3. GEOLOGY OF DAM SITES

3.1 Field Investigation

Geological investigation has been carried out during phase I of the study in order to clarify the sub-surface geological conditions. The investigation consists of field explorations including in-situ tests such as standard penetration test and permeability test to obtain the geotechnical data at six (6) dam sites. The location of the proposed dam sites is given in Figure B.1.1.1. The quantities of investigation are shown as below :

SiteName	Location		CoreBoring			
	Barangay	Municipality	Spot (nos)	Length (m)	SPT (times)	PT (times)
Diversion Dam	Tinago	Camalig	3	60	28	11
No.1	Taladong	Camalig				
No.2	Inarado	Daraga	4	60	36	9
No.3	Gabawan	Daraga				
No.4	Bascaran	Daraga				
No.5	SanRamon	Daraga	3	60	11	

Remarks) SPT : Standard penetration test, PT : Permeability test

(1) Camalig diversion dam site

The Camalig diversion dam is proposed at the Tinago River, where is approximately 50 m upstream from confluence with the Iraya River. The proposed dam site consists of flat plain on the right bank and gentle hill on the left bank, where the alluvial plain is abutted on the foot of Kikuinan mountain. The width of river is ranging from 5 to 10 m.

The proposed dam site is geologically composed of Tertiary Pliocene limestone and Quaternary flood deposits. Limestone is the bed rock with numerous solution cavities showing generally light gray coloured, massive, well consolidated and hard. Bed rock is generally covered with thick alluvial deposits on the river floor and right bank. A few outcrops of the limestone are found only on the foot of the cliff along the river. Although active fault called "San Vicent-Ligao Fault" is distributed at 1 km north from dam site, no evidence of fault structures and fissure zone are observed in and around the dam site.
The alluvial deposits developed on the river bed and right bank. The deposits consist of silt, sand and gravel originating from the eruptions of Mayon Volcano.

(2) No.1 dam site

The No.1 dam is proposed at the Taladong River in Barangay Taladong. A width of valley is 10 m to 20 m.
Bed rock of dam site consists of weathered, soft conglomerate and sandstone of Tertiary Miocene to Pliocene epoch covered by loose alluvial deposits. Several outcrops consisting of rather soft to semi-hard weathered rocks are observed on the cliff along the river. No field evidence of land sliding in large scale is found out around dam site and reservoir areas, because the slopes in the reservoir area are generally of low angle. Major fault and fissure zone are not also identified.

(3) No.2 dam site

The No.2 dam is proposed at Abgao River in Barangay Inarado. The river originates in northern hilly area and flows through the gentle hills. The valley developed widely has width ranging from 170 m to 190 m.

The site is underlain by consolidated sedimentary rocks of a geological age ranging from Tertiary Miocene to Pliocene. Bed rocks are composed of alternating beds of sandstone and shale covered with Quaternary deposits such as talus and river bed deposits. The rocks are generally gray coloured, massive well-consolidated and hard in fresh rocks. The rocks are, however, composed of highly weathered rocks, generally showing brown coloured soft and friable at outcrops.
The Quaternary deposits are brown coloured, mainly composed of un-consolidated silty clay to sandy silt partly containing fragments of bed rock. The deposits predominate on the valley and distribute in the narrow area on the foot of slope. No field evidence of land sliding is observed, because the slopes in the reservoir area are generally of low angle. Major fault and fissure zone is not also found out.

(4) No.3 dam site

The No.3 dam site is proposed at the Subok River in Barangay Gabawan. The dam is proposed at wide and shallow valley, and approximately 30 m downstream from the confluence of three streams.
Geology of dam site is featured by tuff breccia and basaltic andesite lava. Bed rocks are entirely cropped out at river. Tuff breccia distributes on the right bank and at downstream of dam axis showing light gray to pale brown coloured, rather soft and massive rock. On the other hand, the basaltic andesite lava predominates on the left bank and at upstream showing dark gray coloured, hard and cracky rock. According to the field reconnaissance, alluvial sediments consisting of loose sand and silt are estimated to be 2 to 3 m thick on the river bed. No field evidence of land slide and large fault are observed around the dam site.

(5) No.4 dam site

The No.4 dam is proposed at 3 km downstream of the No.3 dam site, the Patagok River in Barangay Bascaran. The site forms relatively steep hills that consist mainly of semi-hard rocks such as volcanic breccia, tuff breccia and tuff intercalated with thin lava, tuffaceous sandstone and conglomerate. The river flows with meanders and joins tributaries at 70 to 80 m upstream and downstream from the dam axis. Outcrops showing various coloured, well-consolidated and massive exposed along the river section. Alluvial deposits are very thin because the valley is steep and narrow.
Although the caving feature is formed at the top of left abutment of dam axis, no evidence of land sliding is found out in the reservoir area. Major fault and fissure zone are not also observed.

(6) No.5 dam site

The No.5 dam is proposed at the Ogod River in Barangay San Ramon which originates near Barangay Anislag and flows west-ward with many meanders. The dam and reservoir areas are composed of gentle to moderate sloping hills. The slope on the left abutment is about 15 to 30 degrees. The right abutment is more gentle with a slope of about 10 degrees. A width of valley is 40 m to 60 m at the dam site.

The dam site is underlain by consolidated sedimentary rocks of Tertiary Miocene to Pliocene epoch. Bed rock is composed of an alternation of sandstone and conglomerate with siltstone lens covered by alluvial deposits. Tuffaceous sandstone showing gray coloured is exposed along the river bed, massive and rather soft to semi-hard rock. Siltstone is light gray and massive ; more soft and less-consolidated than the sandstone ; and distributes at higher portion on the left bank. The Quaternary deposit is brown coloured, mainly composed sandy clay to silty sand with traces of rock fragment. The width of dam is about 15 m to 35 m and thickness ranges from 1 m to 3 m.
No field evidence of land sliding is observed around dam and reservoir areas. Major fault and fissure zone are not also identified.

3.2 Geological Condition of Dam Sites

(1) Camalig diversion dam site

The foundation rock consists of consolidated hard limestone. Bed rock is divided into two zones namely highly weathered rock zone and moderately weathered rock zone due to weathering conditions (refer to Fig B.3.2.1). Highly weathered rock is weakened by weathering generally showing brownish gray coloured, soft and friable. The thickness ranges from 0 m to 9 m at the dam axis. The N-value respectively ranges 32 to more than 50. According to the permeability tests, permeability in the highly weathered rock zone shows considerably high from 36 to more than 100 lugeon unit (in the order of 10^{-4} to 10^{-3} cm/sec).
Moderately weathered rock is pale brown to white coloured consolidated massive hard rock. This zone lies 5 m below the ground surface on the left bank and 10 to 19 m on the right bank. Permeability in the moderately weathered rock is relatively high in the order of 10^{-5} to 10^{-4} cm/sec (6 to 47 lugeon unit). The result of lugeon tests is summarized in Table B.3.2.2 and Figure B.3.2.7, respectively. Lugeon map is given in Figure B.3.2.2.
The river debris are loose to medium dense silty sand and medium plastic, silty clay with a thickness of about 5 m to 10 m. While the N-value of this deposits ranges from 3 to 39, the majority of N-value are less than 20.
The groundwater table exists in shallow depth from the ground surface.

(2) No.2 dam site

Geological conditions of dam site consist of alternating beds of fractured sandstone and shale covered by alluvial sediments. Bed rock is underlain the alluvial sediments consisting of the majority of medium plastic and silty clay with a thickness of about 3 m. Bed rock is divided into three zones such as highly weathered zone, moderately weathered zone and slightly weathered to fresh rock zone (refer to Fig B.3.2.3). Highly weathered rock zone occupys the layer of 6 to 8 m from the ground surface. Highly weathered rock is weakened, generally showing brown coloured soft and friable. The N-value of this zone is generally of 6 to 32, the average N-value is less than 16. This means the layers have insufficient bearing capacity and shear strength for dam foundation. The N-value of the moderately weathered zone is more than 30, and the permeability is mostly less than 2 lugeon unit. Results of permeability tests are shown in Table B.3.2.2 and Figure B.3.2.7 to B.3.2.8, respectively. Lugeon map is provided in Figure B.3.2.4. Moderately weathered rocks are generally grayish brown coloured, well-consolidated massive and hard rocks. Moderately weathered zone lies in a depth of 5 to 8 m below the ground surface. Slightly weathered to fresh rocks are coloured brownish gray to gray, and well-cemented massive and hard. The groundwater table exists in relatively deep portion from the ground surface.

(3) No.5 dam site

Geological condition of dam site consists of rather soft to moderately hard sandstone and conglomerate with siltstone. Bed rock is underlain the alluvial sediments consisting of slight to medium plastic silt with a thickness of about 1 m to 3 m. The N-value of this sediment is of 3 to 22, and the average N-value is less than 10.
Bed rock is divided into three zones, highly weathered zone, moderately weathered zone and slightly weathered to fresh rock zone (Fig B.3.2.5). Highly weathered rock is weakened, generally showing brown coloured soft and friable. This zone is observed at the top of the left bank. Moderately weathered rock is coloured brownish gray and well-consolidated massive and hard rock. This zone underlies the alluvial deposits with a thickness of 3 m to 5 m. The N-value of moderately weathered rock is more than 42, and the permeability is less than 7.5 lugeon unit. Slightly to fresh rock is coloured dark gray and very hard and massive rock. This zone lies 2 m to 7 m below the ground surface. Permeability of this zone shows mostly less than 1 lugeon unit. The ground water table is relatively low because both abutment forms thin ridge.

3.3 Recommendation

(1) Camalig diversion dam site

The alluvial deposits are not reliable for foundation of the structure in term of bearing capacity. Foundation of pile will be required to be more than 20 of N-value. The length of pile will be estimated about 9 m on the right bank, 5 m on the river bed and left bank, respectively.
The design values of formation are presumed as follows:

(i) Alluvial deposit

Left bank : D = 0 ~ 5.55 (m)
N = 7
$\phi = \sqrt{15N} + 15 = 25$ (°)
qu = N/8 = 0.9 (kg/cm^2)
C = qu/2tan (45° = ϕ/2) = 0.29 (kg/cm^2)

River bed : D = 0 ~ 4.4 (m)
N = 11
ϕ = 27 (°)
qu = 1.4 (kg/cm^2)
C = 0.43 (kg/cm^2)

D = 4.4 ~ 10.4 (m)
N = 37
ϕ = 39 (°)
qu = 4.6 (kg/cm^2)
C = 1.1 (kg/cm^2)

Right bank : D = 0 ~ 9.1 (m)
N = 12
ϕ = 28 (°)
qu = 1.5 (kg/cm^2)
C = 0.45 (kg/cm^2)

(ii) Highly weathered bed rock : T = 0.5 ~ 2 (m)
N = 45

where, T : Thickness of complete weathered zone
N : Average N-value
Ø : Angle of shearing resistance
qu : Uniaxial shear strength
C : Cohesion

(2) No.1 dam site

As of the result of field reconnaissance, geological conditions of dam site seems to have enough bearing capacity as foundation.

(3) No.2 dam site

1) Excavation of core trench

Suitable dam foundation is moderately weathered rock. The overburden and unsuitable rock should be respectively removed approximately 6 m at the both abutments and 8 m at the valley bed.
The design values of formations are presumed as follows :

(i) Alluvial deposit : D = 3 ~ 7 (m)
N = 4.7

$\phi = 23\ (^\circ)$
$qu = 0.6\ (kg/cm^2)$
$C = 0.19\ (kg/cm^2)$

(ii) Highly weathered bed rock:

$D = 6 \sim 8\ (m)$
$N = 14.4$
$\phi = 30\ (^\circ)$
$qu = 1.8\ (kg/cm^2)$
$C = 0.52\ (kg/cm^2)$

2) Excavation of shell zone

The alluvial deposits are not reliable for foundation of the shell zone. It is therefore recommended to remove all the river alluvial deposit for the entire dam foundation.

(4) No.3 dam site

Judging from the field reconnaissance, geological condition of damsite seems to be suitable for the foundation of small earth fill dam.

(5) No.4 dam site

According to the field reconnaissance, geological conditions are presumed to be enough bearing capacity and shear strength.

(6) No.5 dam site

Suitable dam foundation is moderately weathered rock zone. The excavation depth for foundation is required about 5 m at the both abutments and 3 m to 5 m at the valley bottom. The alluvial deposit is not reliable for foundation of shell zone of the fill type dam. The high dam will not be recommended at this site, because highly weathered rock zone predominates up to 5 m from the surface at the thin ridge on the left bank. It is recommended to remove all alluvial deposit to prepare dam foundation. The rim grouting will be necessary for water tight at the thin ridge on the left bank.

4. SOIL MECHANICS

4.1 *Field Investigation*

Investigations on soil mechanics were carried out in order to clarify soil mechanics of construction materials for dam such as rock materials, soil materials and concrete aggregates. The field survey was conducted at the following locations :

1)	Rock materials (Concrete aggregates)	:	Fresh rock in/around the proposed dam site, and Flood deposits of Mayon Volcano
2)	Soil materials	:	Highly weathered rock at surface in/around proposed dam sites

Six (6) test pit borings were carried out, and samples were taken from those test pits for physical tests in laboratory. Location and quantities of the field works are given in Fig B.4.1.1 to Fig B.4.1.2 and Table B.1.1.2, respectively.

According to the field reconnaissance and review of data available, soil mechanics of the materials is summarized as follows:

1) Rock in and around the dam sites is mainly composed of clastic sedimentary rocks and pyroclastic rocks of geological age, ranging from Miocene to Pliocene of Tertiary period.

2) Clastic rocks are composed of sandstone, shale and conglomerate which are moderately consolidated soft to semi-hard rocks. Pyroclastic rocks consist of mainly lava flow, agglomerate, volcanic breccia, tuff with interbeded clastic sedimentary rocks. The rocks are also moderately consolidated soft to hard rock. Hard rocks such as lava are limitedly distributed at the north and northeast part of the Study Area. They are overlain by thick weathered zone and somewhere consist of alternating beds of tuff and tuff breccia.

3) Reasonable sources of rock materials including sand and gravel are identified at the flood plain of the Mayon Volcano. There is existing operating gather place near the proposed quarry site. Quantity and quality of rock and sand will be satisfactory for dam construction except for the gravels which are porous and light.

4) Random materials could be borrowed from the damsite. The clastic sedimentary rocks and pyroclastic rocks can be used as the random material.

5) Impervious material can be borrowed from the complete to highly weathered rock zones which exist widely around the dam sites. However, impervious material exists at less than 1 to 3 m thick of top layer of the zone.

6) Sand and gravel can be borrowed from river bed, however, the volume of deposits is very small.

4.2 Laboratory Test

Laboratory tests were carried out for 10 samples taken from the 6 test pits. The test samples including classification of materials are summarized below and the items and quantities conducted in laboratory are listed in Table B.1.1.3.:

Classification	Testpit No.	Damsite No.	Depth (m)	Remarks
Soil Material	TP1	No.5	0.5-1.0	Complete weathered sandstone
			1.0-1.5	Highly weathered sandstone
	TP2	No.4	0.5-1.0	Complete weathered muddstone
			1.0-2.0	Highlyweathered mudstone
	TP3	No.3	0.5-1.0	Complete weathered lapilli tuff
			1.0-2.0	Highly weathered lapilli tuff
	TP4	No.2	2.0-3.0	Complete weathered andstone
			3.5-4.0	Complete weathered sandstone
Rock Material	TP5	--	0.0-0.8	sandand gravel
	TP6	--	0.0-1.0	sandand gravel

4.2.1 Soil physical test

Physical tests were carried out based on the ASTM standard. The results are described below (Table B.4.2.1, to be referred) :

(1) Specific gravity test

The results of specific gravity test for soil particles are :

Soil	Lowest	Highest	Mean
Completeweatheredrocks	2.40	2.65	2.53
Highlyweatheredrocks	2.55	2.60	2.57

Specific gravity ranges from 2.40 to 2.65. The values show a little different from the generally acknowledged value for inorganic soil (ranging 2.6 to 2.8). Only the specific gravity samples which are obtained at TP3 and TP4 show the values of more than 2.6.

(2) Grain size analysis test

The results of grain size analysis are shown in Fig B.4.2.2. The values of Rp (percent of the grains finer than No.200 sieve) for each sample are summarized as follows :

Soil	Rp (%)		
	Lowest	Highest	Mean
Completeweatheredrocks	60	81	71
Highlyweatheredrocks	50	68	59

The Rp value is one of the indications to judge appropriateness of embankment materials for the impervious zone. In general, the soils having Rp of over 20 % are judged to be appropriate, but cracking can easily occur on the materials which have extremely high Rp value.
According to the results of grain size analysis, the materials hardly contain gravels of more than 4.76 mm. However, judging from observation of test pit profiles except TP4, soil materials taken from highly weathered zone are same mixture with gravels in natural condition.

(3) Water content test

Water content test is carried out by using soild samples which the perticle size is less than 4.76 mm. The results are summarized below.

Soil	Water Content (%)		
	Lowest	Highest	Mean
Completeweatheredrocks	50	87	61
Highlyweatheredrocks	59	76	65

The natural water contents of samples are much higher than the liquid limits. However, according to the result of compaction tests, the natural water content of sample is expected to be approximately 35 % which shows mean value of Wopt and WD95. The ambiguity of water content value would be caused by sampling procedure during heavy rainfall.

(4) Atterberg limit test and Shrinkage factor test

Atterberg limit test carried out using the samples of less than 0.42 mm, and the results are summarized below:

Soil	Liquid Limit (%)			Plastic Limit (%)		
	Lowest	Highest	Mean	Lowest	Highest	Mean
Completeweatheredrocks	50	64	54	27	35	30
Highlyweatheredrocks	47	62	52	24	31	29

Fine-grained soil shows moderate to high plasticity and has high resistance against piping phenomena.
The results of shrinkage factor test are summarized below :

Soil	Shrinkage Limit (%)		
	Lowest	Highest	Mean
Completeweatheredrocks	3.9	37.1	22.5
Highlyweatheredrocks	15.6	30.4	24.7

4.2.2 Soil mechanical test

(1) Compaction test

The results of compaction test are shown below :

Soil	γ dmax (t/m^3)	Wopt (%)	D95 (t/m^3)	WD95 (%)	Wf-WD95 (%)
Complete weathered rocks	1.31	31.5	1.25	37.9	22.8
Highly eathered rocks	1.29	32.8	1.22	39.5	25.7
	(1.37)	(28.3)	(1.30)	(33.5)	(26.6)

Remarks) γ dmax : maximum dry density
Wopt : optimum water content
γ D95 : dry density to obtain 95 percent of γ dmax
WD95 : highest water content to obtain 95 percent of γ dmax
Wf : natural water content
( ) : mean except the data of TPI

The value of (Wf-WD95) is considerably high because sampling have been made in the rainy season. Natural water content is anticipated approximately 35 % because of the mean of Wopt and WD95. The value of ranges from 1.12 to 1.38 g/cm^3. Those value are a little different from the generally acknowledged value for soil material (ranging 1.5 to 2.0 g/cm^3).

(2) Triaxial compression test

The results of triaxial compression tests on remoulded samples are shown below (see Table B.4.2.1). The size of specimens is 3.5 cm to 3.7 cm diameter.

Soil	Specimen Condition		Shearing Strength					
			UU		CU			
	γ dmax Wopt	WD95	Cu (kg/cm^2)	ϕu (°)	C (kg/cm^2)	ϕ (°)	C" (kg/cm^2)	ϕ' (°)
Complete weathered rocks	O	--	0.42	6	–	–	--	–
	–	O	0.48	8	–	–	–	–
Highly weathered rocks	O	–	–	–	0.31	12	–	--
	–	O	–	–	0.22	10	–	--
	O	–	–	–	–	–	0.30	21
	–	O	–	–	–	–	0.27	16

Remarks Number shows the mean values except the singularity.

The results of the UU tests gave relatively high cohesion and internal friction except for two UU tests which are conducted of full saturation samples. The materials extending at the dam sites have a little low shearing strength.

(3) Permeability test

The results of permeability tests on remoulded samples are shown below (see Table B.4.2.1). The permeability tests were performed using the 100 mm and 50 mm diameter mould.

Soil	Permeability Coefficient (cm/sec)		
	Lowest	Highest	Mean
Complete weathered rocks	9.2×10^{-8}	4.0×10^{-6}	$8.0 \text{-} 10^{-7}$
Highly weathered rocks	impermeable	2.0 x 10CV	--

Coefficient of permeability of impervious zone is determined to be less than 1×10^{-5} cm/sec for design, because the result of laboratory test shows a value of less than 1×10^{-6} cm/sec.

4.2.3 Concrete aggregate test

Laboratory on quality of concrete aggregate tests were carried out using sand and gravel samples obtained at flood plain of the Mayon Volcano and drilling core of clastic sedimentary rocks at the proposed structure sites. The aggregate tests were carried out based on the ASTM standard. The detailed test results are shown in Table B.4.2.2 and Figure B.4.2.3, respectively.

(1) Specific gravity

The results of specific gravity test are shown below :

Sample	Location	Bulk Specific Gravity	
		Saturated Surface-dry	Oven-dry
Sandand gravel	Busay	2.38	2.25
	Sua	2.43	2.31
Shale	Inarado	2.56	2.47
	San Ramon	1.95	1.58
Limestone	Del Rosario	2.08	1.81

Remarks) Number shows the mean value.

According to the standard of ASTM, the specific gravity of concrete aggregate required 2.5 or over. The results indicate low quality, while sand and gravel are currently utilizing as concrete aggregate in the Study area.

(2) Grain size analysis test

The grain size analysis test for aggregates are summarized below:

Sample	Location	Content of Gravel (%) No Passing 4.76 mm sieve	Content of Fine-grain (%) Passing 74μ sieve
Sandand gravel	Busay	58	3
	Sua	36	1

From the above results, the Mayon flood deposits contain more than 36 % of gravels staying 4.76 mm sieve. These materials are suitable for the aggregates of concrete. If the aggregates contain a lot of particles passing 74 É sieve, the mortar would become weak.

(3) Water absorption test

The test results of absorption are shown below:

Sample	Location	Percentage of Absorption(%)
Sandand gravel	Busay	5.7
	Sua	5.3
Shale	Inarado	3.6
	San Ramon	25.0
Limestone	Del Rosario	15.5

According to the standard of ASTM, the absorption of concrete aggregate should be less than 3.0 %. Sand and gravel of the Mayon flood deposits shows a little high value.

(4) Unit weight test

The test results of unit weight are shown below :

Sample	Location	Unit Weight (g/cc)	
		Loose	Rodded
Sandand gravel	Busay	1.35	1.51
	Sua	1.54	1.71

(5) Soundness Test

The test results of soundness which is carried out by sodium sulfate method for sand and gravel are shown below :

Sample	Location	Soundness Loss (%)	
		Coarse Aggregate	Fineaggregate
Sandand ravel	Busay	1.27	1.24
	Sua	1.24	0.75

Remarks) Coarse aggregate 2" max size
Fine aggregate 4.75 mm max size

The values of soundness loss ranges from 0.75 % to 1.27 % which the materials are stable.

(6) Unconfined compression test

The test results of unconfined compression are shown below :

Sample	Location	Compression Strength (kg/cm^2)		
		Lowest	Highest	Mean
Sandandgravel	Busay	372	619	462
	Sua	305	679	442
Sandstone/conglomerate	San amon	54	77	62

Remarks Number of San Ramon shows the values except the singularity.

According to the standard of ASTM, the compression strength of concrete aggregate and rock material should be more than 500 kg/cm^2. Sand and gravel of the Mayon flood deposits shows a little low value.

4.3 Evaluation of the Construction Materials

4.3.1 Construction materials

According to the geological investigation, the construction materials such as hard rocks for riprap and concrete aggregate are found out in the specified areas of the Study area. They are overlain by thick weathered zone and somewhere consist of alternating beds of low quality rocks. Source of rock material was not found within a distance from each dam sites. Quarry sites of sand and gravel are proposed at Busay and Sua where much volume will be expected. Although the physical test results of material samples indicate a little low quality, the deposits are currently using for concrete aggregates and riprap in the Gabawan SWIM Project adjacent to the Study area.

Earth materials for construction can be obtained from the complete to highly weathered rocks which are widely distributed around the dam sites. Impervious material shall be gathered extensively. Borrow areas are identified at each dam sites (see Fig B.4.1.1(1)).
Since the weathered rocks at the borrow site easily changed into fine material through the exposure to air and water. It should be paid carefully attention to use of unstable weathered rocks.
The irrigation canal routes are covered mainly with weak consolidated rocks such as tuff, tuff breccia, conglomerate, sandstone and shale of the Miocene to Pliocene epoch, and unconsolidated deposits of Quaternary period. The materials composed of sandy silt to silty sand which might be a little erosive.

4.3.2 Design value

Based on the results of laboratory tests, the design values of earth material are presumed as follows:

(i) $$\gamma d = \frac{\Sigma (\gamma dmax \times 0.95)}{n} = 1.24 \ (t/m^3)$$

(ii) $$Wf = \frac{Wopt + WD95}{2} = 35\ \%$$

(iii) $$\gamma t = (1 + Wf/100) \times gd = (1 + 35/100) \times 1.24 = 1.67\ (t/m^3)$$

(iv) $$\gamma sat = \frac{Gs + e}{1 + e} = \frac{2.55 + 1.06}{1 + 1.06} = 1.75\ (t/m^3)$$

where, Gs : 2.25
γd : 1.24
$e = Gs/\gamma d - 1 = 1.06$

(v) $$\gamma sub = gsat - 1 = 0.75\ (t/m^3)$$

(vi) $Cu = \dfrac{0.27 + 0.31 + 0.57 + 0.61 + 0.51}{5} = 0.45\ (kg/cm^2) = 4.5\ (t/m^2)$

$C' = \dfrac{0.20 + 0.27 + 0.39 + 0.26}{4} = 0.28\ (kg/cm^2) = 2.8\ (t/m^2)$

(vii) $\phi u = \dfrac{6.0 + 3.5 + 6.0 + 5.5 + 14.5}{5} = 7^\circ$

$\phi' = \dfrac{20 + 16 + 21 + 15.5}{4} = 18^\circ$

(viii) $k \leq 1 \times 10^{-5}$ cm/sec

5. HYDROGEOLOGY

5.1 General Hydrogeology

Hydrogeology in and around the Study Area is broadly divided into four zones, such as pyroclastic rocks zone in northern part of the Study Area, limestone zone expanding westward from Barangay Del Rosario area, clastic sedimentary rocks zone in the southern to eastern parts of the area and alluvium zone in lower slopes of Mayon Volcano and in southern low land from Kikuinan mountains. The geological and topographical classifications of the Study Area are shown in Fig B.5.1.1.

Pyroclastic rocks form hilly areas and have a plenty springs which originate at portions of cracky lava flow. Limestone zone mainly consists of limestone which is generally coralline and porous, grading from the lower marly facies to an upper section. Clastic sedimentary rocks zone consists of weakly to well cemented sandstone, conglomerate and siltstone. Alluvium in the lower slopes of Mayon Volcano are composed of Mayon pyroclastics and volcanic ejecta, and the alluvium in the southern low land from Kikuinan mountains mainly consists of sand, clayey silt and silty clay.

In accordance with DPWH's data on ground water in and around the Study area, shallow wells which the well depth is ordinary 7.5 m to 10 m, can generally product ground water in a whole areas. Ground water table ranges from 4 m to 6 m below the ground surface, and production yield ranges from 0.3 lit/sec to 0.5 lit/sec. In case of deep wells with a well depth of 15 m to 24 m, ground water table ranges from 6 m to 18 m below the ground surface and seasonally varies from 1 m to 4 m. Production yield ranges from 0.3 lit/sec to 0.5 lit/sec. Well length and ground water depth are summarized in Fig B.5.1.2 and Fig B.5.1.3.

5.2 Test Well Drilling

Test well drillings with a depth of 30 m were provided at the selected three sites in order to clarify the hydrogeological condition. The GW1 well and the GW2 well are located in the south of the Study Area where provides a dominance of clastic sedimentary rocks. Furthermore, the GW3 well is selected in the west of the Study Area, where some potential will be anticipated because of the lithological condition represented by wide predominant limestone. Location map is shown in Fig B.5.2.1.

5.2.1 GW1 test well

Test well No.1 is located on the gentle hill in Barangay San Ramon. Geology of the well is featured by complete to highly weathered sandstone, siltstone and shale. Drilling core up to 20 m from the ground surface is of deeply to totally weathered shale, siltstone and residual soil decomposed after sandstone. This layer is underlain by alternating beds of sandstone and siltstone which are well cemented, indurated and massive formation. According to the permeability test, permeability coefficient of the layer ranges almost 1.84×10^{-5} cm/sec to 2.83 $\times 10^{-5}$ m below the ground surface shows the permeability coefficient to be 9.13×10^{-5} cm/sec of semi-pervious formation. Ground water table was observed at the depth of 8.5 m from the ground surface.

5.2.2 GW2 test well

Test well is located at flat hill side in Barangay Anislag. Geology of the well consists of poorly cemented/indurated and moderately weathered alternating beds of calcareous sandstone and coralline limestone. Drilling core of test well indicates that the bed rock is generally calcareous in composition having numerous solution cavities and highly fractured. The permeability coefficient of this formation is ranging of 3.50×10^{-4} cm/sec to 1.18×10^{-3} cm/sec. This value indicates that the formation is very porous and pervious. Ground water level was generally high, at the depth of 2.6 m from the ground surface.

5.2.3 GW3 test well

Test well No.3 is located on the flat plain in the front of rolling hills in Barangay Del Rosario. The geology of well is massive, moderately weathered and semi-hard to hard limestone. Limestone is generally fossiliferous and coralline. Although the pyroclastic and clastic sedimentary rocks were reported to lie beneath and caps this limestone formation, no evidence of distribution of these rocks were observed in the test well site. The sub-surface investigation by core drilling indicates that the well site is underlain generally by coralline limestone with numerous solution cavities. The permeability of this formation ranges almost 9.75×10^{-5} cm/sec to 1.38×10^{-4} cm/sec except for the highly weathered zone which lies in a depth of 5 m below the ground surface and the permeability coefficient is 1.37×10^{-5} m/sec. Ground water table was measured at the depth of 4.1 m from the ground surface.

5.3 Aquifer Test

5.3.1 Design of test well and procedure

Aquifer tests were conducted in the three exploratory wells. These well design are shown in Fig B.5.3.1. The pump was a 5 Hp submersible pump with a diameter of 101.6 mm. Pumps are set at the depth of 27 m in the three wells. The diameter of the discharge orifice is 56.25 mm.

5.3.2 Result of aquifer test

(1) GW1 test well

First trial, the pump was operated at full capacity of 4.41 lit/sec. The well dried up within 10 minutes of pumping with a drawdown of 15.82 m, and specific capacity of 0.28 lit/sec/m. In the subsequent operation, the pump discharge was reduced to 0.178 lit/sec. The aquifer test lasted for about 25 minutes. In the third trial, the pump discharge was reduced to its allowable minimum discharge rate of about 0.155 lit/sec. The test also lasted for about 25 minutes before the well dried up.

The Boulton's method was applied, however, the data is very limited and the obtained result may not be reliable, so the transmissibility values is calculated based on the recovery conditions using Jacob's method. Transmissibility value is 0.38 m^2/day in the recovery test.

(2) GW2 test well

The constant discharge test was successfully conducted. The analysis result gives transmissibility values of T_1=44 m^2/day and T_1=64 m^2/day using Boulton's method. The Jacob's method was also applied in analyzing both the time-drawdown and the recovery. The results of evaluation are summarized as below.

Well No	Transmissibility (mCQ/day)			Permeability (m/day)
	Time-Drawdown	Recovery	Average	
GW1	T_1 = 1.15 (B)	* T = 0.38 (J)	T = 0.38	0.04
	T_2= 2.44(B)			
GW2	T_1 = 44.0 (B)		T = 41	0.50
	* T_2 = 64.0 (B)			
	T_1 = 162 (J)	T_1 = 117 (J)		
	* T_2 = 26.6 (J)	* TCQ = 32 (J)		
GW3	T_1 = 1.60 (B)	T_1 = 21.6(J)	T = 1.89	0.10
	* T_2= 1.96 (B)	* T_2 = 1.82 (J)		

(B) : Boulton's method (J) : Jacob's method

(3) GW3 test well

The constant discharge test was successfully conducted. Transmissibility values are obtained as follows; T_1=1.60, T_2=1.82 m^2/day for the time-drawdown and T_1=21.6, T_2=1.82 m^2/day based on the recovey using Jacob's method.

5.4 Evaluation of Ground Water Development

5.4.1 Potential yield of limestone and clastic sedimentary rocks

Clastic sedimentary rocks zone and limestone zone have low transmissibility of less than 42 m^2/day
(almost 0.4 m^2/day to 1.8 m^2/day), and potential yield is less than 0.5 lit/sec. The result of aquifer tests are shown below.

Well No.	Loc	Geology	Thickness (m)	Aquifer Transmissibility T (m2/day)	Specific capacity SC (m^2/hr)	Permeability k(m/day)	Potential Yield l/sec
GW-1	San Ramon	Shale/sand stone	15(+)	0.38	0.04	0.04	0.2
GW-2	Anislag	calcareous sand stone/limestone	22(+)	42.0	7.92	0.50	0.5
GW-3	Del Rosario	limestone	20(+)	1.82	0.32	0.10	0.4

5.4.2 Development potential

Based on the potential yield of aquifer tests, the appreciated hydrogeological basin can not be expected in view of topographical and geostructural aspects. Furthermore, storage capacity of aquifer in clastic sedimentary rocks zone is focused to be low in view of lithological aspect. Therefore, there is no potential of a large scale ground water development such as irrigation use, but it can be possible to use the groundwater potential for a small scale domestic use such as spot well development.

As for spring water development, further exploration will need to carry out in pyroclastic rocks zone in northern part of the Study area, specially slopes of Kikuinan mountains.

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TABLES

Table B.1.1.1 Item and Quantity of Geological Investigation(Dam Site)

Location Name	Borehole No.	Depth (m)	Standard Penetration Test (times)	Permeability Test (times)
Diversion Dam Site (Camalig)	BH-1	20	11	4
	BH-2	20	11	4
	BH-3	20	6	3
	Sub Total	60	28	11
No.2 Dam Site (Inarado)	BH-1	15	15	2
	BH-2	17	7	2
	BH-3	20	8	3
	BH-4	8	6	2
	Sub Total	60	36	9
No.5 Dam Site (San Ramon)	BH-1	20	3	4
	BH-2	20	2	4
	BH-3	20	4	3
	Sub Total	60	9	11
Total	10 spots	180	73	31

Table B.1.1.2 Quantity of Geological Investigation(Borrow Area, Quarry Site)

Location Name	Testpit No.	Depth (m)	Remarks
No.5 Dam Site (San Ramon)	TP-1	1.5	Borrow Area
No.4 Dam Site(Bascaran)	TP-2	2.0	Borrow Area
No.3 Dam Site (Gabawan)	TP-3	2.0	Borrow Area
No.2 Dam Site (Inarado)	TP-4	4.0	Borrow Area
Busay	TP-5	1.0	Quarry Site
Sua	TP-6	0.8	Quarry Site
Total	6 spots	11.3	——

Table B.1.1.3 Item and Quantity of Laboratory Test

Item	Quantity				
	Construction Material		Drilling Core		Total
	soil material	Rock material (Aggregate)	Dam Site	Test Well Site	
I. Field Investigation					
(1) Disturbed sampling (physical test)	12	—	—	—	12
(2) Disturbed sampling (mechanical test)	8	—	—	—	8
(3) Disturbed sampling (rock material)	—	2	—	—	2
(4) In-site sieving	—	2	—	—	2
II. Laboratory Test					
II-1 Physical Test					
(1) Specific gravity of soil	20	—	—	—	20
(2) Moisture content of soil	20	—	—	—	20
(3) Gradation	20	—	—	—	20
(4) Atterberg's limits					
Liquid limits	20	—	—	—	20
Plastic limits	20	—	—	—	20
(5) Shrinkage factors	8	—	—	—	8
(6) Specific gravity of gravel	8	—	—	—	8
(7) Water absorption of gravel	8	—	—	—	8
II-2 Mechanical Test					
(1) Compaction test	8	—	—	—	8
(2) Permeability test	16	—	—	—	16
(3) Triaxial compression test(UU)	8	—	—	—	8
(4) —ditto— (CU)	4	—	—	—	4
II-3 Rock Test					
(1) Specific gravity of rock specimen	—	6	3	9	18
(2) Water absorption of rock specimen	—	6	3	9	18
(3) Soundness test by sodium sulfate method	—	2	—	—	2
(4) Unit weight	—	4	4	—	8
(5) Unconfined compression test of rock material	—	6	4	—	10

Table B.1.1.4 Item and Quantity of Hydrogeological Investigation(Test Well Site)

Location Name	Borehole No.	Depth (m)	Permeability Test (times)	Aquifer Test
San Ramon	GW-1	30	6	1
Anislag	GW-2	30	6	1
Del Rosario	GW-3	30	6	1
Total	3 spots	90	18	3

Table B.3.2.1 Result of Standard Penetration Test

Location	Borehole No.	Depth (m)	N-Value	Remarks	Location	Borehole No.	Depth (m)	N-Value	Remarks
Diversion Dam Site (Casalig)	BH-1	0.55~1.00	14	flood deposit	No. 2 Dam Site (Inarado)	BH-1	9.55~9.69	50/14	terrace deposit(?)
		1.55~2.00	4	〃			10.55~10.67	50/12	〃
		2.55~3.00	3	〃			11.55~11.67	50/12	〃
		3.55~4.00	6	〃			12.55~12.84	51/14	〃
		4.55~5.00	20	〃			13.55~13.83	52/13	〃
		5.55~6.00	20	〃			14.55~14.85	50/15	〃
		6.55~7.00	12	〃		BH-2	0.55~1.00	4	top soil
		7.55~8.00	12	〃			1.55~2.00	7	〃
		8.55~9.00	16	〃			2.55~3.00	6	〃
		9.55~10.00	51/30	highly weathered rock			3.55~4.00	10	highly weathered rock
		10.55~11.00	48	〃			4.55~5.00	16	〃
	BH-2	0.55~1.00	3	flood deposit			5.55~6.00	15	〃
		1.55~2.00	3	〃			6.55~7.00	74/30	highly weath to fresh
		2.55~3.00	15	〃		BH-3	0.55~1.00	3	top soil
		3.55~4.00	15	〃			1.55~2.00	6	〃
		4.55~5.00	12	〃			2.55~3.00	11	highly weathered rock
		5.55~6.00	34	〃			3.55~4.00	9	〃
		6.55~7.00	48	〃			4.55~5.00	8	〃
		7.55~8.00	57/30	〃			5.55~6.00	16	〃
		8.55~9.00	34	〃			6.55~7.00	27	〃
		9.55~10.00	39	〃			7.55~8.00	74/30	〃
		10.55~11.00	55/30	highly weathered rock		BH-4	0.55~1.00	3	top soil
	BH-3	0.55~1.00	3	residual soil			1.55~2.00	4	〃
		1.55~2.00	3	〃			2.55~3.00	6	highly weathered rock
		2.55~3.00	5	〃			3.55~4.00	7	〃
		3.55~4.00	18	〃			4.55~5.00	16	〃
		4.55~5.00	5	〃			5.55~6.00	32	〃
		5.55~6.00	32	highly weathered rock	No. 5 Dam Site (San Ramon)	BH-1	0.55~1.00	7	top soil
No. 2 Dam Site (Inarado)	BH-1	0.55~1.00	4	top soil			1.55~2.00	43	moderately weathered rock
		1.55~2.00	10	residual soil			2.55~3.00	63/30	〃
		2.55~3.00	4	〃		BH-2	0.55~1.00	3	top soil
		3.55~4.00	7	〃			1.55~1.80	50/25	moderately weathered rock
		4.55~5.00	15	〃		BH-3	0.55~1.00	7	top soil
		5.55~6.00	20	〃			1.55~2.00	22	〃
		6.55~7.00	32	〃			2.55~3.00	12	〃
		7.55~7.73	50/3	〃			3.55~4.00	42	highly weathered rock
		8.55~8.72	50/2	terrace deposit(?)					

Table B.3.2.2 Result of Permeability Test (Dam site)

Location	Borehole No.	Depth (m)	Section Length (m)	Method	G.W.L (− m)	Maximum Pressure (kgf/cm²)	Lugeon Unit	Permeability Coefficient k(cm/sec)	Critical Pressure Pc(kgf/cm²)	Weathering	Remarks
Diversion Dam Site (Camalig)	BH-1	5.0	−	OET	1.60	0.23	(0.0)	0.0	−	H	flood depoisit
		10.0	−	〃	2.20	0.25	(100+)	1.69E-03	−	〃	limestone
		10.0~15.0	5.0	WPT	1.90	2.23	36.4	(4.75E-04)	−	〃	〃
		15.0~20.0	〃	〃	1.90	6.36	42.7	(5.57E-04)	−	M	〃
	BH-2	5.0	−	OET	0.30	0.33	(83)	1.11E-03	−	H	flood depoisit
		10.0	−	〃	0.50	0.08	(100+)	6.46E-03	−	〃	〃
		11.0~16.0	5.0	WPT	0.60	9.98	19.6	(2.56E-04)	−	M	limestone
		16.0~20.0	4.0	〃	0.70	2.04	47.0	(5.86E-04)	−	S	〃
	BH-3	6.0~11.0	5.0	〃	8.50	10.98	8.4	(1.10E-04)	−	M	〃
		11.0~16.0	〃	〃	13.00	11.47	3.9	(5.09E-05)	−	〃	〃
		16.0~20.0	4.0	〃	13.60	11.53	6.2	(7.73E-05)	−	〃	〃
No.2 Dam Site (Inarado)	BH-1	5.0	−	OET	0.65	0.19	(0.0)	0.0	−	H	residual soil
		10.0	−	〃	1.95	0.24	(25.4)	3.38E-04	−	〃	terrace deposit
	BH-2	5.0	−	〃	1.60	0.20	(0.0)	0.0	−	〃	sandstone
		7.0~12.0	5.0	WPT	2.80	5.60	1.8	(2.35E-05)	2.45	S	〃
	BH-3	5.0	−	OET	1.80	0.23	(0.0)	0.0	−	H	shale
		8.0~13.0	5.0	WPT	1.31	6.16	0.2	(2.61E-06)	2.30	M~S	〃
		15.0~20.0	〃	〃	2.10	6.21	0.01	(1.31E-07)	1.33	S	〃
	BH-4	5.0	−	OET	−	0.53	(0.0)	0.0	−	H	〃
		6.0~8.0	2.0	WPT	6.75	4.59	8.4	(8.92E-05)	1.79	M	〃
No.5 Dam Site (San Ramon)	BH-1	2.0~ 7.0	5.0	〃	0.30	10.24	0.2	(2.61E-06)	−	M~S	sandstone
		7.0~12.0	〃	〃	0.90	10.31	0.4	(5.22E-06)	−	F	sandstone/conglo
		12.0~17.0	〃	〃	2.40	10.45	0.02	(2.61E-07)	−	〃	sandstone/shale
		17.0~20.0	3.0	〃	2.50	10.46	0.1	(1.17E-06)	−	〃	conglomerate
	BH-2	1.0~ 6.0	5.0	〃	0.60	10.27	0.0	0.0	−	M~S	sandstone/conglo /siltstone
		6.0~11.0	〃	〃	0.55	10.27	0.4	(5.22E-06)	−	F	〃
		11.0~16.0	〃	〃	1.20	10.33	0.03	(3.91E-07)	−	〃	sandstone/conglo
		16.0~20.0	4.0	〃	1.25	10.34	0.03	(3.74E-07)	−	〃	〃
	BH-3	4.0~ 9.0	5.0	〃	2.40	6.26	7.5	(9.79E-05)	−	M~S	〃 /siltstone
		9.0~14.0	〃	〃	7.50	6.76	7.9	(1.03E-04)	−	S	〃
		15.0~20.0	〃	〃	6.00	10.81	0.1	(1.31E-06)	−	〃	sandstone/conglo

(Note) OET: Open End Test　　M : Moderately Weathered
WPT: Water Pressure Test　　S : Slightly Weathered
H : Highly Weathered　　F : Fresh
( ): The figure in parenthesis shows the calculated number after lugeon unit or permeability coefficient.

Table B.4.2.1 Summary of Laboratory Test for Borrow Materials

Sample Name	Sampling Location	Sample No.	Depth (m)	PHYSICAL TEST: Grain Size Distribution Gravel %	Sand %	Silt %	Clay %	Spec. Gravity	Natural Water Content %	Atterberg Limits LL %	PL %	PI %	Shrinkage Limit %	Shrinkage Limit Ratio	MECHANICAL TEST: Compaction Test Energy Ec %	ρd max g/cc	Wopt %	95% ρd max g/cc	W(wet) 95% ρd max. %	Triaxial Test (UU) Cu kgf/cm²	φu degrees	(CU) C kgf/cm²	φ degrees	C' kgf/cm²	φ' degrees	Permeability Test k cm/sec
TP-1	San Ramon	1	0.50	0	34	38	28	2.52	82.83	68	46	22														
		2	1.00	0	42	26	32	2.49	95.11	63	41	22														
		3	1.50	17	28	27	28	2.54	33.13	42	32	10														
		4	0.5-1.0	0	40	16	44	2.42	87.07	64	35	29	37.14	1.40	100	1.34	27.00									9.0E-07
																		1.27	35.00							1.5E-06
		5	1.0-1.5	27	23	17	33	2.55	75.50	62	31	31	23.86	1.88	100	1.12	42.00			0.27	6.0					2.0E-07
																		1.06	51.50	0.31	3.5					1.1E-07
TP-2	Bascaran	1	0.50	0	29	39	32	2.41	49.67	40	27	13														
		2	1.00	0	28	56	16	2.41	59.70	45	27	18														
		3	2.00	20	14	56	10	2.61	51.41	49	28	21														
		4	0.5-1.0	10	17	51	22	2.40	53.90	52	27	25	3.89	2.12	100	1.37	27.00			3.3	21.0					9.2E-08
																		1.30	34.00	1.8	19.0					4.0E-06
		5	1.0-2.0	0	12	28	30	2.55	58.99	47	24	23	15.57	1.79	100	1.38	26.00					0.20	12.0	0.20	20	Impermeable
																		1.31	32.00			0.32	6.5	0.27	16	Impermeable
TP-3	Gabawan	1	1.00	0	50	30	20	2.61	42.74	53	32	21														
		2	2.00	24	16	39	21	2.60	30.20	37	26	11														
		3	0.5-1.0	0	33	24	43	2.61	49.86	50	30	20	17.90	1.74	100	1.34	31.50			0.57	6.0					9.2E-08
																		1.27	37.00	0.61	5.5					1.9E-07
		4	1.0-2.0	14	18	36	32	2.60	61.12	47	31	16	30.38	1.35	100	1.36	30.50					0.42	12	0.39	21.0	1.0E-07
																		1.29	35.00			0.12	14	0.26	15.5	Impermeable
TP-4	Inarado	1	1.00	0	12	62	26	2.62	54.65	45	32	13														
		2	2.00	0	13	66	21	2.60	58.20	49	30	19														
		3	3.00	1	27	44	28	2.59	57.09	47	30	17														
		4	4.00	0	16	54	30	2.62	57.98	43	28	15														
		5	2.0-3.0	1	26	27	46	2.58	55.80	52	28	24	26.32	1.58	100	1.27	35.00			4.0	31.0					7.4E-07
																		1.21	41.00	0.51	14.5					1.2E-07
		6	3.5-4.0	0	19	29	52	2.65	56.92	54	30	24	27.36	1.50	100	1.25	37.00									2.5E-08
																		1.19	42.50							3.3E-07

Table B.4.2.2 Summary of Laboratory Test for Rock & Aggregates

Sample Name	Sampling Location	Sample No.	Depth (m)	Grain Size Distribution: Boulders %	Cobbles %	Gravel %	Sand %	Silt %	Clay %	Specific Gravity: Bulk ssd	Bulk dry	Apparent	Absorption %	Unit Weight: Loose g/cc	Rodded g/cc	Soundness Loss %	Comp. Strength kg/cm^2
TP-5	Busay	1	0-0.80	3	32	23	39	3	0								
		Cobbles/Boulders		14" max. size													
		1								2.44	2.35	2.59	3.95				619.89
		2															395.42
		3															371.72
		Coarse Aggregate		2" max. size						2.30	2.19	2.47	5.19	1.35	1.51	1.27	
		Fine Aggregate		4.75mm max. size						2.40	2.22	2.69	7.82	1.54	1.71	1.24	
TP-6	Sua	1	0-1.00	0	17	19	63	1	0								
		Cobbles 8" max. size															
		1								2.41	2.32	2.55	3.98				678.58
		2															304.94
		3															343.16
		Coarse Aggregate		2" max. size						2.42	2.35	2.53	2.99	1.41	1.58	1.24	
		Fine Aggregate		4.75mm max. size						2.47	2.27	2.85	8.91	1.63	1.79	0.75	
Damsite Drilling Core	Inarado (Dam No. 2)	1	7.2-11.0							2.63	2.58	2.71	1.88				
		2	11.0-14.0							2.57	2.50	2.70	2.89				
		3	14.0-16.0							2.48	2.34	2.72	6.01				
	San Ramon (Dam No. 5)	1	2.0- 3.0											2.09			139.09
		2	5.0- 6.0											1.75			54.87
		3	11.0-12.0											1.79			54.37
		4	13.0-14.0											1.92			76.50
Test Well Drilling Core	San Ramon (GW No. 1)	1	2.7- 3.4							1.72	1.26	2.32	35.99				
		2	13.9-14.9							2.20	1.96	2.57	12.05				
		3	23.3-24.3							1.93	1.52	2.56	26.84				
	Del Rosario (GW No. 3)	1	0.8- 5.0							2.02	1.72	2.45	17.42				
		2	5.0- 7.1							2.03	1.72	2.47	17.49				
		3	7.1-10.0							2.03	1.76	2.42	15.55				
		4	10.0-15.0							2.30	2.05	2.72	11.88				
		5	15.0-20.0							2.21	1.99	2.56	11.33				
		6	20.0-30.0							1.89	1.59	2.28	19.24				

Table B.5.2.1 Result of Permeability Test (Test well site)

Location	Borehole No.	Depth (m)	Section Length (m)	Method	G.W.L (−m)	Maximum Pressure (kgf/cm²)	Lugeon Unit	Permeability Coefficient k(cm/sec)	Critical Pressure Pc(kgf/cm²)	Weathering	Remarks
San Ramon	GW-1	5.0	−	OET	−	0.51	−	0.0	−	H	siltstone
		10.0	−	〃	6.10	0.39	−	1.84E-05	−	〃	shale
		15.0	−	〃	14.71	1.50	−	0.0	−	〃	siltstone
		15.0〜20.0	5.0	WPT	14.50	7.49	4.2	2.18E-05	5.49	〃	shale
		20.0〜25.0	〃	〃	7.50	6.79	7.4	9.13E-05	−	M〜S	sandstone/siltstone
		25.0〜30.0	〃	〃	7.40	6.78	2.8	2.83E-05	3.78	S 〃	siltstone
Anislag	GW-2	2.0〜 5.0	〃	〃	1.03	6.16	11.2	4.75E-04	5.16	M	calcareous sandstone
		5.0〜10.0	〃	〃	0.90	6.12	13.1	4.77E-04	−	〃	〃 /limestone
		10.0〜15.0	〃	〃	0.75	2.10	32.3	1.18E-03	−	〃	limestone
		15.0〜20.0	〃	〃	0.78	5.12	11.4	4.08E-04	−	〃	〃
		20.0〜25.0	〃	〃	0.78	6.12	19.0	4.64E-04	−	〃	calcareous sundstone
		25.0〜30.0	〃	〃	3.75	6.11	12.1	3.50E-04	−	〃	〃
Del Rosario	GW-3	5.0	−	OET	−	0.52	−	1.37E-05	−	H	〃
		5.0〜10.0	5.0	WPT	4.80	6.51	3.9	4.93E-05	−	M	〃
		10.0〜15.0	〃	〃	4.12	6.44	6.4	9.87E-05	−	〃	〃
		15.0〜20.0	〃	〃	4.10	7.45	7.5	9.75E-05	−	〃	〃
		20.0〜25.0	〃	〃	4.26	7.47	7.3	1.38E-04	−	〃	〃
		25.0〜30.0	〃	〃	4.34	7.47	6.9	1.14E-04	−	〃	〃

(Note) H : Highly Weathered zone
M : Moderately Weathered zone
S : Slightly Weathered zone

OET : Open End Test
WPT : Water Pressure Test

THE FEASIBILITY STUDY ON
THE WESTERN LEGAZPI IRRIGATION AND
RURAL DEVELOPMENT PROJECT IN THE PHILIPPINES

FIGURES

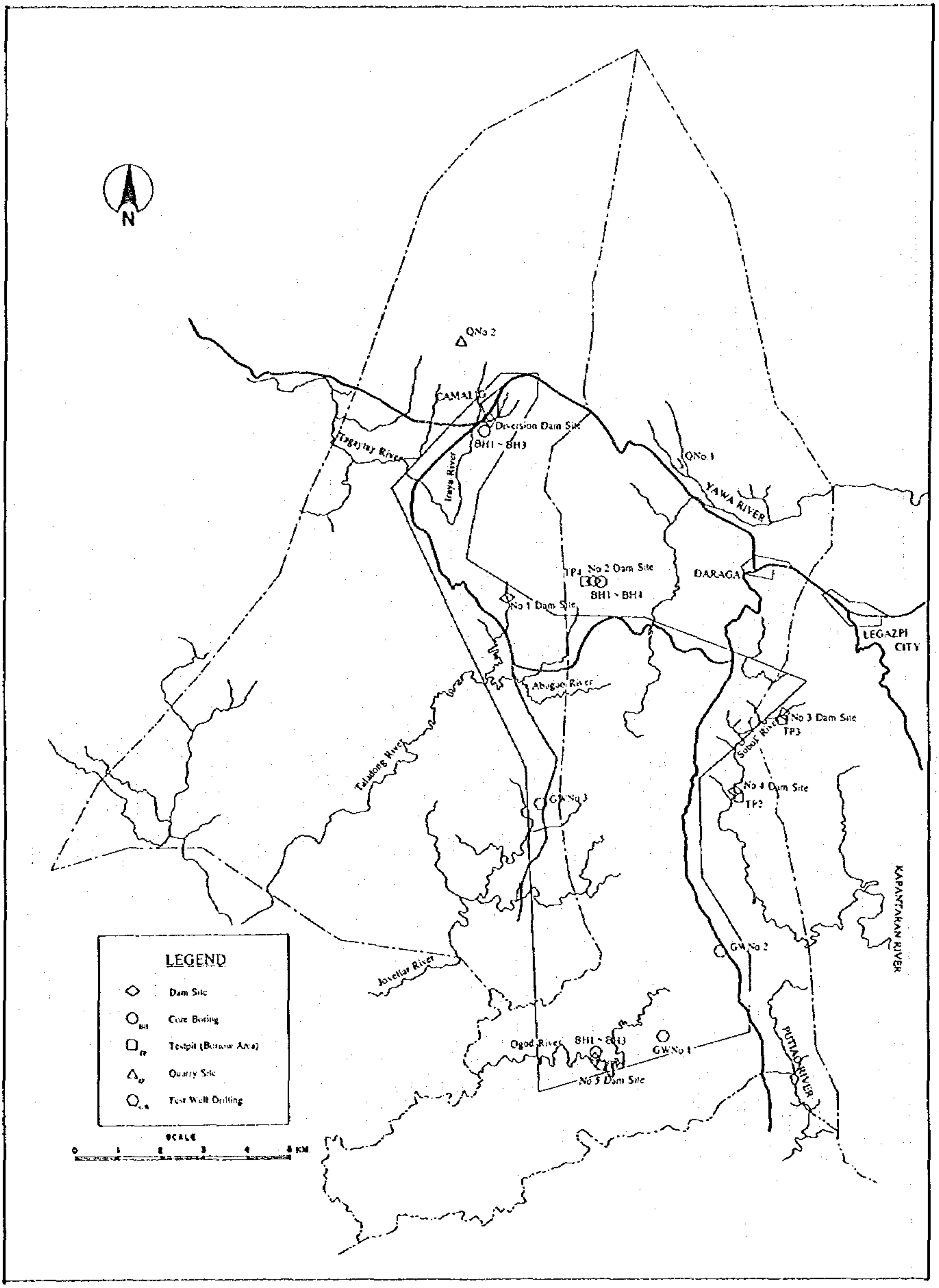


Fig B.1.1.1 Location Map of Investigation

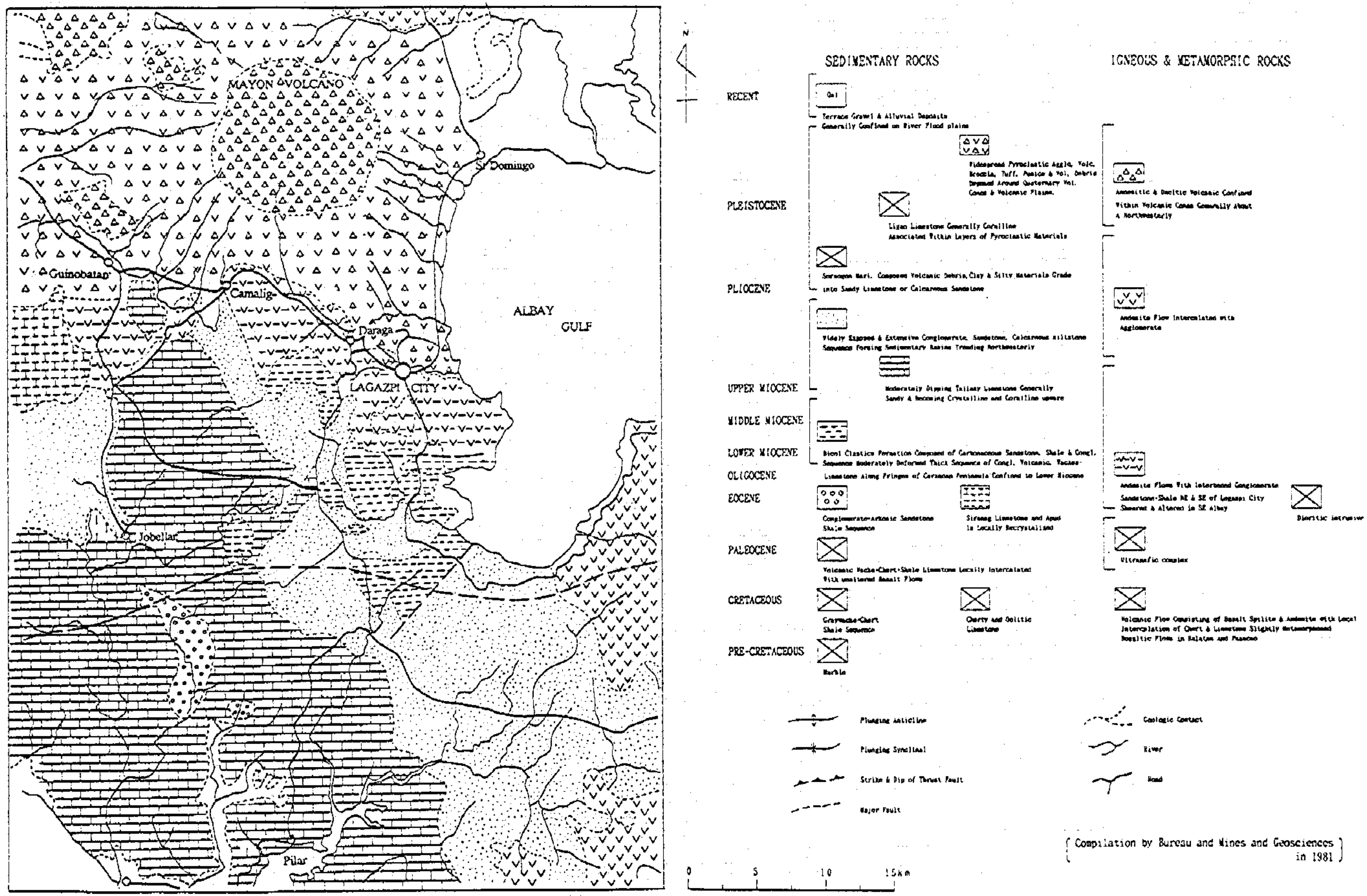


Fig B.2.2.1 Regional Geological Map

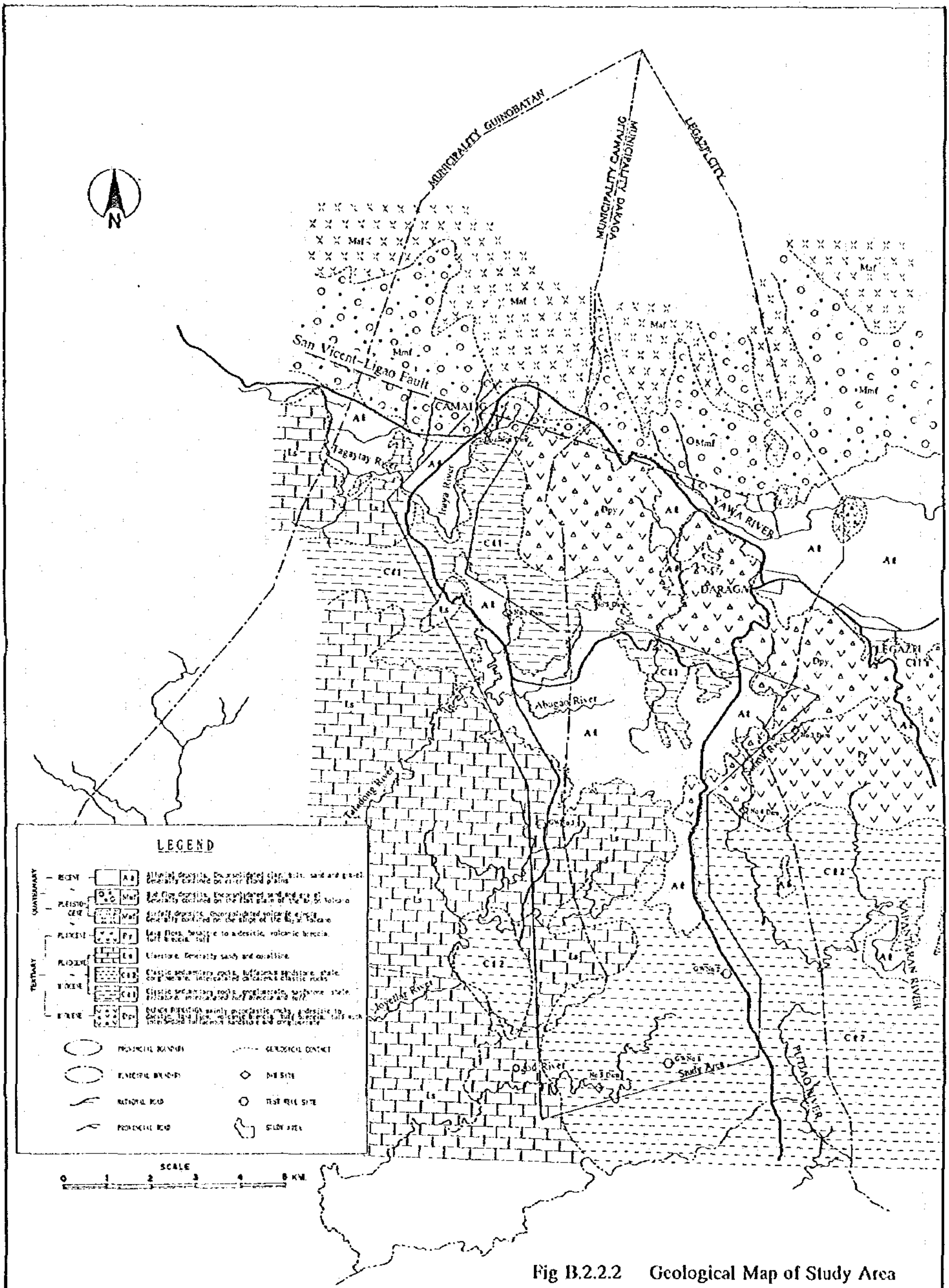
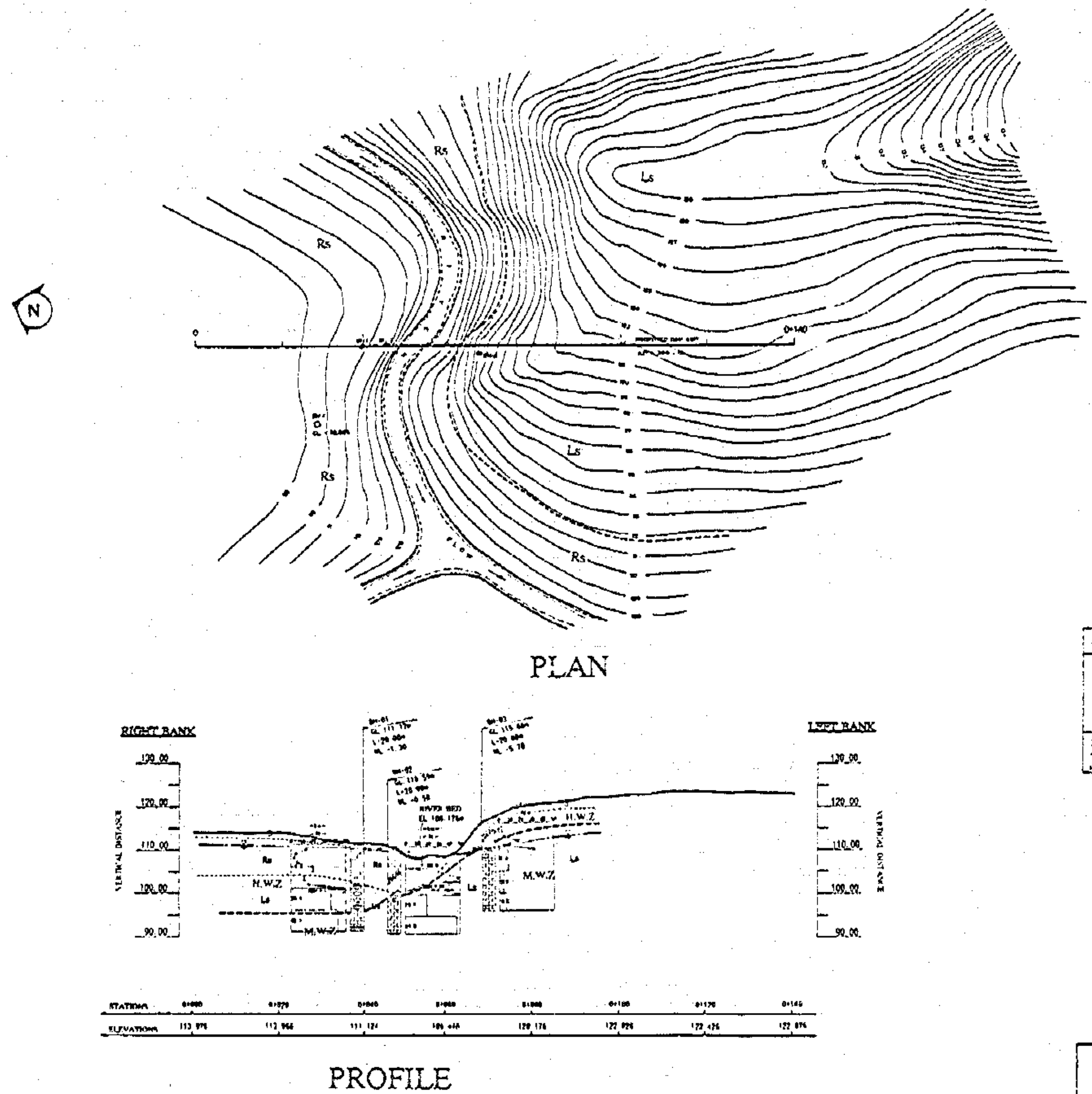


Fig B.2.2.2 Geological Map of Study Area

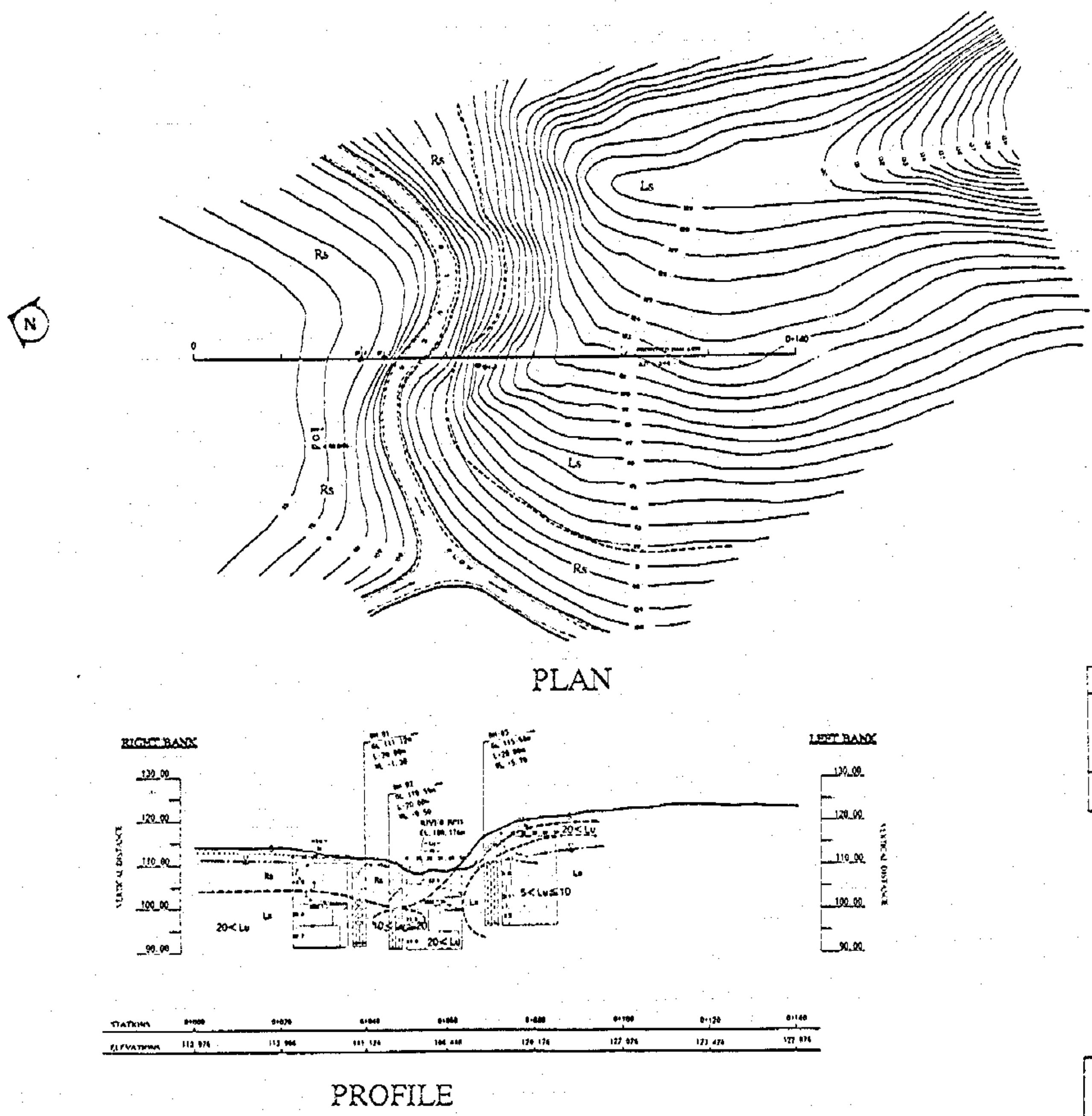


LEGEND

AGE	GEOLOGICAL NAME	DESCRIPTION
Quaternary	Surface soil (S)	Brown colored sandy silt to silty clay with traces of fragment. Very loose.
	River deposit(Rs)	Gray to darkgray colored sand, gravel and silt. Unconsolidated soft and loose deposit.
Tertiary Pliocene	Limestone (Ls)	White colored, massive, hard rock with solution cavities and pores.

●	Bore Hole
	Assumed Geological Boundary
	Assumed Groundwater Table
	Assumed Weathering Boundary (Profile)
H.W.Z	Highly Weathered Zone
M.W.Z	Moderately Weathered Zone

Fig B.3.2.1 Geological Map and Geological Profile of Diversion Dam Site



LEGEND

AGE	GEOLOGICAL NAME	DESCRIPTION
Quaternary	Surface soil (S)	Brown colored sandy silt to silty clay with traces of fragment. Very loose.
Quaternary	River deposit(Rs)	Gray to darkgray colored sand, gravel and silt. Unconsolidated soft and loose deposit.
Tertiary	Limestone (Ls)	White colored, massive, hard rock with solution cavities and pores.

- ● Bore Hole
- Assumed Geological Boundary
- Assumed Groundwater Table
- Assumed Permeability Boundary

Fig B.3.2.2 Geological Map and Lugeon Map of Diversion Dam Site

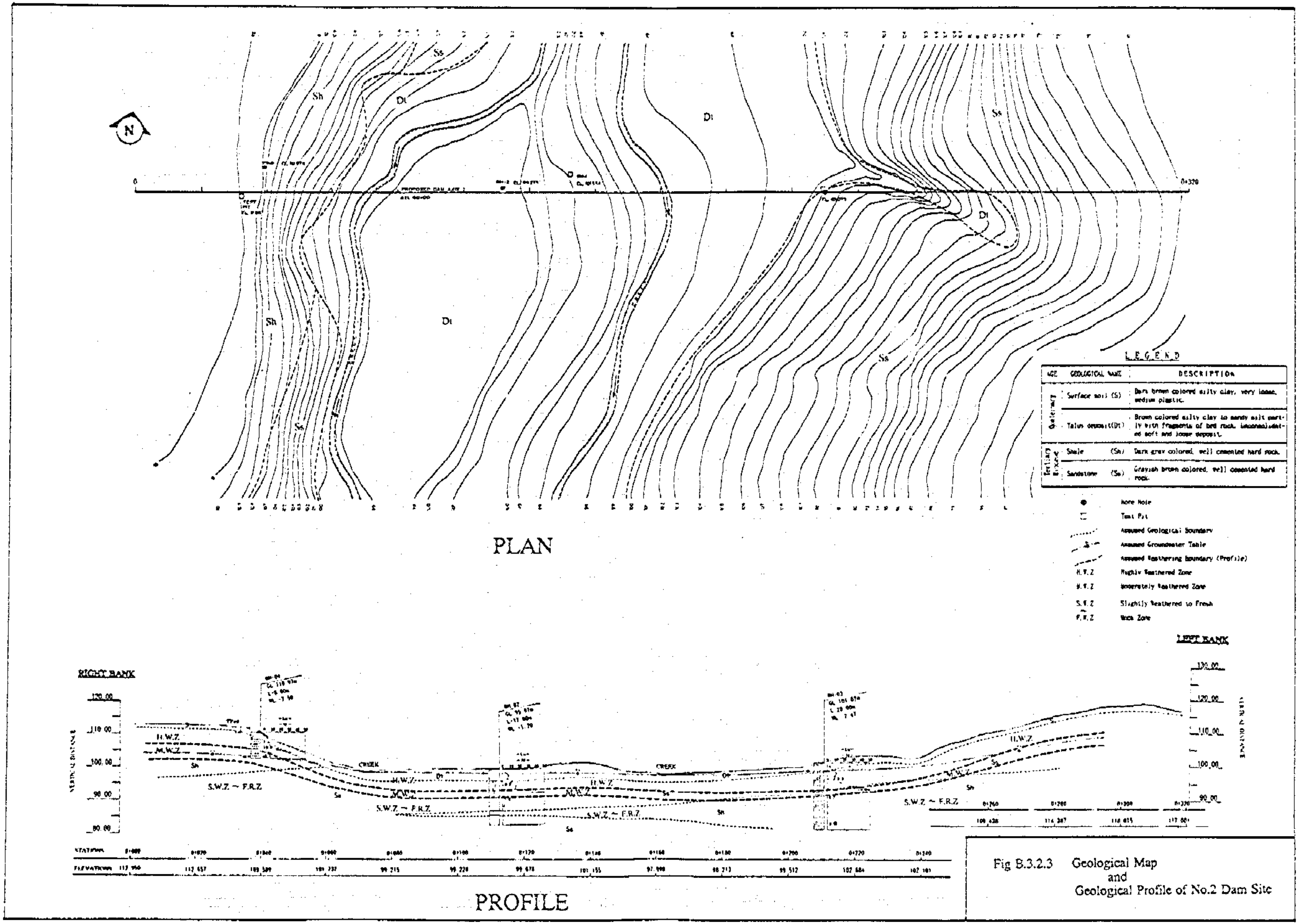


Fig B.3.2.3 Geological Map and Geological Profile of No.2 Dam Site

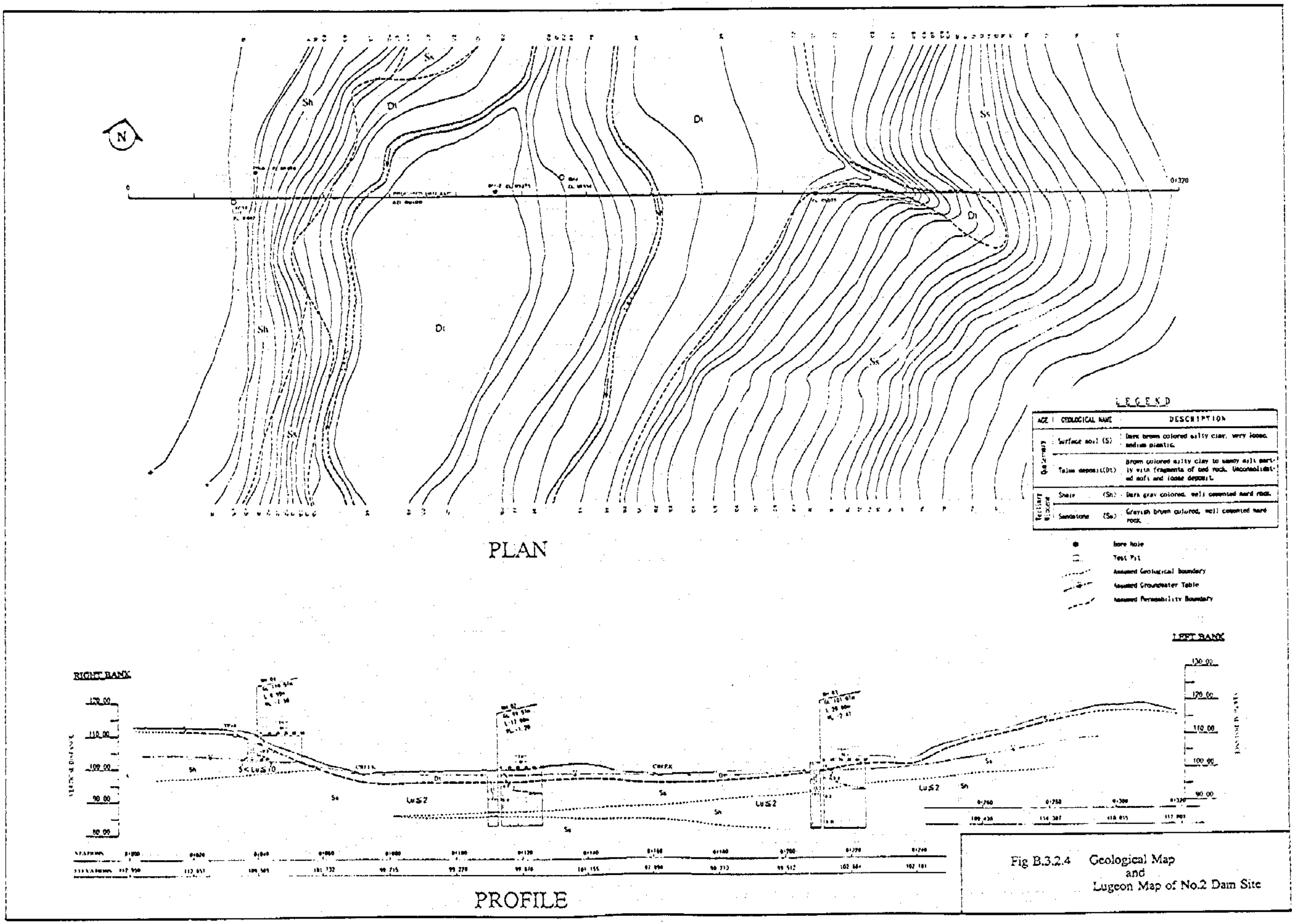
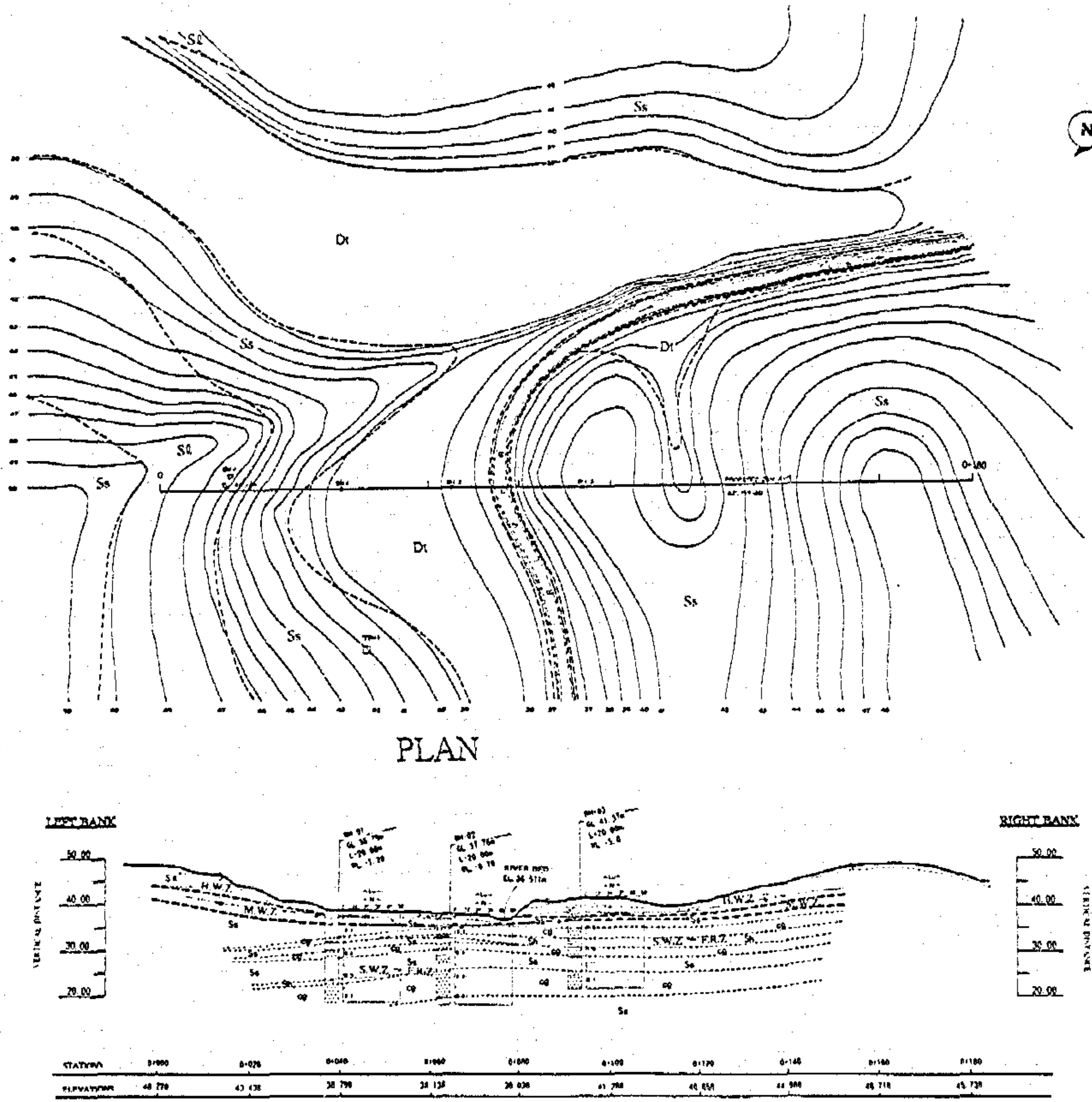


Fig B.3.2.4 Geological Map and Lugeon Map of No.2 Dam Site



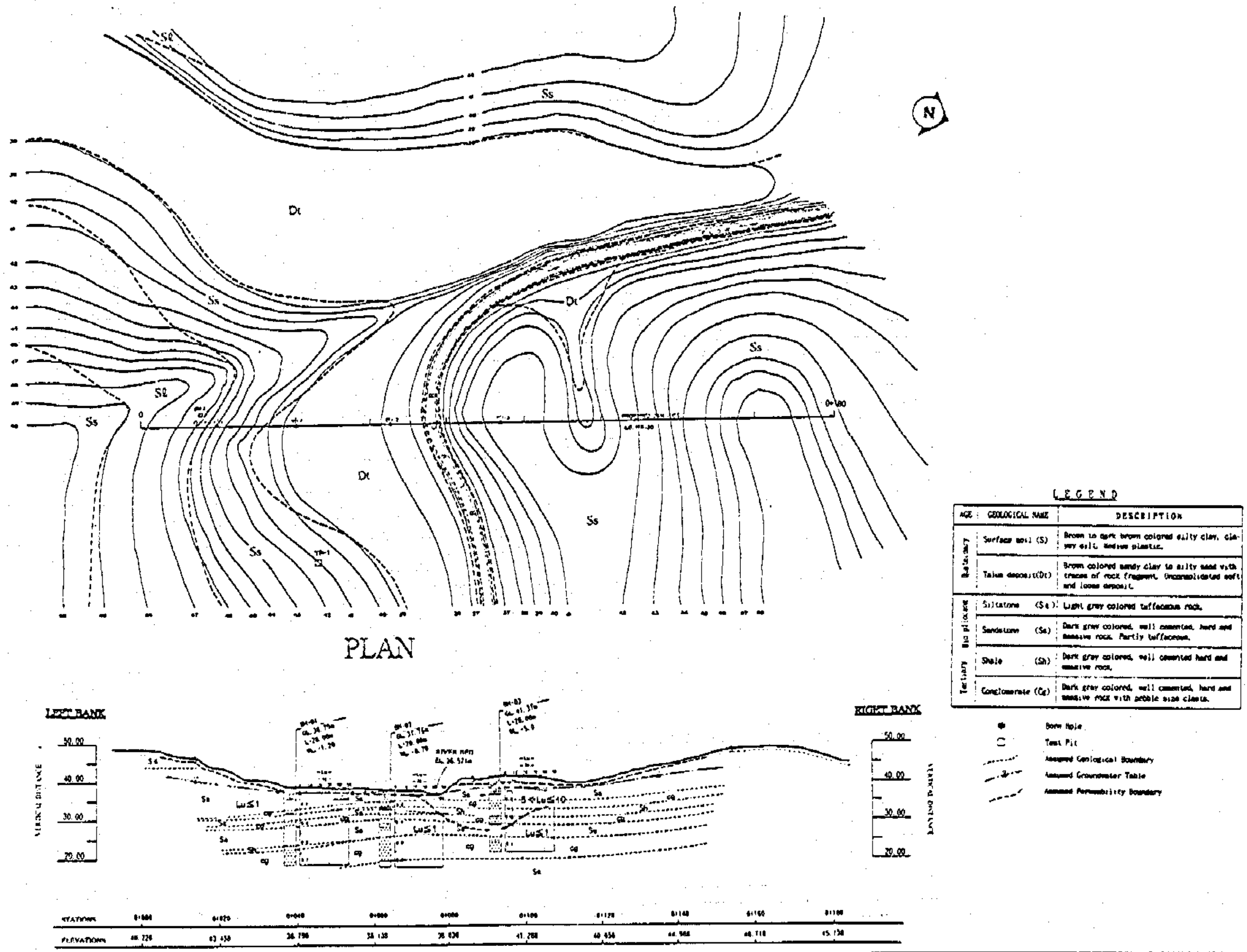
PROFILE

LEGEND

AGE	GEOLOGICAL NAME	DESCRIPTION
Quaternary	Surface soil (S)	Brown to dark brown colored silty clay, clayey silt, medium plastic.
	Talus deposit(Dt)	Brown colored sandy clay to silty sand with traces of rock fragment. Unconsolidated soft and loose deposit.
Tertiary Neo pliocene	Siltstone (Sl)	Light gray colored tuffaceous rock.
	Sandstone (Ss)	Dark gray colored, well cemented, hard and massive rock. Partly tuffaceous.
	Shale (Sh)	Dark gray colored, well cemented hard and massive rock.
	Conglomerate (Cg)	Dark gray colored, well cemented, hard and massive rock with pebble size clasts.

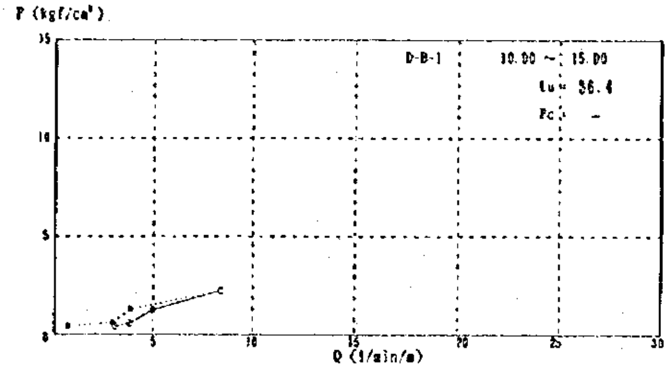
- Bore Hole
- Test Pit
- Assumed Geological Boundary
- Assumed Groundwater Table
- Assumed Weathering Boundary (Profile)
- H.W.Z Highly Weathered Zone
- M.W.Z Moderately Weathered Zone
- S.W.Z ~ F.R.Z Slightly Weathered to Fresh Rock Zone

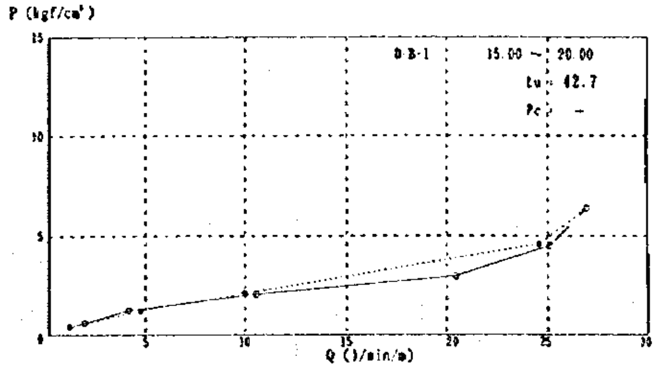
Fig B.3.2.5 Geological Map and Geological Profile of No.5 Dam Site

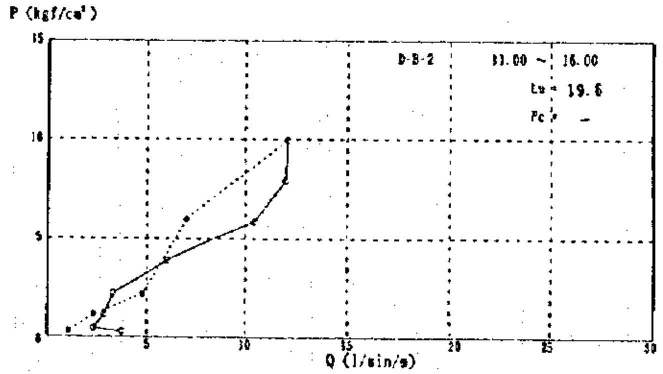


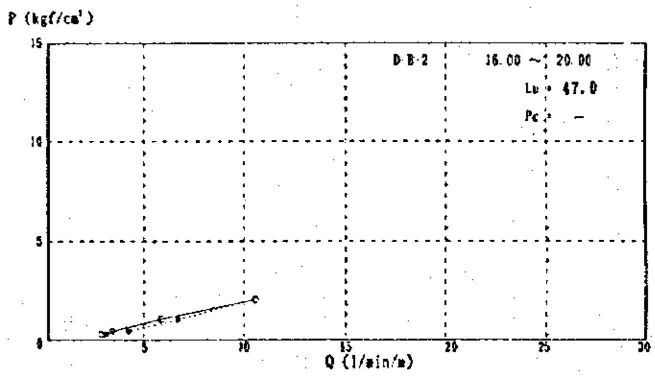
PROFILE

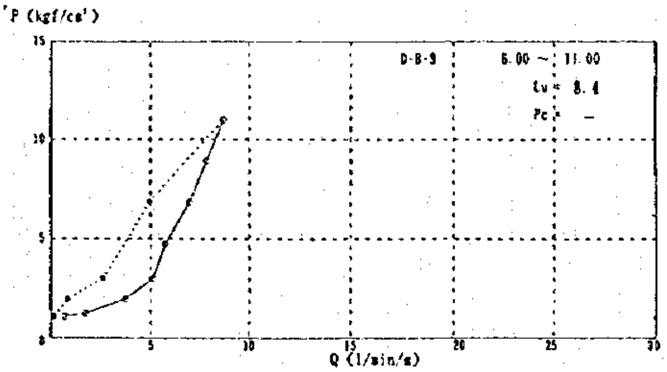
Fig B.3.2.6 Geological Map and Lugeon Map of No.5 Dam Site

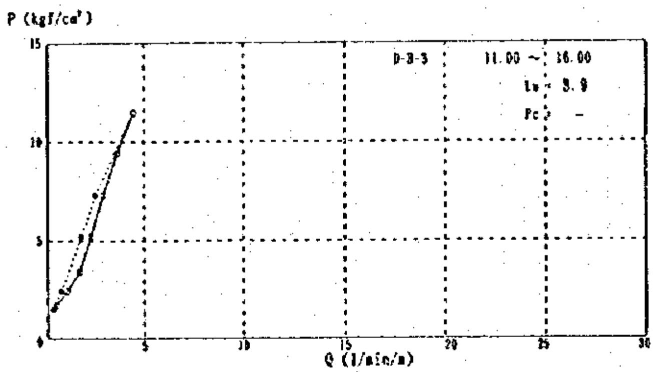












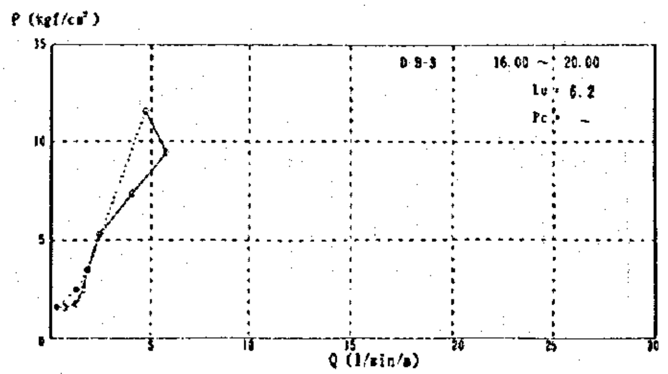


Fig B.3.2.7 Result of Permeability Test
(Diversion Dam Site)

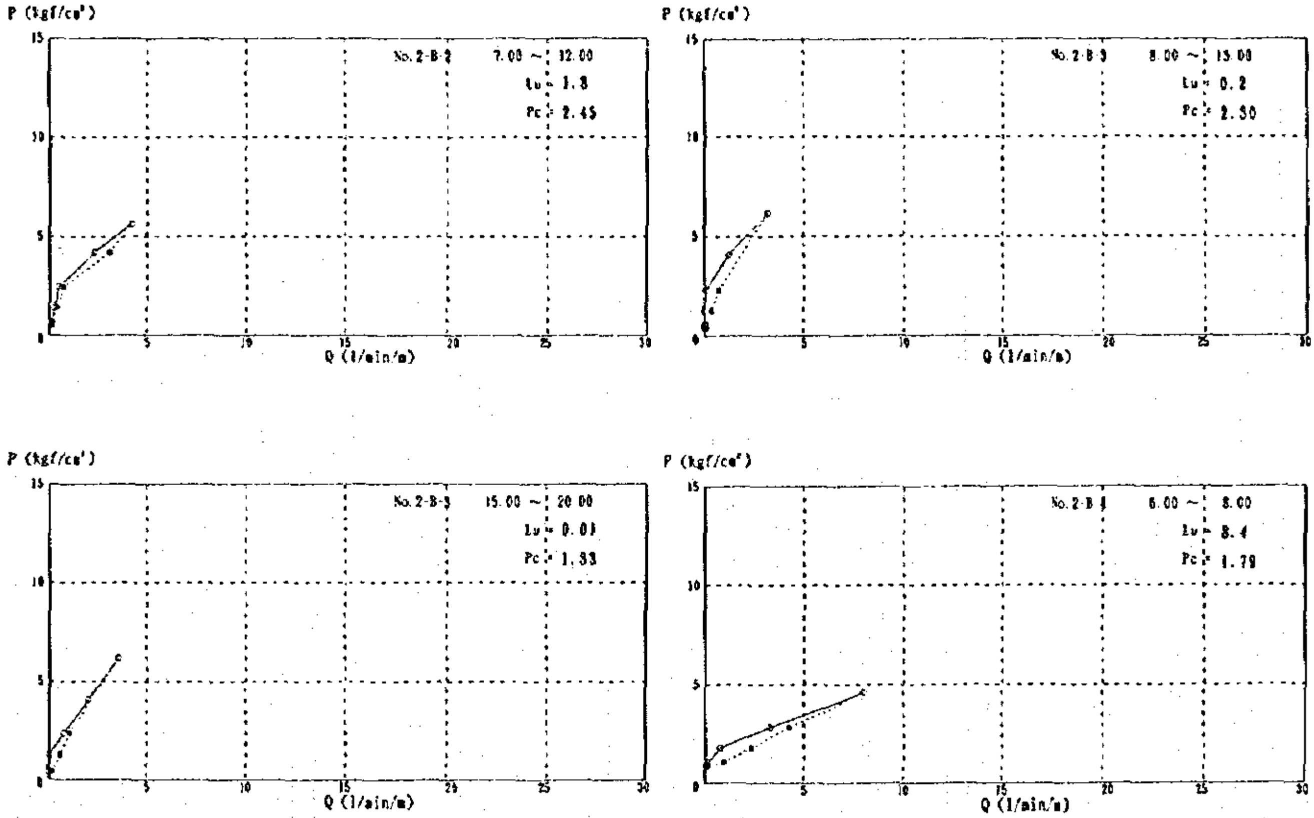


Fig B.3.2.8 Result of Permeability Test
(No.2 Dam Site)

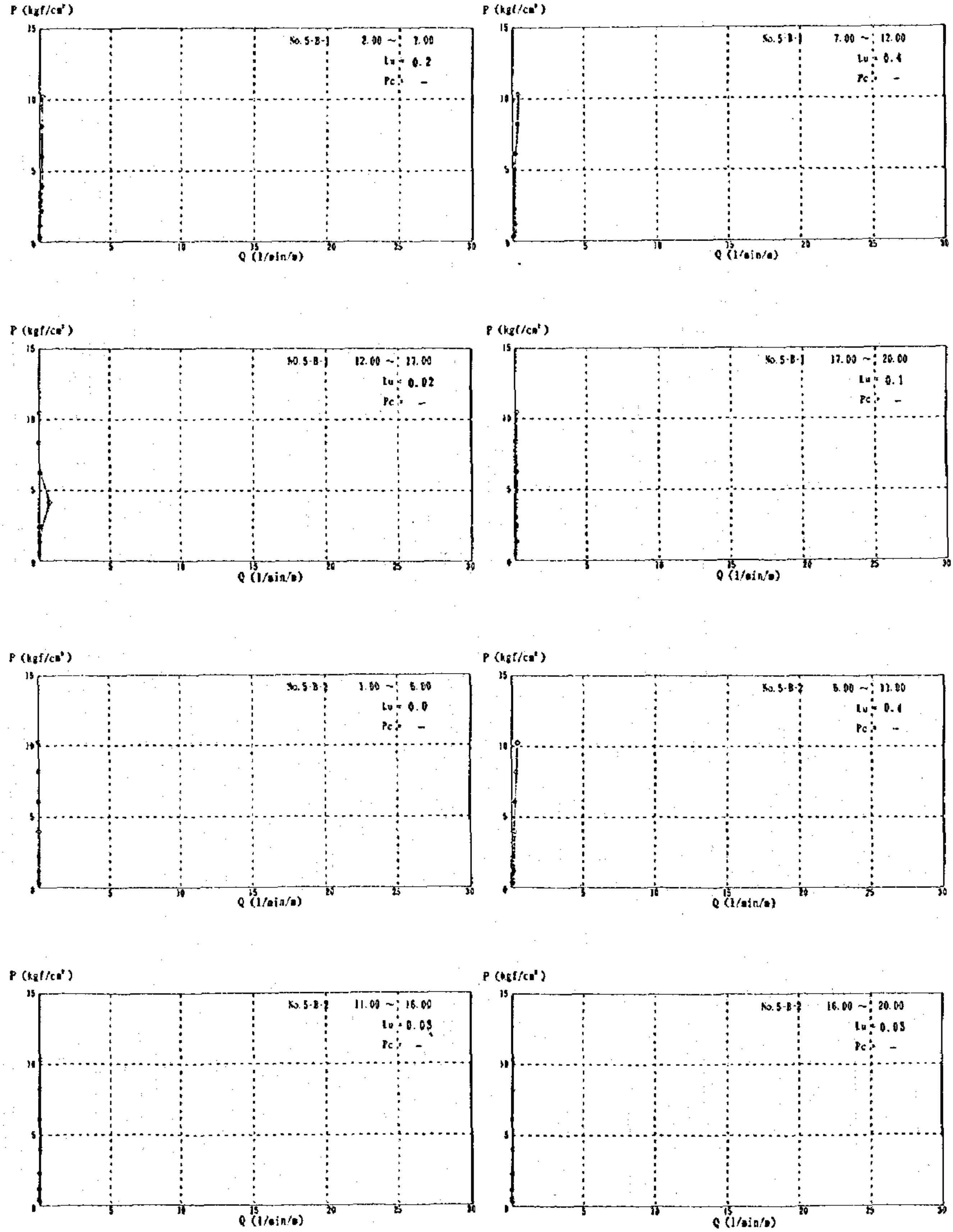
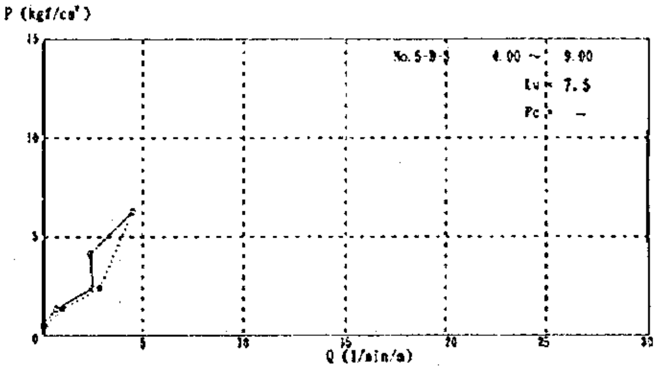
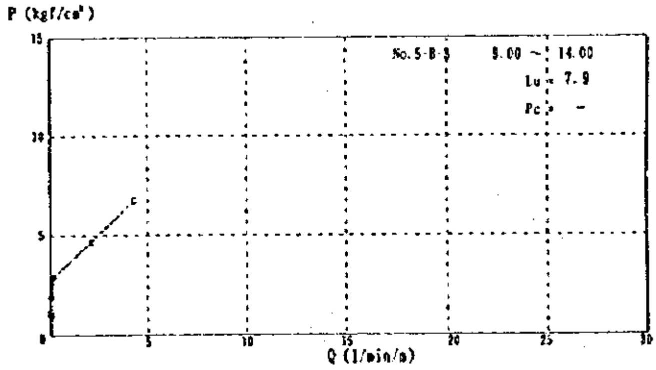


Fig B.3.2.9(1) Result of Permeability Test
(No.5 Dam Site)





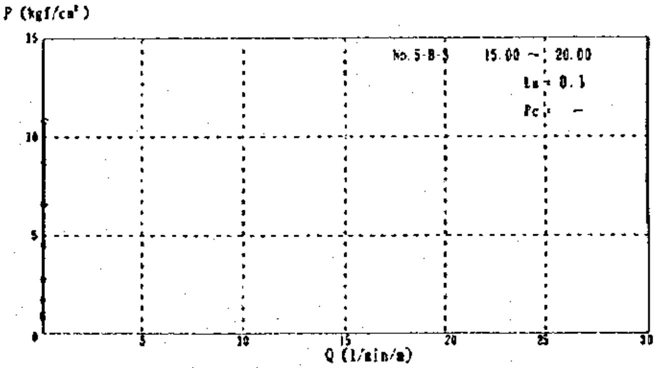
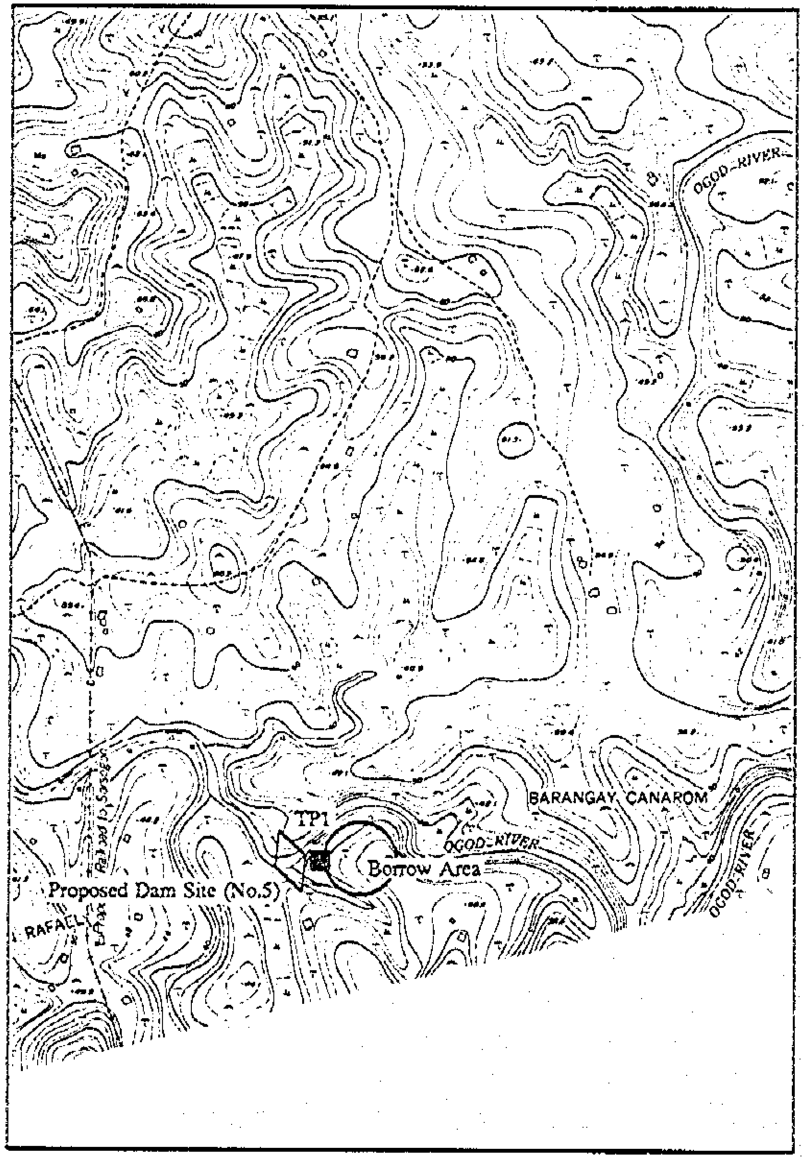
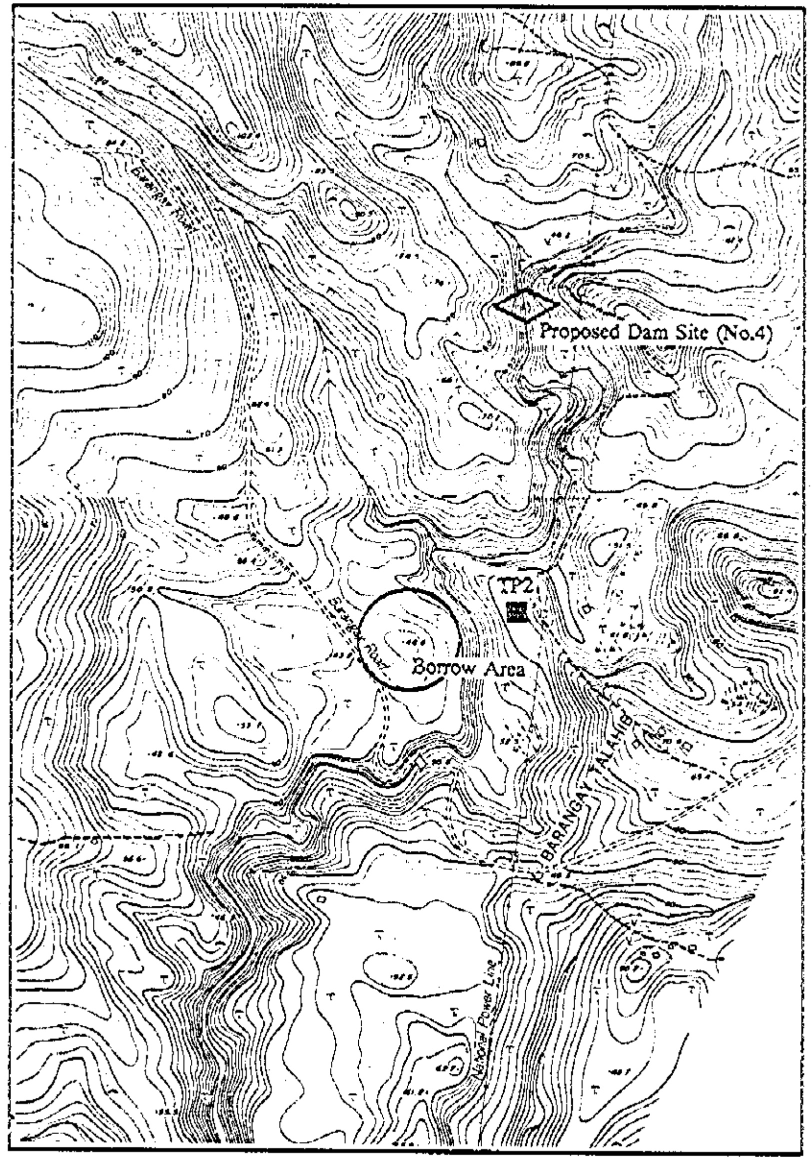


Fig B.3.2.9(2) Result of Permeability Test
(No.5 Dam Site)

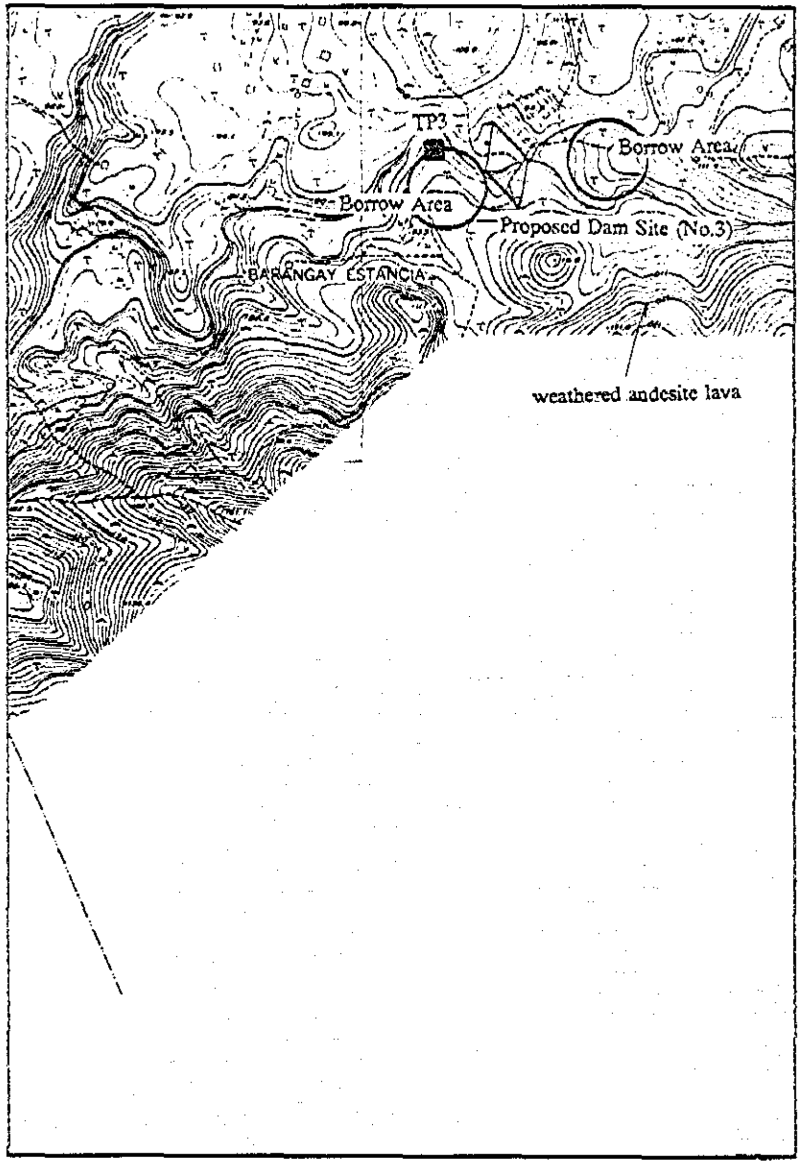


(No.5 Dam Site)

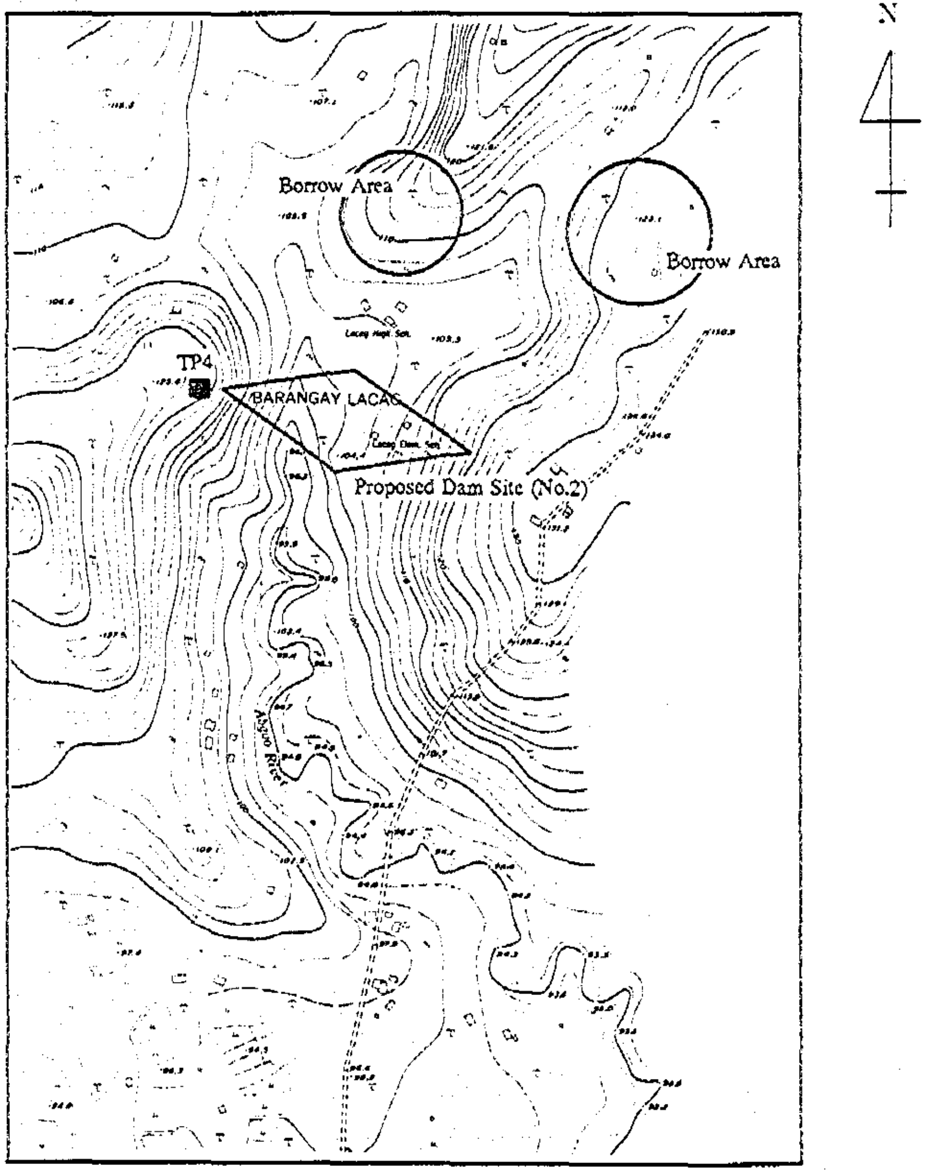


(No.4 Dam Site)

Fig B.4.1.1(1) Location Map of Borrow Area (1)
(S=1/8,000)



(No.3 Dam Site)



(No.2 Dam Site)

Fig B.4.1.1(2) Location Map of Borrow Area (2)
(S=1/8,000)

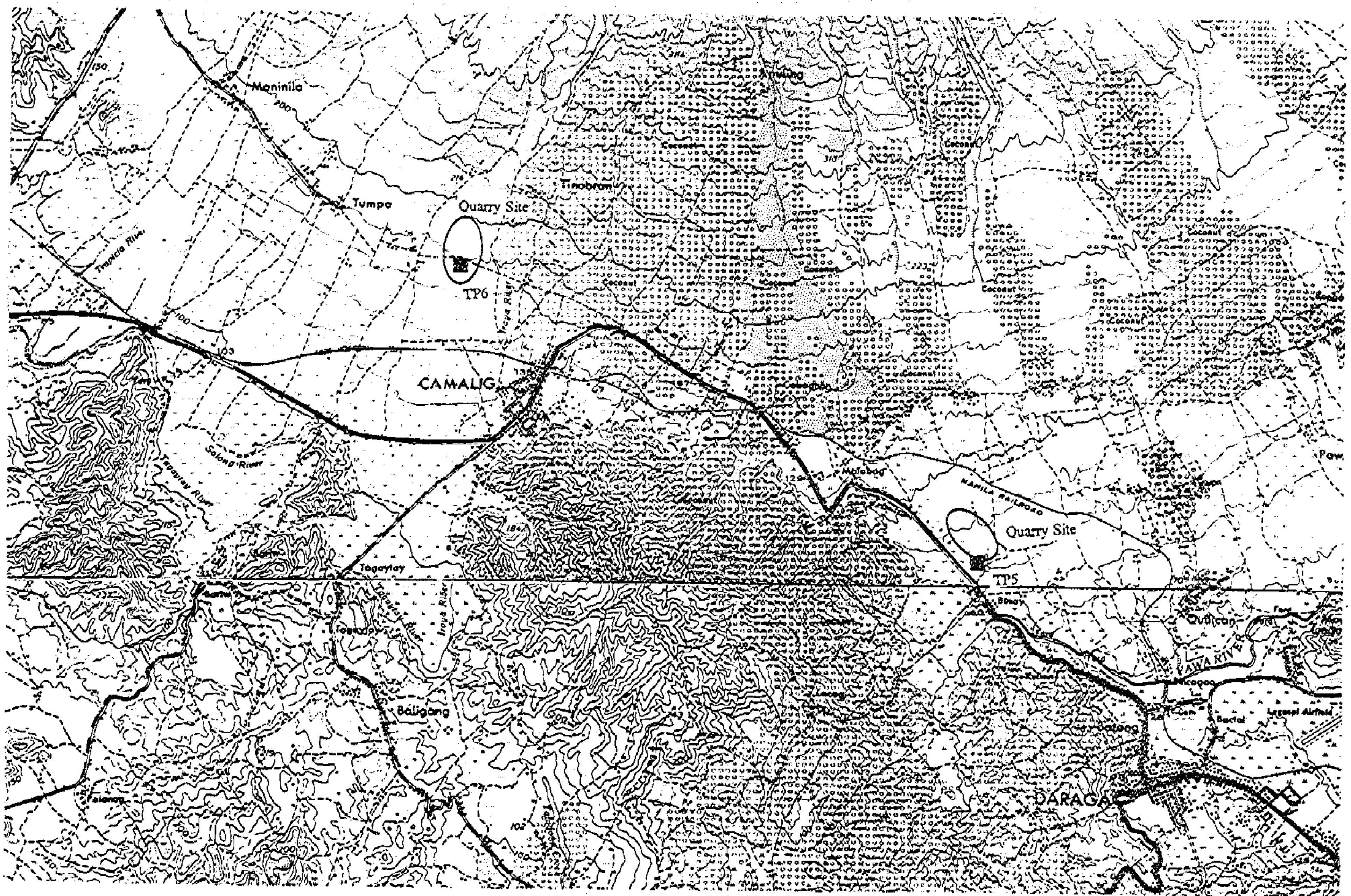
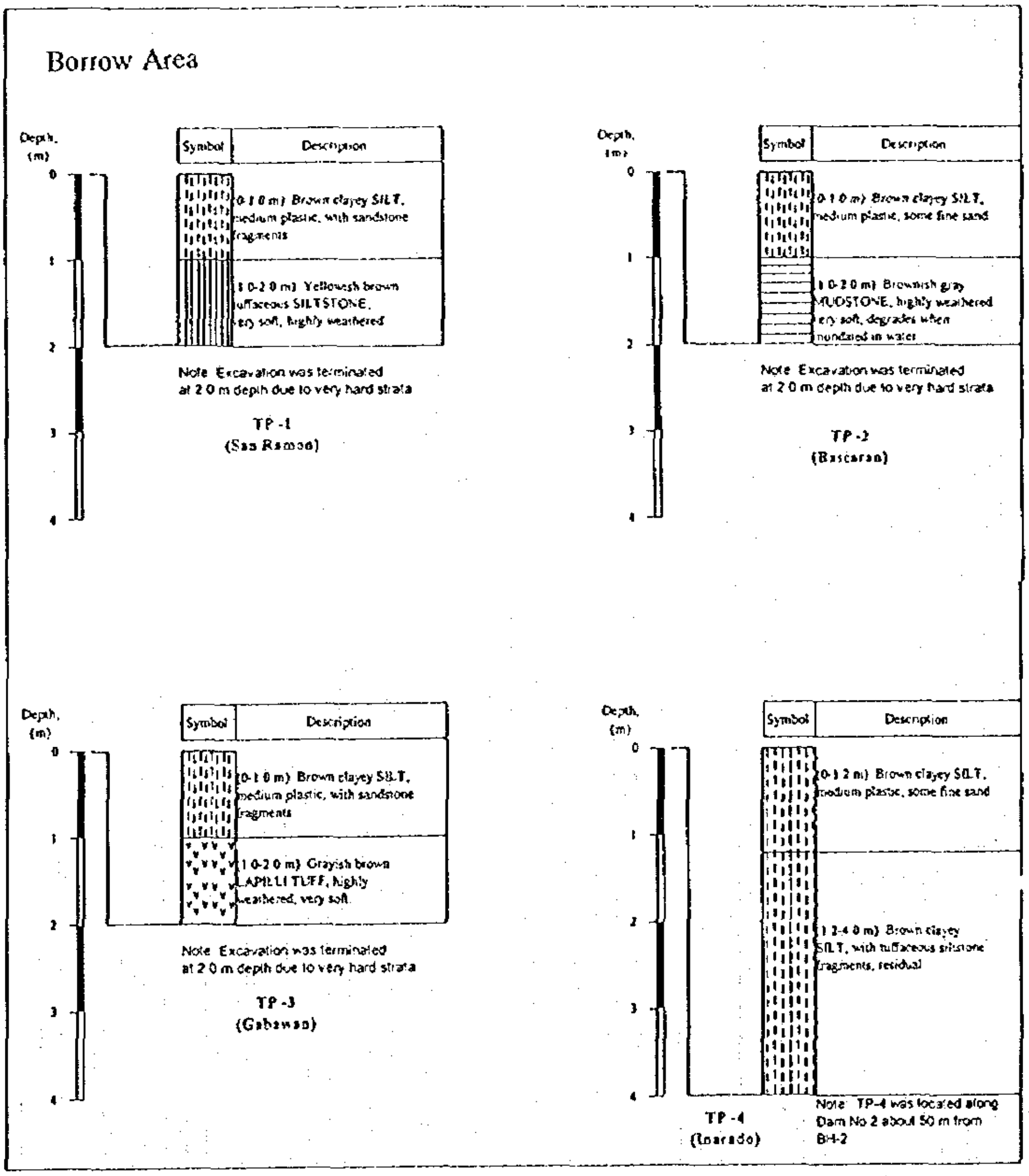


Fig B.4.1.2 Location Map of Quarry Site

(S=1/50,000)



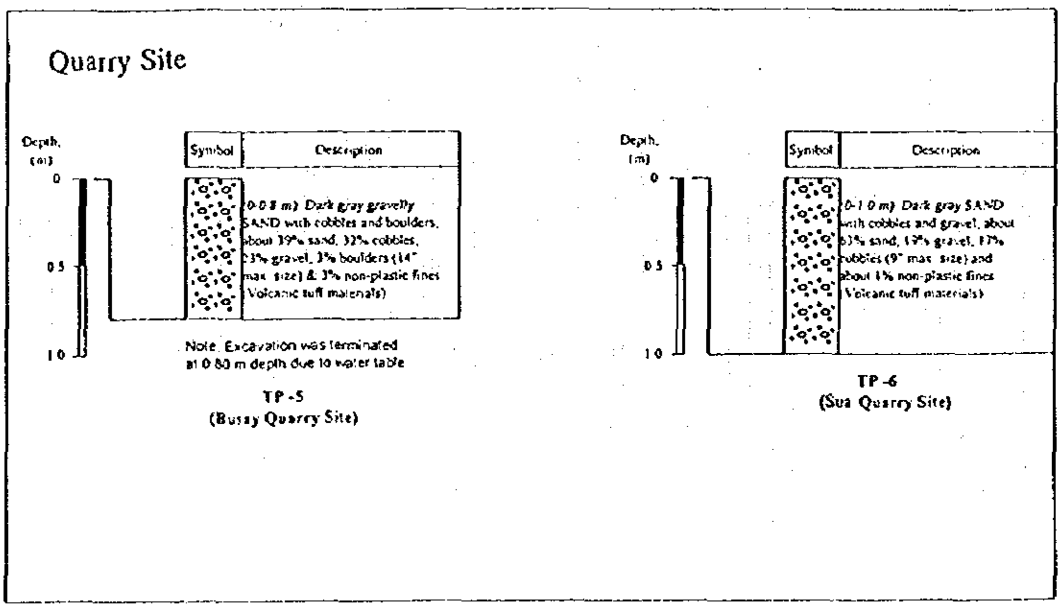


Fig B.4.1.3 Test Pit Log

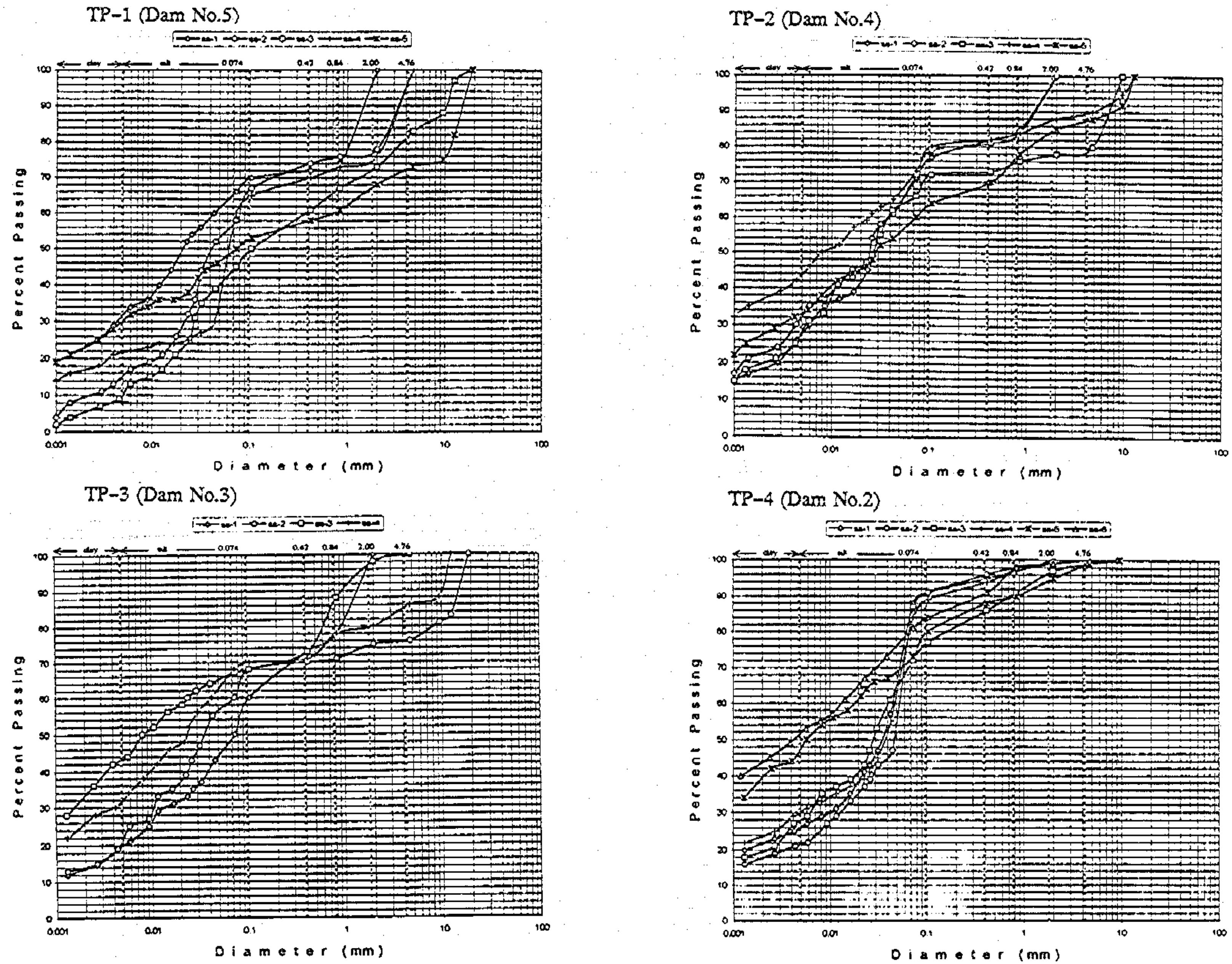
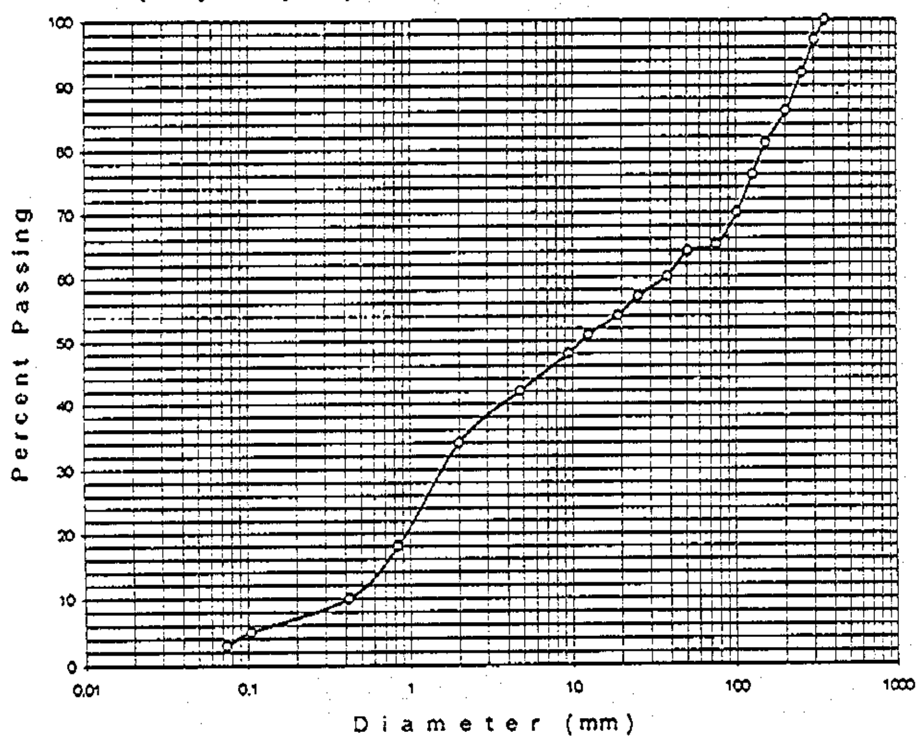


Fig B.4.2.1 Grain Size Analysis Curve of Soil Materials

TP-5 (Busay Quarry Site)



TP-6 (Sur Quarry Site)

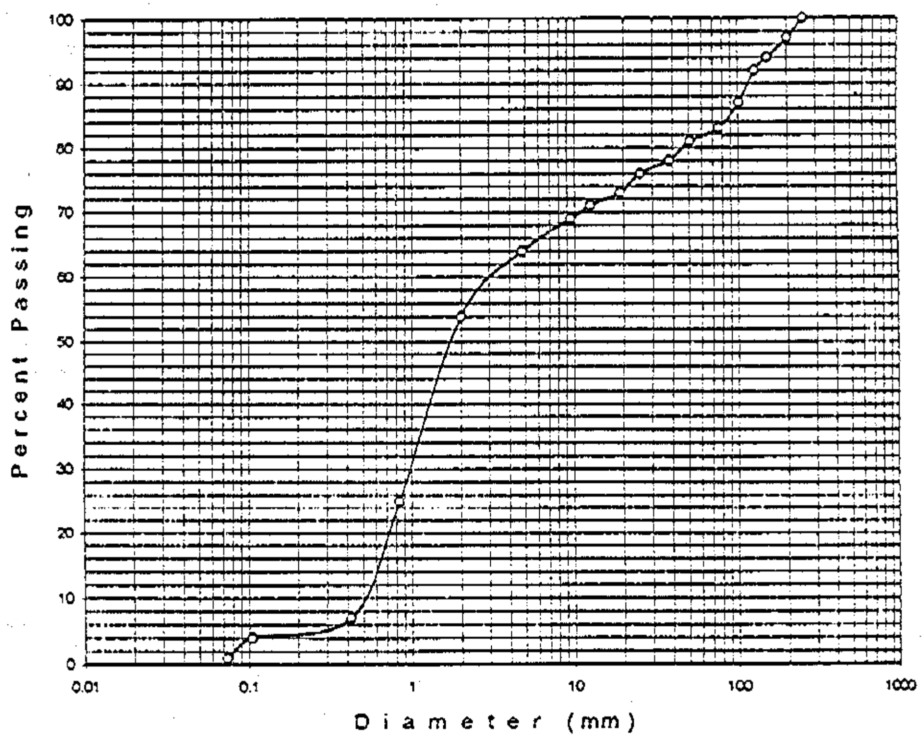
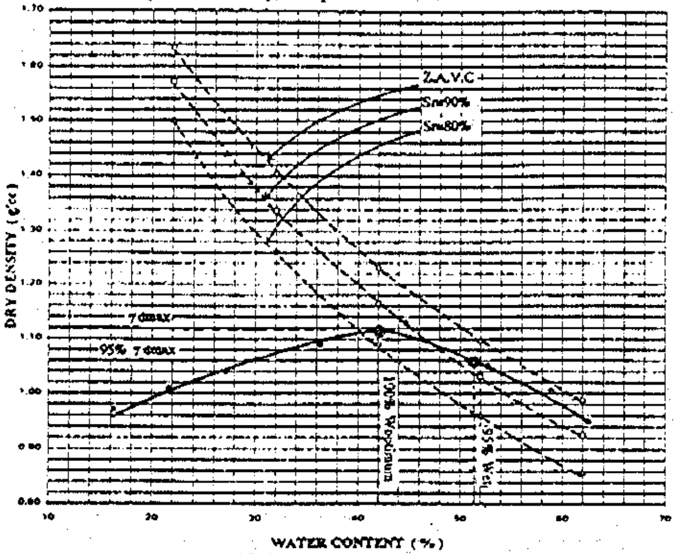


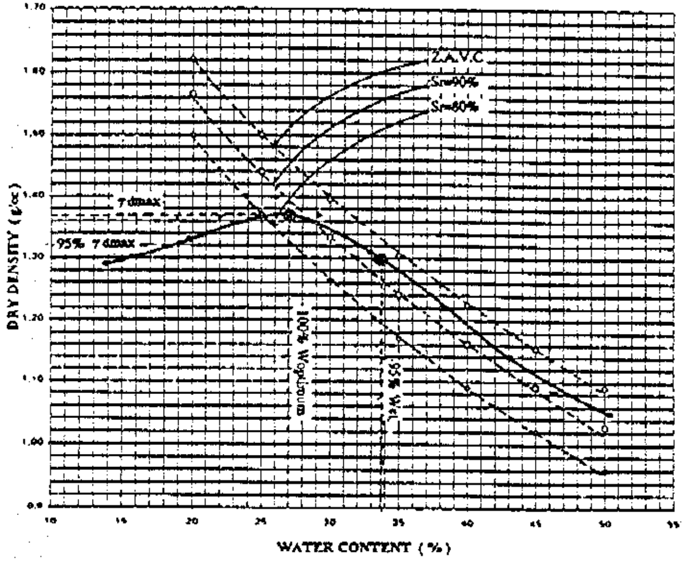
Fig B.4.2.2 Grain Size Analysis Curve of Aggregates

TP-1 (Dam No.5), Dep=0.5 ~ 1.0m



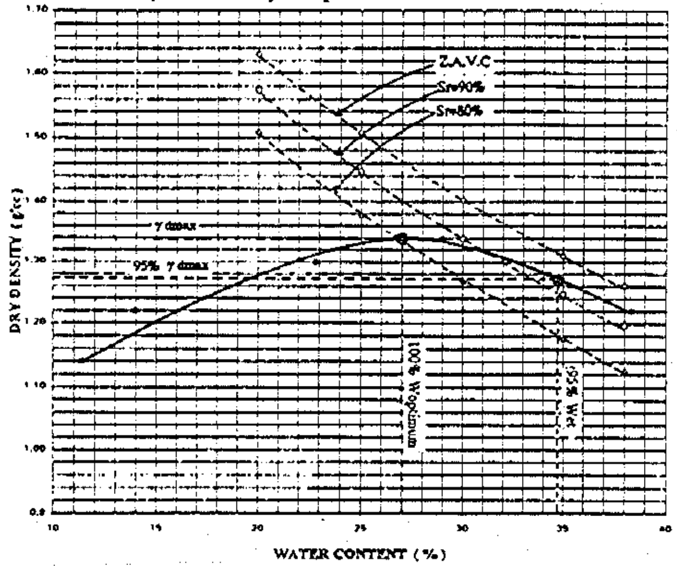
MAXIMUM DRY DENSITY = 1.12 g/cc   OPTIMUM MOISTURE CONTENT = 42.00 %

TP-2 (Dam No.4), Dep=0.5 ~ 1.0m



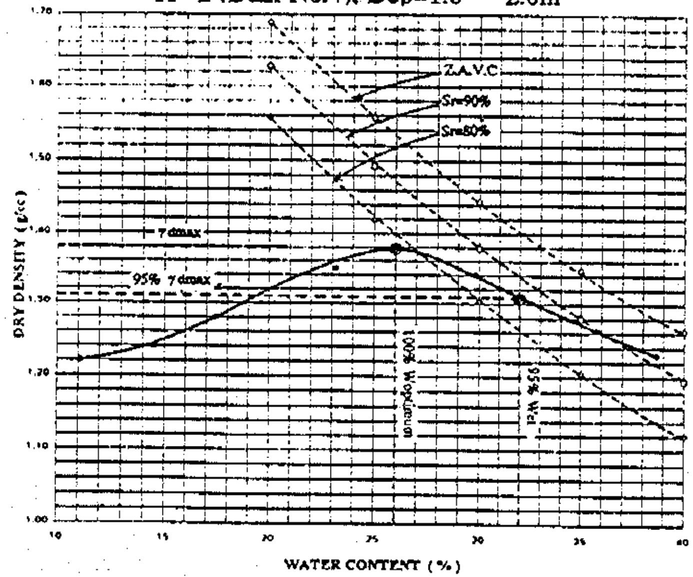
MAXIMUM DRY DENSITY = 1.37 g/cc   OPTIMUM MOISTURE CONTENT = 27.00 %

TP-1 (Dam No.5), Dep=1.0 ~ 1.5m



MAXIMUM DRY DENSITY = 1.34 g/cc   OPTIMUM MOISTURE CONTENT = 27.00 %

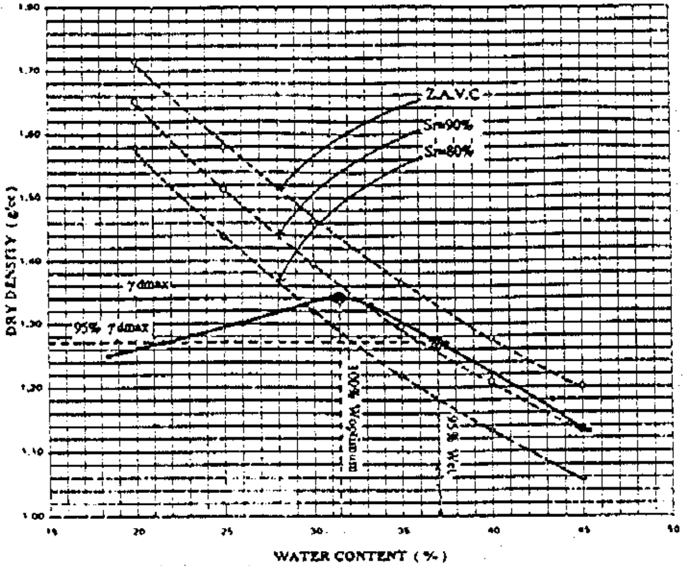
TP-2 (Dam No.4), Dep=1.0 ~ 2.0m



MAXIMUM DRY DENSITY = 1.38 g/cc   OPTIMUM MOISTURE CONTENT = 26.00 %

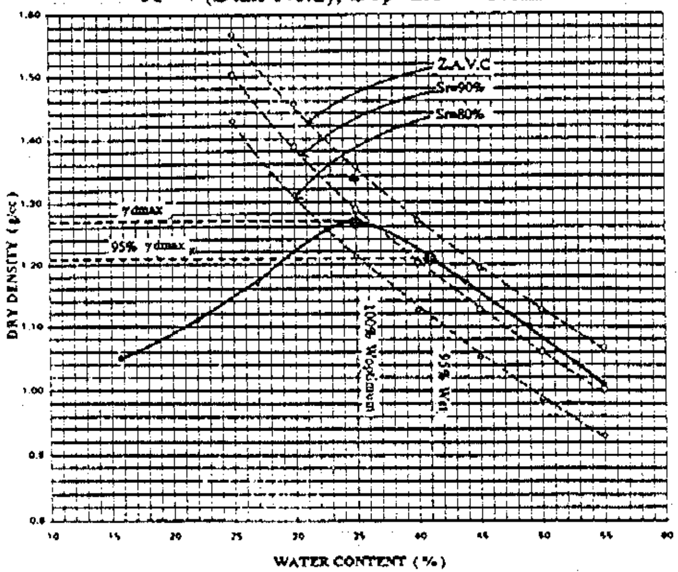
Fig B.4.2.3 Compaction Curve (1)

TP-3 (Dam No.3), Dep=0.5 ~ 1.0m



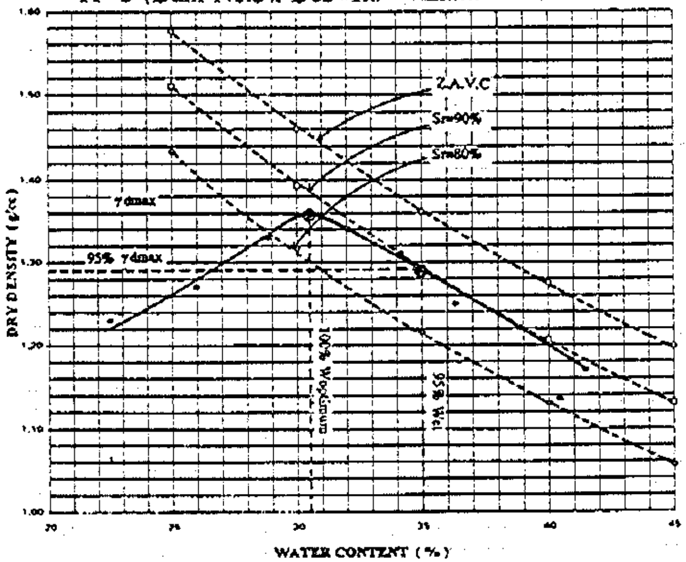
MAXIMUM DRY DENSITY = 1.34 g/cc OPTIMUM MOISTURE CONTENT = 31.34 %

TP-4 (Dam No.2), Dep=2.0 ~ 3.0m



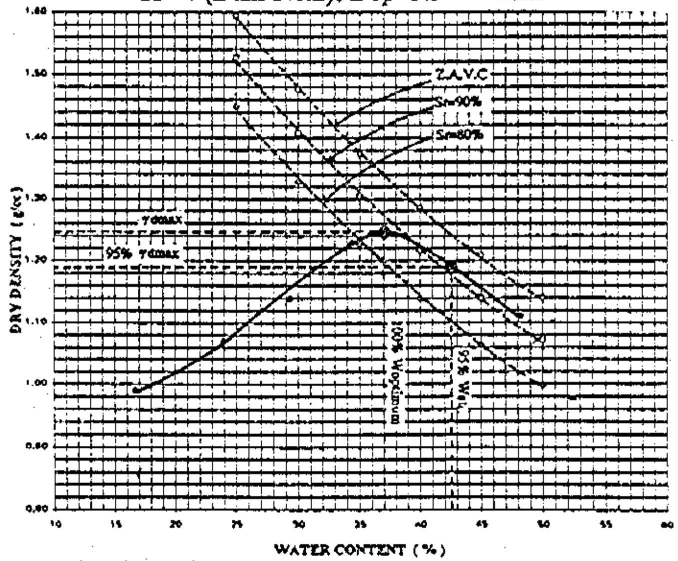
MAXIMUM DRY DENSITY = 1.27 g/cc OPTIMUM MOISTURE CONTENT = 35.00 %

TP-3 (Dam No.3), Dep=1.0 ~ 2.0m



MAXIMUM DRY DENSITY = 1.36 g/cc OPTIMUM MOISTURE CONTENT = 30.50 %

TP-4 (Dam No.2), Dep=3.5 ~ 4.0m



MAXIMUM DRY DENSITY = 1.25 g/cc OPTIMUM MOISTURE CONTENT = 37.00 %

Fig B.4.2.4 Compaction Curve (2)

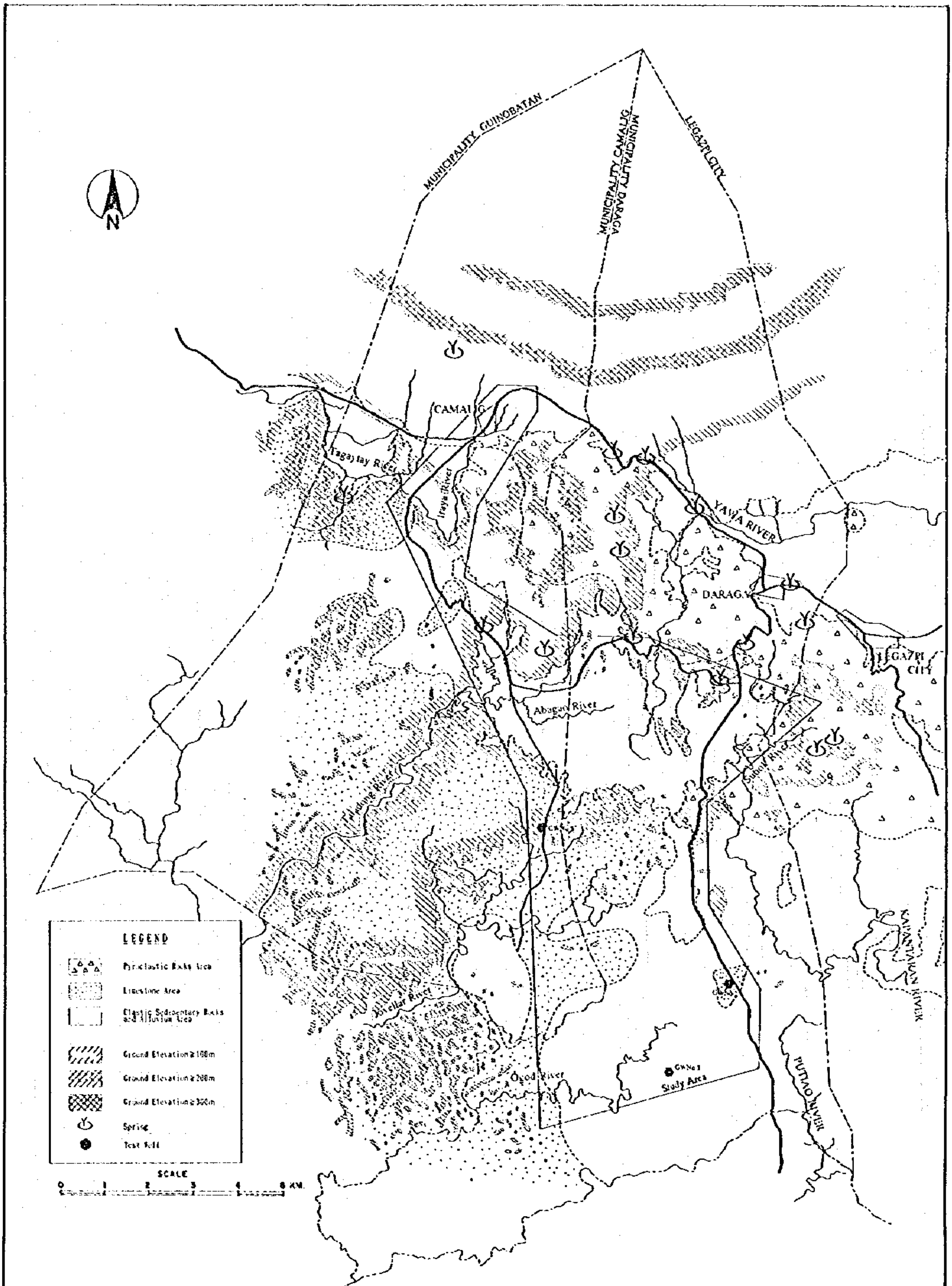


Fig B.5.1.1 Geological and Topographical Classification Map

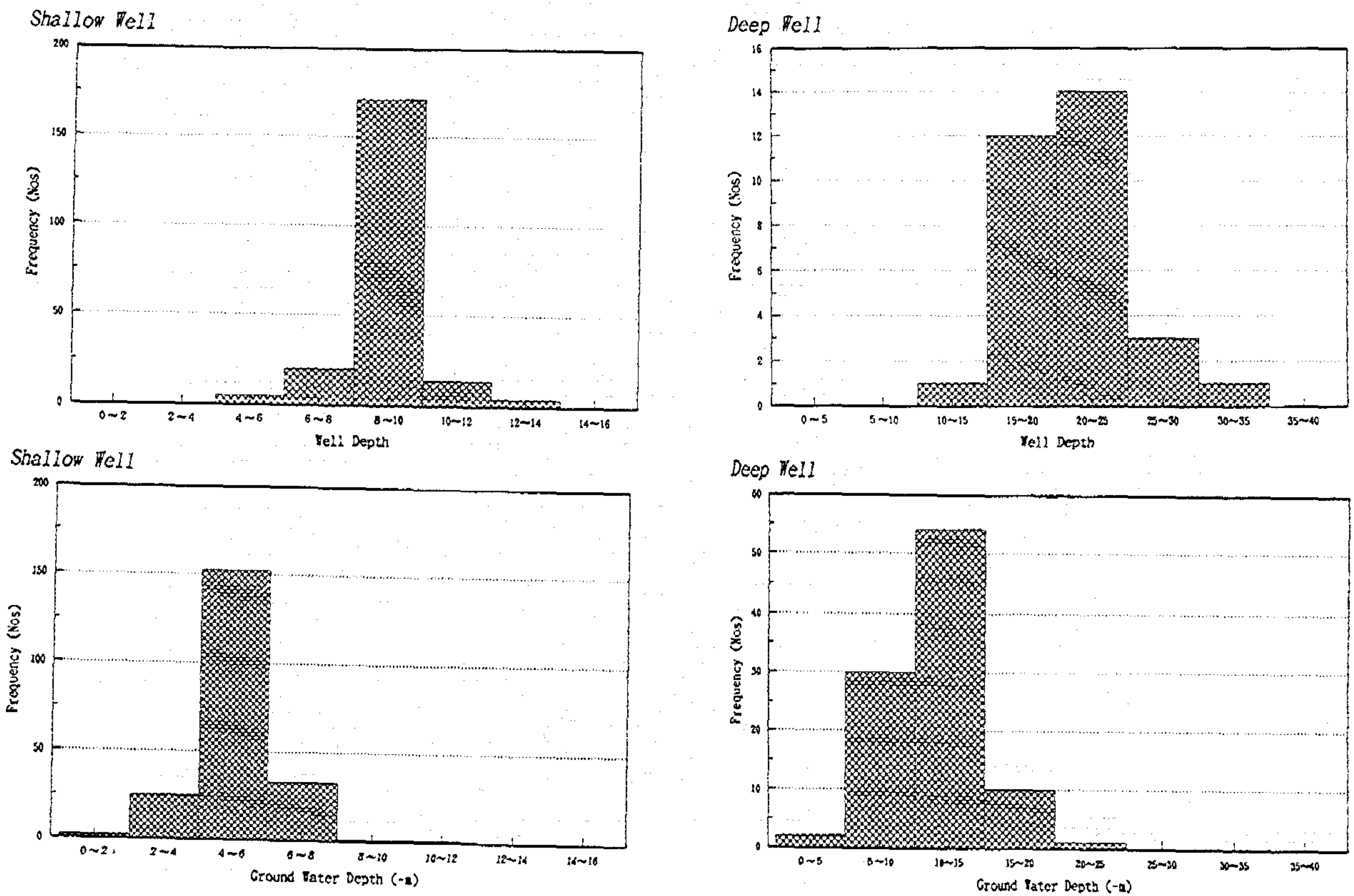
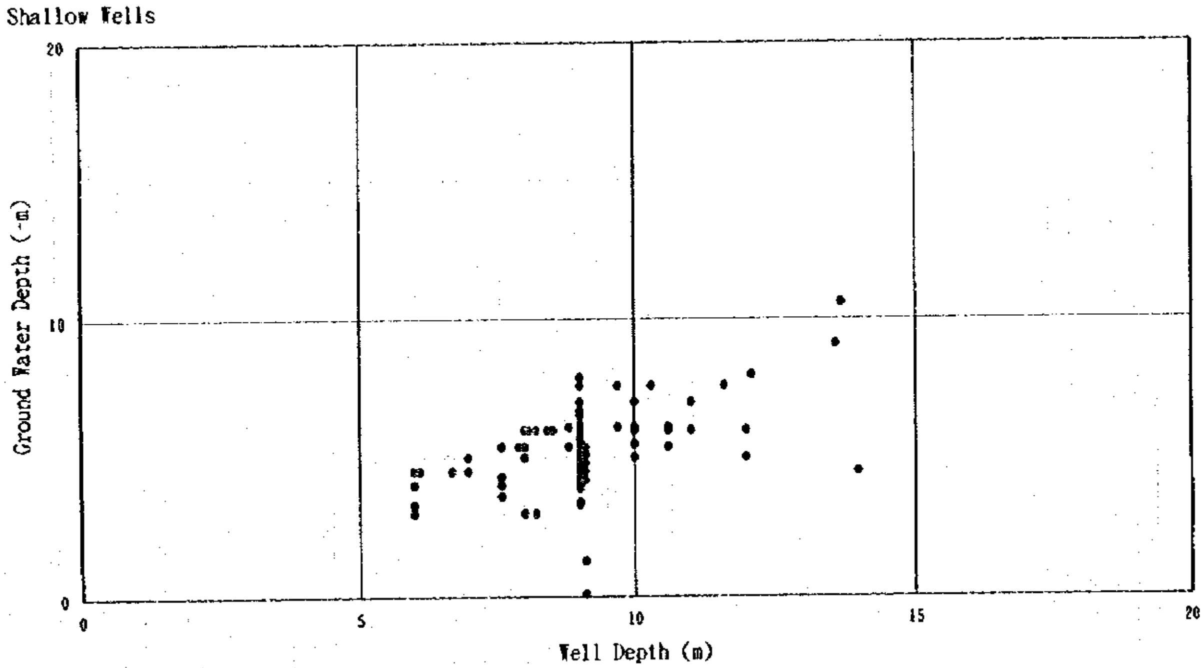


Fig.B.5.1.2 Frequency of Well Depth and Ground Water Depth



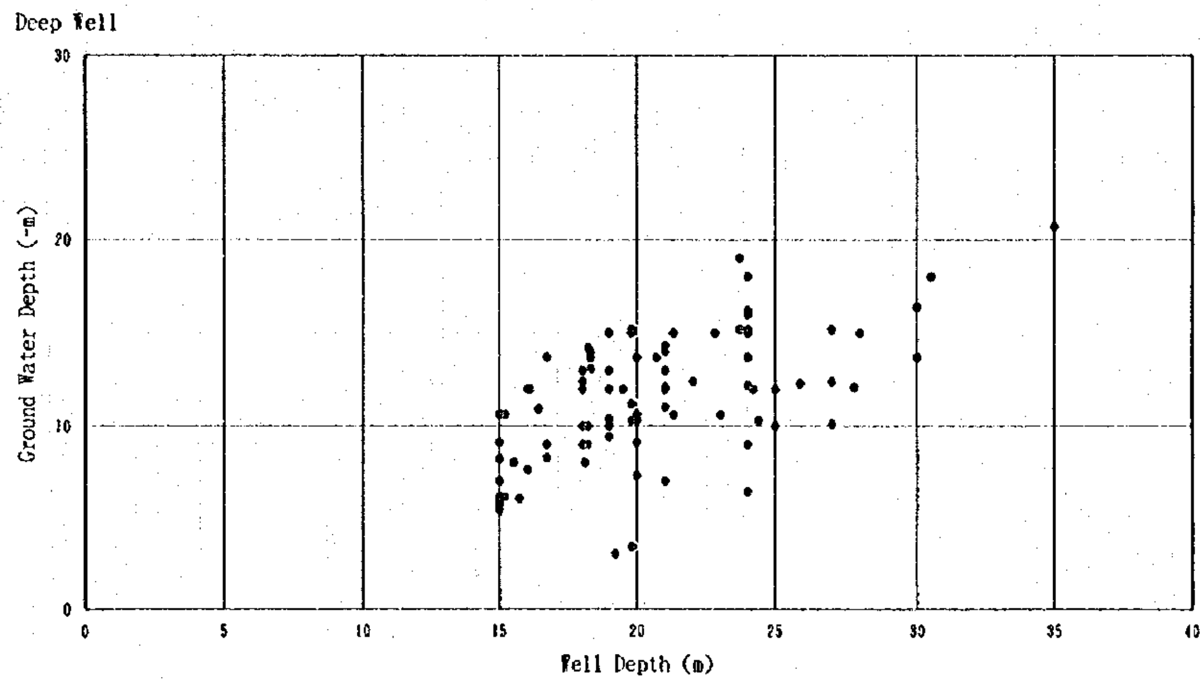
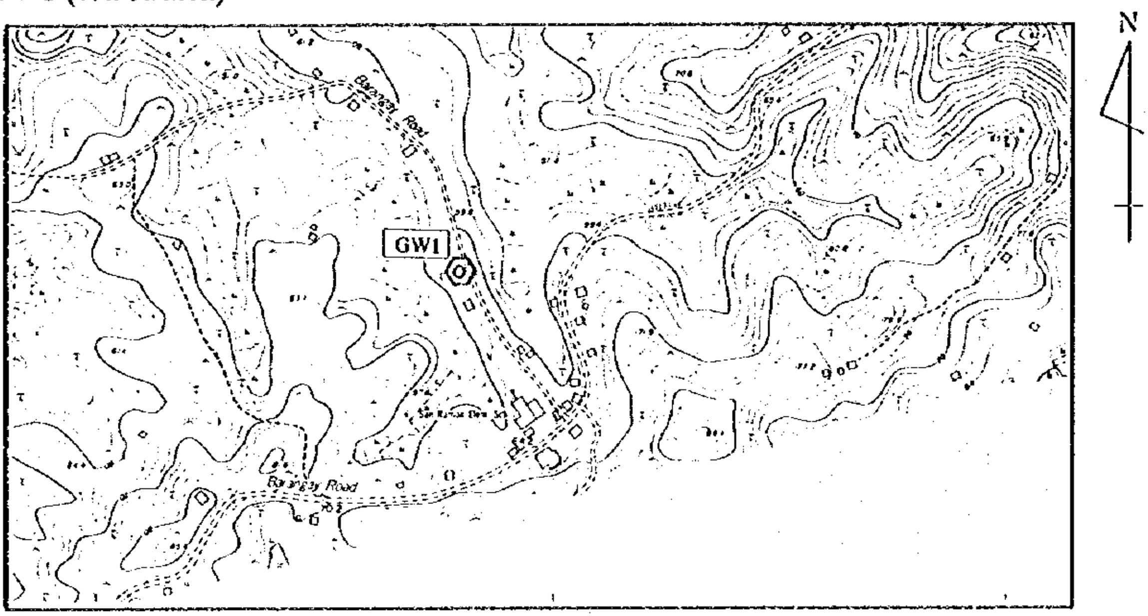
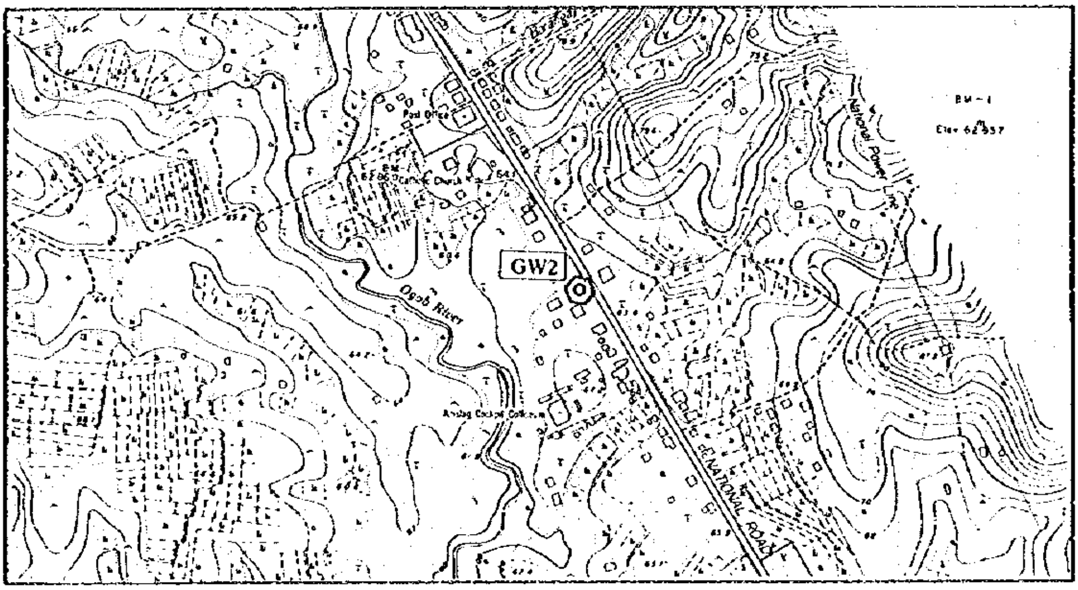


Fig.B.5.1.3 Relation between Well Depth and Ground Water Depth

GW1 (San Ramon)



GW2 (Anislag)



GW3 (Del Rosario)

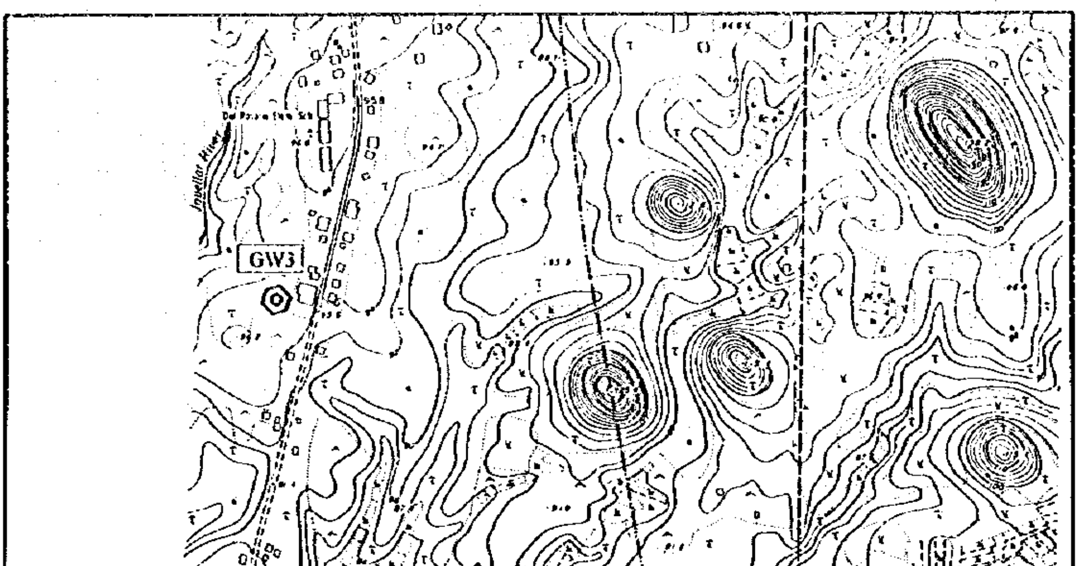


Fig B.5.2.1 Location Map of Test Well Site (S=1/8,000)

Fig B.5.2.2(1) Drill Log of Test Well (GW 1)

HOLE NO: GW-1
TOTAL DEPTH: 30.00 M
MACHINE: TONE

NAME OF PLACE: SAN RAMON, DARAGA, ALBAY
GROUND ELEVATION:
DIAMETER: 73 mm

LOCATION:
DEPTH OF WATER TABLE: -8.50m
ANGLE FROM VERTICAL: 90°

BOUNDARY (m)	ROCK NAME (FORMATION)	COLOUR	WEATHERING	DESCRIPTION
0.80	TOP SOIL	REDDISH	COMPLETELY WEATHERED	**0.00 - 0.80 m:** TOP SOIL, SILTY CLAY, FIRM WHEN DRY, WITH TRACES OF ROCK FRAGMENTS
2.70	SANDSTONE	DARK GRAY	DEEPLY TO COMPLETELY WEATHERED	**0.80 - 2.70 m:** SANDSTONE, DEEPLY TO COMPLETELY WEATHERED, ALMOST RESIOUAL SOIL
3.40	SANDSTONE	DARK GRAY	MW	**2.70 - 3.40 m:** SANDSTONE, MEDIUM WEATHERED, WELL CEMENTED/ INDURATED, BROKEN/FRACTURED
4.00	SILTSTONE	REDDISH	DW	**3.40 - 4.00 m:** SILTSTONE, DEEPLY WEATHERED MATRIX, EASILY CRUMBLED BY FINGER PRESSURE
5.10	SILTSTONE	REDDISH	COMPLETELY WEATHERED	**4.00 - 5.10 m:** SILSTONE, COMPLETELY WEATHERED OR DECOMPOSED, MEDIUM TO HIGH PLASTIC, FIRM WHEN DRY
14.70	SHALE	BLACK	COMPLETELY WEATHERED	**5.10 - 14.70 m:** SHALE, COMPLETELY DECOMPOSED, STICKY, WITH OCCASIONAL PIECES OF BROKEN SHELLS (FOSILS), HIGH PLASTIC, WITH SILTSTONE LENSE AT THE DEPTH OF 14.70 - 15.10 m.
15.10	SILTSTONES		DW	
20.00	SHALE	BLACK	COMPLETELY WEATHERED	**15.10 - 20.00 m:** SHALE, SAME AS IN SECTION 5.10 - 14.70 m
22.00	SANDSTONE			**20.00 - 22.00 m:** DRILL CUTTINGS PROBABLY SANDSTONE
30.00	SILTSTONE	GRAYISH	SLIGHT TO MEDIUM WEATHERED	**22.00 - 30.00 m:** SILTSTONE SLIGH TO MEDIUM WEATHERED, HARD AND WELL CEMENTED/INDURATED, BROKEN/ FRAGMENTED DUE TO THE DRILLING OPERATION SLUDGE AT SECTIONS 23.30 – 27.00 m 27.00 – 28.00 m

CONDITION: CORE DRILLING (0.00 - 20.00 m); CORE DRILLING (20.00 - 30.00 m)
BIT (DIAMETER): NQ = 73 mm
CASING: NX = 89 mm
G.W.L. (-m): 8.50

DEPTH (m)	CORE RECOVERY	R.Q.D. (%)
0-1	100	0
1-2	100	0
2-3	100	0
3-4	100	0
4-5	100	0
5-6	100	0
6-7	100	0
7-8	100	0
8-9	100	0
9-10	100	0
10-11	100	0
11-12	100	0
12-13	100	0
13-14	100	0
14-15	100	0
15-16	100	0
16-17	100	0
17-18	100	0
18-19	100	0
19-20	100	0
20-21	0	0
21-22	0	0
22-23	90	0
23-24	80	0
24-25	30	0
25-26	0	0
26-27	10	0
27-28	95	34
28-29	0	0
29-30	25	0

P.T. (• Lugeon Value (Lu) • P. Coefficient (K) • Yield Point (PC))

DEPTH (m)	METHOD	DIAMETER	P.T.
0-5	PERCOLATION TEST CONSTANT	85 mm	k=0.0
5-10	PERCOLATION TEST CONSTANT	85 mm	k=1.84E-05
10-15	PERCOLATION TEST CONSTANT	85 mm	k=0.0
15-20	WATER PRESSURE TEST (WPT) - DESCENDING	85 mm	Lu=4.2 k=2.18E-05 Pc=5.49
20-25	WATER PRESSURE TEST (WPT) - DESCENDING	85 mm	Lu=7.4 k=9.13E-5
25-30	WATER PRESSURE TEST (WPT) - DESCENDING	85 mm	Lu=2.8 k=2.83E-05 Pc=3.78

Fig B.5.2.2(2) Drill Log of Test Well (GW 2)

HOLE NO: GW-2
TOTAL DEPTH: 30.00 M
MACHINE: TONE

NAME OF PLACE: ANISLAG, DARAGA, ALBAY
GROUND ELEVATION:
DIAMETER: 73 mm

LOCATION:
DEPTH OF WATER TABLE: -2.60m
ANGLE FROM VERTICAL: 90°

BOUNDARY (m)	ROCK NAME (FORMATION)	COLOUR	WEATHERING	DESCRIPTION
1.10	TOP SOIL	DARK BROWN		0.00 - 1.10 m: TOP SOIL, SILTY CLAY, MEDIUM PLASTIC
1.70		YEL-LOWISH BROWN	DW TO TW	1.10 - 1.70 m: LIMESTONE, DEEPLY TO TOTALLY WEATHERED, EASILY BROKEN BY FINGER PRESSURE
8.00	CALCAREOUS SANDSTONE WITH LIMESTONE INCLUSION	BUFF		1.70 - 8.00 m: CALCAREOUS SANDSTONE WITH INCLUSION OF LIMESTONE WITH SOLUTION CAVITIES, MEDIUM WEATHERED, SLIGHTLY HARD
10.50	CALCAREOUS SANDSTONE	GRAY		8.00 - 10.50 m: CALCAREOUS SANDSTONE, SLIGHTLY INDURATED / CEMENTED, SLIGHTLY HARD AND JOINTED
14.40	CONGLOMERATIC LIMESTONE	DIRTY WHITE		10.50 - 14.40 m: CONGLOMERATIC LIMESTONE, SLIGHTLY INDURATED, WITH VOLCANIC CLASTS
18.50	CORRALINE LIMESTONE		MEDIUM WETHERRED	14.40 - 18.50 m: CORRALINE LIMESTONE WITH INCLUSION OF CALCAREOUS LIMESTONE, MEDIUM WEATHERED, WITH NUMEROUS SOLUTION CAVITIES
30.00	CALCAREOUS SANDSTONE WITH LIMESTONE INCLUSION	BUFF		18.50 - 30.00 m: CALCAREOUS SANDSTONE WITH INCLUSION OF CORRALINE LIMESTONE, WITH NUMEROUS SOLUTION CAVITIES, SLIGHTLY HARD, MASSIVE TO JOINTED AND SLIGHTLY DARK

CONDITION: CORE DRILLING; BIT (DIAMETER): NQ = 73 mm; CASING: NX = 89 mm; G.W.L. (-m): 2.60

DEPTH (m)	CORE RECOVERY	R.Q.D. (%)
0-1	100	0
1-2	100	0
2-3	60	20
3-4	45	0
4-5	50	0
5-6	90	24
6-7	90	16
7-8	100	61
8-9	80	51
9-10	90	50
10-11	60	27
11-12	0	0
12-13	40	0
13-14	0	0
14-15	50	0
15-16	60	0
16-17	30	0
17-18	70	25
18-19	80	23
19-20	85	18
20-21	80	0
21-22	100	40
22-23	85	46
23-24	85	72
24-25	90	90
25-26	100	35
26-27	87	0
27-28	80	0
28-29	85	12
29-30	80	15

P.T. (• Lugeon Value (Lu) • P. Coefficient (K) • Yield Point (PC))

METHOD	DIAMETER	P.T.
WATER PRESSURE TEST - DESCENDING	85 mm	Lu=11.2, k=4.75E-04, Pc=5.16
WATER PRESSURE TEST - DESCENDING	85 mm	Lu=13.1, k=4.77E-04
WATER PRESSURE TEST - DESCENDING	85 mm	Lu=32.3, k=1.18E-03
WATER PRESSURE TEST (WPT) - DESCENDING	85 mm	Lu=11.4, k=4.08E-04
WATER PRESSURE TEST (WPT) - DESCENDING	85 mm	Lu=19.0, k=4.64E-04
WATER PRESSURE TEST (WPT) - DESCENDING	85 mm	Lu=12.1, k=3.50E-04

Fig B.5.2.2(3) Drill Log of Test Well (GW 3)

HOLE NO: GW-3
TOTAL DEPTH: 30.00 M
MACHINE: MINDRILL

NAME OF PLACE: DEL ROSARIO, CAMALIG, ALBAY
GROUND ELEVATION:
DIAMETER: 73 mm

LOCATION:
DEPTH OF WATER TABLE: -4.10m
ANGLE FROM VERTICAL: 90°

BOUNDARY (m)	ROCK NAME (FORMATION)	COLOUR	WEATHERING	DESCRIPTION
1.10	TOP SOIL	DARK BROWN		0.00 - 1.10 m: TOP SOIL, SILTY CLAY, FIRM WHEN DRY, WITH TRACES OF WEATHERED LIMESTONE FRAGMENTS
5.00			DEEPLY TO COMPLETELY WEATHERED	1.10 - 5.00 m: LIMESTONE, DEEPLY TO COMPLETELY WEATHERED
15.30	LIMESTONE	DIRTY WHITE	MEDIUM WEATHERED	5.00 - 15.30 m: LIMESTONE NEARLY CRYSTALLINE, MEDIUM WEATHERED, WITH SOLUTION CAVITIES
	LIMESTONE	DIRTY WHITE	MEDIUM WEATHERED	15.30 - 30.00 m: LIMESTONE CORALLINE, CONSISTING OF NUMEROUS SOLUTION CAVITIES OR VERY POROUS, JOINTED

CONDITION: CORE DRILLING; BIT (DIAMETER): NQ = 73 mm; CASING: NX = 89 mm; G.W.L. (-m): 4.10

DEPTH (m)	CORE RECOVERY	R.Q.D. (%)
0-1	100	0
1-2	100	0
2-3	100	0
3-4	100	0
4-5	100	0
5-6	100	26
6-7	90	20
7-8	30	10
8-9	30	22
9-10	100	68
10-11	90	28
11-12	90	11
12-13	30	0
13-14	0	0
14-15	70	16
15-16	100	32
16-17	100	25
17-18	100	0
18-19	80	30
19-20	80	35
20-21	100	0
21-22	70	10
22-23	30	13
23-24	30	0
24-25	45	33
25-26	80	20
26-27	50	16
27-28	57	40
28-29	60	0
29-30	87	37

P.T. (• Lugeon Value (Lu) • P. Coefficient (K) • Yield Point (PC))

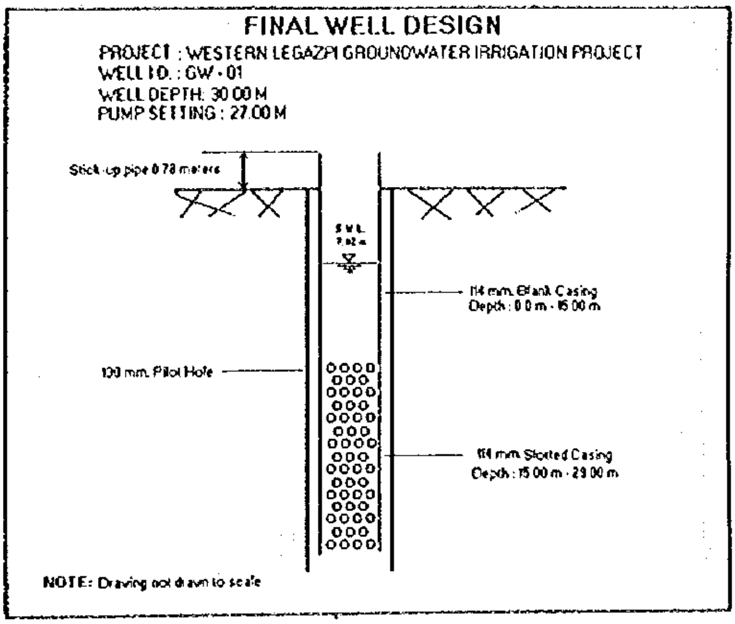
DEPTH (m)	METHOD	DIAMETER	P.T.
0-5	PERCOLATION - CONSTANT	85 mm	k=1.37E-05
5-10	WATER PRESSURE TEST - DESCENDING	85 mm	Lu=3.9, k=4.93E-05
10-15	WATER PRESSURE TEST - DESCENDING	85 mm	Lu=6.4, k=9.87E-05
15-20	WATER PRESSURE TEST (WPT) - DESCENDING	85 mm	Lu=7.5, k=9.75E-05
20-25	WATER PRESSURE TEST (WPT) - DESCENDING	85 mm	Lu=7.3, k=1.38E-04
25-30	WATER PRESSURE TEST (WPT) - DESCENDING	85 mm	Lu=6.9, k=1.14E-04

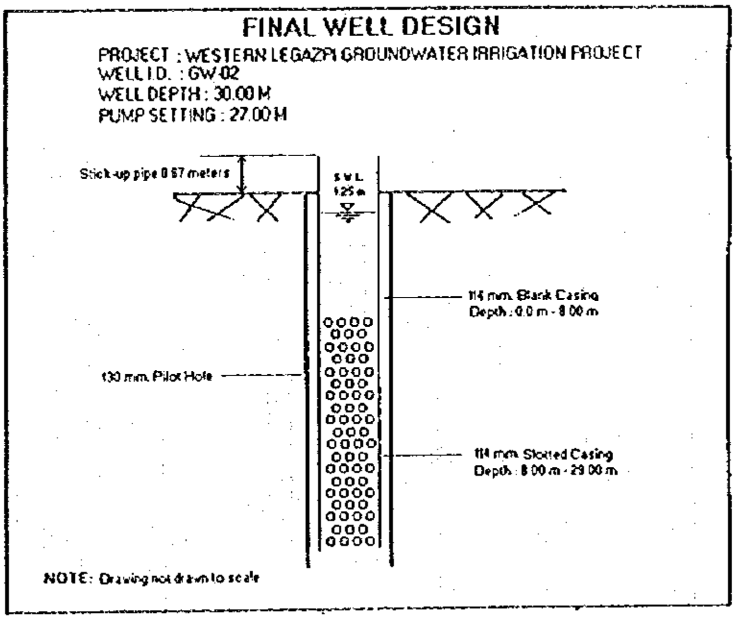
PREPARED BY

WILSON LAYAOEN
SENIOR GEOLOGIST

NOTED BY

R. A. HERNANDEZ
PRESIDENT





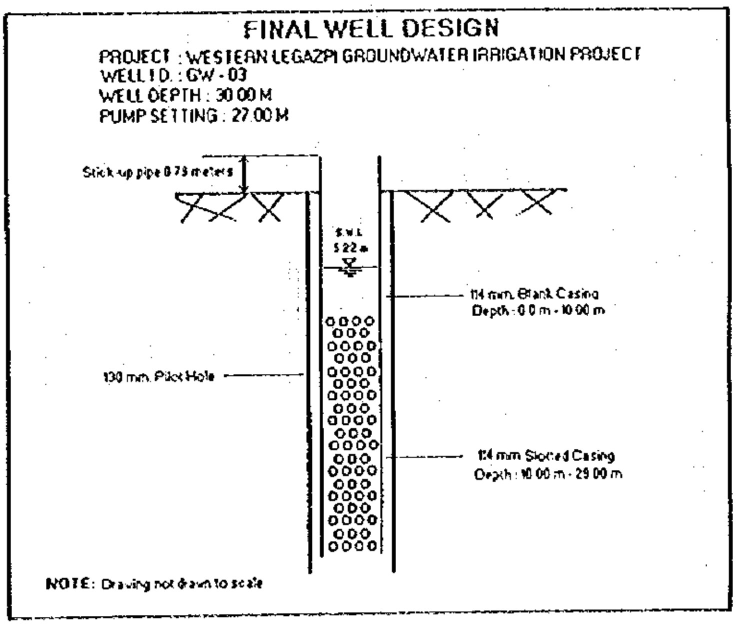


Fig B.5.3.1 Test Well Design

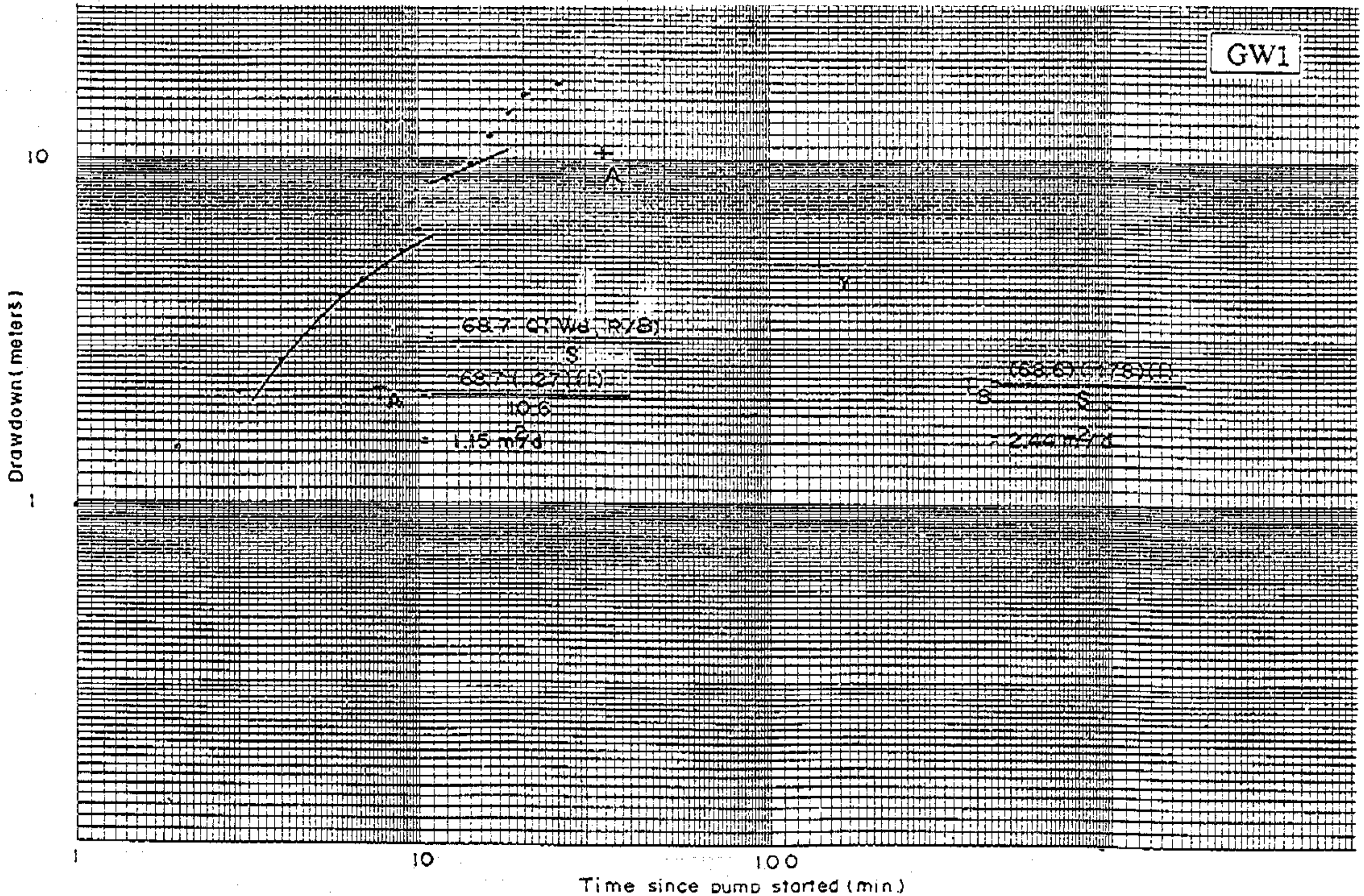


Fig B.5.3.2 (1) Time–Drawdown Curve (GW1)

(After Boulton,1963,Prikett,1965)

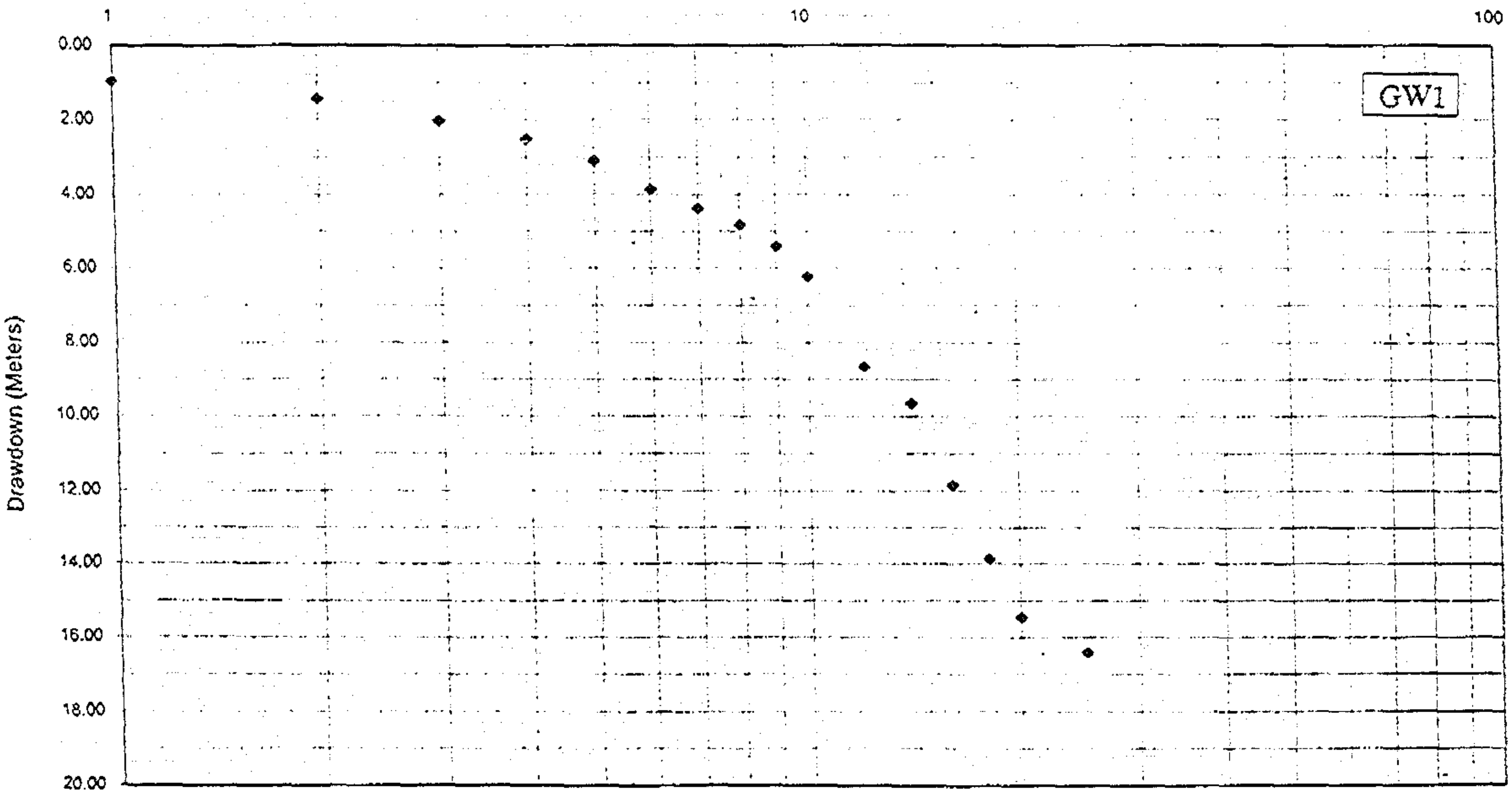


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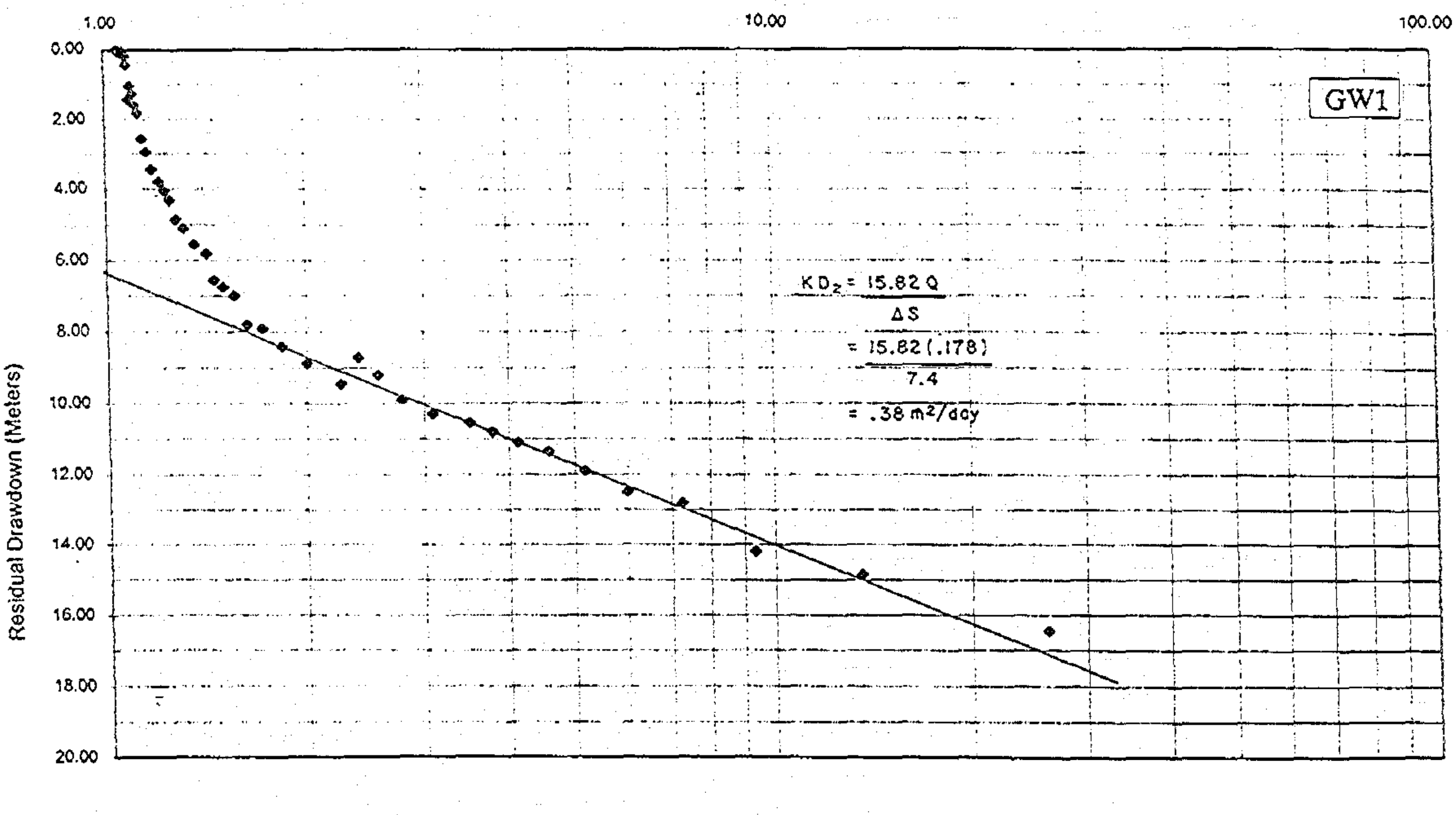
Fig B.5.3.2 (2) Time–Drawdown Curve (GW1)
(Second Trial Pumping)



fn: GW1-rec

Fig B.5.3.2 (3) Time-Residual Drawdown Curve (GW1)
(Second Trial Recovery)

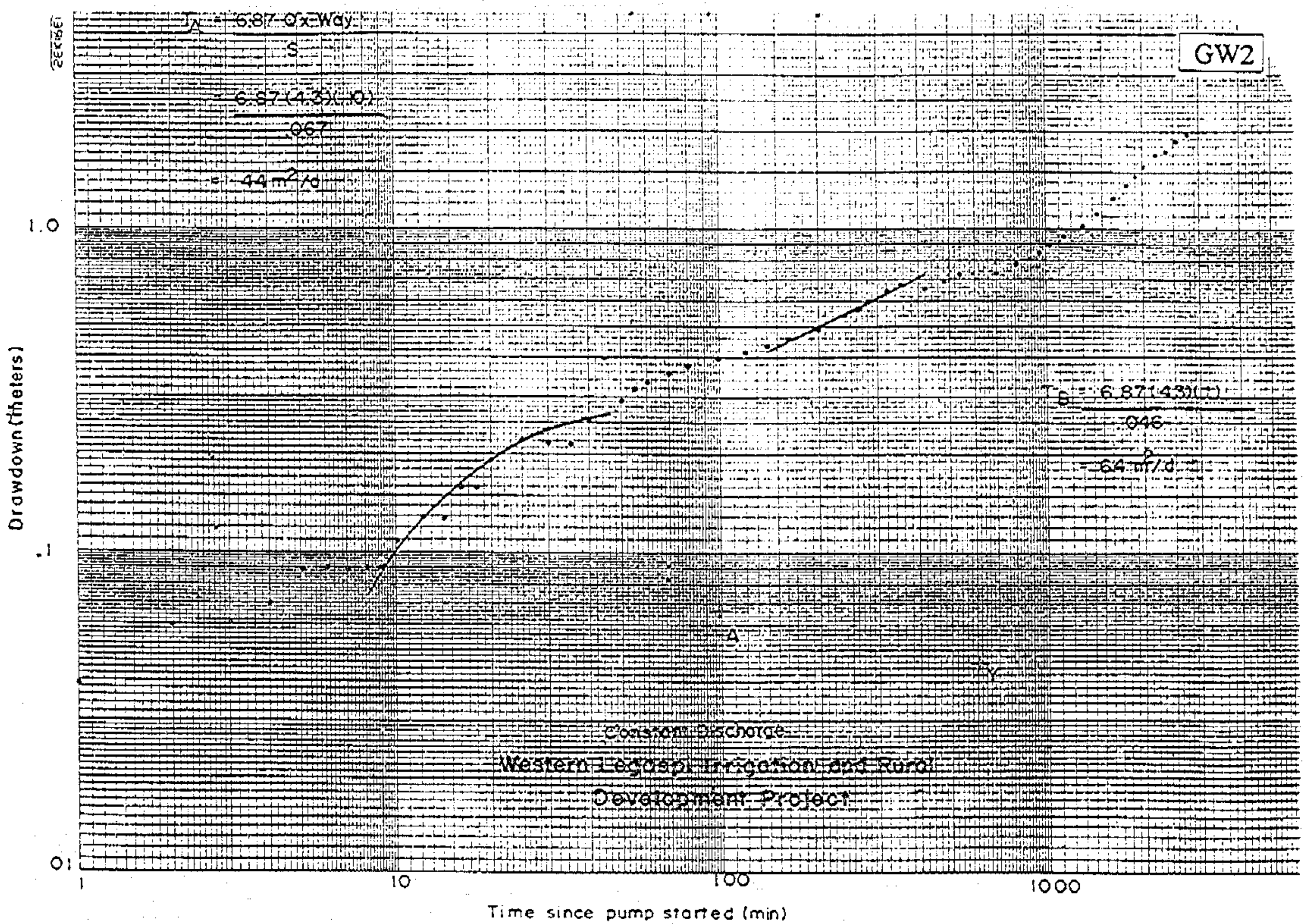


Fig B.5.3.3 (1) Time–Drawdown Curve (GW2)
(After Boulton,1963,Prikett,1965)

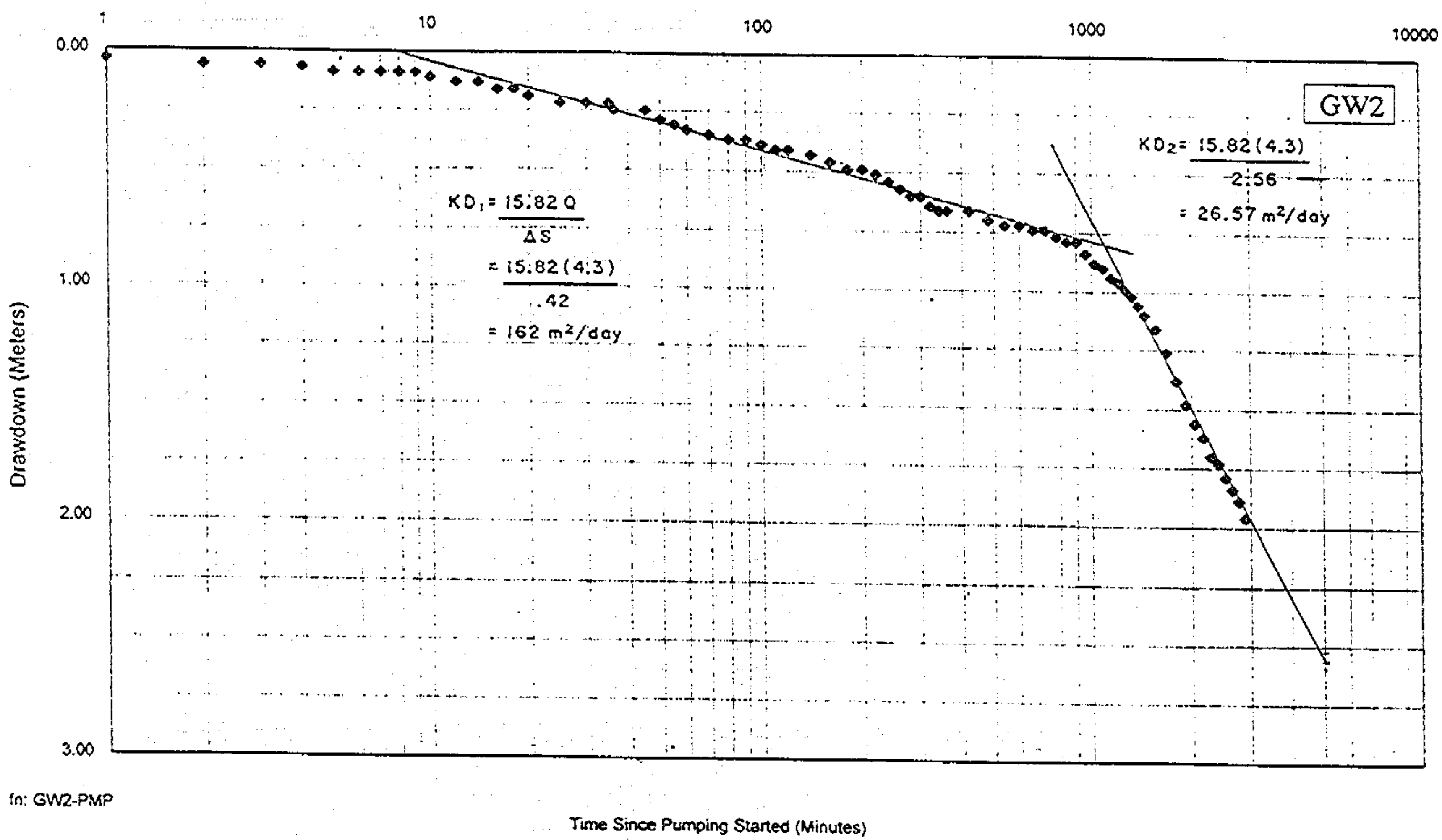


Fig B.5.3.3 (2) Time–Drawdown Curve (GW2)
(Pumping)

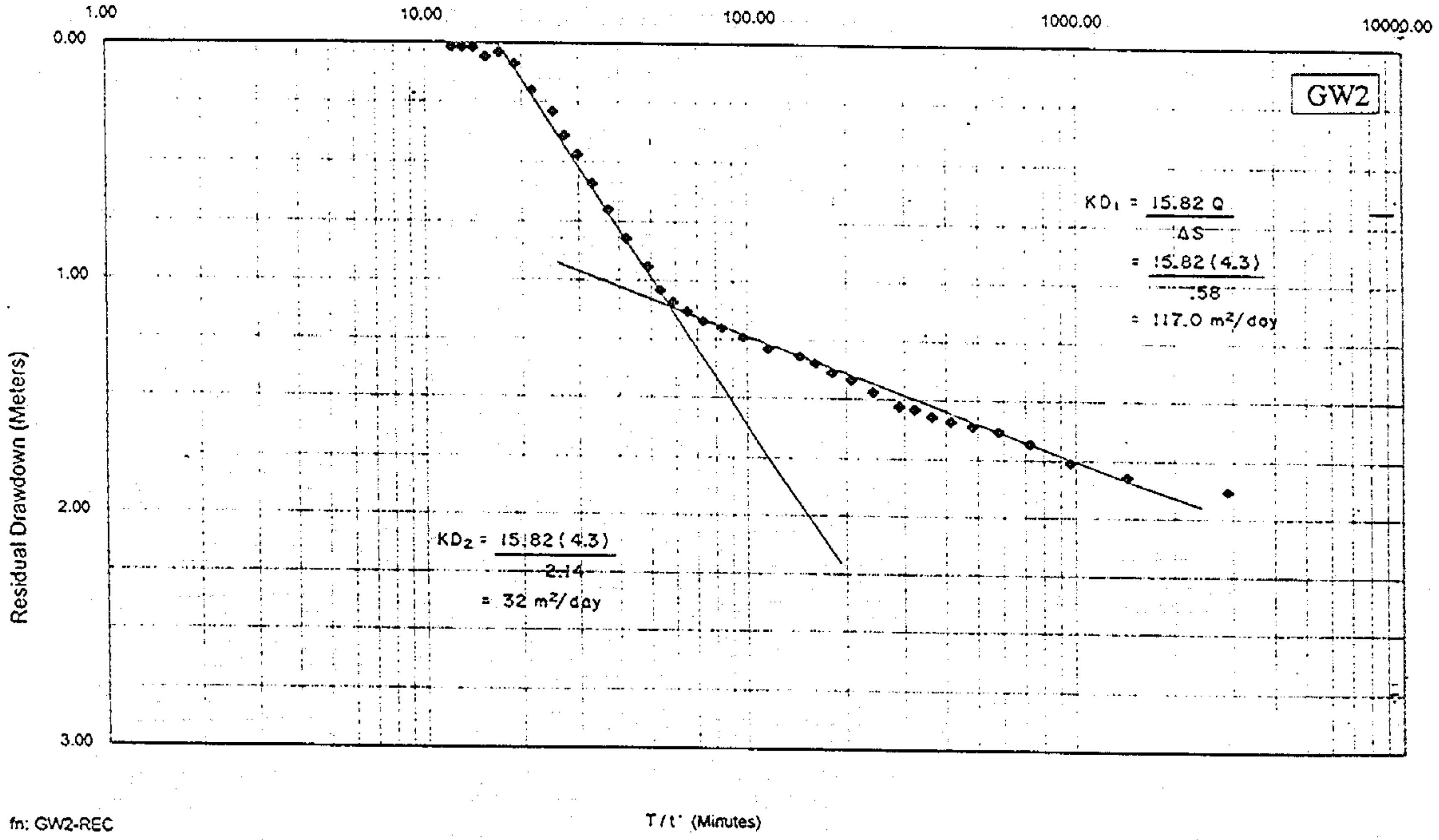


Fig B.5.3.3 (3) Time–Residual Drawdown Curve (GW2)
(Recovery)

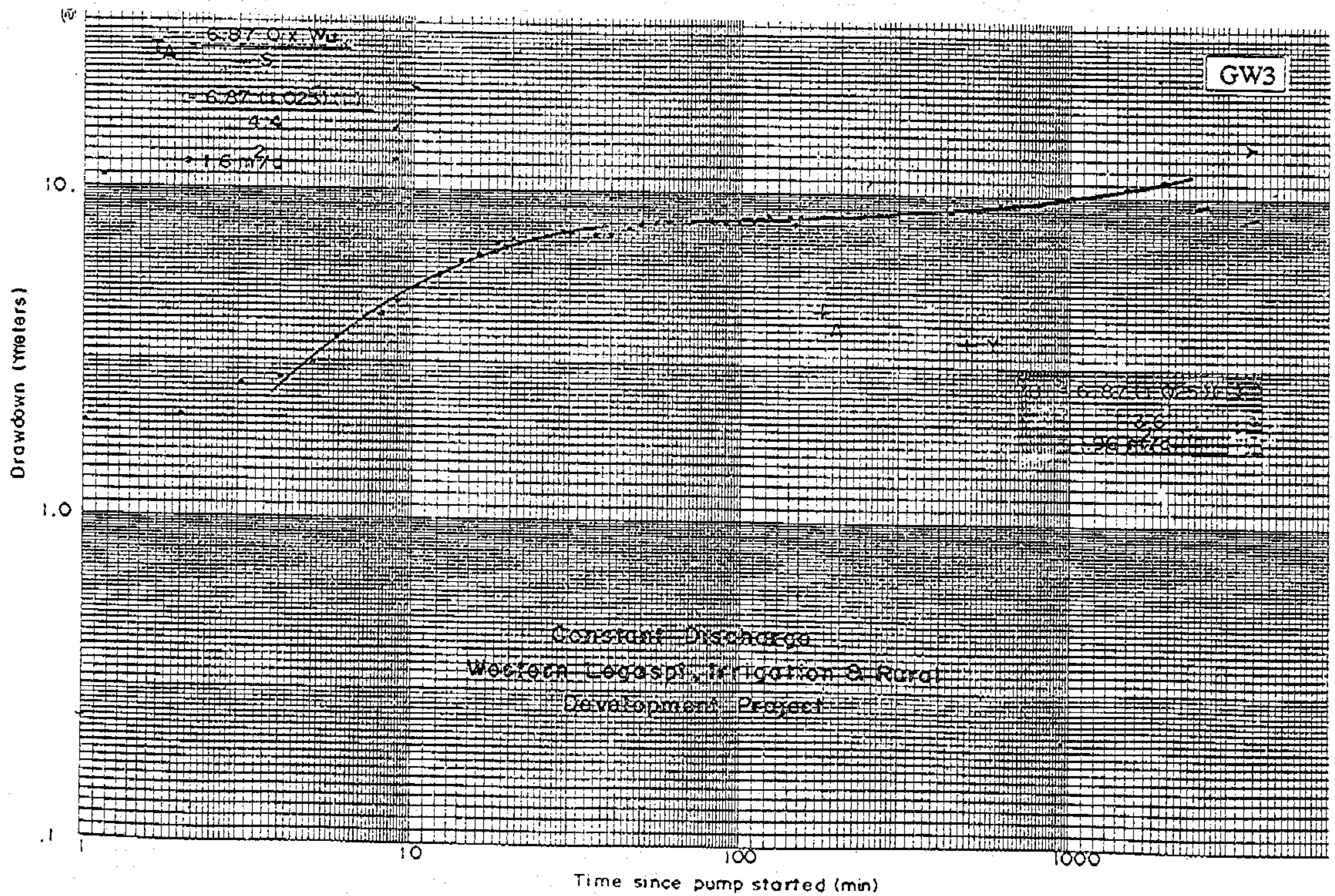


Fig B.5.3.4 (1) Time–Drawdown Curve (GW3)
(After Boulton,1963,Prikett,1965)

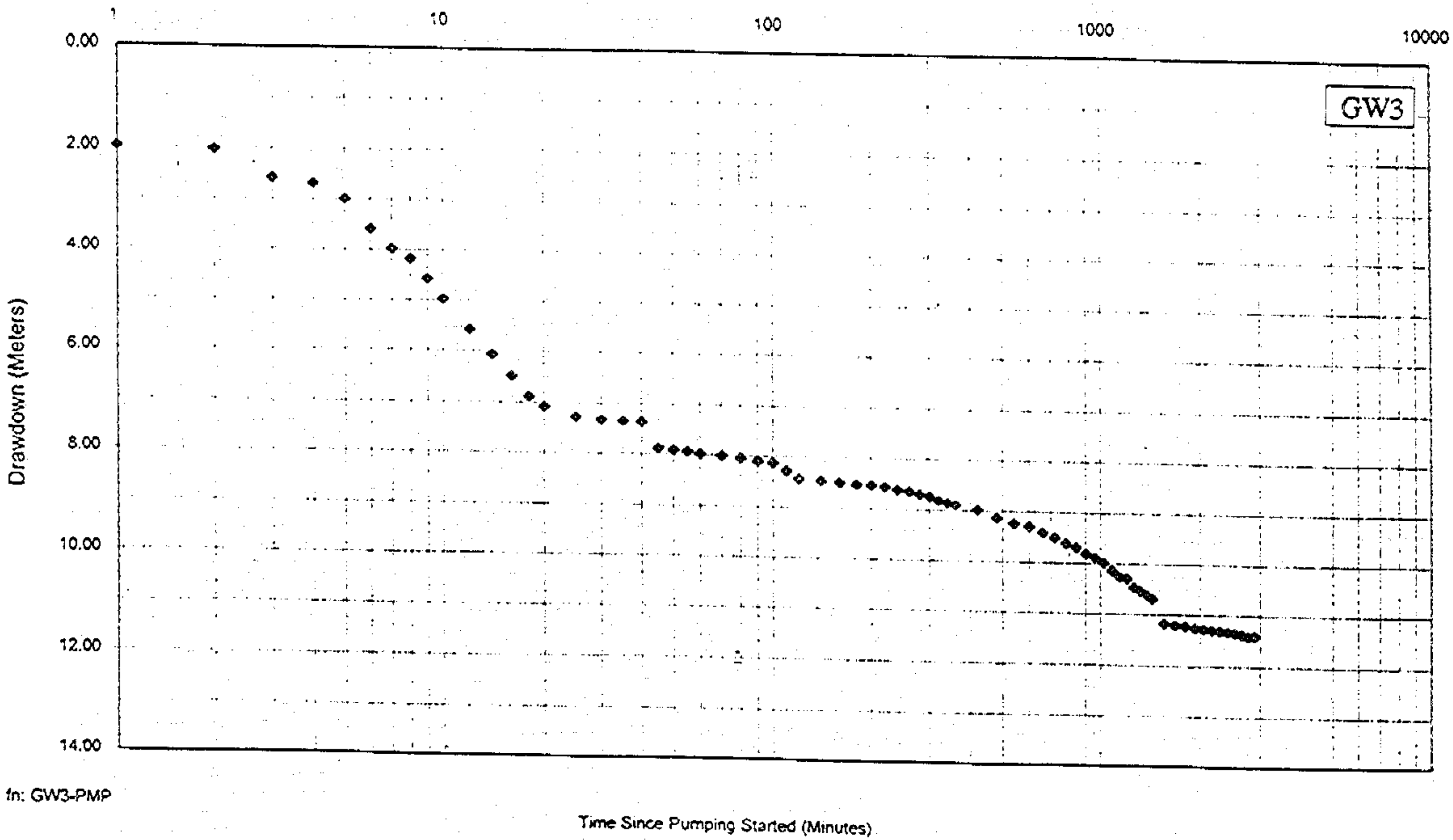
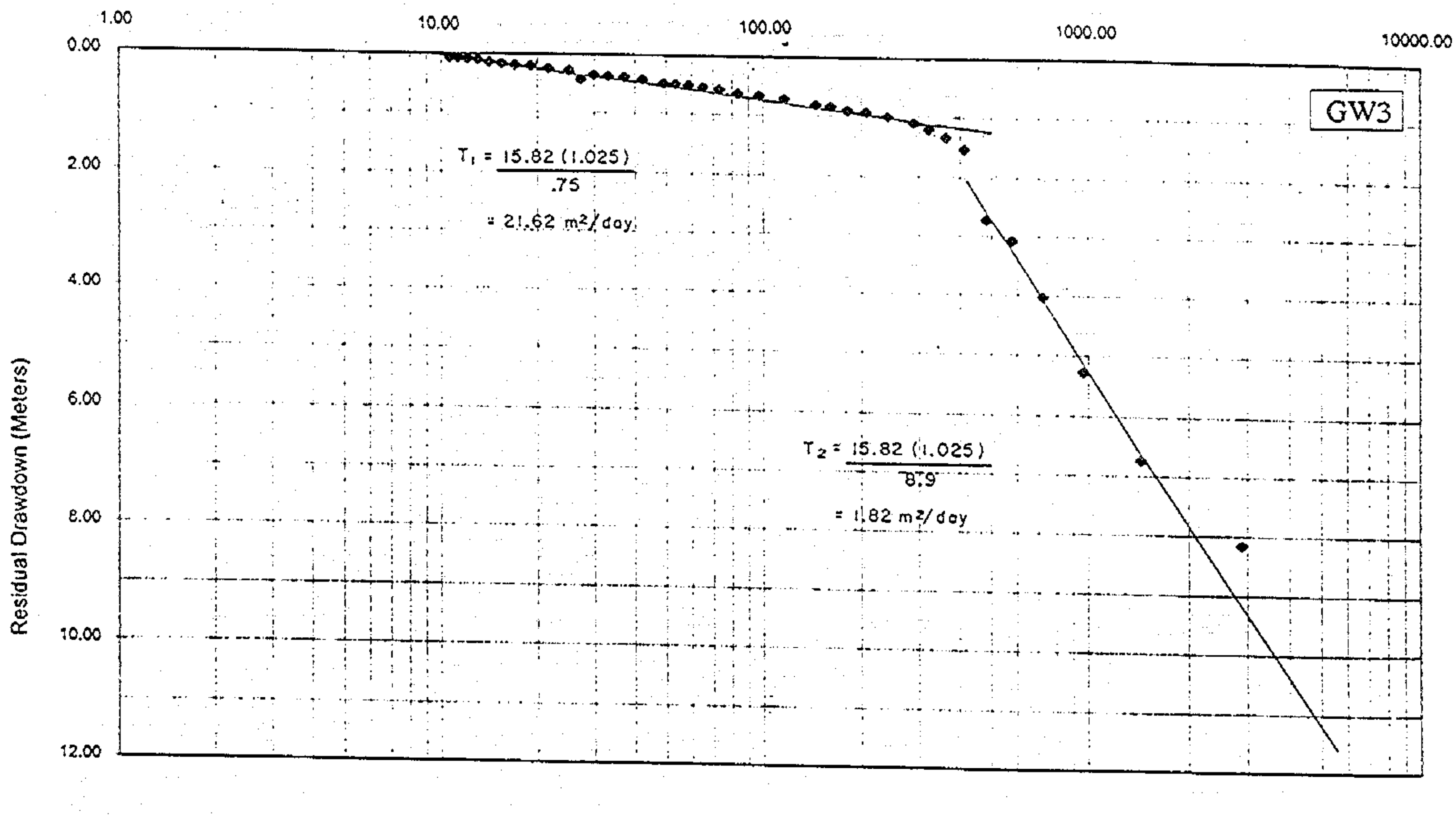


Fig B.5.3.4 (2) Time–Drawdown Curve (GW3)
(Pumping)



fn: GW3-REC

Fig B.5.3.4 (3) Time–Residual Drawdown Curve (GW3)
(Recovery)

THE FEASIBILITY STUDY ON
THE WESTERN LEGAZPI IRRIGATION AND
RURAL DEVELOPMENT PROJECT IN THE PHILIPPINES

ANNEX C

SOIL AND LAND USE

ANNEX - C
SOIL AND LAND USE

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1. CLIMATE, LAND FORM, AND GEOLOGY IN THE STUDY AREA

1.1 Climate

The climate in the Study area is classified as Type II, which has no significant dry season and a period of very pronounced rainfall from November to January. The Northeast Monsoon prevails from October to March and brings significant amount of rainfall to the Study area. The period of maximum rainfall is from October to January. The Southwest Monsoon prevails from May to October. During this period the climate in the area is warm and humid with increasing rate of rainfall. The month of lowest rainfall is April, with an average of 156 mm recorded at Legazpi meteorological station. The mean monthly rainfall recorded in Legazpi and Guinobatan are presented below.

(Unit: mm)

Month	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
Legazpi	301	185	186	156	176	241	254	264	263	334	485	484	3,330
Guinobatan	155	81	73	88	160	249	310	269	318	294	267	325	2,590

Source: Legazpi, PAGASA, (1961 - 1993); Guinobatan, PCA (1956 - 1983)

The mean monthly temperature in the Study Area ranges from 25.4°C in January to 28.3°C in May. The mean annual temperature is 26.9°C with the average maximum temperature of 30.7°C and the average minimum temperature of 23.4°C. The mean monthly temperatures recorded at Legazpi station is presented below.

Unit: °C

Month	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
Max.	28.6	29.1	30.1	31.3	32.3	32.2	31.7	31.6	31.5	31.0	30.1	29.1	30.7
Mean	25.4	25.7	26.4	27.5	28.3	28.2	27.7	27.8	27.6	27.2	26.7	26.0	26.9
Min.	22.3	22.2	22.8	23.7	24.3	24.1	23.8	23.9	23.7	23.3	23.3	22.9	23.4

Source: Legazpi PAGASA (1961 - 1993)

The Study area has often been affected by typhoons. The period of higher frequency of typhoons is from June to December.

1.2 Land Form

The general topography of the area varies from gently sloping to rolling and hilly. The gently sloping areas consist of relatively narrow plains along the course of small rivers and cricks. The rolling and hilly areas are composed of low elevation hills. Elevations above mean sea level within the Study area vary from about 34 m in the lowest point to some 245 m in the highest elevation. Approximately 46 per cent of the land have slope in the range of 0 to 8%. About 23 per cent of the land have slope in the range from 8 to 18%. Some 28 per cent of the land have slope in the range of 18 to 25%, and only some 3% of the land have slope greater than 25%.

1.3 Geology

The soils in the Study Area developed from several geological formations. The soils in the northwest area lying at the foot of Mayon volcano, near by Camalig town, are formed from mud flows deposits. The soils of the northeast part of the Study area are formed mostly from pyroclastic rocks, andesites, tuff and tuffaceous sandstone. The soils of the western, southwestern and parts of the hills in the central part are formed from limestone. Most of the soils in the Eastern and Southern parts of the Study area are formed from clastic sedimentary rock of tuffaceous sandstone and shale conglomerate, intercalated with calcareous clastic rocks. The soils of the central plains are originated from unconsolidated alluvial deposits.

2. SOILS OF THE STUDY AREA

2.1 Previous Soil Studies Covering the Study Area

A soil survey of Albay province at reconnaissance level was conducted in 1948, updated in 1964 by the Bureau of Soils, Department of Agriculture and Natural Resources. A second study entitled "Albay Land Resources Evaluation Project" was published by the bureau of Soils and Water Management, Department of Agriculture, Region 5. The report includes several maps related to land evaluation at scale of 1:50,000. These two previous studies on soil and land resources evaluation covering the Study area were used as references for the present soil survey.

2.2 The Soil Survey Carried Out for the Present Feasibility Study

A soil survey at semi-detailed level was carried out by JICA Study Team for the Western Legazpi Irrigation and Rural Development Project. The soil survey was sublet to a local consulting firm. Fifty (50) soil pit adequately distributed within the Study Area were open to describe the characteristics of soil profiles. The soil profiles open during the survey were described up to a depth of 150 cm (Ref. Table C 2.2.1). Three (3) soil samples from each soil profile representing the layers of 0 to 30 cm, 30 to 60 cm, and 60 to 100 cm, respectively, were taken for laboratory analysis of the physical and chemical soil properties relevant to agriculture production. The laboratory analysis included soil particle distribution, pH, organic matter content, Nitrogen, Phosphorous, Exchangeable bases such as Ca, Mg, Na, and K, Cation Exchange Capacity (CEC), and base saturation percentage (BSP) (Ref. Table C 2.2.2).

A soil classification map at scale 1:25,000 was prepared on the basis of the survey results. Soil mapping units were classified on the basis of the slope map prepared using the topographic map at scale 1:4000 (Ref. Fig. C - 2.2.1).

2.3 Soil Classification

Soils in the Study area are classified into four series on the basis of results of the semi-detailed soil survey. Each soil series is sub-divide into soil mapping units differentiated by land slope, natural drainage condition, and flood hazard as described below.

(1) Legazpi Soil Series

Legazpi soil series is classified as Order Entisol, sub-order Psament, great group Tropopsament. The representative soil profiles of Legazpi series are pits numbers 7, 32, 33, and 35 (Ref. Table C - 2.2.2). The dominant soil texture in the surface 30 cm soil layer is sandy loam. The internal drainage varies from very poor to moderately well drained. The pH varies from 5.5 to 7.6. The content of organic matter varies from low to medium (1.7% to 2.9%). The base saturation percentage is medium (range from 42 to 52%), and cation exchange capacity is from low to medium (8 to 19 meq/100 gr. of soil). The Legazpi soil series comprises an area of approximately 710 ha, it is sub-divided into three soil mapping units differentiated by internal drainage and flooding hazard (Ref. Fig. C - 2.2.1).

(2) Bascaran Soil Series

The Bascaran series is the most extensive soil type in the Study area, comprising a total area of about 6,510 ha. This soil series is classified as Order Alfisol, sub-order Aqualf, great group Endoaqualf. The representative soil profiles of Bascaran soil series are pits number 19, 21, 22, and 25 for the lowland areas, and pits number 9, 13, and 15 for the upland areas. The dominant texture of the surface and sub-surface soil horizons are clay loam in the lowlands and sandy clay loam in the upland areas. The internal drainage varies from poor to moderately well drained. The pH is between 6.2 to 7.0. The content of organic matter in the surface horizon is low (1.2%) in uplands, and medium in the lowlands (from 2.3 to 3.9%). The base saturation percentage is high in the lowlands (more than 60%) and medium to high in uplands (42 to 72% in uplands). The cation exchange capacity is high in the lowlands (more than 27 meq/100 gr. of soil) and medium to high in the uplands (23 to 45 meq/100 gr. of soil). The Bascaran soil series is sub-divided into four units differentiated by land slope, soil erosion, natural drainage condition, and flood hazard.

(3) Libon Soil Series

The Libon soil series is classified as Inceptisol, sub-order Ochrept, great group Euthrochrept. The representative soil profiles are pits number 39, 40, and 42. This soil series occurs in the uplands. The soil is moderately deep, with dominant clay texture, and imperfect internal drainage. The pH in the surface layer is from 6.1 to 6.5. The content of organic matter varies from low to medium (1.8 to 2.8%). The base saturation percentage is mostly medium (about 55%); and cation exchange capacity is medium to high (22 to 26 meq/100 gr. of soil). The Libon series comprises a total area of about 680 ha sub-divided into three mapping units differentiated by internal drainage condition and land slope.

(4) Tigaon Soil Series

Tigaon soil series is classified as Order Alfisol, sub-order Hapludalf, great group Typical Hapludalf. The representative soil profiles of this series are pits number 3, 4, 30, 45, and 49. The dominant textures of surface and sub-surface soil horizon are clay loam and clay. The internal drainage of this soil is imperfect. The pH of surface layer is in the range of 5.5 to 6.4. The content of organic matter is between low to medium (1.6 to 2.6%). The base saturation vary from medium to high (42 to 69%), and cation exchange capacity is also from medium to high (22 to 60 meq/100 gr. of soil). The Tigaon series comprises an area of about 2,290 ha sub-divided into three mapping units differentiated by land slope and soil erosion.

2.4 Main Soils Features Relevant to Agriculture Development in the Study Area

A main feature of soils in the Study area is the poor natural internal drainage in large parts of the lowland soils and some areas of uplands. The poor natural internal drainage of soils is not a mayor constraint for cultivating paddy rice, but artificial improvement of drainage is necessary to facilitate land preparation, control of weeds, and harvesting activities in paddy fields. Improvement of drainage in lowlands is a requirement for introducing the cultivation of upland crops. In gently slopping uplands where diversified annual upland crops will be grown, planting on ridges is recommended to reduce negative effects due to imperfect internal drainage.

Sloping lands are prone to soil erosion due to frequent and intensive rainfall occurring in the area. Special attention should be given to the implementation of proper land management and protection to minimize soil erosion in sloping lands devoted to annual crops production.

The chemical properties of soil in the Study area do not present mayor limitations for agriculture production. The pH varies mostly in the range from 6.5 to 7.0. The cation exchange capacity and base saturation vary from medium to high. The content of plant macronutrients such as nitrogen (N), phosphorous (P) and potassium (K) is low, therefore adequate levels of fertilizers must be applied to obtain high yields. The content of calcium (Ca) and magnesium (Mg) is high in most soils of the area, this might cause induced deficiency of essential micronutrients such as zinc (Zn).

3. LAND SUITABILITY CLASSIFICATION

3.1 Method and Criteria for Land Suitability Classification

The suitability of the land in the Study area was evaluated following the procedure of FAO Framework for Land Evaluation. The land utilization types considered for evaluation of land suitability were paddy field, diversified annual crops, and tree crops. The land characteristics considered relevant for suitability classification are soil internal drainage, land slope, soil texture, fertility, and soil depth. The parameters used for land suitability classification are set on the basis of slight modification to FAO's general criteria as described bellow.

Factor Evaluated	Highly Suitable (S1)	Moderately Suitable (S2)	Marginally Suitable (S3)	Not Suitable (N)
Internal Drainage				
Diversified Annual Crops	Well	Not Used	Imperfect	Poor or Excessive
Perennial Crops	Well	Not Used	Imperfect	Poor or Excessive
Rice	Well to Poor	Not Used	Not used	Excessive
Slope (%)				
Diversified Annual Crops	0 to 5	5 to 15	15 to 20	More than 20
Perennial Crops	0 to 8	8 to 15	15 to 25	More than 25
Rice	0 to 5	5 to 15	16 to 25	More than 25
Soil Texture				
Diversified Annual Crops	Fine to medium	Not Used	Coarse	Very coarse
Perennial Crops	Fine to medium	Not Used	Coarse	Very coarse
Rice	Fine	Medium	Moderately Coarse	Coarse
Fertility (CEC) (meq/100gr of soil)				
Diversified Annual Crops	More than 24	16 to 24	Less than 16	Not Used
Perennial Crops	More than 25	16 to 24	Less than 17	Not Used
Rice	More than 26	16 to 24	Less than 18	Not Used
Soil Depth (cm)				
Diversified Annual Crops	More than 75	50 to 75	25 to 50	Less than 25
Perennial Crops	More than 150	100 to 150	50 to 100	Less than 50
Rice	More than 60	51 to 60	20 to 50	Less than 20

3.2 Result of Land Suitability Classification

Considering the above said factors, a total land area of 5,770 ha is classified as moderately suitable (S2) for rice cultivation either under rainfed or irrigated condition. For growing diversified annual crops and perennial crops an area of 1,740 ha is classified as moderately suitable (S2) and 7,580 ha are classified as marginally suitable (S3). The main factors down-grading the suitability for diversified annual and perennial crops are the clayey texture of and imperfect internal drainage of soils. The land suitability classification is summarized as follows. (Ref. Table C 3.1.1 and Fig. 3.1.1).

(Unit: ha)

Suitability Class	Land Utilization Type: Rice	Diversified Annual Crops	Tree Crops
Highly Suitable (S1)	0	0	0
Moderately Suitable (S2)	5,770	4,270	4,120
Marginally Suitable (S3)	0	5,110	5,260
Not Suitable (N)	4,420	810	810
Residential/Roads/Others	420	420	420
Total	10,610	10,610	10,610

4. PRESENT LAND USE IN THE STUDY AREA

The Study area comprises a total of 10, 610 ha. Approximately 7,080 ha or 66.7% of the total Study area is devoted to coconut plantation. About 1,770 ha are cultivated to annual crops, mainly rice and corn. Paddy fields occupy about 1,350 ha or 12.7% of the total Study area. About 1,225 ha of paddy fields are cultivated under rainfed condition. Upland crops planted in open areas, not inter-cropped under coconuts, occupy about 420 ha or 4% of total area. Corn is the major crop planted in the open uplands. Shrubs and grass lands or fallow land occupy 1,340 ha or 12.6% of the total area. Residential areas, roads, and other types of land use occupy about 420 ha or 4% of the total Study area. The present land use is summarized below (Ref. Tables C 4.1.1 and C 4.1.2 and Fig. C 4.1.1).

Land Use	Area (ha)	Per cent of Total
Paddy Field	1,350	12.7
Coconut	7,080	66.7
Open Upland crop areas	420	4.0
Shrubs & Grass	1,340	12.6
Residential/Roads/Others	420	4.0
Total	10,610	100.0

Land slope is a major factor to be considered for appropriate management of the uplands. The study area is characterized by intensive and continuous rainfall pattern. Soil erosion and land degradation might occur on sloping lands if proper land management practices are not implemented. The present land use by slope range in the upland of the Study area is summarized as follows:

Slope	Coconut Land		Annual Crop Land		Shrub and Grass		Total	
Range (%)	(ha)	(%)	(ha)	(%)	(ha)	(%)	(ha)	(%)
0 - 3	2,180	30.8	205	48.8	385	28.7	2,770	31.3
3 - 8	1,025	14.5	120	28.6	175	13.1	1,320	14.9
8 - 18	1,440	20.3	95	22.6	435	32.4	1,970	22.3
18 - 25	2,330	32.9	-	-	170	12.7	2,500	28.3
25 - 40	105	1.5	-	-	175	13.1	280	3.2
Total	7,080	100	420	100	1,340	100	8,840	100

5. PROPOSED LAND USE

The land use plan in the Study area is formulated based on physical, climatic, and socio-economic considerations. The major factors considered in defining the land use plan include land suitability, present land use, crop adaptability on various soil conditions, the possibility to provide irrigation, lengthy periods of heavy rains, frequent strong typhoons, socio-economic status such as low income level of farmers and high incidence of tenancy, farmers preference, and government agricultural policies.

Considering the conditions described above, it is recommended that the land devoted to coconut plantation be maintained without major changes in area. The opening of coconut lands for cultivation of rainfed annual crops is not recommended. Instead, the extension and intensification of inter-cropping farming system under the coconut is highly recommended. The inter-cropping farming system presents several advantages compared with mono-cropping such as increasing intensity of land utilization, increase yield of crops, make a more efficient use of farm labor, and increase farmers' income. Also, because of the predominance of tenant farm operators, inter-cropping farming system seems more acceptable than converting the coconut land to rainfed annual crops. The introduction of measures for soil conservation and improvement of fertility to increase crop productivity is more manageable with the inter-cropping farming system under coconut than in open upland farming system.

The idle lands with slope up to 25% that are presently covered with shrubs and grass are proposed to be devoted for cultivation of annual or perennial crops with the use of proper land management for improvement of soil fertility and minimize soil erosion. The idle lands with slope greater than 25% should be devoted to perennial crops and protected with the introduction of land conservation measures.

The framework of future land use for the entire Study area is summarized as follows:

Land Use	Present		Future With Project	
	(ha)	(%)	(ha)	(%)
Irrigated Paddy Field	125	1.2	445	4.1
Rainfed Paddy Field	1,225	11.5	815	7.6
Coconut land	7,080	66.7	7,080	66.7
Annual Upland Crops	420	4.0	910	8.5
Perennial Crops (Abaca, Coffee, Pili)	-	-	780	7.3
Shrub & Grass	1,340	12.6	40	0.3
Sub-total	10,190	96.0	10,070	95.0
Protected Marginal Land	0	0	80	0.7
Residential/Roads/Others	420	4.0	460	4.3
Total	10,610	100.0	10,610	100.0

The proposed land use in the model project areas include 130 and 190 ha of irrigated paddy field in Camalig diversion and Dam No. 2 lowland model project areas, respectively. The proposed land use in Magogon and San Ramon upland model project areas are shown in Figure C 5.1 and C 5.4 respectively.