- According to the future demand predicted in the Chapter 4, power will grow at a rate of 300 kW a year through the end of 1990s and the beginning of 2000s. Sites having firm power of less than 700 kW are eliminated because those sites provide no scale merit.

- It is considered that the firm power at Naradaw site has a potential to exceed 700 kW, though it is 470 kW in **Table 5-3**.

Since Gantong site and Naradaw site are predicted to be suitable for small scale hydro power, the Team prepared several development plans at each site in order to check and compare both sites exactly. The Team made 8 new or revised development plans in this study. Another several sites the Team found out are not indicated in this report because the economy of those sites is less.

As a result, 5 sites 14 development plans shown in the **Table 5-4** and **5-5** are prepared as alternative schemes to be studied.

5.1.3 Study Procedure

Five sites, 14 development plans will be studied from both technical and economic view points as follows: **Fig. 5-4** shows the development plans. **Fig. 5-5** shows hydro-power planning procedure.

(1) Using topographic map of 1/50,000, locate intakes, headraces, ponds, penstocks, power stations and tailraces.

(2) Calculate the gross head from the water level of the intake and the tailrace. Then calculate the head loss using a simplified formula. Then calculate the net head by subtracting the head loss from the gross head.

(3) Calculate the catchment area of the development plan using the topographic map of 1/50,000 and a planimeter.

Prepare a river runoff duration (daily average flow quantity) by using data measured at the Bedukan gauging station. The river runoff duration at each development plan is estimated by converting the runoff duration at Bedukan G.S. Considering water quantity for other use such as other power generation, agriculture, drinking, leak and discharge, calculate the available water quantity for power generation. (See **Fig. 5-6**)

(4) The design maximum discharge is assumed to be 70% of annual flow duration. The **Chapter 9** refers to a detail study of the maximum design discharge.

(5) The combined efficiency of hydraulic turbine and generator is 82%. The efficiency change in response to discharge will be neglected.

(6) Each plan should comprise a pond to ensure the daily adjustment of the intake water. This pond contributes to the increase in the output during a peak hour in dry days, and decrease the total installed capacity in the Ranau system. It is assumed that the pond has a capacity for 1-hour consumption at the maximum rate. It is also, assumed that the output in a peak hour can be increased up to 1.5 times the daily average output.

(7) Calculate power to be generated using the following formulae:

Installed capacity = 8 x He (net head) x Q (design max. discharge)

Firm power = 8 x He x Q_{95} x (0.9 or 0.8)

Firm peak power = 8 x He x 1.5Q_{95} x (0.9 or 0.8)

Q_{95} means 95% flow in a year. 0.8 will be adopted at sites where other water utilizations are predicted, or much water should be discharged from a diversion weir.

(8) Calculate the annual energy generated using the runoff duration curve at a site as follows:

Annual energy generated = Output x Number of operating days x 24 hours x (1 or 0.9)

0.9 will be adopted in dry days.

(9) Calculate the plant factor by the following formula:

Plant factor = Annual energy/Installed capacity x 365 days x 24 hours

(10) The construction cost consists of preparatory cost, civil works cost, turbine and generator cost, contingencies, and engineering cost. In this site selection stage, the construction cost for each plan is estimated by an identical simplified method. Most of labors, materials and construction machinery for civil works will be procured in Malaysia. The cost of civil works is estimated from the unit prices used in planning the Carabau hydro power station. The unit prices are adjusted considering inflation and applied improvement in the specifications. The cost of the turbine and generator, which will be imported, is estimated based on the international price level.

(11) The economy of each plan will be evaluated based on the construction cost per kWh, which is calculated by dividing the construction cost by the annual energy. As unit price of generated electricity is proportional to the index, the smaller the construction cost per kWh, the more economical the plan is.

5.2 Study on Alternative Schemes

5.2.1 Naradaw Site

(1) Site Description

Naradaw site is located in the area upstream of the confluence of the Liwagu and Mesilau rivers 6 km west of Ranau Town. This site has a mountainland of elevations from 840 to 1,440 m, through which the Liwagu River and the Mesilau River flow meandering down from west-northwest to east-southeast. The gradient of the Liwagu river is approximately 1/19, while that of the Mesilau River is approximately 1/15. The widths of the Liwagu River and the Mesilau River are generally from 15 to 25 m. The relative height of the ridge and valley bottom is 100 to 500 m. Slopes are generally of inclinations 20 to 45 degrees, and parts of the slopes show old or new forms of landslides.

(2) Development Plans

With respect to Naradaw site, the Team studied five development plans named Naradaw A, B, C, D and E. Naradaw A and C were investigated or proposed in the Hydro power projects in Sabah and Sarawak by Asian Development Bank (ADB).

Naradaw D, having an installed capacity of 1,540 kW, is the most economical among five plans. Naradaw D comprises two intakes at the Liwagu River and the Mesilau River, and a powerhouse at the junction of the two rivers. A net head is estimated to be 165 m. This development plan includes two headraces of steel pipe (3,240 m length) and a penstock (624 m length) located on the ground.

Two turgo impulse type turbines and two generators generate electricity with maximum discharge of 1.17 m^3/s diverted from catchment areas of 59.2 km^2. The area of about 5.5 km long between the intake and the powerhouse does not include other water-utilizing facilities or concentration of population.

Therefore, it is considered to be feasible to divert water from the river for power generation on condition that small amount of necessary water is discharged to the river from the intake dam for conserving aquatic animals and plants. The geography is suitable to construct a pond with enough capacity in the area.

The firm peak power is expected to be 1,100 kW. The annual energy is expected to be 11.9 GWh. The construction cost per kWh is expected to be 0.9 - 1.0 M$/kWh.

Naradaw A is similar to Naradaw D except that the intakes of Naradaw A are located more downstream than those for Naradaw D. Naradaw A is featured by: the installed capacity of 1,340 kW; the net head of 126 m; and the construction cost per kWh of around 1.1 M$/kWh. With respect to Naradaw site, the economy of power generation is proportional to the net head. That is to say that development plans having higher net heads should be sought.

Naradaw A is divided between Naradaw B (850 kW) located at the Liwagu River and Naradaw C (490 kW) located at the Mesilau River. In these three plants, the bigger the plant capacity is, the cheaper the construction cost per kW is. This is an example of scale merit and seems to be caused by factors of: fixed costs for preparatory works and access roads for transportation of materials and equipment; and civil work costs proportional to the square root of the design discharge. Considering the scale merit, the plant should be of full capacity for the forecast power demand.

Naradaw A requires the removal of several houses and the fields located along the planned site for penstock. Naradaw E dispenses with the need for the removal by locating the power house at an upstream point of the Mesilau River. Naradaw E has a smaller net head and worse economy in comparison with Naradaw A. To ensure the economy of power generation, it is imperative to remove the houses and the fields. The removal should be compensated enough.

(3) Geology

Naradaw site is composed of sedimentary rocks called the Crocker Formation overlain by the Pinosuk Gravels, the terrace deposit the colluvium and the alluvium. A geological map of the project area is shown in Fig. 5-7.

The Crocker Formation is made up of sandstone, shale, siltstone, and mudstone, and these are stratified in the form of alternations. Folds and minor faults are prominently developed in this formation. The formation strikes N70°E and dips 70°S in the vicinity of the confluence between the Liwagu River and the Mesilau River. The Pinosuk Gravels are sand-gravel layers overlying the Crocker Formation in unconformity and is distributed at ridges higher than EL. 900 to 1,200 m. The terrace deposit and the alluvium are distributed along the Liwagu River and the Mesilau River overlying the Crocker Formation and the Pinosuk Gravels in uncomformity. Rounded gravels of boulder size from 0.5 to 2 m in diameter are mainly comprised in these deposits, and there are numerous rounded gravels larger than 5 m in diameter.

The colluvium or the talus deposit are distributed at mid-slope elevations for the foots of mountains.

Engineering geological evaluations are as follows:

(a) Although sandstone of the Croker Formation is exposed partially in the vicinities of the intake dam sites on the Liwagu River and the Mesilau River, the alluvium and the terrace deposit are mainly deposited. Above EL. 1,000 m at the Mesilau River, there is a possibility of the Pinosuk Gravels being deposited. Regarding the intake dam sites finally selected, it will be necessary to carry out geological investigations on the alluvium, the terrace deposit and the Pinosuk Gravels to ascertain permeabilities, ground-water levels, and thicknesses of layers.

(b) The headrace routes of the Liwagu River and the Mesilau River are mainly located in an area of distribution of the Crocker Formation. Weathering has progressed in the Crocker Formation at slopes and ridges. In the surface reconnaissance made this time, one recent landslide area was found on the route of the headrace along the Liwagu River. This landslide area is of small scale and it may be considered not to be a landslide of a degree to make implementation of the project impossible,but it will be necessary to provide stabilization measures for the landslide area. It is estimated that the slopes of the headrace route other than this landslide area are more or less stable judging by the condition of vegetation. However, since there are multiple forms of old landslides at parts of the slope, it will be necessary to carry out geological investigations to ascertain their degrees of stability.

(c) The Crocker Formation is distributed at the ridge of the head tank and the penstock route. According to the surface reconnaissance just made, it is estimated that this ridge is in a stable condition judging by the conditions of topography, vegetation, and land use. However, it will be necessary to carry out geological investigations to ascertain the weathered condition of the Crocker Formation and the depth of the supporting base.

(d) The terrace deposit and the alluvium are distributed at the powerhouse and tailrace sites. It will be necessary to carry out geological investigations here to determine the supporting base of the powerhouse.

5.2.2 Gantong Site

(1) Site Description

Gantong site is located in the area downstream of the confluence of the Liwagu River and the Mesilau River 6 km west of Ranau Town. This area comprises a mountainland of EL. 650 to 1,110 m, through which the Liwagu River meanders down from northwest to southeast or west to east. The gradient of the Liwagu River in the project area is approximately 1/19. The width of the river is generally 15 to 30 m. The relative height of the ridge and valley bottom is 100 to 550 m. Slopes are generally inclined 20 to 45 degrees, and old or new forms of landslides are to be seen midway up or at foots of slopes.

(2) Development Plans

With respect to Gantong site, the Team investigated five development plans named Gantong A, B, C, D and E. Each of Gantong A, B and C comprises an intake at a point located 100 m downstream from the junction of the Liwagu River and the Mesilau River, and a headrace and a powerhouse located on the left bank of the river. Near the junction of the rivers, there exists some traces of old river course. They may cause complicated turbulent flow in floods. To avoid this disadvantage, the intake is planned to be located 100 m downstream from the junction. The headrace of steel pipe is located on the ground.

An underground tunnel of 1,000 m length is planned at the area where there exist two landslides. Gantong A, B, and C have the installed capacity of 1,600 kW, 2,140 kW and 2,340 kW. Each construction cost per kWh exceed 1.2 M$/kWh because of expensive tunnel cost.

Gantong D and E are planned on the premise that Naradaw A or D is constructed. Each plan have a diversion weir at just downstream side of the Naradaw powerhouse, and a headrace located on the right bank of the river.

Gantong D, having an installed capacity of 1,610 kW, is the most economical among five plans. Gantong D has a net head of 144 m because of a large river bed slope. The steel pipe headrace measures about 1,920 m. The penstock measures 2,010 m. Design max. discharge of 1.40 m^3/s is diverted from a catchment area of 65.5 km^2. The area between the intake and the powerhouse, where river runoff will be reduced, does not include other water-utilizing facilities or concentration of population. Therefore, it is considered to be feasible to divert water from the area for power generation on condition that small amount of necessary water is returned to the river from the intake dam for conserving aquatic animals and plants. From the geography of the area, constructing a pond is possible, but the capacity might be limited. The firm peak power is expected to be 12.4 kW. The annual energy is expected to be 1,280 GWh. The construction cost per kWh is expected to be around 1.1 M$/kWh.

Gantong E, has an installed capacity of 1,640 kW. As the powerhouse is placed at the tributary Kihunut, River Water is diverted from the Liwagu River to the Kihunut River. On the downstream of the intake dam where runoff will be reduced in dry days, drinking water is diverted for supplying the Ranau town. The drainage of the town also flows into the river. To insure the existing water-utilization and to avoid the contamination of river water, it is necessary to return a certain amount water from the intake dam to the downstream. This restriction - constant return of water - decreases power generation (kW, kWh) significantly during dry days.

(3) Geology

Gantong site, similarly to Naradaw site, is composed of the Crocker Formation and overlying the Pinosuk Gravels, the terrace deposit, and the alluvium. A geological map of the project area is shown in **Fig. 5-7**.

The Crocker Formation is made up of sandstone, shale, siltstone, and mudstone, and these are stratified in the form of alternations. Folds and minor faults are prominently developed in the formation. The bed strikes N50° to 25°W and dips 20° to 40°W. The Pinosuk Gravels are sand-gravel layers overlying the Crocker Formation in unconformity and is distributed above elevations of 900 to 1,200 m at the left-bank side of the Liwagu River. The terrace deposit and the alluvium are distributed along the Liwagu River overlying the Crocker Formation in unconformity. These deposits consists mainly of rounded gravels of boulder size from 0.3 to 2 m, in diameter, and rounded gravels of adamellite 5 m or more in diameter are also contained at places.

Further, the colluvium or the talus deposit are partially distributed at mid-slopes and the foots of mountains.

Engineering geological evaluations are as follows:

(a) At the intake dam site, although hard sandstone of the Crocker Formation is distributed at parts of the abutments, alluvium and the terrace deposit are mainly deposited.

(b) The headrace route is mainly located in an area of distribution of the Crocker Formation. According to the surface reconnaissance just made, there were two landslide areas seen on the headrace route at the left bank of the Liwagu River. These landslide areas are of large scale, and since erosion by the Liwagu River is still progressing at bottom parts, there is a possibility of collapses occurring again. Therefore, it will be difficult to provide a headrace at the surface of these portions and avoiding them by tunneling will be necessary. The slopes on the headrace route excepting these landslide areas can be conjectured to be stable under present circumstances as judged by the condition of vegetation. However, since some forms of old landslides can be recognized at parts of the slope, it will be necessary to carry out geological investigations to ascertain their properties and stabilities.

(c) The Crocker Formation is distributed at the ridge where the head tank and penstock route would be located. According to the surface reconnaissance just made, although weathering has progressed at this ridge, it is estimated to be stable judging by the topographical conditions and state of vegetation. However, in order to confirm the degree of stability, it will be necessary to carry out geological investigations.

(d) The powerhouse and tailrace sites are located in an area of distribution of the terrace deposit and the alluvium.

5.2.3 Pakai Site

(1) Site Description

Pakai site is located at the right bank of the Liwagu River, in the vicinity of the boundary between the Ranau Plain and hilly land. This area consists of hills of EL. 410 to 870 m and a plain of EL. 450 to 600 m. The Liwagu River, after flowing east through the Ranau Plain, changes course 150 degrees to flow to the southwest. The gradient of the Liwagu River in the project area is approximately 1/53. The width of the Liwagu River is 20 to 30 m in the vicinity of the intake dam site, and 40 to 70 m in the vicinity of the powerhouse site. The relative height between the ridge of the hills and the valley bottom is 200 to 350 m. The slopes of the hill area generally indicate gentle inclinations of 10 to 25 degrees.

(2) Development Plans

At Pakai site, the installed capacity is expected to be 2,700 kW. A headrace and penstock provide the net head 173 m by taking a shortcut of the winding river, though the river bed slop is not so steep in comparison with those of other sites. The headrace consists of a 1,000 m long tunnel and a 3,360 m long steel pipe. The planned plant operates on water of max. 1.96 m^3/s drawn from a catchment area of 88.9 km^2. On the downstream of the intake dam, drinking water is drawn for supplying the Ranau town. The drainage of the town also flows into the river. To insure the existing water-utilization and to avoid the contamination of river water, it is necessary to return a certain amount water from the intake dam to the downstream. This restriction -constant return of water - decreases power generation (kW, kWh) significantly during a period of water shortage. The firm peak power is expected to be 850 kW. The annual energy is expected to be 17.7 GWh. The construction cost per kWh will range from 1.2 to 1.3 M$/kWh.

(3) Geology

Pakai site is composed of the Trusmadi Formation, and the overlying the Pinosuk Gravels, the terrace deposit, and the alluvium. A geological map of the project area is shown in **Fig. 5-7**.

The Trusmadi Formation consists of sandstone, slate, shale, siltstone, and mudstone, and these are stratified in the form of alternations. Folds and minor faults are developed in this formation. The bed in the vicinity of the powerhouse site strikes N42°E and dips 28°E. The Pinosuk Gravels are gravel layers overlying the Trusmadi Formation in uncomformity, occupies the western half of the Ranau Plain, contains a large number of rounded adamellite gravels exceeding 5 m in diameter, and is thickly deposited. The terrace deposit overlie the Trusmadi Formation and the Pinosuk Gravels in unconformity, and are widely distributed to occupy the eastern half of the Ranau Plain. Alluvium overlie the sedimentary rocks in unconformity and are distributed along the Liwagu River. The terrace deposit and the alluvium are mainly composed of rounded gravels of diameter 0.2 to 1 m.

The colluvium or the talus deposit are distributed locally in the hill area.

Engineering geological evaluations are as follows:

(a) The alluvium and the terrace deposit are mainly distributed at the intake dam site.

(b) The headrace route is located in an area of distribution of the Trusmadi Formation. Regarding the tunnel section planned at the upstream side of the headrace route, it is expected that weathering of the basement is deep, and moreover, there exist a multiple number of faults. Because of this, it will be necessary for adequate shoring and drainage measures to excavate the tunnel. Regarding the headrace route excepting the tunnel section, since weathering of the basement has progressed, it is expected that embedment of the supporting base will need to be made deep. The slopes of the hill area where the route is to be provided have gentle slopes, and are estimated to be in stable conditions at the present time. It will be necessary here to grasp the weathered condition of the basement rock and the depth of the supporting base.

(c) The ridge where the head tank and penstock route is located in an area of distribution of the Trusmadi Formation and the terrace deposit. According to the field investigations just made, it may be estimated from the state of vegetation that this ridge is in a stable condition. However, it will be necessary for geological investigations to be carried out to ascertain the weathered condition of the basement and depth of the supporting base.

(d) The terrace deposit and the alluvium are distributed at the powerhouse and tailrace sites.

5.2.4 Kauluan Site

(1) Site Description

Kauluan site is located sandwitched between the Mesilau River and the Liwagu River approximately 9 km northwest of Ranau Town, a part of this area overlapping with the Naradaw project area. This area comprises a mountainland of elevations from 950 to 1,510 m, and the Mesilau River meanders down through this area from north to south or from northwest to southeast. The gradient of the Mesilau River in this project area is approximately 1/10.

The width of the Mesilau River is approximately 10 to 25 m. The relative height between ridge and valley bottom is 150 to 300 m. Slopes are generally inclined from 20 to 45 degrees, and old or new forms of landslides are to be seen at parts of the slopes.

(2) Development Plan

At Kauluan site, the installed capacity is expected to be 1,150 kW. The net head from an intake located on the Mesilau River to a powerhouse located on the Liwagu River reaches as large as 412 m. The headrace measures 1,740 m. The penstock measures 2,630 m. A catchment of 22.2 km^2 provides the planned plant water of max. 0.35 m^3/s. The area between the intake and the powerhouse, where the amount of water will be reduced, does not include other water-utilizing facilities or concentration of population. Therefore, it is considered to be feasible to divert water from the area for power generation on condition that small amount of necessary water is returned to the river from the intake dam for conserving aquatic animals and plants. The Mesilau PH-1 power plant, a catchment area of 11 km^2, diverts water from the Mesilau River to the Liwagu River. Therefore, during a period of water shortage, the discharge of the Kauluan plant decreases significantly, and the power generation (kW, kWh) decreases resultantly. The firm peak power is expected to be 620 kW. The annual energy is expected to be 8.8 GWh. The construction cost will range from 1.2 to 1.3 M$/kWh. The extremely large net head covers the little kWh and contributes to the small construction cost.

(3) Geology

Kauluan site, similarly to Naradaw site, is composed of the Croker Formation overlying strata such as the Pinosuk Gravels, the terrace deposit, and the alluvium. A geological map of the project area is shown in **Fig. 5-7**.

The Crocker Formation comprises sandstone, shale, siltstone, and mudstone, and these are stratified in the form of alternations. This formation has development of folds and minor faults. This strata mostly strikes NW-SE and dips 40° to 55S. The Pinosuk Gravels are sand-gravel layers overlying the Crocker Formation in unconformity and is distributed above 1,000 to 1,300 m. The terrace deposit and the alluvium overlie the Crocker Formation in unconformity and are distributed along the Mesilau river and the Liwagu river. These deposits consist mainly of rounded gravels of boulder size from 0.5 to 2 m in diameter, while rounded gravels of adamellite 5 m or more in diameter are also contained in large number.

Engineering geological evaluations are as follows:

(a) The Pinosuk Gravels and the alluvium are distributed at the intake dam site.

(b) The headrace route at the right-bank side of the Mesilau River is located in an area of distribution of the Pinosuk Gravels. This gravel layer is poorly consolidated and includes parts that are still unsolidified so that collapses due to rainfall easily occur and resistance to erosion is weak. Because of this, in case of providing the headrace at the surface, it will be necessary for measures against collapsing of slopes to be taken along considerable lengths of the route. Regarding the slope of the Pinosuk

Gravels, it will be necessary for geological investigations to be made to ascertain the stability.

(c) The head tank site and the penstock route are located, the upper half in the Pinosuk Gravels and the lower half in the Crocker Formation. The ridge on which the penstock would be installed may be estimated to be in a stable condition judging by the condition of vegetation. However, it will be necessary for geological investigations to be carried out to ascertain the weathered condition of the Crocker Formation and the depth of the supporting base.

(d) The powerhouse site and tailrace site are planned at the left bank of the Liwagu River where the terrace deposit and the alluvium are distributed.

5.2.5 Lamas Site

(1) Site Description

Lamas site is located at the middle stretch of the Kegibangan River 32.5 km south of Ranau. This area is a mountainland of EL. 500 to 2,400 m, through which the Kegibangan River flows down in a straight line from west to east. The Kegibangan River in the project area has a gradient of approximately 1/5, and this is a stream with an extremely steep inclination. The relative height between the ridge and the valley bottom is 1,400 to 1,900 m, and slopes generally are steep, from 30 to 40 degrees.

(2) Development Plans

Lamas 2 is expected to have an installed capacity of 8,400 kW. The net head reaches 652 m owing to the steep river bed slope of as steep as 1/5. The headrace of steel pipe measures 3,360 m. The penstock measures 1,370 m. A catchment area of 72.9 km^2 supply the planned plant design maximum discharge of 1.61 m^3/s. The area between the intake dam and the powerhouse, where the amount of water will be reduced, may not include other water-utilizing facilities or concentration of population. Therefore, it is probably considered to be feasible to divert water from the area for power generation on condition that small amount of necessary water is returned to the river from the intake dam for conserving aquatic animals and plants. The steep geography does not seem to allow the construction of a pond.

The firm peak power is expected to be 4,450 kW. The annual energy is expected to be 65 GWh. The construction cost per kWh will range from 0.5 to 0.7 M$/kWh. Lamas 2 requires new construction of around 70 or 80 km long access roads and 32.5 km long power transmission line. However, the larger power plant with high net head covers the above disadvantage and contributes to the favorable construction cost per kWh. Unfortunately, the plant cannot be started with a full power of 8,400 kW, because the demand in the Ranau distribution system will be too small at the beginning of the operation.

Therefore, under the condition that Lamas 2 will be developed step by step in harmony with the demand increase in the Ranau system. Lamas 3 is expected to have an installed capacity of 2,100 kW. The layout of Lamas 3 is similar to that of Lamas 2. The design maximum discharge of Lamas 3 is 0.4 m^3/s. The firm peak power is expected to be 2,600 kW. The annual energy is expected to be 18.4 GWh. The construction cost per kWh will range from 0.9 to 1.0 M$/kWh. The large net head contributes to the small construction cost. However, the economy is worse than that of Lamas 2, because scale merit cannot be expected.

The geology and geography of the site is assumed to be suitable for dam construction. A reservoir type power station of more than 10 MW seems to be feasible.

The Liwagu Hydro project (165 MW) is planned at the downstream side of the Lamas. The Lamas may not obstruct this project, because the Lamas is planned to be located above the high water level of the reservoir for the Liwagu Hydro project.

The Lamas site has three problems. One problem is that the present small demand in the Ranau distribution system impedes the development of the Lamas. Another problem is that there is no available access road for site surveys. The other is that the Lamas contains unknown factors in the construction cost, because access roads or others of the Lamas must beaffected and changed by the Liwagu Hydro project. In 2010 when these problems may be solved, the Lamas site will possibly be the most important power source for the Ranau system.

(3) Geology

Field investigations have not been made for Lamas site so that the geological conditions are unknown, but according to P. Collenette (1958), it may be expected that sedimentary rocks of the Trusmadi Formation are distributed.

5.3 Selection of Optimum Site

The Narada site was selected as the optimum site as a result of comprehensive study mentioned in Section 5.2 and the following considerations:

- The construction cost per kWh is the smallest. The site is the most economical.
- The site is remote from the Ranau town and population concentrated areas. Therefore, it will be easier to minimize the effect of the project on the social and natural environment if appropriate measures are taken.
- The geography of the site is suitable to construct a pond of ample capacity, which contributes to the increase in the supply capacity (kW) in a peak hour during dry days.
- The civil works do not include tunnel. Therefore, malaysian firms can construct the works without difficulty.

5.4 Subjects to be Studied

The following two subjects were studied:

(a) Decrease in output due to corrosion of steel pipe headraces: It is very hard to avoid corrosion of pipe-made headraces. In the long headraces at Naradaw, increase of friction loss due to corrosion can not be neglected. It will cause decrease in flow velocity in the headraces then result in decrease in power generation year by year. Therefore, the output decrease should be predicted and considered in planning long-term demand and supply programs. As a result of flow velocity calculations using the Manning Formula with an assumption that the surface roughness of headraces changes from 0.013 to 0.015 after several years, the maximum flow decreases from 1.18 m^3/s to 1.08 m^3/s. This means that the maximum output of 1,600 kW will decrease to about 90% in several years after starting the operation.

(b) Leakage from intake dam: River beds are made of thick sedimentary layers consisting or rocks of as large as several meters in diameter, gravels, sand and silt. From the economical view-point of small-sized hydro power, both intake dams will be constructed on the sedimentary layers. Some amount of water leaks out of the dams. Predicting the amount of leakage is one of keys in designing a dam. Also, leakage must be counted in estimating the hydro supply capability during dry days. Approximate amount of leakage from a dam is calculated as 0.01 to 0.03 m^3/s assuming that the permeability coefficient is 1×10^{-1} cm/s. At the planned dam sites, 95% flow is expected to be 0.22 m^3/s for the Mesilau River, and 0.40 m3/s for the Liwagu River. The predicted leakage of 0.01 to 0.03 m^3/s, which is less than 10% of the water quantity, does not seem to be a matter of concern. Leakage amount is proportional to the difference between intake water level and downstream water level. Therefore, the dam height should be lowered as possible.

Table 5-1 Hydro Power Supply Capability

Day	Percent of the Time	Power (KW)						Energy (GWh)		
		Average			Peak					
	%	Mesilau	Carabau	Total	Mesilau	Carabau	Total	Mesilau	Carabau	Total
145	40	250	1,620	1,870	250	1,800	2,050	0.9	5.7	6.6
183	50	250	1,390	1,640	250	1,780	2,030			
256	70	250	910	1,160	250	1,300	1,550	0.7	3.3	4.0
301	83	250	690	940	250	1,080	1,330			
347	95	80	470	550	80	860	940			
365	100	50	270	320	50	660	710	0.4	1.7	2.1
Total								2.0	10.7	12.7

Table 5-2 Energy Demand and Supply

Unit: GWh

Year	Demand	Carabau Mesilau		Naradaw		Hydro	Diesel
		Used	Discharge	Used	Discharge		
	(1)	(2)	12.7-(2)	(3)	10.1-(3)	(2)+(3)	(1)-(2)-(3)
1993	8.9	7.7	5.0			7.7	1.2
4	10.2						
1995	11.6						
6	12.9	10.0	2.7			10.0	2.9
7	14.3						
8	15.7	11.0	1.7			11.0	4.7
9	17.2						
2000	19.0	11.7	1.0	4.6	5.5	--	--
1	20.3						
2	21.8	12.2	0.5	6.0	4.1	--	--
3	23.5						
4	25.2	12.7	0	6.9	3.2	--	--
2005	27.1						
6	28.7	12.7		8.2	1.9	--	--
7	30.5						
8	32.3	12.7		8.6	1.5	--	--
9	34.3						
2010	36.6	12.7		9.1	1.0	--	--
1	37.9						
2	39.3	12.7		9.6	0.5	--	--
3	40.7						
4	42.1	12.7		10.1	0	--	--
2015	43.6	12.7		10.1		--	--
Tentative schedule							

Table 5-3 Summary of 20 Sites at Upper Liwagu River Basin

No.	River Name	Site Name	Type of P/S		Catchment Area	Design Flows	Water Levels		Gross Head	Installed Capacity	Screening			
			Storage	Run off River			Head	Tail			Net Head	95% Flows	Firm Power	
					km^2	m^3/s	ft	ft	m	MW	m	m^3/s	kW	
1	Bambangan	Tembaga		O	15	1.0	4,000	3,300	213	1.7	181	0.20	290	X
2	Kegibangan	Walau	O		510	40.4	800	650	46	16				
3	Kegibangan	Barambang	O		33	2.4	1,200	920	85	2				
4	Kegibangan	Lamas 2		O	68	3.7	4,000	1,750	686	22	583	0.88	4,100	O
5	Kegibangan	Lamas 1	O		68	4.4	4,250	1,750	762	29				
6	Kegibangan	Pudau	O		303	21.7	1,085	990	29	5				
7	Kegibangan	Tinonun	O		391	28.6	990	880	34	8				
8	Liwagu	Lobok		O	14	0.8	4,000	3,500	152	1.0	129	0.18	190	X
9	Liwagu	Gantong A		O	67	3.9	2,800	2,200	183	6.2	156	0.87	1,090	O
10	Liwagu	Gantong B		O	67	3.9	2,800	2,000	244	8.2	207	0.87	1,440	O
11	Liwagu	Pakai		O	97	5.6	2,050	1,360	210	10.2	179	1.26	1,800	O
12	Liwagu	Kigiok B	O		200	11.4	1,480	1,200	85	8.4				
13	Liwagu	Kigiok A	O		200	11.4	1,500	1,410	27	2.6				
14	Liwagu	Nampasan	O		390	23.3	1,260	1,140	37	7.3				
15	Mesilau	Kauluan		O	23	1.6	4,650	3,200	442	5.9	376	0.30	900	X
16	Mesilau	Naradaw		O	29	1.8	3,400	2,800	183	2.8	156	0.38	470	O
17	Mindahuan	Solong	O		54	4.1	2,948	750	670	23.8				
18	Samalang	Peropot		O	145	9.2	1,610	1,510	30	2.3	26	1.89	390	X
19	Tabasan	Serpong B	O		161	8.8	1,750	1,350	122	9.2				
20	Tami Tamis	Nimbalai	O		25	1.4	2,300	1,300	305	3.5				

Source: Hydropower Options Study - Inventory of Identified Site, Liwagu River Basin. Tonkin & Taylor 1990

Estimated by JICA Team o 700 kW or more
X less than 700 kW

Table 5-4 Data Summary Sheet (1), Small Hydro Power Project at Upper Liwagu River Basin

No.	Site Name	River	Installed Capacity kW	Annual Energy GWh	Const. Cost 1/ 1000 M$	Cost/kW M$	Cost/kWh M$	Rank	Note
1	Naradaw A	Liwa/Mesi	1,340	10.3	11,410	8,515	1.11		1/
2	Naradaw B	Liwagu	850	6.6	8,656	10,184	1.31	1	Carabau based unit prices are adopted for the cost of civil works tentatively.
3	Naradaw C	Mesilau	490	3.7	6,090	12,429	1.65		
4	Naradaw D	Liwa/Mesi	1,540	11.9	11,410	7,409	0.96		
5	Naradaw E	Liwa/Mesi	1,070	8.3	10,620	9,925	1.28		
6	Gantong A	Liwagu	1,600	12.3	16,580	10,363	1.35		
7	Gantong B	Liwagu	2,140	16.5	21,290	9,949	1.29	2	
8	Gantong C	Liwa/Mon	2,340	18.1	25,300	10,812	1.40		
9	Gantong D	Liwagu	1,610	12.4	13,510	8,391	1.09		
10	Gantong E	Liwa/Kihop	1,700	11.2	14,340	8,435	1.28		
11	Pakai	Liwagu	2,700	17.7	22,270	8,248	1.26	3	
12	Kauluan	Mesilau	1,150	8.8	10,980	9,548	1.25	3	
13	Lamas 2	Kegibangan	8,400	65.0	37,790	4,500	0.58		
14	Lamas 3	Kegibangan	3,180	27.7	29,080	9,145	1.05	-	

Table 5-5 Data Summary Sheet (2), Small Hydro Power Project at Upper Liwagu River Basin

No.	Site Name	River	Catch. Area	Water Level		Net Head	Disch-arge	Installed Capacity	Firm Peak Power	Annual Energy	Plant Factor
				Head	Tail						
			km^2	ft	ft	m	m^3/s	kW	kWh	GWh	%
1	Naradaw A	Liwa/mesi	60.3	3,260	2,780	126	1.33	1,340	1,060	10.3	88
2	Naradaw B	Liwagu	31.9	3,260	2,780	126	0.84	850	750	6.6	89
3	Naradaw C	Mesilau	28.4	3,230	2,780	125	0.49	490	310	3.7	86
4	Naradaw D	Liwa/Mesi	59.2	3,400	2,780	165	1.17	1,540	1,100	11.9	88
5	Naradaw E	Liwa/Mesi	60.3	3,260	2,870	100	1.33	1,070	840	8.4	88
6	Gantong A	Liwagu	65.5	2,730	2,200	137	1.45	1,600	1,260	12.3	88
7	Gantong B	Liwagu	65.5	2,730	2,000	184	1.45	2,140	1,700	16.5	88
8	Gantong C	Liwa/Mon	78.5	2,730	2,000	168	1.74	2,340	1,850	18.1	88
9	Gantong D	Liwagu	63.5	2,760	2,200	144	1.40	1,610	1,280	12.4	88
10	Gantong E	Liwa/Kihoput	63.5	2,760	2,200	149	1.40	1,700	1,320	11.2	75
11	Pakai	Liwagu	88.9	2,050	1,360	173	1.96	2,700	850	17.7	75
12	Kauluan	Mesilau	22.2	4,650	3,200	412	0.35	1,150	620	8.8	87
13	Lamas 2	Kegibangan	72.9	4,000	1,750	652	1.61	8,400	4,450	65.0	88
14	Lamas 3	Kegibangan	72.9	4,000	1,750	652	0.61	3,180	3,180	27.7	99

Figure 5-1 Hydro Power Supply Capability in a Year

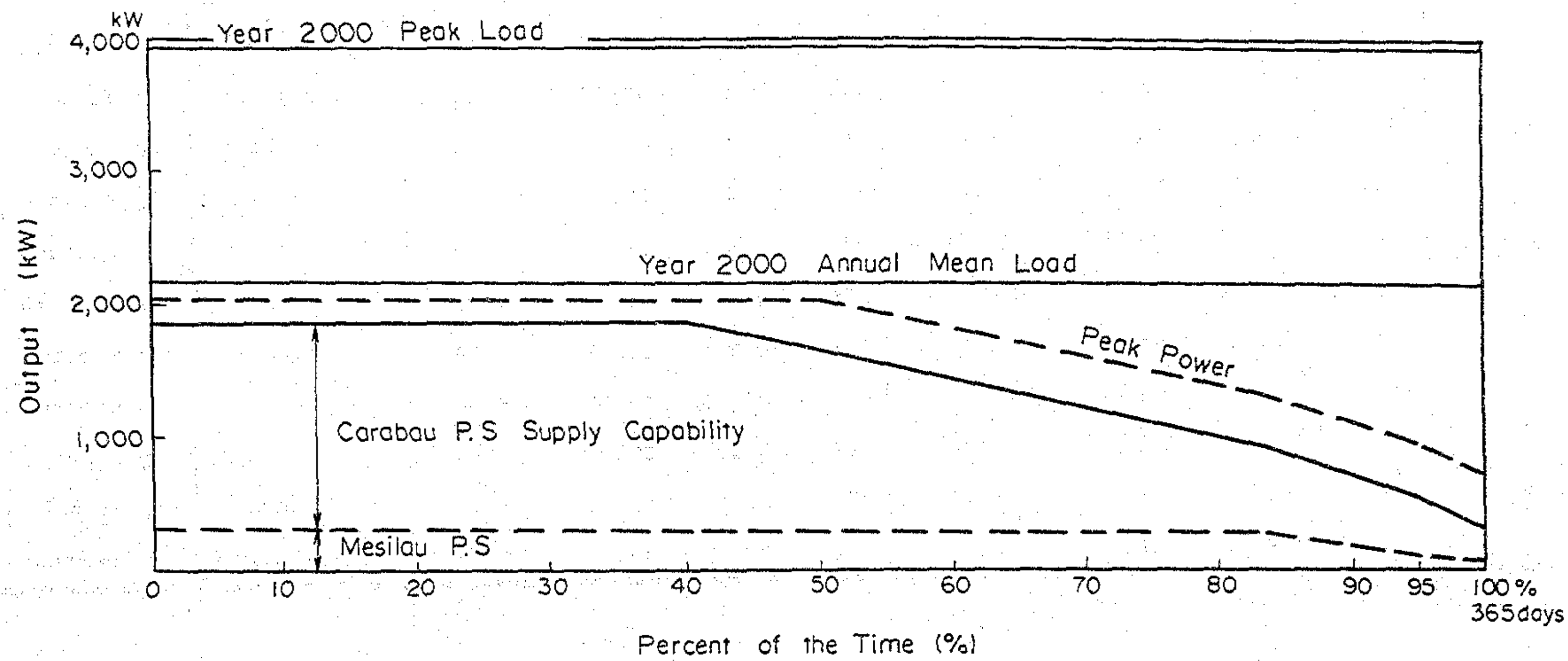


Figure 5-2(1) Daily Load Duration

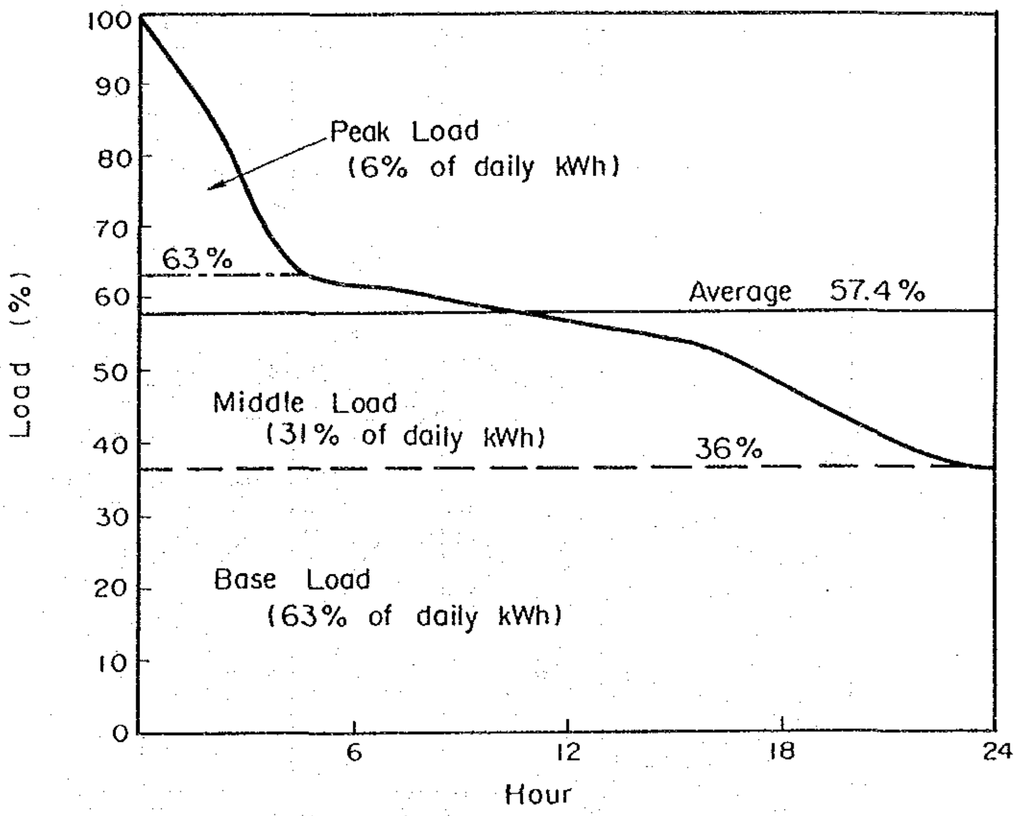


Figure 5-2(2) Supply Capability of Carabau P.S and Mesilau P.S

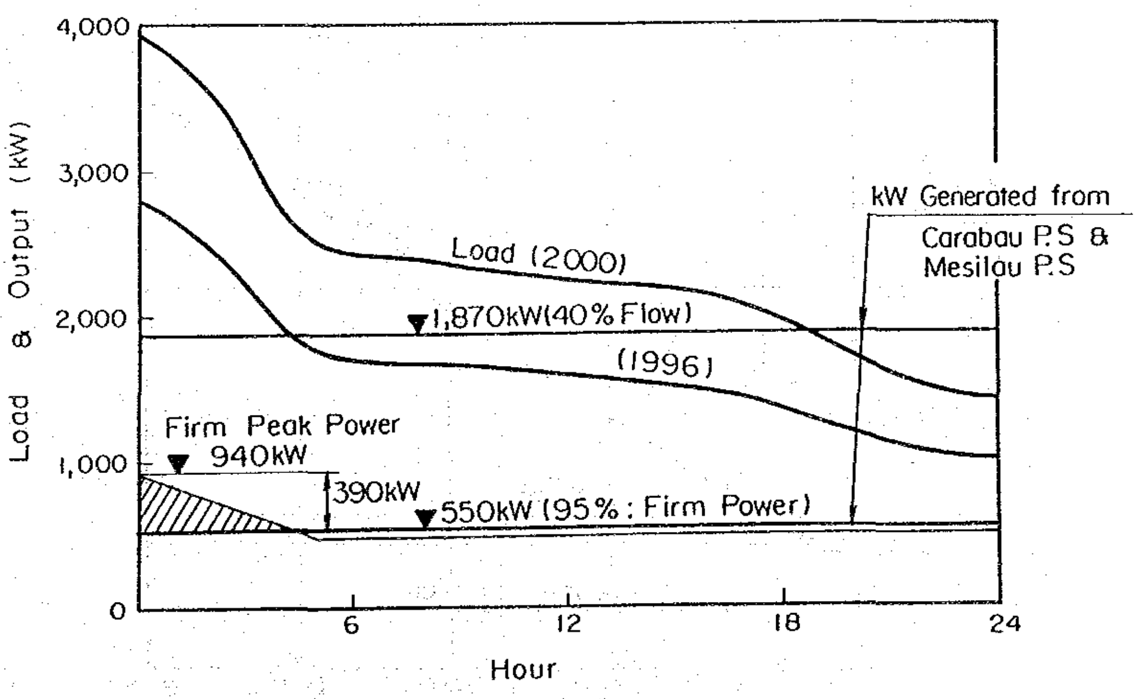
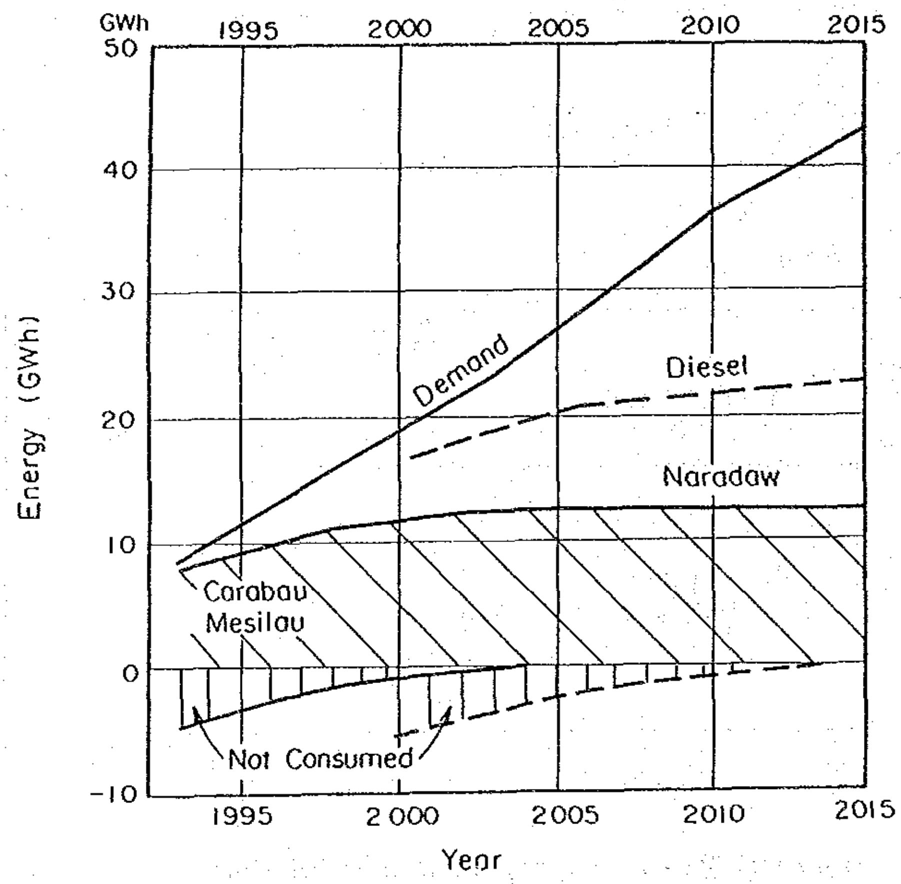
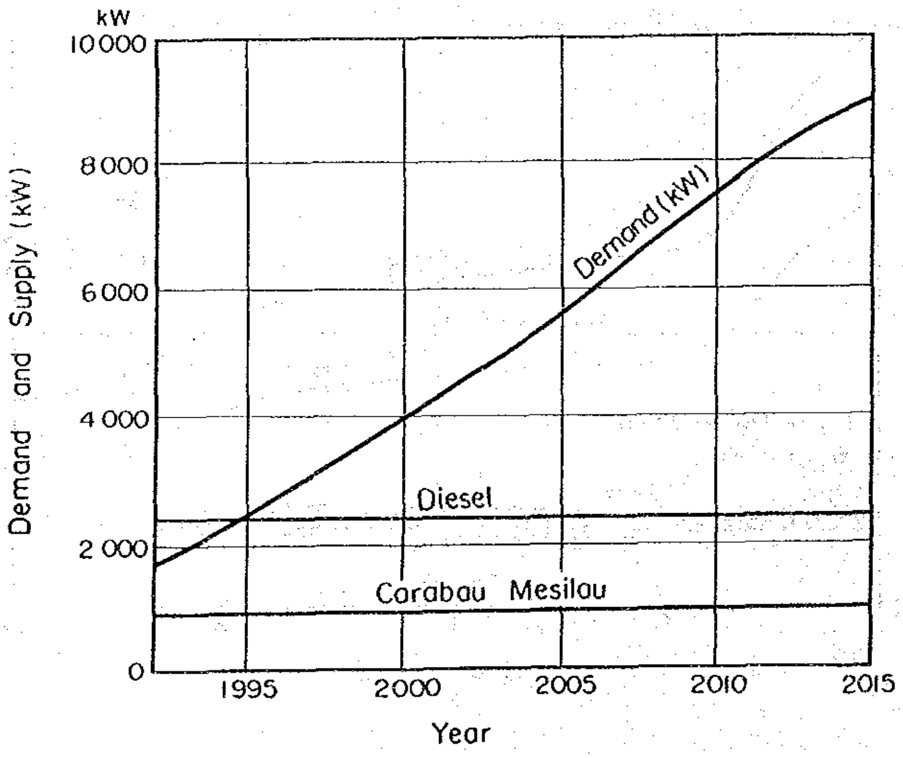


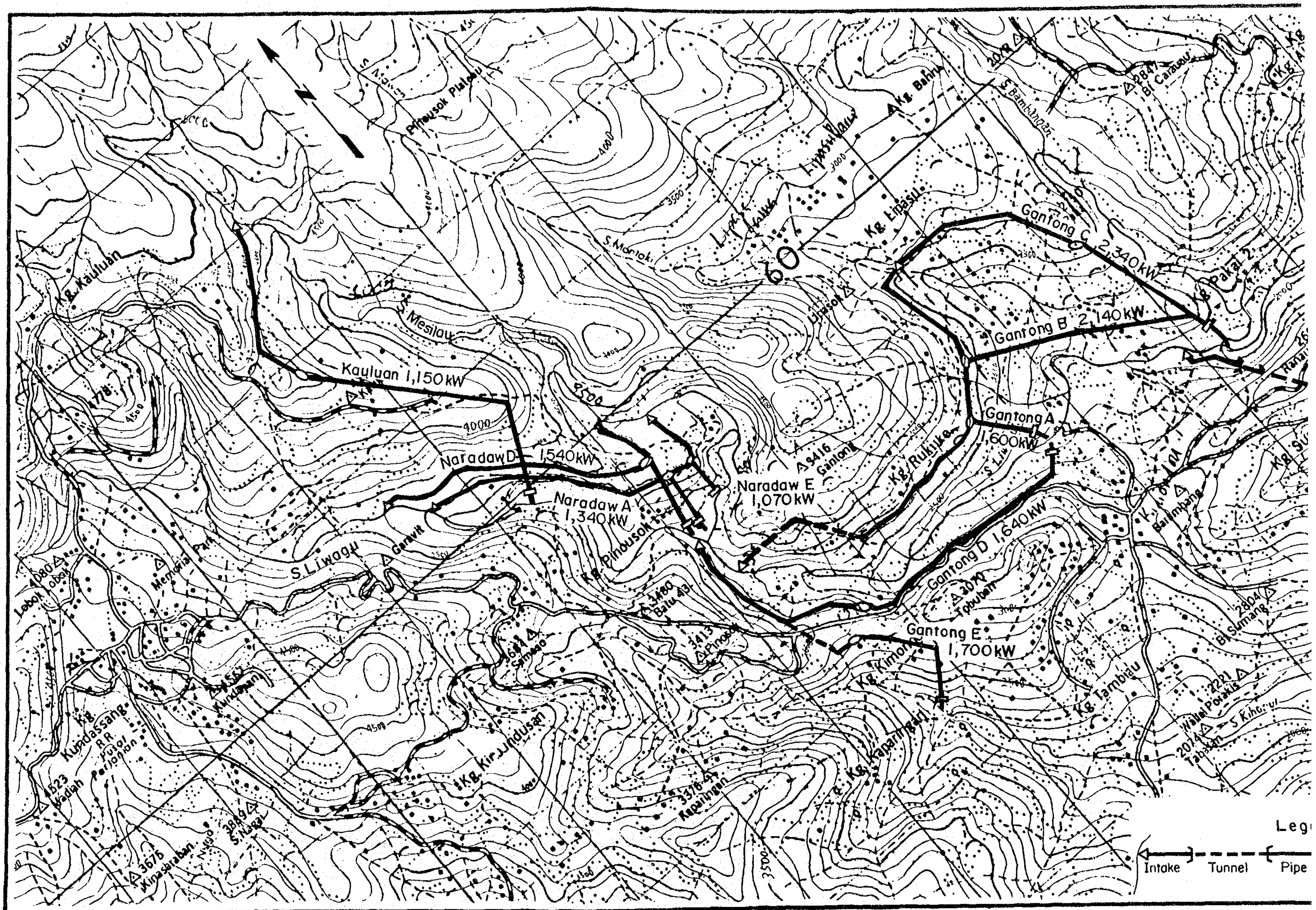
Figure 5-3 Demand and Supply

(1) KWh Balance



(2) KW Balance





Kauluan 1,150 kW
Naradaw D 1,540 kW
Naradaw A 1,340 kW
Naradaw E 1,070 kW
Gantong A 1,600 kW
Gantong B 2,140 kW
Gantong C 2,340 kW
Gantong D 1,640 kW
Gantong E 1,700 kW
Kg. Kauluan
S. Liwagu
S. Mesilau
Kg. Limbasu
Kg. Pinousok
Kg. Rukiuke
Kg. Kimolo
Kg. Tambiau
Kg. Kirunduan
Kg. Kundassang
Kg. Pakal 2
Pinousok Plateau
Memorial Park
Intake
Tunnel
Pipe

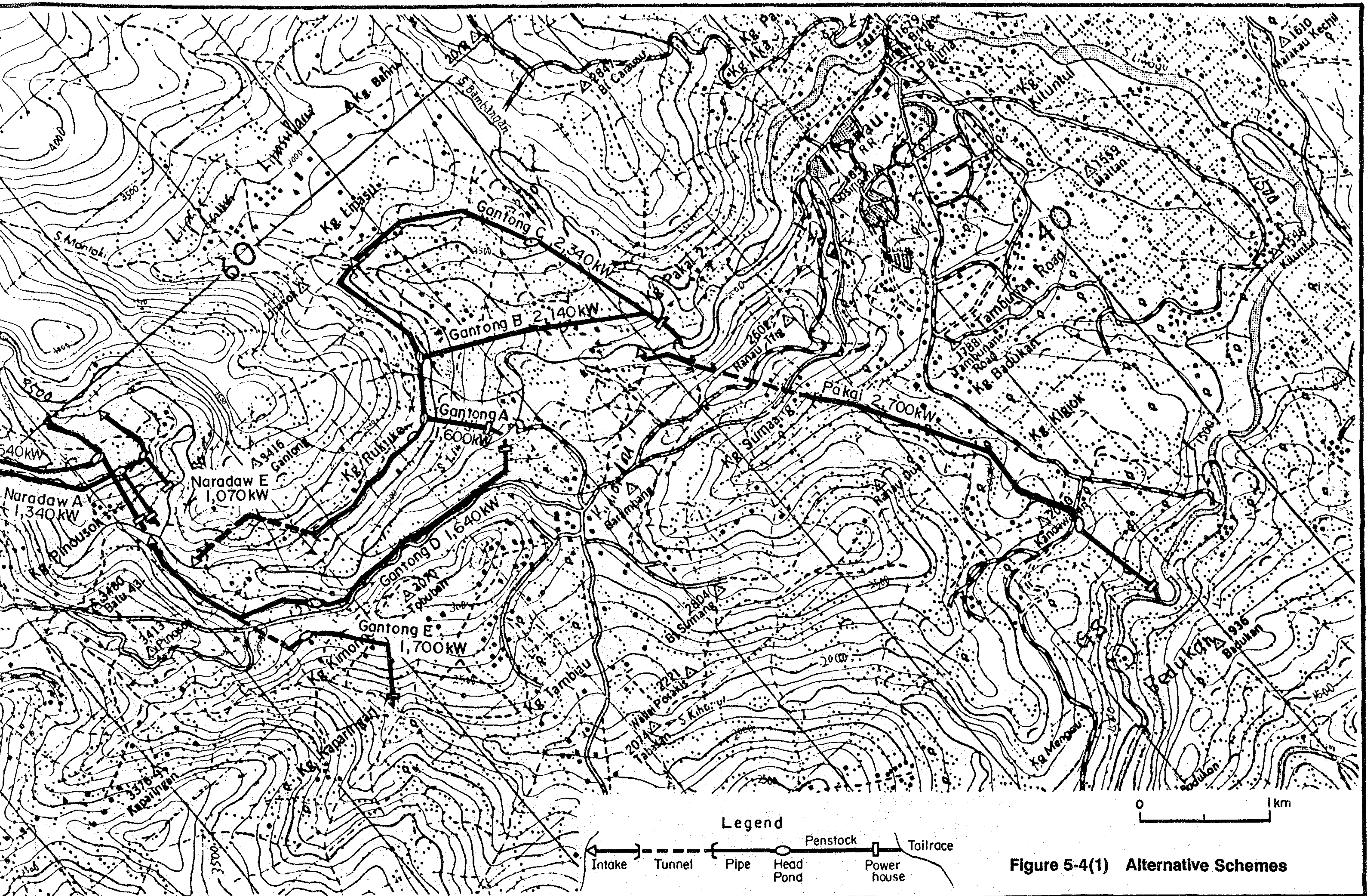


Figure 5-4(1) Alternative Schemes

Figure 5-4 (2) Alternative Scheme

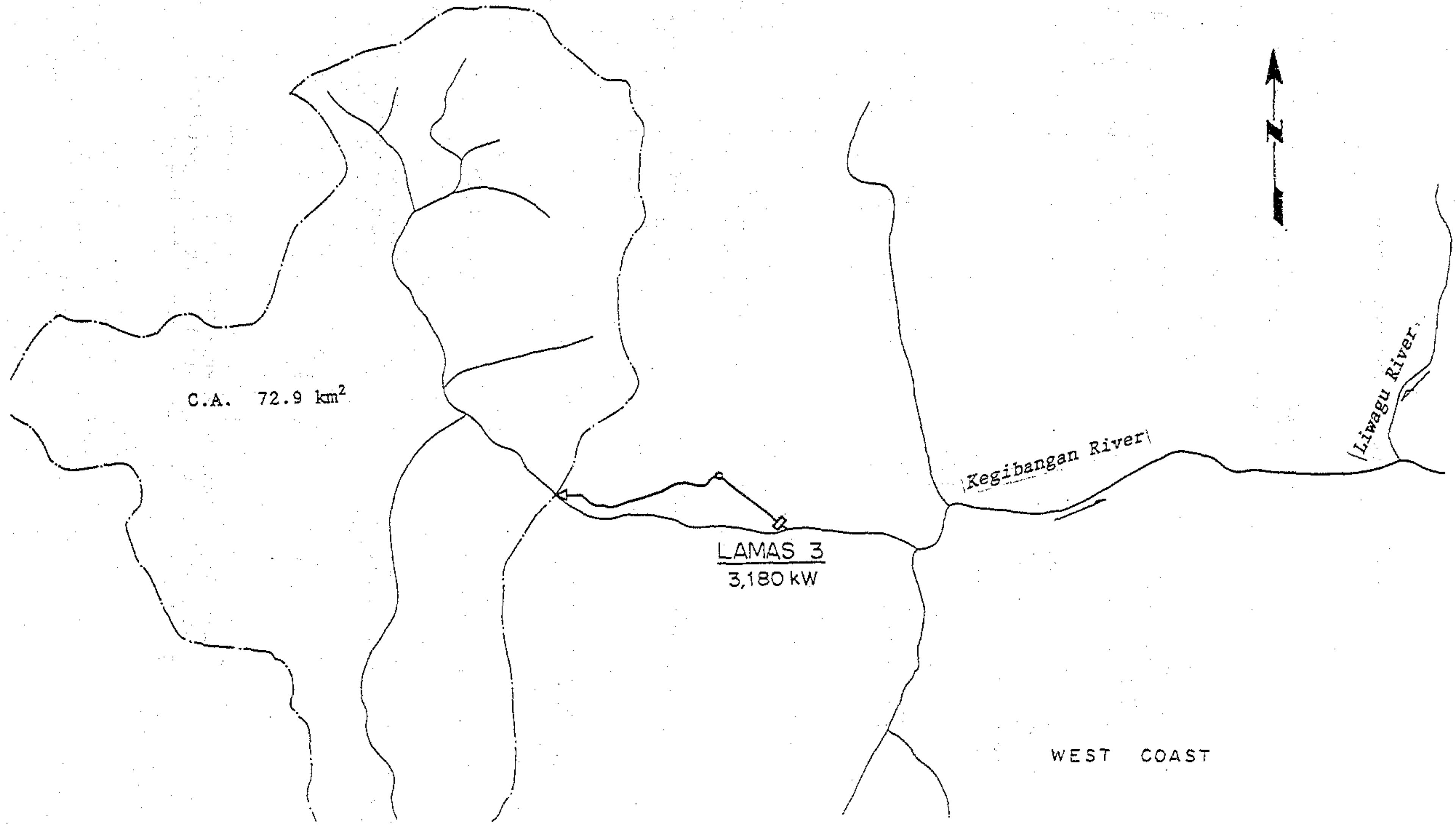


Figure 5-5 Hydro-power Planning Procedure

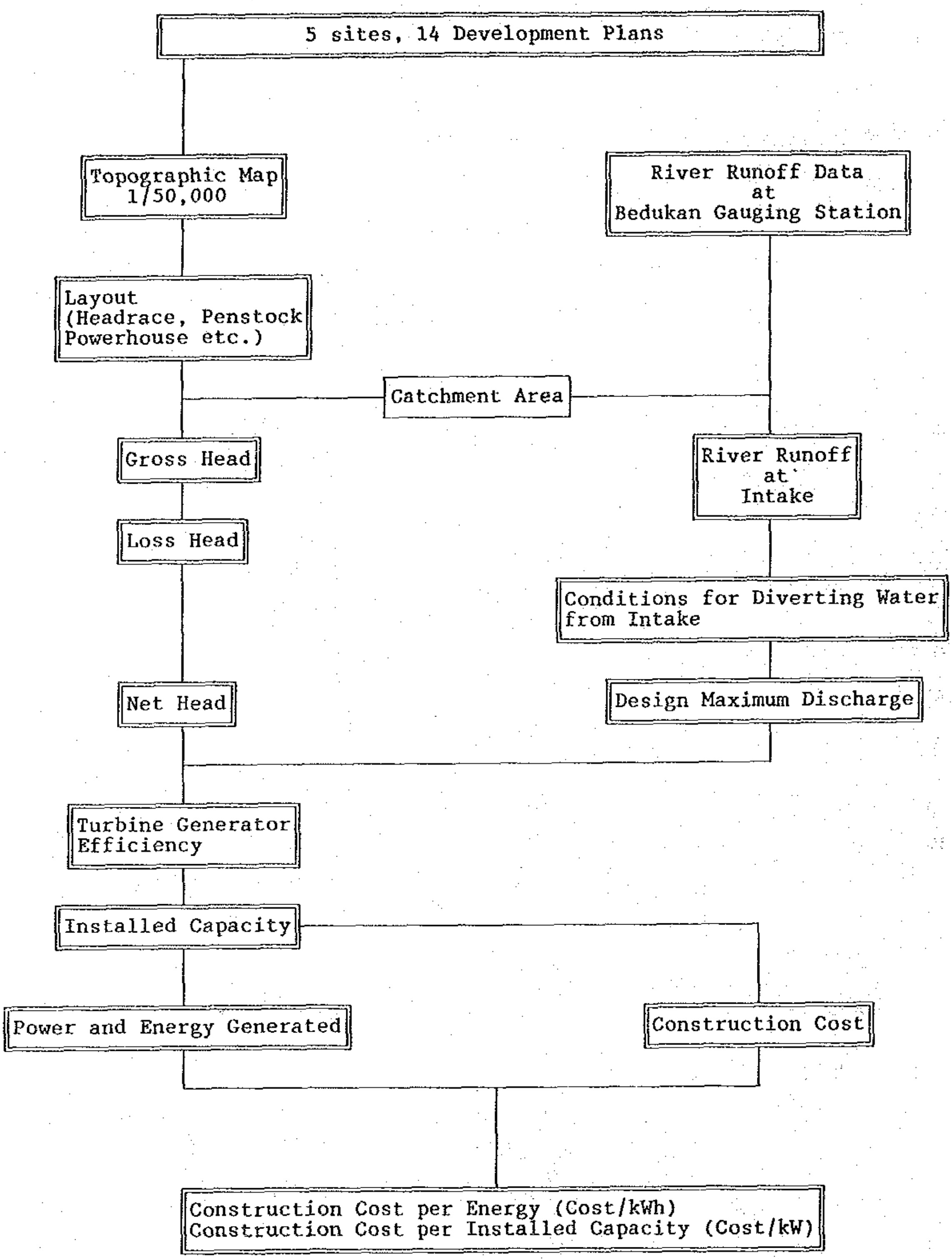
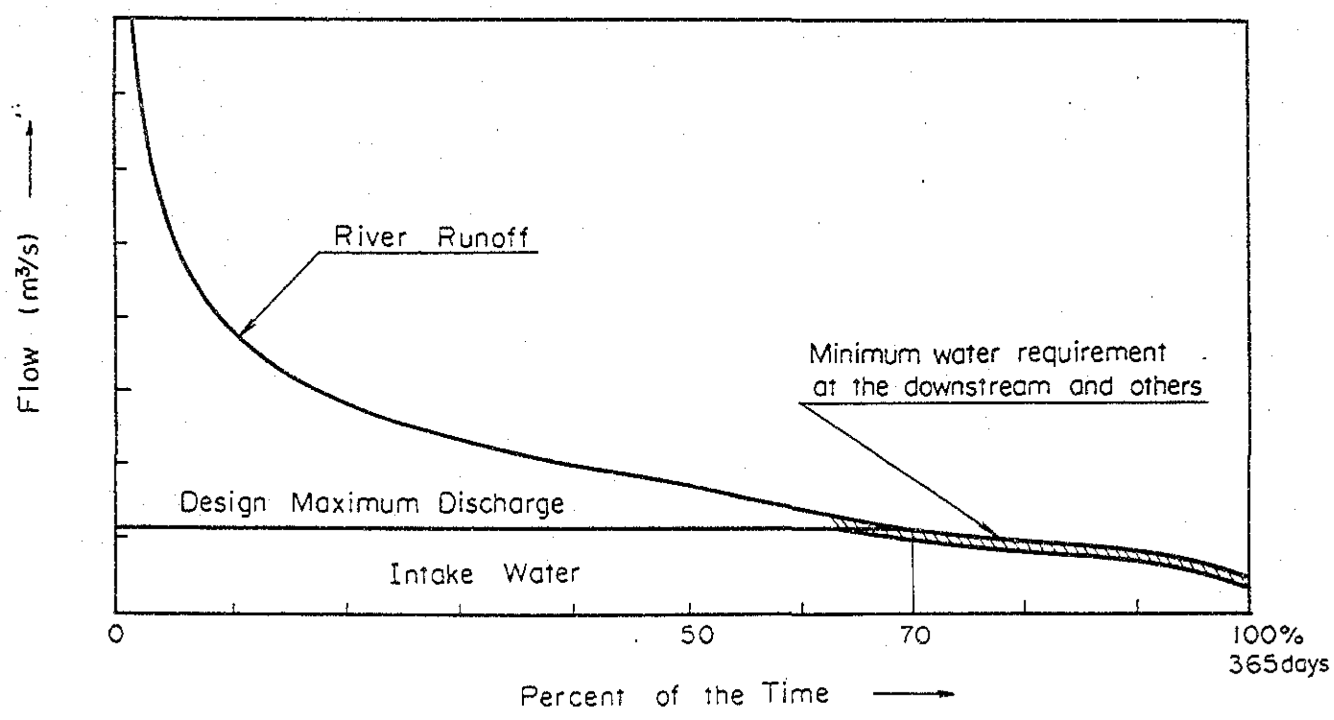
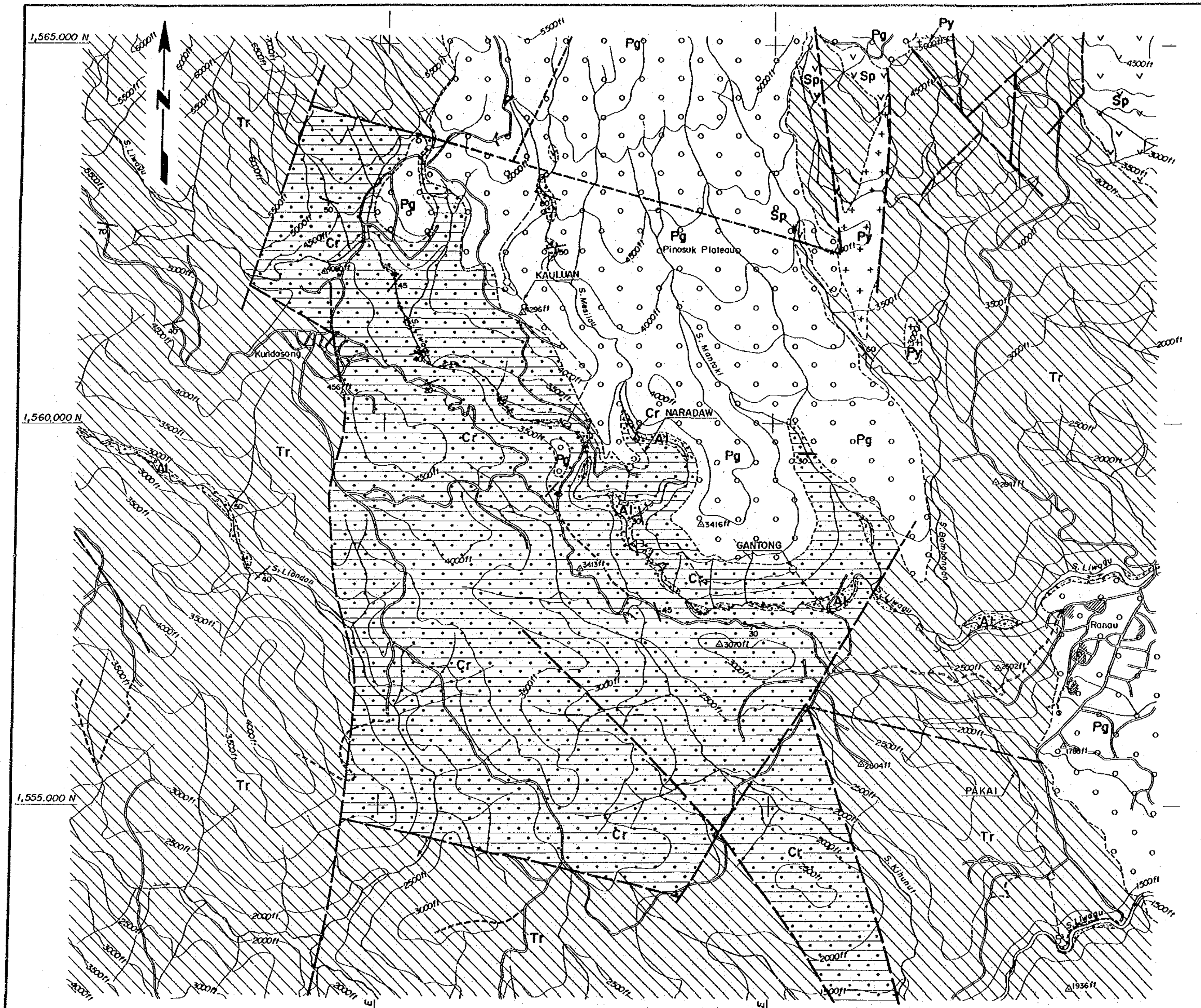


Figure 5-6 Discharge Duration and Intake Water at a Site





LEGEND

QUARTERNARY

Al — Alluvium. Mainly boulder gravel

Pg — Pinosuk Gravels. Gravel up to boulder size, sand and clay

TERTIARY

Py — Porphry

Sp — Serpentinite

Cr — Crocker Formation. Sandstone, siltstone, shale and mudstone

Tr — Trusmadi Formation. Slate, siltstone, sandstone and mudstone

Geological boundary

Probable fault

Inferred fault beneath superficial cover

60 Strike of strata with dip in degrees

Recent landslide scarp

Note:

This map is compiled and modified from "COLLENETTE, P. (1958)", "JACOBSON, G. (1970)" "GEOLOGICAL SURVEY OF MALAYSIA (1985): GEOLOGICAL MAP OF SABAH" and "AKIYAMA, Y. (1987)"

0 — 2 km

SMALL SCALE HYDROELECTRIC POWER DEVELOPMENT PROJECT AT UPPER LIWAGU RIVER BASIN

GEOLOGICAL MAP OF PROJECT AREA

Figure 5-7

Chapter 6 TOPOGRAPHIC MAPS

Chapter 6

TOPOGRAPHIC MAPS

Contents

6. TOPOGRAPHIC MAPS

6.1 Existing Maps

Existing maps available for use in study of the Project are of scales 1/50,000, 1/12,500 and 1/2,500.

The 1/50,000 topographic maps were published by the Directorate of National Mapping in 1986. The entire Upper Liwagu Basin is covered, and the maps can be effectively used for selection of the development project site.

The 1/12,500 and 1/2,500 topographic maps were recently prepared by the Department of Land Survey, (DLS) Sabah, and presented on this time by SEB. In particular, the left-bank side of the Upper Liwagu River Basin has been charted in the maps of scale 1/2,500 and these maps can be utilized for planning the layout of the optimum development site for the Project. As a result of obtaining these 1/2,500 topographic maps, it has become unnecessary for 1/5,000 topographic mapping to be done from 1/30,000 aerial photographs which had been planned at the beginning.

6.2 Topographical Survey

Topographical maps with a diminishing scale of 1/500 were prepared in accordance with the technical specifications created by the JICA study team by using a topographical survey technique for the projected and surrounding areas including the intake dams, the headponds, the penstock line and the power station. Prior to the topographical survey, a traverse survey and a level survey were conducted to allow the coordinates of the respective projected areas to be incorporated into the public coordinate system. A reference point was established within each projected area to facilitate the following works.

(1) Traverse survey

A traverse survey was performed over a distance of approximately 12 km using a station of triangulation, Trig Batu 43, Trig Gantong and Trig Samaso, as datum points. These datum points belong to the national coordinate system of the State of Malaysia whose spheroid is based on Mt. Everest and the plane coordinates are calculated using the rectified skew and orthomorphic methods.

(2) Level survey

A national level point, BM206033, with a height from the mean sea level was used as the datum point for a direct level survey over a length of 19 km.

(3) Setting Bench Marks

Bench marks were set up in each of the projected area as shown below, and a detailed description of the bench marks were prepared. (See **Appendix 1**)

Embedded Bench Mark	:	Projected area for the Liwagu river intake dam (TMB 1)
		Projected area for the Mesilau river intake dam (TMB 2)
		Projected area for penstocks (TMB 7)
		Projected area for the power station (TMB 3)
Simplified Bench Mark	:	The bridge side of the Liwagu river (TMB 6)
		The landslide point (TMB 5)

(4) Topographical survey

The field survey for preparing topographical maps with a diminishing scale of 1/500 and a main curve distance of 1 meter was executed by the stadia survey method using a theodolite.

Amounts of work are as shown below:

Projected area for the Liwagu river intake dam:	0.014 km^2
Projected area for the Mesilau river intake dam:	0.015 km^2
Projected areas for the headpond, penstocks and the power station:	0.115 km^2

(5) Summary

The surveys were executed as originally planned, starting on September 24, 1991 and concluding on January 31, 1992.

The survey work was commissioned to a local company, Surcom Service, by Sabah Electricity Board (SEB), and was completed under the technical guidance rendered by the study team. After completing the initial field survey during the first dispatch, the study team formulated a set of specifications that they submitted to SEB. During the second dispatch, the team provided a course of technical guidance with technicians of the local survey organization through the counterpart is SEB.

The inspection of the results of survey was executed in Japan by examining copies of the surveyed items. The result of the inspection showed an excellent accuracy in the results of the traverse and level survey. A similar inspection was conducted also for the 1/500-scale topographical positive print maps. Although there were some missing items including small houses, rocks and pedestrian sidewalks, the maps were very easy to read and provided sufficient information for the survey purpose executed this time.

Chapter 7 GEOLOGY

Chapter 7

GEOLOGY

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7. GEOLOGY

In this Chapter, the topography, geology, engineering geology and seismology are presented for the hydroelectric power development project of Naradaw site, which has been selected as the optimum project site based on information obtained in the Identification Stage and the Field Investigation Stage.

7.1 Outline of Investigation

7.1.1 Field Investigations

Of field investigations made by the JICA Study Team, geological field investigations have been carried out in three stages described below.

From July 15, 1991 to August 13, 1991:

- Collection of geological information.
- Planning geological investigation works.
- Site reconnaissance.

From September 22, 1991 to October 6, 1991

- Site reconnaissance.
- Presentation and explanation of technical specification.

From November 27, 1991 to December 11, 1991:

- Engineering supervision of investigation works.
- Site reconnaissance.

The geological field investigations in the Identification Stage have been carried out at 4 sites, which are accessible among the 5 sites that have been selected by screening process based on existing data/information. Topographical maps used for the field investigation were mainly 1/10,000 scale maps which were produced by enlarging 1/50,000 scale maps, and 1/2,500 scale topographical maps were also used for Naradaw site. Based on the results of these field investigations, Naradaw site was selected. The JICA Study Team prepared the technical specifications for geological investigation works on Naradaw site, and submitted and explained these specifications to Sabah Electricity Board (SEB).

The geological field investigation in the Field Investigation Stage mainly consisted of technical supervision of geological investigation works which was ordered by SEB to the contractor. In addition to this supervision, some geological reconnaissance were also performed.

7.1.2 Geological Investigation Works

The geological investigation works (including the geological mappings were implemented by SEB at the major structures which were to be built according to the optimum development plan on Naradaw site in the Identification Stage.

SEB ordered the works to a contractor to perform the works according to the technical specifications prepared by the JICA Study Team. The works were performed by Applied Geotechnics, a local contractor in Sabah.

The outline of methods and quantities of the works is shown in **Table 7-1** below.

Table 7-1 Outline of Geological Investigation Works

Location	Investigation Item	Volume
Liwagu Intake Dam	Boring (including permeability test and standard penetration test).	2 bores, (30 m in total length).
Mesilau Intake Dam	Boring (including permeability test and standard penetration test).	2 bores, (30 m in total length).
Headpond*1	Boring (including permeability test and standard penetration test).	2 bores, (40 m in total length).
Penstock	Boring (including permeability test and standard penetration test).	2 bores, (40 m in total length).
Powerhouse	Boring (including standard penetration test).	2 bores, (40 m in total length).
Whole Naradaw Area	Geological mapping (1/5,000).	10 km^2
Liwagu Intake Dam	Geological mapping (1/500).	0.014 km^2
Mesilau Intake Dam	Geological mapping (1/500).	0.015 km^2
Penstock to Powerhouse	Geological mapping (1/500).	0.115 km^2

Note: *1; Alternative waterway (A)

The specific volumes of the works are presented in **Table 7-2**.

Results of these geological investigation works have been described by Applied Geotechnics as the "Report of Geological Investigation at Upper Liwagu Mini Hydro Project Site, Kundasang, Ranau". A part of this report is attached to this Report as **Appendix 2**.

Seismic prospecting survey that is proposed in the Scope of Study was canceled by the request from SEB. The survey shall be conducted in future at the time of detailed design.

7.1.3 Existing Data

The existing geological and seismic data related to this project have been acquired from Geological Survey of Malaysia in Sabah at the time when the first field investigation was performed. A list of these existing geological data is presented at the end of this Chapter as references.

In preparation of this Chapter, these existing data and the report on the geological investigation works mentioned above were referred to together with results of investigations by the JICA Study Team.

Table 7-2 List of Geological Investigation Works

[CORE DRILLING WORK]

Hole No.	Site	Coordinate	Elevation (m)	Depth (m)	Permeability T.		*3 SPT times	*4 CPT times
					*1 OET times	*2 PT times		
LI-1	Liwagu Intake Dam	E765,742.5 N662,788.5	1,049.91	15.00	5	1		10
LI-2	Liwagu Intake Dam	E765,732.5 N662,777.5	1,049.81	15.00	5	1		10
LI-3	Mesilau Intake Dam	E767,644.5 N662,603.5	1,035.96	15.00	6			10
LI-4	Mesilau Intake Dam	E767,623.3 N662,597.5	1,035.34	15.00	6		2	8
LT-1	*5 Headpond	E767,818.0 N661,692.5	1,031.62	20.00	5	2	2	8
LT-2	*5 Headpond	E767,725.5 N661,707.5	1,035.53	20.00	5	2	5	5
LP-1	Penstock	E767,727.0 N661,434.0	975.08	20.00	5	2		10
LP-2	Penstock	E767,717.0 N661,237.0	913.65	20.00	5	2	8	2
LP-3	Power House	E767,712.0 N661,075.0	861.67	20.00			9	2

Note: *1 OET : Open-end test (Field permeability test in unconsolidated deposit)
*2 PT : Packer test (Field permeability test in bed rock)
*3 SPT : Standard penetration test (Penetration test in topsoil and weathered bedrock)
*4 CPT : Cone penetration test (Penetration test in gravel)
*5 : Alternative waterway (A)

[GEOLOGICAL MAPPING]

Item	Site	Scale	Quantity	Remarks
Interpretation of Aerial Photograph	Naradaw Area	1/25,000	over 10 km^2	
Geological Mapping	Naradaw Area	1/5,000	10 km^2	including route maps, photos and sketches
Geological Mapping	Liwagu Intake Dam	1/500	0.014 km^2	including route maps, photos and sketches
Geological Mapping	Mesilau Intake Dam	1/500	0.015 km^2	including route maps, photos and sketches
Geological Mapping	Penstock to Power House	1/500	0.115 km^2	including route maps, photos and sketches

7.2 Regional Geology

7.2.1 Topography

(1) Northern Sabah

Northern Sabah is located in the northern part of Borneo. This region is surrounded by the South China Sea with its west coast and the Sulu Sea with its east coast.

The chief topographical feature of this region is characterized by the Crocker Range and the Trusmadi Range, belts of hills which stretch from southwest to northeast along the west coast, and the Kinabalu massif existing in the middle of these mountain ranges. The average height of the hills is between 600 m and 1,200 m, rising to over 2,000 m along a central spine. In particular, Mt. Kinabalu is the highest peak in the South East Asia, with its height being 4,101 m.

These hills and mountains form the watershed for many rivers, such as the Wariu River, the Labuk River and the Sugut River, which either flow into the South China Sea or the Sulu Sea.

The Liwagu River, on which this Project has been planed, rises from the south slope of Mt. Kinabalu, flows to the southeast to join the Kegibangan River and form the Labuk River, and then drains into the Sulu Sea. The total length of the river is approximately 220 km.

(2) Ranau Area

Ranau area, where the project site is proposed, is a region covering area 24 km from east to west and 22 km from north to south on the south and east slope of Mt. Kinabalu (EL. 4,101 m). The geography of this area is in a stage of maturity.

This area is located in the northeastern part of the Crocker Range. The greater part of the area consists of mountains and hills of elevation between 500 and 4,100 m, with a plain of elevation between 400 and 600 m called Ranau Plane to be seen at the eastern part of this area. There is also a plateau, named Pinosuk Plateau, on the southern slope of Mt. Kunabalu, with its elevation ranging from 900 m to 1,800 m.

The Liwagu River in the Ranau area, which rises from Mt. Kinabalu, flows down from northwest to southeast, and turns to the south on the Ranau Plane. The Liwagu River has many tributaries, and one of them, the Mesilau River is a stream which deeply dissects the Pinosuk Plateau.

As mountains and plateaus are deeply dissected by various rivers such as the Liwagu River, some landslides and collapses are observed at parts of steep slopes.

Naradaw site, which has been selected as the optimum development plan, is planned along the Liwagu River and the Mesilau River.

7.2.2 Geology

(1) Northern Sabah

A stratigraphy of Northern Sabah is shown in **Table 7-3**, and a regional geological map in **Fig.7-1**.

The oldest rocks in northern Sabah are made up of metamorphic rocks that formed in Triassic time or before. These metamorphic rocks are the oldest rocks in Borneo, and called Crystalline Basement. These rocks appear around Mt. Kinabalu and some areas around the Labuk River and the Tungud River. The thick layers of sedimentary rocks of the "Northwest Borneo Geosyncline" from Cretaceous time to early Miocene time unconformably overlie the

Crystalline Basement. These sedimentary rocks are widely distributed in northern Sabah, and constitutes major mountain body. The ultrabasic and plutonic rocks intruded into the above mentioned sedimentary rocks from Oligocene time to Pliocene time. These igneous rocks are distributed in the Mt. Kinabalu Area and around Telupid. Finally, it is deemed that the landform of northern Sabah which was nearly the present status of landform was made in the beginning of Quaternary age.

(2) Ranau Area

Ranau area is composed of metamorphic rocks in Triassic time or before, sedimentary rocks and igneous rocks in Tertiary time and young deposits in Quaternary time. To describe these geological formations in the order from old rocks, they are as presented below.

Crystalline Basement:

The Crystalline Basement of the metamorphic rocks in the Ranau area which was formed in Triassic time or before, and consists of gneiss and schist. These rocks are locally exposed around Mt. Kinabalu.

Sedimentary Rocks:

Sedimentary rocks in the Ranau area consist of sandstone, slate, shale, siltstone and mudstone which were formed from Paleocene to time to Miocene time, and called the Trusmadi Formation and the Crocker Formation. These formations unconformably overlie the Crystalline Basement, and they are widely distributed in the Ranau area. Folds and faults are well developed in this formation due to the intrusion of igneous rocks in miocene time.

Igneous Rocks:

Igneous rocks consist of serpentine, porphyry, granodiorite and adamellite which intruded into the above mentioned formation during Miocene time. The adamellite is exposed in Mt. Kinabalu.

Quaternary Deposit (Pleistocene):

A Quaternary deposit in Pleistocene time is called Pinosuk Gravels. The Pinosuk Gravels unconformably overlie igneous rocks and sedimentary rocks, and forms a plateau named Pinosuk Plateau. The Pinosuk Gravels consist of rounded gravels, sand and silt, and regarded to be a sedimentary layer formed by the periglacial action of Mt. Kinabalu.

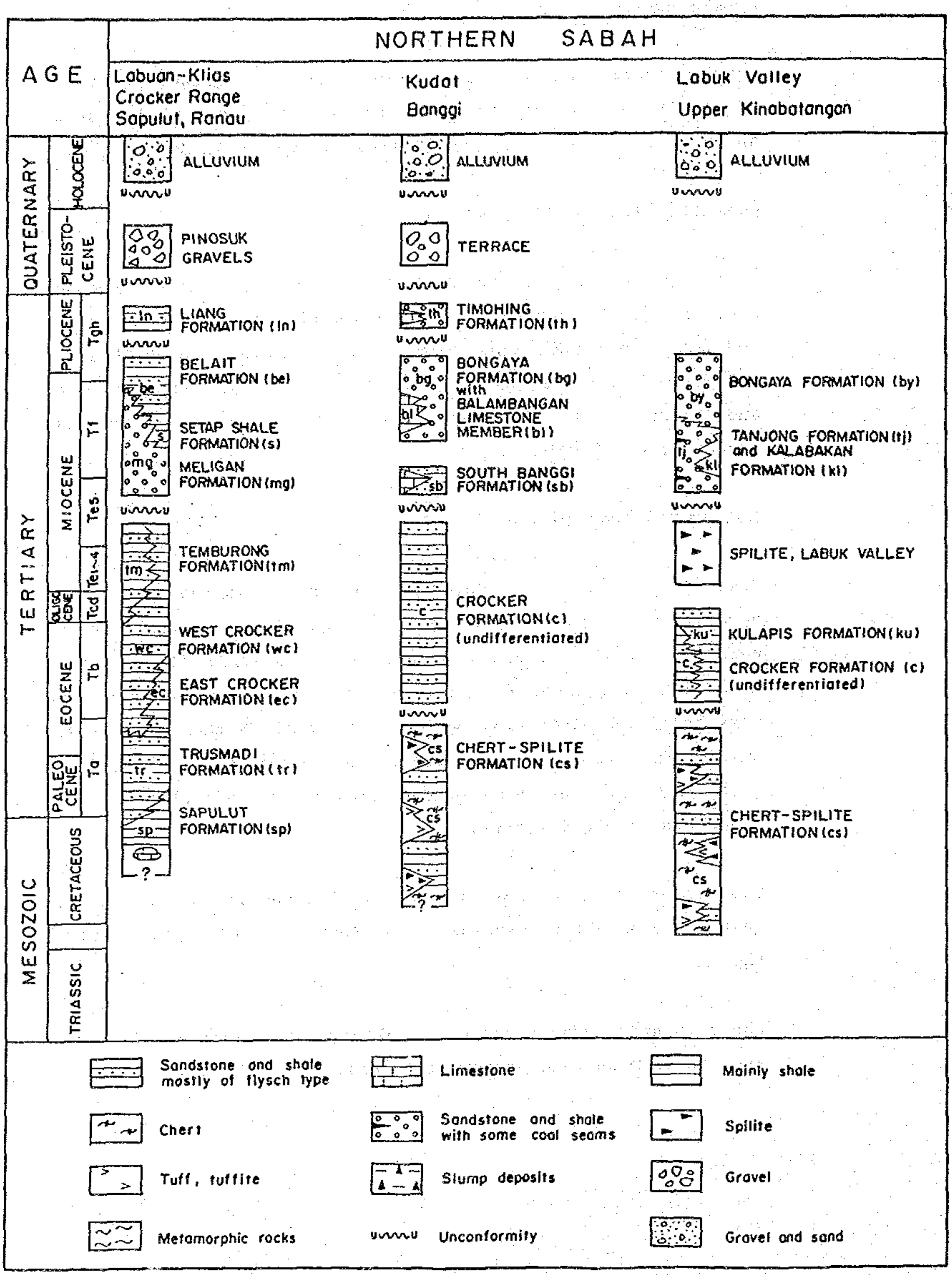
Quaternary Deposits (Holocene):

Quaternary deposits in Holocene time are composed of terrace deposit, alluvium, colluvium and talus deposit, etc. The terrace deposit and the alluvium unconformably overlie the Trusmadi Formation, the Crocker Formation and the Pinosuk Gravels, and they are distributed along major rivers such as the Liwagu River and the Mesilau River. They consist of rounded gravels, sand and silt, and contain may rounded gravels of adamellite which diameters exceed 5 meters.

The project site is composed of the Crocker Formation and the Quaternary deposits covering it, as shown in a geological map of **Fig.7-2**.

The main structural trend of the Crocker Formation in the Ranau area is from west-to-northwest to east-to-southeast.

Table 7-3 Stratigraphy of Northern Sabah



Note : This table is compiled and modified from "ANNUAL REPORT 1988, GEOLOGICAL SURVEY OF MALAYSIA"

7.3 Geological Outline of Naradaw Area

Fig. 7-2 shows a geological map of Naradaw area.

7.3.1 Topography

The Naradaw area is located in the upstream area of the confluence of the Liwagu River and the Mesilau River which exists 6 km to the west of Ranau Town. This area is found mountains and hills of elevation from 840 to 1,440 m. Through this area, the Liwagu River flows from west-to-northwest to east-to-southeast, and the Mesilau River flows from northwest to southeast or from north to south, and the two rivers join at a point to the south of Naradaw Village. The average gradient of the Liwagu River is approximately 1/19, and that of the Mesilau River approximately 1/15. The width of the Liwagu River and the Mesilau River is generally from 15 to 25 m. The relative height of ridge and river beds is from 100 to 150 m. Slopes generally have gradient of 20 to 45 degrees, and old and new forms of landslides are observed at some portions of the slopes.

7.3.2 Geology

The Naradaw area consists of sedimentary rocks of the Crocker Formation, the Pinosuk Gravels, terrace deposit, recent alluvium, colluvium, landslide deposit and talus deposit.

The Crocker Formation is made up of sandstone, shale and siltstone which form alternating layers. Slump structures, folds and faults are abundant in this formation. The formation strikes N70°E and dips 20°S in the vicinity of the confluence of the Liwagu River and the Mesilau River.

The Pinosuk Gravels are gravel layers that overlie the Crocker Formation. They are distributed on the ridges higher than elevation 900 to 1,200 m.

The terrace deposit and the recent alluvium cover the Crocker Formation and the Pinosuk Gravels, and they are distributed along the Liwagu River and the Mesilau River. These deposits mainly consist of round gravel from 30 to 200 cm in diameter, but rounded gravels having diameters over 5 meters are frequently included in the deposits.

The colluvium, the landslide deposit and the talus deposit are widely distributed on slopes and feet of mountains. As it is difficult to accurately classify these deposits, they are shown together on the attached map without classifying them.

7.4 Geology of Project Site

7.4.1 Liwagu Intake Facility Site

Fig. 7-3 shows a geological map of the Liwagu intake facility site.

(1) Topography

The Liwagu intake facility site is located on the Liwagu River, which is 2.7 km to the northwest of the confluence of the Liwagu River and the Mesilau River. The Liwagu River flows from west to east in this vicinity. The elevation of the river bed at the dam site is 1,048 m, where the river width is approximately 20 m, and the river gradient is approximately 1/10. On the left bank, there is a terrace having relative height of around 1 to 2 m and 20 m in width, and beyond this terrace is a steep slope which gradient is from 38° to 40°. The right bank is also a steep slope of 30°to 42° beyond a terrace which is 2 to 3 m in relative height and about 5 m in width. There is a small stream at approximately 25 m to downstream from the right bank of the dam site.

The terraces and slopes around the intake facility site are all covered by virgin forest except for a part to the upstream of the right bank of dam site. The trace of flood was confirmed up to 1 to 2 m from above the existing river bed based on the status of vegetation. There is no mark of landslide on the slopes near the intake facility site.

(2) Geology

The Liwagu intake facility site consists of the bed rock of the Crocker formation, the terrace deposit, the recent alluvium, the colluvium and the talus deposit, as shown in Fig.7-3.

No outcrop of the bed rock is found in the vicinity of the intake facility site, and the bed rock is covered with the recent alluvium, the terrace deposit and the colluvium. Outcrop of the bed rock is scarce in the nearby areas, and only outcrop is found at a part of right bank to the downstream. The bed rock at this outcrop strikes N50°W and dips 35°S. Results of core drilings conducted at approximately 30 m upstream of the dam site the bed rock of sandstone reached 0.8 to 3 m below river bed. Although this sandstone is found no bedding plane and hard, discontinuous planes such as joints are remarkably developed. These discontinuous planes are severely de-colored by oxidization due to weathering. Concerning faults, two faults have been confirmed by drill hole LT-1. Nd-value of sandstone measured by cone penetration test was more than 50. The permeability coefficient of sandstone based on Packer test is 5.8×10^{-4} to 8.9×10^{-4} cm/sec. Water levels in drill holes after drilling were 0.097 m deep in dill hole LT-1, and 4.60 m deep in drill hole LT-2. As for the reason why the water level of drill hole LT-2 was lower than the water level of the Liwagu River, it was surmised that there is an underground water path through discontinuous planes (cracks) in the bed rock which locally reduced the underground water level.

The recent alluvium at the dam site are mainly composed of rounded gravels of 10 to 30 cm in diameter. At downstream to the dam site, large gravels of adamellite over 5 m in diameter are scattered. Results of core drillings indicate that the thickness of the recent alluvium is from 0.8 to 3 m, and it is inferred that his thickness is similar at the dam site. Nd-value is more than 50, and the permeability coefficient measured by the open-end test is 1.1×10^{-2} cm/sec. The terrace deposit that distributes on both banks at the dam site and the headpond site is composed of rounded gravels of 10 cm or more in diameter the, similarly to the deposits of current river bed. The thickness of the deposit is inferred to be 1 to 4 m.

The colluvium and the talus deposit distributed on slopes are mainly composed of angular gravels of 1 to 10 cm in diameter which fell or moved from the upper part of the slopes. The thickness of the deposits is inferred to be 2 to 3 meters.

(3) Geotecnical Evaluations

Geotecnical evaluations of the Liwagu Intake Facility Site deduced by the geological investigations so far conducted are as presented below.

- It is inferred that the intake dam can be constructed on the foundation of the recent alluvium, the terrace deposit, etc. consisting of gravel layers and the bed rock of the Crocker Formation. The characteristics of these deposits and bed rock are such that they have sufficient bearing strength as the foundation of an intake dam which height is only several meters. It would also be possible to use the terrace deposit as the foundation of the headpond.

- The gravel layers such as the recent alluvium and the terrace deposit, and the Crocker Formation which would form the foundation of the intake dam have high permeability. In addition, a location was found in the Crocker Formation where the ground water level is lower than the surface water level of the Liwagu River. For these reasons, it would be necessary to conduct sufficient study on the measure of leakage of water in later stages.

- Although slopes near the intake facility site are covered with the colluvium and the talus deposit. They are in stable condition. Since the slopes will be slightly excavated in constructing the dam, and the groundwater level will rise from 0 to 2 m at feet of the slopes due to the dam, the effect on the stability of the slopes will be slight, and it is expected that the current stability of the slopes will be maintained as long as the vegetation and the river route are kept in current conditions.

7.4.2 Mesilau Intake Facility Site

Fig. 7-4 shows a geological map of the Mesilau intake facility site.

(1) Topography

The Mesilau intake facility site is located on the Mesilau River, which is 1.7 km to the north of the confluence of the Liwagu River and the Mesilau River. The Mesilau River meanders down from north to south in the area of the intake dam site. The elevation of river bed at the intake dam site is 1.035 m, the river width is about 30 m, and the river gradient is approximately 1/11. There is a terrace having relative height of 2 to 6 m on the left bank. To the right bank, there is a steep slope having gradient of 18° to 40° beyond a terrace having relative elevation of about 2 to 6 m and width of about 15 m. The headpond is planned on the terrace of the right bank.

The terraces and slopes around the intake facility site is covered with virgin forests. The mark of past flood was confirmed up to 1 to 2 m above river bed by observing the status of vegetation. No trace of landslide was observed on the slopes near the proposed intake facility site.

(2) Geology

At the Mesilau intake facility site, the Pinosuk Gravels, the recent alluvium, the terrace deposit, and the talus deposit are distributed as shown in **Fig.7-4.**

The outcrop of the Pinosuk Gravels is not found near the intake facility site, and the Pinosuk Gravels is covered with the recent alluvium, the terrace deposit and the talus deposit. The result of core drillings at dam site indicates that the Pinosuk Gravels exists at depth of 5.5 to 6.3 meters below beneath the current river bed, and this layer is a heterogeneous gravel layer of poor sorting mainly composed of angular to subangular gravels of 6 to 50 cm in diameter. These are sandstone gravels in matrix of sand and silt, which are slightly consolidated. Nd-value of the Pinosuk Gravels is more than 50, and the permeability coefficient measured by open-end test is 4.0×10^{-4} to 8.3×10^{-3} cm/sec. Water levels in drill holes after drilling were 1.37 m deep in drill hole LI-3 and 1.38 m in drill hole LT-4.

The recent alluvium at the dam site is composed of rounded gravels of 10 to 300 cm in diameter. Large gravels of adamellite over 5 m in diameter are scattered in the areas near the dam site. Results of core drillings indicate that the thickness of the recent alluvium is 5.5 to 6.3 m. The permeability coefficient *measured by open-end test is* 3.6×10^{-3} *to* 1.7×10^{-2} cm/sec.

The terrace deposit which is distributed on both banks of the intake dam and the headpond site are mainly composed of rounded gravels of 10 to 300 cm in diameter, similarly to the recent alluvium. It is inferred that the depth to the Pinosuk Gravels is around 7 to 10 meters.

The talus deposit distributed on slopes are mainly composed of gravels of 5 to 200 cm in diameter which fell from the upper part of the slopes. Their thickness is estimated to be more than 2 to 5 m.

(3) Geotecnical Evaluations

Geotecnical evaluations of the Mesilau intake facility site established by the geological investigations so far conducted are as presented below.

- In view of its scale, it is deemed possible to construct the intake dam on the foundation of gravel layers consisting of the recent alluvium and the terrace deposit. It would also be possible to base the headpond on the foundation of the terrace deposit.

- The permeability of the recent alluvium and the terrace deposit, which will form the foundation of the intake dam, is high. In view of this fact, it would be required to study the measures of leakage of water in later stages.

- The talus deposit are distributed on slopes around the site. The slopes seem be in stable condition. Since there will be slightly excavation on these slopes in constructing the dam, and the groundwater level will rise from 0 to 2 m at feet of the slopes due to the intake dam the effect of construction of the intake dam on the stability of slopes would be slight, and it is anticipated that the stability of slopes can be maintained so long as the vegetation and the river route are kept nearly to the current conditions.

7.4.3 Liwagu Pipeline Route

Fig. 7-2 shows a geological map of the Liwagu pipeline route.

(1) Topography

The Liwagu pipeline route is a route that runs from the Liwagu intake facility site to the top of the ridge located to the north of Naradaw Village, which total length is approximately 2.7 km. This pipeline mostly passes of mountain slope on the left bank of the Liwagu River at elevations from 1,046 to 1,022 m. The slope on which this pipeline passes is the southeastern slope of the ridge between the Liwagu River and the Mesilau River, with the maximum gradient of the slope being 50° to 20°, and the average gradient 25° to 30°. Cultivated farm lands and habitation exist on the top to meddle of this ridge. New collapses as well as old collapses was observed in some parts of the slope near the pipeline route. One new collapse was observed on the pipeline route. This new collapse is located approximately 0.2 km to the downstream from the Liwagu intake facility site, and it is 25 m wide and 25 m high.

(2) Geology

As shown in Fig. 7-2, the Liwagu pipeline route passes the Area where the Pinosuk Gravels, the colluvium, the talus deposit, landslide deposit and the Crocker Formation are distributed.

A part of the upstream section of the pipeline route extending for approximately 1.6 km is covered with the Pinosuk Gravels and other parts of this section are covered with the colluvium, the talus deposit and the landslide deposit. The bed rock of the Crocker Formation is distributed in the downstream section of 1.1 km.

The colluvium, the talus deposit and the landslide deposit that exist along the route of pipeline have usually collapsed or moved down the slope and thickly accumulate on the feet of slopes. These deposits mainly consist of angular gravels of 1 to 20 cm in diameter, sand and silt. The angular gravels are mainly composed of weathered sandstone of the Crocker Formation.

The Pinosuk Gravels is distributed in the pipeline route near a point which is 0.8 km to the downstream of the Liwagu intake facility site where elevation is 1,040 m. The Pinosuk Gravels is a gravel layer containing many rounded adamellite gravels of 30 cm or more in diameter.

Outcrops of the Crocker Formation are observed along the Liwagu River and the road. In this area, condition of the outcrops on the bed rock is generally not good. The Crocker Formation at outcrops consists of alternative layers of sandstone, shale, silt-stone and mudstone. This formation is characterized by flysch phase, and slump structures such as slump folding and slump breccia are observed. The formation in this area strikes

NW-SE or NWN-SES, and dips 20° N or S to 60° N or S. The strike and dip of the Crocker formation have remarkable variations because deformation and folding due to slump is severe, accompanied by creep deformation in slopes. Generally speaking, the development of cracks and weathering of this formation are outstanding.

(3) Geotecnical Evaluations

Geotecnical evaluations of the Liwagu pipeline route established by the geological investigations implemented up to the present time are stated below.

- It is inferred that the slopes on which the Liwagu pipeline route is currently planned are in stable condition for most of the sections, under the present conditions of topography, geology and vegetation. However, a new collapse was identified on the pipeline route approximately 0.2 km downstream of the Liwagu intake facility site. This collapse is 25 m wide and 25 m high. Although this collapse is small in scale and is not such a collapse that prohibits the implementation of this plan, attention must be given on the existence of this collapse in designing the pipeline.

- For the Liwagu pipeline, a route which mostly passes along steep slopes of mountains is being planned. For this reason, it would be required, in order to avoid disturbing the stability of slopes, to minimize excavation works on slopes, make provisions for protection of slopes, and provide appropriate draining facilities for rainwater.

- In installing the pipeline, it would be required to drive saddles down to sufficiently bearing stratum so that deformation of pipeline, such as the one caused by differential settlement, is avoided as much as possible.

7.4.4 Mesilau Pipeline Route

Fig. 7-2 shows a geological map of the Mesilau pipeline route.

(1) Topography

The Mesilau pipeline route runs from the Mesilau intake facility site to the top of a ridge which is to the north of Naradaw Village, the total length of the route being approximately 1.0 km. This pipeline runs mainly on mountain slope having elevation of 1,036 m to 1,022 m located on the right bank of the Mesilau River. The route passes the northeastern side slope of a ridge between the Liwagu River and the Mesilau River that runs to the direction of southeast. This slope has the maximum gradient of 45° to 15°, and the average gradient of 25° to 30° The top and slope of surrounding ridge on the pipeline have cultivated farmlands. A part of the downstream section of the pipeline route passes farm land. No clear evidence of landslide is found on slopes near the route.

(2) Geology

The area where the Mesilau pipeline route passes are distributed with the Crocker Formation, the terrace deposit, colluvium and talus deposit, as shown in **Fig.7-2**.

Along the upstream section of approximately 0.8 km of the pipeline route, the terrace deposit, the colluvium and the talus deposit are distributed in the order of this description from the upstream side to the downstream side. The Crocker Formation is mainly distributed in the downstream section of approximately 0.2 km.

The terrace deposit is made up of rounded gravels of 10 to 300 cm in diameter.

The colluvium the and talus deposits have fallen or moved from the slope top, and have thickly accumulated on the feet of slopes. These deposits mainly consist of angular gravels of 1 to 10 cm in diameter, sand and silt.

The Crocker Formation is not exposed along the route, and outcrops exist in some part of banks of the Mesilau River. It is inferred that the Crocker Formation along the route is embedded in the alternative layers of sandstone, shale, siltstone and mudstone, similarly to the ground along the Liwagu pipeline route. In this area, no continuous, large scale fault has been identified.

(3) Geotecnical Evaluations

The following geotecnical evaluations have been established for the Mesilau pipeline route based on the geological investigations conducted so far.

- The slopes on which the Mesilau pipeline route is being planned is regarded to be in stable condition so far as current conditions of topographical, geological and vegetation are maintained.

- In constructing a road along the Mesilau pipeline on slopes where the gradient is steep, it would be required to reduce the amount of excavation on the slopes to the minimum, to make provisions to protect slopes, and provide appropriate draining facilities for rainwater, in order to avoid disturbing the stability of the slopes.

- In constructing the pipeline, it would be required to drive down saddles down to sufficiently bearing stratum in order to avoid deformation of the pipeline due to differential settlement, etc.

7.4.5 Penstock Route

Fig. 7-5 shows a geological map of the penstock route.

(1) Topography

The penstock is planned on the route that runs from the joining point of the Liwagu pipeline route and the Mesilau pipeline route to the powerhouse, with the total length of 780 m. The Penstock Route is located on the southern end of a ridge between the Liwagu River and the Mesilau River from elevation 1,027 m to 854 m. A slope where the Penstock route runs have gradient of 2° to 32°, with the average gradient being 20°, and the ridge behind this route is being utilized for pastures, farm lands and human settlement. Old scarps of landslides are observed on steep slopes around the Penstock route.

(2) Geology

The areas where the penstock route passes is distributed with the bed rock of the Crocker Formation, and the terrace deposit, the colluvium and the talus deposit covering the bed rock.

Along the penstock route, the colluvium and the talus deposit are distributed in the section from elevation 1,030 to 1,000 m, and the section from elevation 980 to 945 m. These colluvium and talus deposit are composed of angular gravels of 1 to 10 cm in diameter, sand and silt, which have been supplied from the Crocker Formation. The angular gravels mainly consist of weathered sandstone. Results of core drillings on drill hole LP-1 and LP-2 indicated that the thickness of the colluvium and the talus deposit is from 1.9 to 4.6 m. N-value of these deposits is from 9 to 24, and the permeability coefficient by open end test is 1.2×10^{-4} to 2.0×10^{-4}cm/sec.

Near the penstock route, the Crocker Formation is exposed on the slope at elevation of nearly 970 m and 946 m. The Crocker formation strikes E-W and dips 20°N. The Crocker Formation at outcrops is composed of alternative layers of sandstone, shale and siltstone. These rocks are generally fractured, and development of cracks and weathering are outstanding. Results of core drillings indicate N-value of the Crocker formation of more than 13 to 50. In particular, N-value of siltstone is 13 to 27, being lower than N-value of sandstone. The permeability coefficient measured by packer test is 6.4×10^{-5} to 5.0×10^{-4} cm/sec. The water level in the holes after drilling was 17.63 m deep in drill hole LP-1, and 8.37 m deep in drill hole LP-2. Continuous and large scale fault hasn't been identified in this site.

The terrace deposit is distributed at the end of the penstock route is mainly composed of rounded gravels of 10 to 300 cm in diameter. Rounded gravels in diameter exceeding 5 m are scattered on the terrace.

(3) Geotecnical Evaluations

Geotecnical evaluations of the penstock route as established by the geological investigations conducted so far are as presented below.

- The slope of the ridge on which the penstock route is planned has low groundwater level and stable under the current conditions of vegetation and land utilization, and it is deemed possible to install the penstock.

- In installing the anchors and supports of the penstock, it would be required to excavate or drive piles down to sufficiently bearing stratum in order to assure the stability of anchors, since N-value in the bed rock is low on this ridge.

7.4.6 Powerhouse Site

Fig. 7-5 shows a geological map of powerhouse site.

(1) Topography

The powerhouse site is located on the terrace on the left bank of the Liwagu River at a location which is 100 m upstream from the confluence of the Liwagu River and the Mesilau River. This terrace has relative hight of 4 to 6 m above the current river bed.

(2) Geology

As illustrated in **Fig.7-5**, the powerhouse site is covered with the terrace deposit.

The terrace deposit is mainly composed of rounded gravels of 10 to 300 cm in diameter, and rounded gravels of adamellite, having diameters over 5 m, are scattered. Results of core drilling on drill hole LP-3 indicate N-value of 8 to more than 50, and measured values are widely scattered. The depth to the bed rock of the Crocker Formation is 17.1 m.

(3) Geotecnical Evaluations

A geotecnical evaluation of the powerhouse site based on the results of geological investigations conducted so far are as presented below.

- The powerhouse site is distributed on the terrace deposit, which is deemed to have sufficient bearing capacity as the foundation of a small scale powerhouse.

7.5 Seismicity

In this Section, the geological structures related to seismicity and seismic activity in the project area are described.

7.5.1 Geological Structure

Borneo has been formed by the Indo-China orogenic movement from Permian to Jurassic time and the Himalayan orogenic movement from Cretaceous to Quaternary time. The old formation of Borneo formed by the Indo-China orogenic movement, and today is exposed in the southwestern region of Borneo. The young formation is formed from the Himalayan orogenic movement is widely exposed in northeastern part of Borneo including Sarawak and Sabah States. This young formation lies from southeast to northwest direction.

The project area is located in sedimentary rocks, which is called the Northwest Borneo Geosyncline and formed during the period from Cretaceous to Tertiary time. In this region, folds and faults have been developed by intrusion of ultra-basic rocks and acidic rocks that occurred during the period from Miocene to Oligocene time of Tertiary age. Mountainous terrain almost similar to the current topography, including Mt. Kinabalu, is formed by the beginning of Quaternary age.

To analyze the general topography of Borneo from the new point of plate tectonics, Borneo is located at the southeastern part of the Eurasia Plate (Sunda Shelf), and borders the India Plate to the south and the Philippine Sea Plate to the east. The northeastern part of Borneo is a part of the belt which has been upheaved by the plunging of the India Plate and the Philippine Sea Plate into the Eurasian Plate (Sunda Shelf). In the region from the central part to the southeastern part of Sabah State, where the project area is included, ophiolite are found in the sedimentary rocks of Cretaceous age and Tertiary age. The ophiolite are deemed to be the obduction slab created by a oceanic crust of the Sulu Sea pushed up by the Eurasian Plate of the southeastern part of Borneo.

7.5.2 Seismicity

Borneo is separated from the Philippine Island Arc by more than 800 km, and from the Indonesian Island Arc by more than 500 km. For this reason, the seismicity on Borneo is less frequent as compared to those on the Philippine Island Arc or the Indonesian Island Arc. Seismicity maps of the world are shown in **Fig.7-6** and **Fig.7-7**.

Peninsular Malaysia and the southwestern region of Borneo form a part of the Sunda Shelf which is a part of Eurasian Plate, and this region is structurally stable in tectonic activities. On the other hand, the northeastern region of Borneo including Sabah State is moderately active in tectonic activities. The seismotectonic setting map of Malaysia is presented in **Fig.7-8**.

In the seismological data of earthquakes of Sabah State, 51 earthquakes are recorded during the period from 1897 to 1991. These records are given in **Appendix 2**. The maximum observed intensity map based on the modified Mercalli Scale, for the period from 1875 to 1983, is presented in **Fig.7-9**, and the distribution of earthquake epicenters of Sabah State is presented in **Fig.7-10**. As indicated by these figures, the earthquakes in Sabah State have magnitude of 4 to 5.9, and earthquakes having hypocenters at levels shallower than 70 km are dominant.

In the Ranau area where the project site is located, 5 earthquakes have been recorded so far. The recent earthquakes in the Ranau area are the two earthquakes that occurred at 18:59 and 19:17 on May 26, 1991. The former earthquake had a magnitude of 5.2, with the epicenter located at 21 km to the southeast of Ranau town, and the depth of hypocenter was approximately 33 km. The latter earthquake had a magnitude of 5.1, with epicenter located at 14 km to the southeast of Ranau town, and the hypocenter was approximately 33 km deep. The modified Mercalli Scale in Ranau area was V to VII. As for the damages caused by these earthquakes, it has been reported that cracks were formed in building pillars and walls in Ranau town. These earthquakes had the second highest magnitude among those observed up to today, being next to the earthquake occurring on May 18, 1966 (with 5.3 magnitude).

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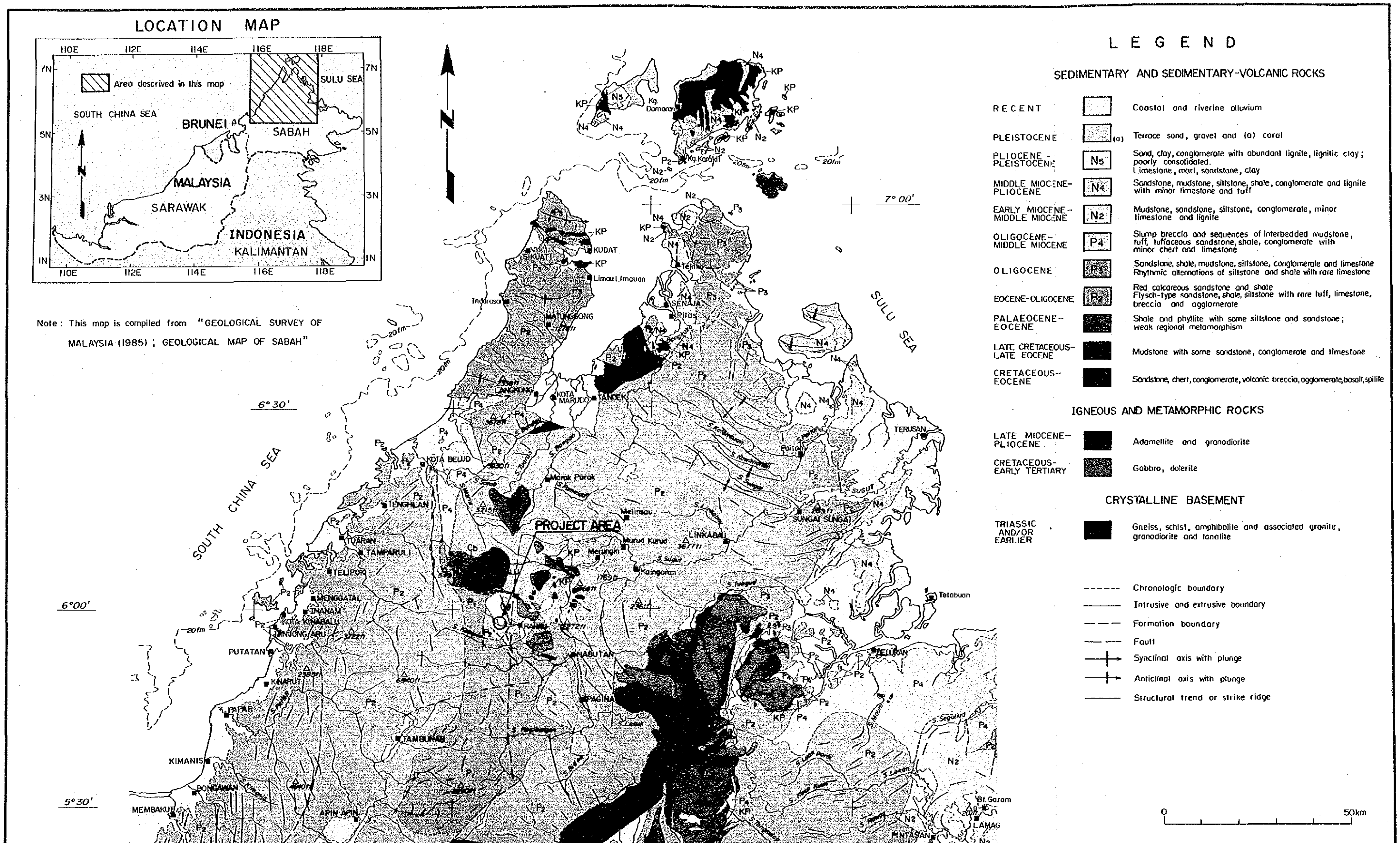
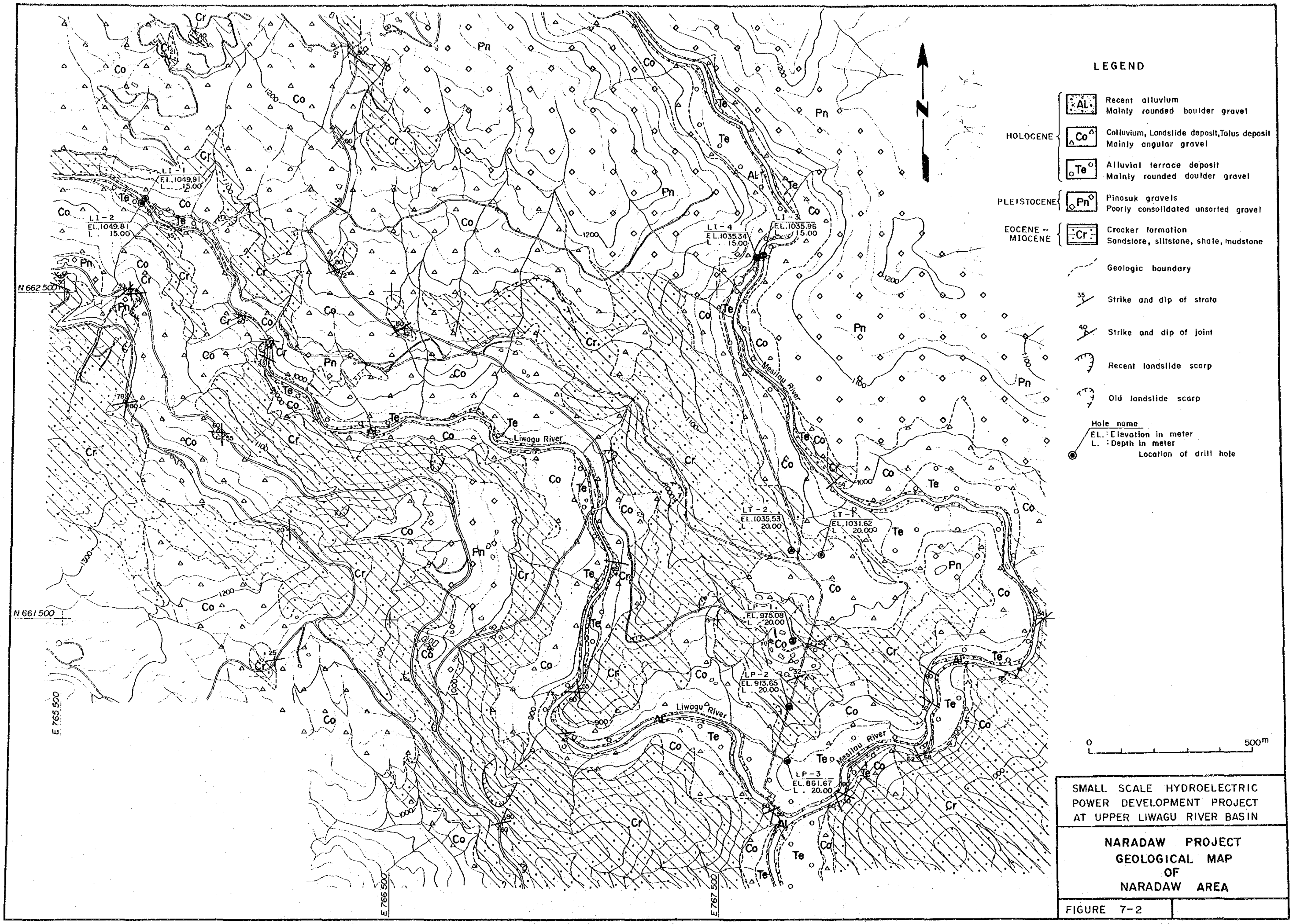


SMALL SCALE HYDROELECTRIC POWER DEVELOPMENT PROJECT AT UPPER LIWAGU RIVER BASIN

REGIONAL GEOLOGICAL MAP

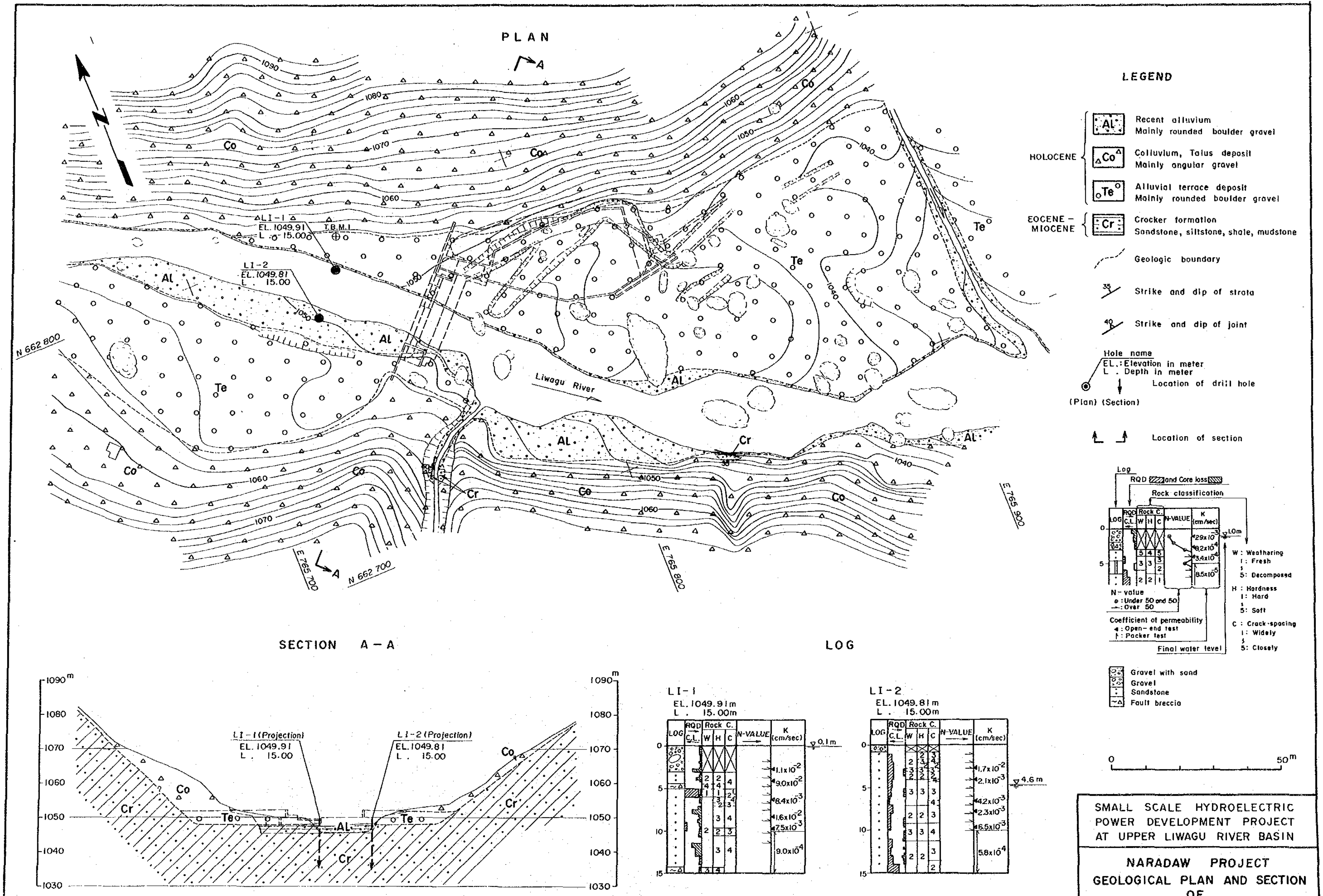
FIGURE 7 - 1



SMALL SCALE HYDROELECTRIC POWER DEVELOPMENT PROJECT AT UPPER LIWAGU RIVER BASIN

NARADAW PROJECT
GEOLOGICAL MAP OF NARADAW AREA

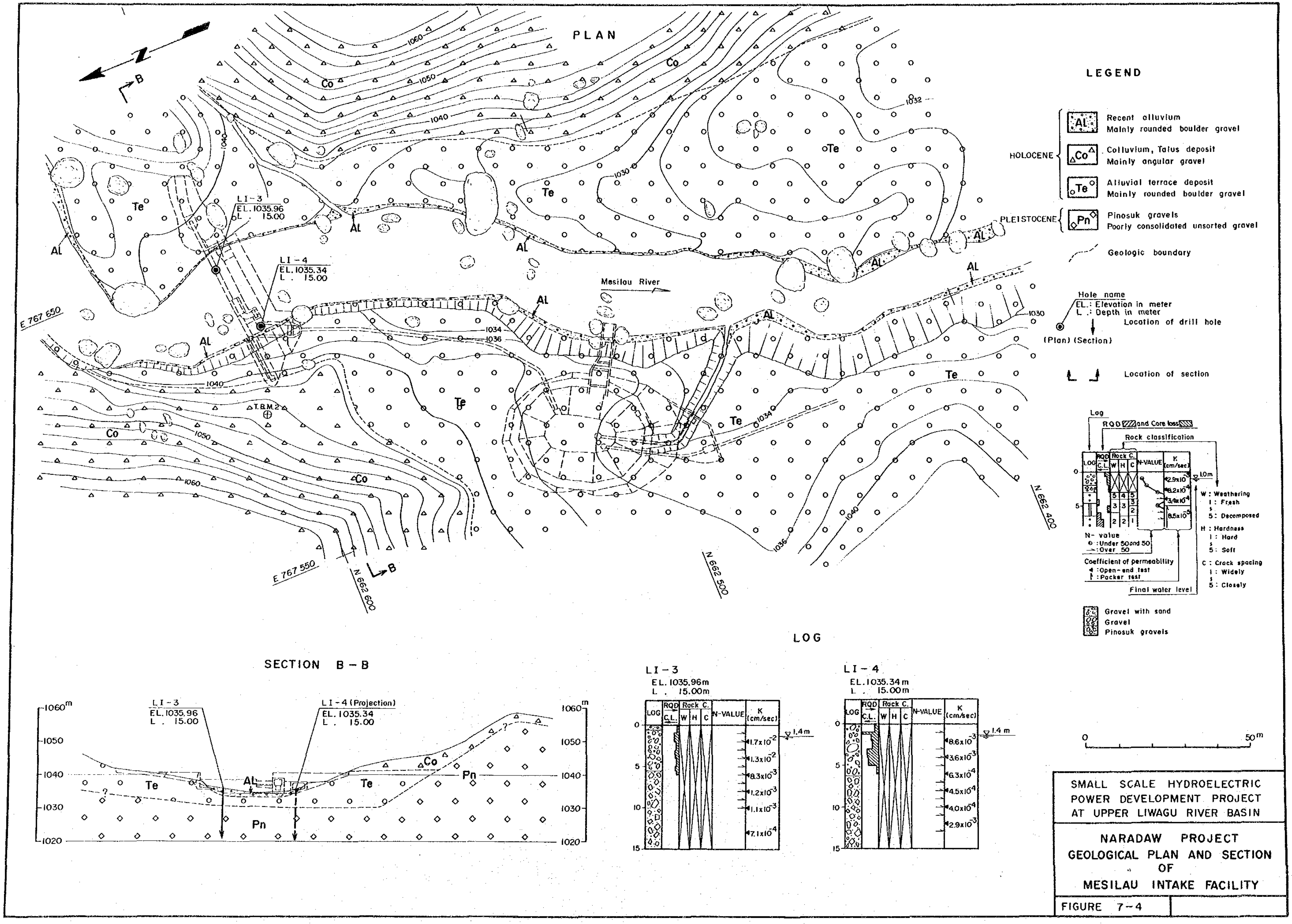
FIGURE 7-2



SMALL SCALE HYDROELECTRIC POWER DEVELOPMENT PROJECT AT UPPER LIWAGU RIVER BASIN

NARADAW PROJECT
GEOLOGICAL PLAN AND SECTION OF LIWAGU INTAKE FACILITY

FIGURE 7-3



SMALL SCALE HYDROELECTRIC POWER DEVELOPMENT PROJECT AT UPPER LIWAGU RIVER BASIN

NARADAW PROJECT
GEOLOGICAL PLAN AND SECTION OF MESILAU INTAKE FACILITY

FIGURE 7-4