuk	2.56	2.31	1.63	3.39	1320	1497	26.60	1.9	1.6	0.1	4.1	2.3	5.8	55.2	>5
TPG- 8	Susuk	2.46	2.33	3.73	3.65	1368	1431	19.20	1.8	0.7	0.1	4.5	3.1	4.2	44.7	>5
TPG- 9	Susuk	2.40	2.27	1.01	4.08	1371	1488	20.40	1.9	1.3	0.5	4.9	2.9	6.1	48.0	>5
TPG-10	Susuk	2.33	2.30	3.09	4.52	1358	1394	25.00	5.1	1.1	0.1	5.5	2.6	6.9	47.6	>5

CHAPTER 4

ELECTRIC POWER DEMAND AND POWER SUPPLY PLAN

4. ELECTRIC POWER DEMAND AND POWER SUPPLY PLAN

4.1 Outline of Aceh and North Sumatra Provinces

The population of Aceh and North Sumatra provinces is a little over 7% of the population for all of Indonesia; the share of GRDP, 9%; and PLN's electrical energy sales in Aceh and North Sumatra provinces, 6%; as shown in the table below. The Aceh and North Sumatra provinces have a little less than 40% of the total population of Sumatra Island, about 30% of the GRDP and over 49% of the electrical energy sales, though most of these are in North Sumatra province.

Medan, the capital of North Sumatra province, is the largest city on Sumatra Island and, after Jakarta and Surabaya, is the third largest city in Indonesia. There has recently been a rapid increase in industrial power sales in Medan, indicating the success of the industrialization campaign.

Aceh province is on the northern end of Sumatra Island, with Banda Aceh as its capital. Electric power sales in Aceh province from 1981 to 1989 are only one-eighth of the sales in North Sumatra province, but show an average annual increase of about 16.4%, which is larger than the 14.9% increase in North Sumatra province. Fueled by the strong increase in industrial demand (39.0% average annual increase), this high rate is expected to continue.

Principal Indexes for Aceh and North Sumatra Provinces

Principal Indexes	All Indonesia (a)	All Sumatra Island (b)	North Sumatra Province (c)	Aceh Province (d)	(c + d) / a (e)	(c + d) /b (f)
1. Population (in thousands)						
a) 1980	147,490	28,016	8,361	2,611	0.074	0.392
b) 1987	171,614	34,715	9,902	3,153	0.076	0.376
c) Average annual growth (%)	2.19	3.11	2.45	2.73	-	-
2. GRDP (billion rupees) (constant 1975 rupees)						
a) 1978	15,307.7	4,359.7	908.2	315.9	0.080	0.281
b) 1986	26,016.0	7,657.5	1,506.8	938.6	0.093	0.319
c) Average annual growth (%)	6.85	7.29	6.53	14.58	-	-
3. PLN power sales (GWh)						
a) 1981	7,845.5	860.2	409.7	45.8	0.058	0.530
b) 1989	23,434.8	2,828.4	1,248.4	153.9	0.060	0.496
c) Average annual growth (%)	14.66	16.04	14.94	16.36	-	-

Sources: 1) National Census 1980, Population Projection 1985-95.
2) PLN Commercial Information 1985/86
3) Indonesia Statistics 1986
4) PLN Statistics 1989/90

Power Demand in Aceh and North Sumatra Provinces (PLN's energy sales)

Year	Power sales (Unit: GWh)									
	All Indonesia	Aceh Province			North Sumatra Province			Total for Aceh and North Sumatra Provinces		
		Industrial	Residential and Commercial	Total	Industrial	Residential and Commercial	Total	Industrial	Residential and Commercial	Total
1981	7,845.5	2.8	43.0	45.8	100.4	309.3	409.7	103.2	352.3	455.5
1982	9,101.0	3.9	53.1	57.0	120.2	343.6	463.8	124.1	396.7	520.8
1983	9,999.7	4.3	59.4	63.7	135.4	366.9	502.3	139.7	426.3	566.0
1984	11,039.3	7.4	57.3	64.7	157.2	377.1	534.3	164.6	434.4	599.0
1985	12,644.2	9.5	62.6	72.1	268.2	405.6	674.1	277.7	468.2	745.9
1986	14,786.4	13.8	75.9	89.7	413.0	550.9	963.9	426.8	626.8	1,053.6
1987	17,076.8	14.1	89.5	103.6	445.7	461.2	906.9	459.8	550.7	1,010.5
1988	19,992.8	22.3	101.0	123.3	496.0	525.2	1,021.2	518.3	626.2	1,144.5
1989	23,434.8	39.0	114.9	153.9	652.5	595.8	1,248.3	691.5	710.7	1,402.2
	Average annual growth (%)									
1981-86	13.5	37.6	12.0	14.4	32.7	12.2	18.7	32.8	12.2	18.3
1981-89	14.7	39.0	13.1	16.4	26.4	8.5	14.9	26.8	9.2	15.1

Sources: 1) PLN Commercial Information 1985/86
2) Indonesia Statistics 1986
3) PLN Statistics 1989/90

4.2 Demand and Supply of Power over the Past 10 Years

The following tables show the demand for capacity and power supply over the past 10 years, 1979-89, in Aceh and North Sumatra provinces.

Power Demand and Supply of Power in Aceh Province for the Past 10 Years

Year	Sold Energy (MWh)	Generated Energy (MWh)	Losses (%)	Installed Capacity (MW)	Available Capacity (MW)	Peak Load (MW)
1979	31,380	43,589	28.0	22.8	20.4	10.2
1980	37,558	52,276	28.2	23.0	17.6	12.2
1981	45,831	65,863	30.4	28.7	22.1	15.5
1982	57,015	78,155	27.0	30.2	24.1	17.2
1983	63,685	84,731	24.8	43.1	36.5	19.6
1984	64,707	97,936	33.9	46.4	39.2	20.8
1985	72,121	106,665	32.4	48.6	39.1	24.1
1986	89,679	124,347	27.9	111.3	83.1	28.8
1987	103,584	146,528	29.3	147.1	121.1	37.3
1988	123,258	173,745	29.1	150.0	113.5	43.8
1989	153,929	208,900	26.3	150.7	111.2	52.3
Average annual growth (%)	17.2	17.0	-	20.8	18.5	17.8

Source:
1) INFORMASI KOMERSIAL 1983/84, 1984/85, 1985/86, 1986/87
2) DATA SISTEM KELISTRIKAN PLN WILAYAH I
3) REALISASI PENGUSAHAAN TAHUN 1988/89
4) PEAK LOAD, PRODUCTION AND INSTALLED CAPACITY, DPS/12 NOV. 1990
5) LAPORAN PEMBANGKITAN TENAGA LISTRIK, DALAM BULAN MARET 1990

Power Demand in North Sumatra Province for the Past 10 Years

Year	Sold Energy (MWh)	Generated Energy (MWh)	Losses (%)	Installed Capacity (MW)	Available Capacity (MW)	Peak Load (MW)
1979	267,095	342,600	22.0	N.A.	N.A.	75.7
1980	420,508	455,123	27.6	170.1	N.A.	97.9
1981	409,741	580,990	29.5	176.9	N.A.	112.1
1982	463,802	663,790	30.1	184.5	N.A.	126.1
1983	502,251	715,949	29.8	213.1	163.5	129.8
1984	534,273	779,569	31.5	345.6	294.1	156.9
1985	674,138	934,675	27.9	348.3	271.8	198.2
1986	863,905	1,103,426	21.7	363.1	209.2	217.1
1987	906,891	1,135,758	20.2	386.6	217.0	227.0
1988	1,021,151	1,352,936	24.5	506.3	323.1	280.2
1989	1,248,335	1,635,000	23.7	629.5	415.2	311.8
Average annual growth (%)	16.7	16.9	-	15.6	16.8	15.2

Source:
1) INFORMASI KOMERSIAL 1983/84, 1984/85, 1985/86, 1986/87
2) PENGUSAHAAN SISTEM KELISTRIKAN PLN WILAYAH-II/S.U.
3) FASILITAS KELISTRIKAN DIAREA PLN WILAYAH-II/S.U.
4) REALISASI PENGUSAHAAN TAHUN 1988/89
5) PEAK LOAD, PRODUCTION AND INSTALLED CAPACITY, DPS/12 NOV. 1990
6) LAPORAN PEMBANGKITAN TENAGA LISTRIK, DALAM BULAN MARET 1990

4.2.1 Residential Demand

Residential demand for electricity, which varies between regions, shows annual average growth rates of 9 to 21% for PLN branch offices in the two provinces, as shown below. Downtrends in average power consumption per household are apparently affected by new customers whose power consumption is relatively small.

Changes in Residential Demand

Province	PLN Branch Office	1979, 1981		1984		1988		Annual average growth (%)	
		Demand (GWh)	Use per customer (kWh)	Demand (GWh)	Use per customer (kWh)	Demand (GWh)	Use per customer (kWh)	Demand (%)	Use per customer (%)
Aceh	B. Aceh	* 12.1	1,170	20.7	705	27.7	655	9.6	- 6.2
	Lhok Seumawe	-	-	9.5	1,042	20.6	606	21.3	- 12.7
	Langsa	7.9	1,053	7.1	720	13.7	571	6.3	- 6.6
	Meulaboh	-	-	-	-	6.5	445	-	-
	Total	20.0	1,121	37.4	856	68.5	587	14.7	- 6.9
North Sumatra	Medan	**143.6	1,141	161.5	1,035	220.2	926	6.3	- 2.9
	Bindjai	16.4	596	25.0	576	44.5	467	15.3	- 3.4
	Pematang Siantar	31.1	814	44.6	656	66.9	567	11.6	- 5.0
	Sibolga	9.8	635	16.0	483	29.2	423	16.9	- 5.6
	Total	200.8	971	247.1	822	360.5	693	8.7	- 4.7

Source: DATA SISTEM KELISTRIKAN PLN WILAYAH I & II
Notes: * Demand for Aceh Province is for 1979
** Demand for North Sumatra is for 1981

4.2.2 Commercial Demand

In Aceh and North Sumatra provinces, commercial demand for electricity increased with annual average growth rates of 4 to 8% as shown in the following table, which is a little less than half the growth rate of residential demand. Average power consumption per customer shows an annual downtrend in Aceh but an uptrend in North Sumatra province.

Changes in Commercial Demand

Province	PLN Branch Office	1979, 1981		1984		1988		Annual average growth (%)	
		Demand (GWh)	Use per customer (kWh)	Demand (GWh)	Use per customer (kWh)	Demand (GWh)	Use per customer (kWh)	Demand (%)	Use per customer (%)
Aceh	B. Aceh	* 4.2	1,870	4.5	1,200	5.7	1,026	3.5	- 4.8
	Lhok Seumawe	-	-	3.3	1,236	5.9	1,193	-	-
	Langsa	3.1	1,444	1.4	1,150	2.0	1,003	- 4.8	- 4.0
	Meulaboh	-	-	-	-	1.3	726	-	-
	Total	7.3	1,662	9.3	1,205	14.9	1,109	8.3	- 4.4
North Sumatra	Medan	**38.6	3,637	44.2	3,745	47.1	3,853	2.9	0.8
	Bindjai	4.0	1,265	4.7	1,361	5.4	1,463	4.4	2.1
	Pematang Siantar	6.4	1,965	8.8	2,062	11.1	2,150	8.2	1.3
	Sibolga	2.7	1,132	3.0	993	4.3	1,136	6.9	0.1
	Total	51.7	2,658	60.7	2,689	67.9	3,830	4.7	5.4

Source: DATA SISTEM KELISTRIKAN PLN WILAYAH I & II
Notes: * Demand for Aceh Province is for 1979
** Demand for North Sumatra is for 1981

Comparison of Commercial and Residential Demand

	Province	1979	1981	1984	1988
1. Ratio of sold energy (Commercial/Residential)	Aceh	0.365	-	0.249	0.218
	North Sumatra	-	0.257	0.246	0.188
2. Ratio of number of customers (Commercial/Residential)	Aceh	0.248	-	0.176	0.155
	North Sumatra	-	0.094	0.075	0.048

4.2.3 Public Demand

In Aceh and North Sumatra provinces, public demand for electricity had annual average growth rates of 8 to 25% as shown below. The average power consumption per customer shows an annual downtrend, but compared with the residential demand, the sales ratio and the ratio of the number of customers has been generally stable.

Changes in Public Demand

Province	PLN Branch Office	1979, 1981		1984		1988		Annual average growth (%)	
		Demand (GWh)	Use per customer (kWh)	Demand (GWh)	Use per customer (kWh)	Demand (GWh)	Use per customer (kWh)	Demand (%)	Use per customer (%)
Aceh	B. Aceh	* 1.5	4,632	6.8	4,545	9.4	4,230	22.6	- 1.0
	Lhok Seumawe	-	-	2.3	4,061	4.3	3,196	-	-
	Langsa	1.0	4,562	1.5	3,534	2.5	2,710	10.7	- 5.6
	Meulaboh	-	-	-	-	1.4	1,549	-	-
	Total	2.5	4,605	10.7	4,263	17.6	3,234	24.8	- 3.9
North Sumatra	Medan	**43.1	19,355	50.0	17,279	69.5	16,195	7.1	- 2.5
	Bindjai	4.8	6,668	6.5	5,751	7.8	3,955	7.2	- 7.2
	Pematang Siantar	6.0	5,621	8.2	4,818	12.5	4,110	11.1	- 4.4
	Sibolga	2.2	3,417	2.9	2,419	6.2	2,486	16.0	- 4.4
	Total	56.1	12,055	67.6	9,557	96.0	8,135	8.0	- 5.5

Source : DATA SISTEM KELISTRIKAN PLN WILAYAH I & II
Notes : * Demand for Aceh Province is for 1979
** Demand for North Sumatra is for 1981

Comparison of Public and Residential Demand

	Province	1979	1981	1984	1988
1. Ratio of sold energy (Public/Residential))	Aceh	0.120	-	0.286	0.257
	North Sumatra	-	0.279	0.274	0.266
2. Ratio of number of customers (Public/Residential)	Aceh	0.030	-	0.057	0.047
	North Sumatra	-	0.022	0.023	0.023

4.2.4 Industrial Demand

In Aceh and North Sumatra provinces, the annual average growth rates of industrial demand are as high as 24 to 34% as shown below, a much higher percentage than the 20% average growth rate for all Indonesia.

The demand in Aceh province is centered in the Band Aceh and Langsa districts and in the Medan district in North Sumatra province.

The average power consumption per customer for both provinces is relatively high, with about a 12% annual average growth rate and is an indication of the remarkable progress in industrialization.

Changes in Industrial Demand

Province	PLN Branch Office	1979, 1981		1984		1988		Annual average growth (%)	
		Demand (GWh)	Use per customer (MWh)	Demand (GWh)	Use per customer (MWh)	Demand (GWh)	Use per customer (MWh)	Demand (%)	Use per customer (%)
Aceh	B. Aceh	* 1.0	19.3	3.6	19.7	8.7	45.7	27.2	10.1
	Lhok Seumawe	-	-	1.0	16.9	4.5	39.5	-	-
	Langsa	0.6	17.5	2.7	54.3	8.5	121.9	34.3	24.1
	Meulaboh	-	-	-	-	0.5	8.1	-	-
	Total	1.6	18.6	7.4	25.1	22.3	50.6	34.0	11.8
North Sumatra	Medan	**87.8	283.2	126.7	279.0	377.7	373.9	23.2	4.0
	Bindjai	6.5	29.6	17.9	61.4	28.2	76.2	23.3	14.5
	Pematang Siantar	4.2	12.4	10.4	27.8	50.3	130.6	42.6	40.0
	Sibolga	1.7	24.3	1.7	19.3	6.7	46.9	21.6	9.8
	Total	100.2	106.7	156.7	129.6	462.0	231.8	24.4	11.7

Source: DATA SISTEM KELISTRIKAN PLN WILAYAH I & II
Notes: * Demand for Aceh Province is for 1979
** Demand for North Sumatra is for 1981

Comparing the demand for power in Aceh province for the four categories: residential, commercial, public and industrial, residential demand is about 55% and industrial demand about 20% of the total. In the last nine years, industrial has demand showed a remarkably high annual average growth rate of about 34%.

In North Sumatra province, residential demand is about 35% and industrial demand about 46% of the total but industrial demand has the highest growth. Industrial demand also shows the highest annual average growth rate of about 24% for the last seven years.

4.3 Electric Power Demand Forecast

4.3.1 Forecast Conditions

(1) Forecast period

The forecast is based on data from 1988 and 1989 and is for 15 years from 1989 to 2004.

(2) Demand by categories

Demand is forecast on the basis of PLN's electricity charges for the four categories listed below. The forecast is done with a method similar to the method used by PLN.

Residential demand
Commercial demand
Public demand
Industrial demand

(3) Selecting demand forecast areas and load centers

The Wampu Hydroelectric Power Project is located in North Sumatra province and will be connected to the province's 150 kV transmission system. The forecast was based on consideration of the progress made in the expansion planning of this system, centered on the capital, Medan, a large power consumption area, and the planning of the 150 kV system for Aceh province which will also be connected to the system. Centering on existing and planned 150/20 kV substations, 23 areas (nine in Aceh and 14 in North Sumatra) were selected as load centers for forecasting demand, as shown in Figs. 4-1 and 4-2.

Forecasts were not done for areas not connected to the main system, such as mountain areas, separate islands, low population and remote areas.

4.3.2 Forecast Method

(1) Residential demand

(a) Populations and numbers of households

The Gompertz method and logistics were used to estimate populations and number of households in load centers on the basis of the 1971 and 1980 censuses by Kabpaten (regency) and the Central Statistics Bureau's 1985-95 Population Projection by province.

Table 4-1 shows the 1987 population projections for the load centers and estimated populations based on the year 1987 for years after that up to 2004.

(b) Numbers of household members

Numbers of household members were estimated using past population and numbers of household members in the regencies where load centers are located.

(c) Electrification ratio

The target for the electrification ratio in 2004 was determined on the basis of records from 1971 to 1987 for areas with load centers, by extending those trends up to 2004.

High and low targets of electrification ratios were assumed. Table 4-2 shows the electrification ratios of individual load centers in 1988 and high and low targets in 2004.

(d) Power consumption for residential use

Based on records of electrical usage in PLN branch offices for Aceh and North Sumatra provinces in surrounding areas from 1971 to 1988, the electrification ratio, the annual average power consumption of existing residential customers in 1988 and new residential customers are determined for each load center as shown in Table 4-3.

With the difference in the high and low estimates as 0.2%, two estimates were made for the annual average increases in power consumption for existing and new residential customers.

(2) Commercial demand

The number of commercial customers increases in proportion to the number of residential customers. Forecasts were made from changes in the ratio of the number of commercial to residential customers in branch offices in regencies with load centers and the increases in consumption and annual average growth rates per commercial customer. These forecasts are shown in Table 4-4.

(3) Public demand

Similar to commercial demand, the number of public customers increase in proportion to residential customers. Forecasts were made from changes in the ratio of the number of public to residential customers in branch offices in regencies with load centers and the increases in consumption and annual average growth rates per public customer. These forecasts are shown in Table 4-5.

(4) Industrial demand

As mentioned in Section 4.2.4, the industrial demand in Aceh and North Sumatra provinces has recently been increasing extremely rapidly and now is about 50% of the total demand. This means that the forecast of industrial demand has a large influence on the forecast for the overall demand. The electric generation plan based on this forecast will then have a large influence on the development of industry, showing the necessity for extreme care in making forecasts of industrial demand. Accepting the difficulty of forecasting with limited data and information and the difficulty of predicting the future business climate and economic growth, the following method was used.

1) Separate forecasting was done for current customers and new customers

i) Forecast of demand for current industrial customers

a) Forecast of the rate of increased demand of current industrial customers

The average annual growth in demand and GRDP and the elasticity between them for 1981 to 1987 for both Aceh and North Sumatra provinces are shown in the following table.

Average Annual Growth in Demand and GRDP and Their Elasticity

Item	Annual Growth and Elasticity	
	Aceh	North Sumatra
(a) Average annual growth of demand for all industries (%)	30.0	28.0
(b) Fraction of growth from new customers	0.5	0.3
(c) Average annual growth from existing customers (%) (a) × {1-(b)}	15.0	20.0
(d) Annual growth in GRDP (%)	11.0	6.0
(e) Elasticity {1+(c)/100}/{1+(d)/100}	1.04	1.13

The annual average increase in GRDP for both provinces is given in the fifth five year plan (Repelta V:1988-93) as 7%. In this report, a high estimate of 7% and a low estimate of 6% were adopted, as shown in the following table.

Estimate of Growth of GRDP in Aceh and North Sumatra Provinces

Year	Estimate of Growth of GRDP (%)			
	High Estimate		Low Estimate	
	Aceh	North Sumatra	Aceh	North Sumatra
1989 - 94	7.0	7.0	6.0	6.0
1994 - 99	6.7	6.7	5.7	5.7
1999 - 04	6.5	6.5	5.5	5.5

The annual average growth in industrial demand is a factor of elasticity with GRDP and is forecast to be as shown in the following table.

Estimated Annual Average Growth of Demand for Existing Industrial Customers

Year	Estimated Annual Average Growth of Demand for Existing Industrial Customers (%)			
	High Estimate		Low Estimate	
	Aceh	North Sumatra	Aceh	North Sumatra
1989 - 94	11.2	21.0	10.1	19.9
1994 - 99	10.9	20.7	9.8	19.5
1999 - 04	10.6	20.4	9.5	19.3

Note: Annual average growth of demand for existing industrial customers = Elasticity × Growth of GRDP

ii) Forecast of demand for new industrial customers

a) Waiting customers

The number of customers waiting to join the power system were estimated, taking into consideration the plan to expand the power transmission and distribution system, from the PLN lists at each load center and shown in Tables 4-6 and 4-7.

b) Captive power (customers with independent power generation)

New customers who currently are generating their own electricity and who will join the PLN system are predicted to start being supplied with power from PLN when their generating equipment becomes too old. With the life time of the equipment assumed as 20 years, the customers switching to PLN from old equipment after 20 years are estimated as given in Tables 4-6 and 4-7.

c) Demand for new industrial customers

The increase in demand from new customers is estimated at 5% annually for both categories 5 years after the PLN system is added.

4.3.3 Demand Forecasts

The high-estimate forecasts for the demands (energy sales) and peak loads for each load center in Aceh and North Sumatra provinces are given in Tables 4-8 and 4-9. The low-estimate forecasts are given in Tables 4-10 and 4-11.

The high-estimate forecasts by customer categories for energy sales, power generated, peak load and losses for both provinces are shown in Table 4-12 and the low-estimate forecasts are shown in Table 4-13.

The forecasts for energy sales, power generated and peak loads for both provinces are compared with PLN's June 1991 revised demand forecast (DSP/21 June 1991) and shown in Figs. 4-3, 4-4, and 4-5. The forecasts in this study concentrated on the load centers connected to the power system while PLN's forecasts include separate islands, depopulated areas and remote areas not connected to the system in the two provinces and is consequently higher.

The forecasts from this study are summarized in the following table.

Summary of Demand Forecasts

Item		Forecasted Demand by Years				Annual average growth rate (%)		
		1989	1994	1999	2004	1989-94	1994-99	1999-04
Energy sales (GWh) (Both provinces)	High estimate	1,397.0	2,948.8	5,815.1	11,866.6	16.1	14.5	15.3
	Low estimate	1,397.0	2,710.9	5,054.1	9,649.1	14.2	13.3	13.8
Power generated (GWh) (Both provinces)	High estimate	1,857.8	3,795.6	7,242.1	14,287.8	15.4	13.8	14.6
	Low estimate	1,857.8	3,489.9	6,296.1	11,618.3	13.4	12.5	13.0
Peak load (MW) (Both provinces)	High estimate	362.5	722.3	1,382.5	2,777.1	14.8	13.9	15.0
	Low estimate	362.5	662.4	1,201.8	2,250.4	12.8	12.7	13.4

4.3.4 Forecast of Load Curves

The load curves were forecast as follows:

(1) The typical daily load curves as shown in Fig. 4-6 are assumed, which were previously used in forecasting demand for the various categories (residential, commercial, public and industrial).

(2) The scale of the daily load curves are determined so that the one year total value of daily electrical energy according to the daily load curves on weekdays and holidays for the respective demand categories corresponds with the forecast value of electrical energy for the respective demand categories in the corresponding year.

(3) The load curves by demand categories are totaled by time zones to form the entire load curve.

Figure 4-7 shows assumed weekday load curves for every five year after 1989, which were prepared by the method explained above. According to these curves, after about 10 years North Sumatra province peak load will be very large in comparison to Aceh province peak load and the daytime peak load in both provinces is expected to become larger than the evening time peak load.

4.4 Power Supply Plan

4.4.1 Existing Power Generating Facilities

As of the end of 1989, the existing PLN and independent power generating facilities (captive power) in the Aceh and North Sumatra provinces are listed below:

PLN Power Generating Facilities in Aceh and North Sumatra Provinces

Item No.	Province	District, Branch Office	Type of Generators	No.of Generators	Installed Capacity/ Percentage (kW)/(%)	Available Capacity (kW)	Percentage of Available Capacity (%)
I	Aceh Province	1) Banda Aceh	D	43	12,708	9,284	73.1
		2) Lhok Seumawe	D & H	45	10,185	6,656	65.4
		3) Langsa	D	38	6,926	5,077	73.3
		4) Meulaboh	D	63	12,357	10,643	86.1
		5) Lueng Bata	D	39	108,494	80,398	74.1
		Subtotal	D & H	228	150,670	112,058	74.4
II	North Sumatra Province	1) System Medan	D, G & S	28	544,687	355,190	65.2
		2) Siantar	D	87	22,602	12,116	53.6
		3) Binjai	D & H	89	24,167	17,290	71.5
		4) Sibolga	D & H	100	38,020	30,608	80.5
		Subtotal	D,G.S,H	304	629,476	415,204	66.0
III	Total for both		1) D	508	272,058 (34.9%)	191,557 (36.3%)	70.4
			2) G	8	241,132 (30.9%)	199,740 (37.9%)	82.8
			3) S	4	260,000 (33.3%)	130,000 (24.7%)	50.0
			4) H	12	6,956 (0.9%)	5,965 (1.1%)	85.8
		Total	D,G.S.H	532	780,146 (100.0%)	527,262 (100.0%)	67.6

Note: D = Diesel
H = Hydroelectric (including small hydroelectric)
G = Gas turbine
S = Steam

Note: Refer to Tables 4-14 (1), (2), (3), (4), (5), (6), and (7) for details of existing PLN power generating facilities located in these states.

Captive Power Generating Facilities in Aceh and North Sumatra Provinces

Item No.	Province	Type of Generators	No. of Generators	Installed Capacity (kW)	Remarks
I	Aceh Province	1) Diesel	123	46,507	
		2) Gas T.	4	56,688	
		Subtotal	127	103,195	
II	North Sumatra	1) Diesel	400	442,963	
	Province	Subtotal	400	442,963	Note 1)
III	Total for both	1) Diesel	523	489,470	
		2) Gas T.	4	56,688	
		Total	527	546,158	Note 2)

Note 1): In addition to the facilities in North Sumatra Province listed above, Indonesia•Asahan•Aluminum (INALUM) owns power generating facilities at two locations along the Asahan river basin system (total power output: 523 MW), which are used for aluminum production. In recent year, PLN has been supplied with up to maximum of 30 MW of supplementary power by this company.

Note 2): Refer to Tables 4-15(1) and (2) for details of existing independent power generating facilities located in these states.

Total Capacity of Power Generating Facilities (PLN + Captive Power) in Aceh and North Sumatra Provinces

Number	Province	PLN facilities	Captive power facilities	Total	Remarks
I	Aceh Province	150,670 (11.4%)	103,195 (7.8%)	253,865 (19.2%)	
II	North Sumatra Province	629,476 (47.4%)	442,963 (33.4%)	1,072,439 (80.8%)	Excluding INALUM's facilities
III	Total for both	780,146 (58.8%)	546,158 (41.2%)	1,326,304 (100.0%)	

As shown above, the total capacity of power generating facilities in Aceh and North Sumatra provinces as of the end of 1989 was approximately 1,326 MW, of which approximately 59% is supplied by PLN facilities and approximately 41% by captive power facilities. This indicates that a great part of the power consumed was supplied by captive power facilities.

4.4.2 PLN Long Term Power Development Plan

During the study for this project, a long-term power development plan has been prepared by PLN, which is listed in Table 4-16.

New facilities are planned at 13 locations in order to satisfy the increasing demands in power supply during the period from 1991 to 2004, including nine (9) locations for hydroelectric power generation including the Wampu Hydroelectric Power Project, two (2) locations for geothermal, one (1) location for combined cycle, and one (1) location for gas turbine power generation, for a total 2,361 MW.

However, of the 13 plans only the Renun Hydroelectric Power Project is ready for construction. Other plans are still at the initial stage or at the end of the feasibility study stage, or otherwise are at the basic design stage.

4.4.3 Balance Between Supply and Demand

(1) Start of operation of the Wampu hydroelectric power plant

Figures 4-8 and 4-9 show the expected peak load curve based on the PLN long-term power development plan and the demands expected by the present study, and also show the balance between supply and demand according to the peak load curve expected by PLN.

The Wampu hydroelectric power plant is scheduled to start operations in 2002, in consideration of time required for initial stages of the detailed design and construction periods. The start up times for other plants, on the other hand, are determined according to the PLN long-term power development plan.

(2) Balance between supply and demand

In order to determine whether or not the balance between supply and demand of power by PLN system is maintained, a comparison study was conducted, based on the PLN long-term power development plan, between the expected peak load forecast in this study and the estimated available power generation capacity. The results of the study are shown in Tables 4-17 and 4-18.

From the results, if it is assumed the minimum required total power output is 110% of the expected peak load (reserve power is 10% of the peak load), the total power generation capacity of all these plants will not be adequate in any year except in 1994, 1998, and 1999, as shown in Fig. 4-11, when one unit of the largest-capacity generators in the system is shut down for periodic inspections and another large-capacity unit fails, if the available capacity during this time is estimated at 70% of total installed capacity. Especially in the year 2000 and after, we are worried that there will be a considerable shortage of the total capacity of power generated in relation to the peak load.

With regard to the available generation capacity, if it is assumed that the available output of a power plant is 85% of the whole plant capacity, and it is assumed that utilization factor is 35% for gas turbine plants and 65% for other plants, the generation capacity reserve may be maintained at more than 25% up to the year 2000, after which it will, however, decline to less than 20% after 2001. Especially after 2003, there is likely to be a shortage in reserve capacity for power generation.

It is necessary to urgently finalize any new power development plans and to improve the actual utilization factors of power plants.

4.4.4 Effects of the Wampu Hydroelectric Power Plant on the Power System

The Wampu hydroelectric power plant site is relatively close to Medan, approximately 60 km away from it. Medan has the largest load in the linked power system in the two states. The plant will be connected to the system with 150 kV transmission lines. In 2002, when operation of the Wampu plant is scheduled to start, the total installed capacity of the overall system and the total peak load are expected to be 2,900 MW and 2,077 MW, respectively. The total capacity of Wampu hydroelectric power plant, 84 MW, will be about 2.9% and 4.0% of these totals and only relatively minor effects (fluctuations in voltage) on the system are expected as indicated below if any failures occur at the Wampu hydroelectric power plant.

(1) Voltage fluctuations in the 150kV system caused by Wampu power plant generators being shut down

Voltage fluctuations in the 150kV system when one or two of the Wampu power plant generators are shut down are shown in the following table.

According to the power system analysis, only a 0.4% (with one unit down) or a 1.0% (both units shut down) voltage drop would occur at the 150kV busbar of the Wampu power plant, see the following table.

Wampu generators being shut down will not cause major voltage fluctuations on the 150kV busbar of the main substation.