APPENDIX H

WELL TEST

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WELL TEST

1. GENERAL

The objective of the well test is to obtain the basic data necessary to evaluate shallow and deep well development possibilities by conducting machine boring, various well logging, and pumping tests in the areas selected based on the results of the hydrogeological surveys and geoelectric prospecting in the Eastern Region of Rwanda.

The outline and schedule of the conducted well tests are as follows:

1.1 TEST BORING

- Well logging (relative resistivity, spontaneous potential, spontaneous radioactivity, groundwater temperature, and electric conductivity)
- Pumping tests (preliminary pumping, interval pumping, continuous pumping and recovery tests)

Planned Test	Actually Conducted Test
. 5 well boring (total well depth: 540 m)	Bored 7 wells (total well depth: 663.5 m)
. Complete well logging in 5 wells	Complete well logging in 5 wells
. Complete pumping tests in 5 wells	Complete pumping tests in 5 wells

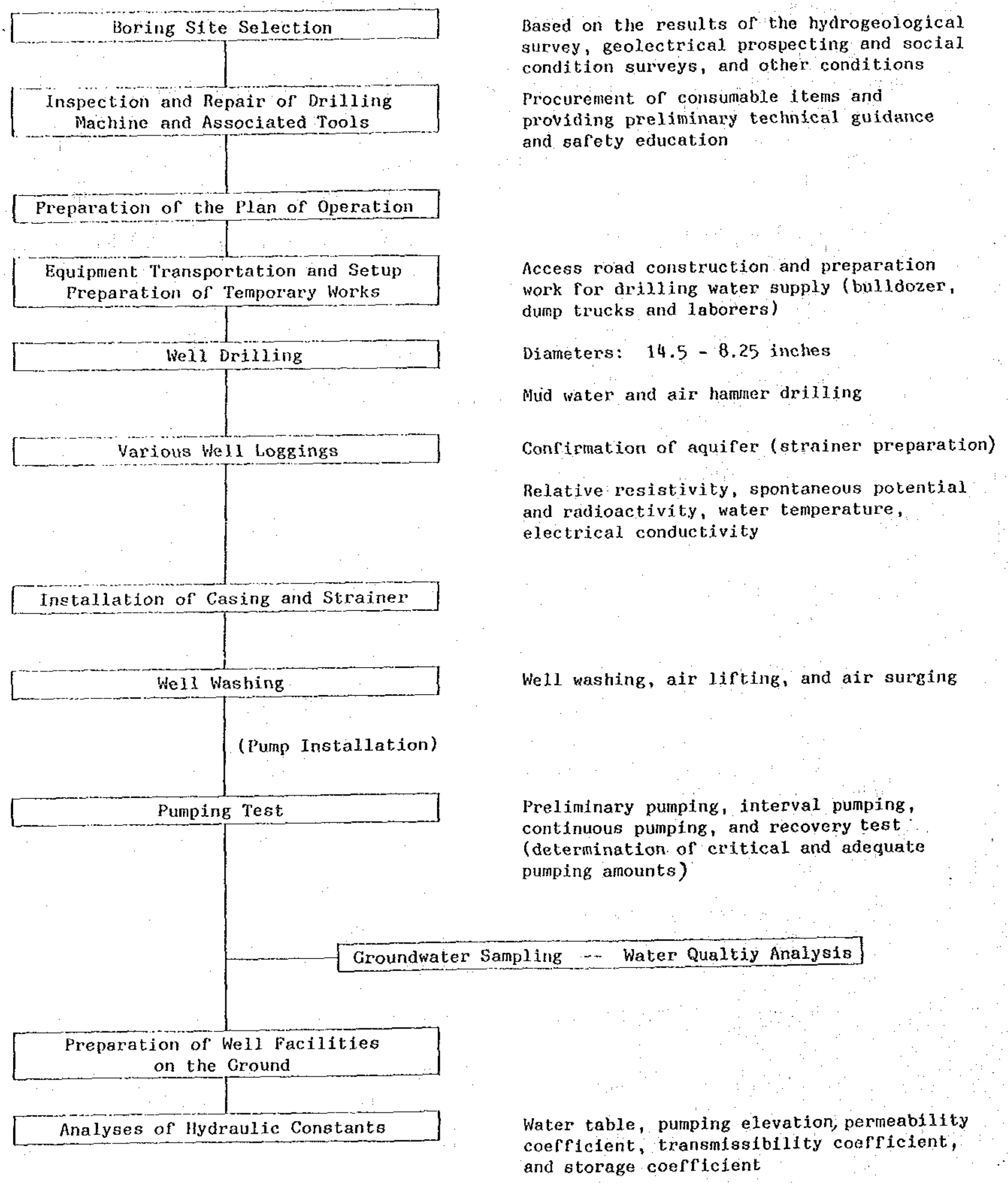
1.2 TEST PERIOD

- December 6, 1989 through March 15, 1990 (the First Field Survey)
  Boring Nos. 1, 2 and 3
- June 30 through August 17, 1990 (the Second Field Survey)
  Boring Nos. 4 and 5

2. CONTENTS OF THE TESTS

2.1 TEST SCHEDULE

The major study work process is as follows:



Based on the results of the hydrogeological survey, geolectrical prospecting and social condition surveys, and other conditions

Procurement of consumable items and providing preliminary technical guidance and safety education

Access road construction and preparation work for drilling water supply (bulldozer, dump trucks and laborers)

Diameters: 14.5 - 8.25 inches

Mud water and air hammer drilling

Confirmation of aquifer (strainer preparation)

Relative resistivity, spontaneous potential and radioactivity, water temperature, electrical conductivity

Well washing, air lifting, and air surging

Preliminary pumping, interval pumping, continuous pumping, and recovery test (determination of critical and adequate pumping amounts)

Water table, pumping elevation, permeability coefficient, transmissibility coefficient, and storage coefficient

Boring Test Process

Based on the above process, boring tests were conducted at the five selected sites. The tests were scheduled as follows:

1989, 6, Dec. - 1990, 7, Jan.: Preparation
1990, 8, Jan. - 1990,16, Jan.: Drilling of Br-1
1990,24, Jan. - 1990,31, Jan.: Drilling of Br-3
1990, 2, Feb. - 1990, 9, Feb.: Drilling of Br-2
1990,10, Feb. - 1990,15, Mar.: Repair Works
1990,20, Jun. - 1990,10, Jul.: Repair Works
1990,11, Jul. - 1990,25, Jul.: Drilling of Br-4
1990, 1, Aug. - 1990,10, Sep.: Drilling of Br-5.1, 5.2, 5.3
1990,11, Sep. - 1990,17, Sep.: Clearing

2.2 NUMBER OF TEST BORING

The following test boring were made for the Study:

Table List of Test Boring

Fiscal Year	Site No.	Machine Boring Depth(m)			Well Logging(m)	Pumping Test (set)
		Soil	Rock	Total		
1989	Br.1	22.5	80.5	83.0	83.0	1
	Br.2	23.9	57.1	81.0	81.0	1
	Br.3	15.0	66.0	81.0	81.0	1
1990	Br.4	6.0	144.0	150.0	150.0	1
	Br.5-1	2.1	75.9	78.0	78.0	-
	Br.5-2	1.7	34.3	36.0	36.0	-
	Br.5-3	1.4	103.1	104.5	104.5	1
TOTAL		72.6	560.0	633.5	633.5	5

3. TEST METHOD

3.1 MACHINE BORING

Machine boring was conducted by using a truck-mounted power swivel-type drill. Bore holes were drilled to the diameters of 8.25 to 14.5 inches and they were finished to the diameter of 8 inches.

The bit mounted on the tip of the boring machine's drill rod rotates at high speed which both cuts and crushes the ground. The material loosened by the bit is carried upward in the hole by the rising mud water.

Ground strata conditions can be evaluated by inspecting the slime contents and the variations of the bit's rotating speed and pressure strength.

The mud forms a clay lining on the wall of the well, but, if wall caving occurs, a casing must be installed in the well.

Fig. H.2 shows the drilling rig and the arrangement of the rig and associated equipment.

The air hammer method was also adopted for deep well drilling. In this method, a reciprocating hammer piston that is powered by compressed air directly strikes the drilling bit in the cylinder liner. The extra-hard tip of the bit cuts and crushes rocks. The loosened rock pieces are blown out of the hole by compressed air.

3.2 WELL LOGGING

Immediately after drilling a well, resistivity logging, spontaneous potential logging, spontaneous radioactivity logging, water temperature measurements, and electrical resistivity logging are made.

The objectives of well logging are mainly for confirming aquifer strata and to determine a strainer installation section. Electrical conductivity logs can be utilized to distinguish fresh water and brine and to detect the existence of metal ions in the groundwater.

A probe containing various sensors (a combination probe) was used to simultaneously measure the relative resistivity, spontaneous potential (SP), and spontaneous radioactivity of the well.

The probe was initially set either at the top or bottom of the well and was gradually lowered or raised during the course of taking continuous measurements. The elevation of the probe was determined by measuring the length of the cable attached to the guide ring.

The measured data together with the depth measurements were automatically recorded by a data recorder situated above ground. The recorder's printer printed out the data.

Pole spaces of 16 and 64 inches were used for the relative resistivity logging.

Groundwater temperature and electrical conductivity were measured at 1 m intervals.

The details of both resistivity and SP logging are given as follows:

i) Resistivity Logging

The resistivity logging was done, using normal device procedure. The electrode spacings were generally 16 cm (short normal) and 64 cm (long normal). The measuring range was generally 1,000 ohm meter (F.S.). In case of high resistivity rocks, the test was repeated up to a maximum range of 510 ohm meter (F.S.). A rough range was determined, while lowering the probe in the hole. The measuring speed was around 5 meter/minute. A continuous depth/resistivity plot was recorded with the ascent of the probe from the borehole. In case of anomalies, test was repeated.

ii) Self Potential (SP)

The same instrument was used in SP logging, switching on the SP knob. The range of measurement was generally 50 mV (F.S.). A continuous depth/SP plot was recorded with the ascent of the same probe. The measuring speed was around 3 meter/minute.

3.3 PUMPING TEST

The purpose of the pumping test is to obtain data necessary for establishing a pumping plan by examining the hydraulic constants (permeability, transmissibility and storage coefficients) of the ground in the Study Area. The hydraulic constants can be obtained by analyzing a well's water level difference created by groundwater pumping and water recharging operations.

The hydraulic constants can be utilized for determining the adequate pumping amount and the size of the radius of influence, estimating the future lowering of the groundwater table and determining appropriate well spacings and the locations of recharging wells.

The pumping test is the means for obtaining the data necessary for analyzing the various hydraulic coefficients that indicate the basic characteristics of aquifers.

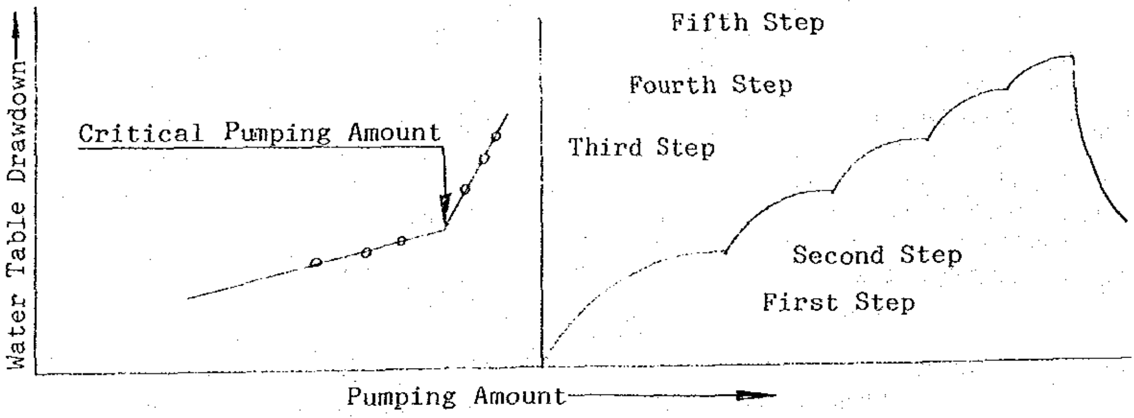
The pumping tests were conducted in the following manner:

i) The preliminary pumping tests were conducted for the purpose of examining the amounts of the wells' critical pumping amounts and groundwater table drawdown and to determine the amounts of step-type pumping for the interval pumping tests. Thorough well cleaning was made during the preliminary pumping test period.

ii) Interval Pumping Test
The interval pumping test is used to determine the critical pumping amount of a well by changing the groundwater pumping amount step-by-step according to the relationship between the pumping amount and the water table drawdown obtained by the preliminary pumping test.

For the Study, the pump discharge amount was changed four or five times and the pumping under each different discharge amount was continued until the water table was stabilized.

Based on the data obtained by the interval pumping test, the critical pumping amount was determined by preparing the S-Q curve as shown figure below.



Relationship between Pump Amount and Water Table Drawdown of the Interval Pumping Test

iii) Continuous Pumping Test

Continuous pumping tests were conducted to obtain various data by continuing pumping operations over a long period of time with rational discharge amounts determined by the interval pumping tests. The aquifers' hydraulic constants were calculated based on the obtained data. Each Pumping test continued for a period of approximately eight hours. Water table measurements were made according to the time intervals shown in Table below as a general principle.

Time Intervals for Water Table Measurements
for Continuous Pumping Tests

Time from start of pumping or pumping rate increase (minutes)	Time interval between observations (minutes)
0 - 10	1
10 - 60	5
60 - 120	10
120 - 300	20
300 and longer	60 - 120

iv) Recovery Tests
After discontinuing the pumping, the rates of recovery of the water level in the pumped wells were measured to examine the water table recovering conditions.

v) Analysis Method
The permeability coefficient, transmissibility coefficient, and the storage coefficient of the aquifers can be analyzed from the data obtained by the pumping tests by using equilibrium equations or non-equilibrium equations. Representative equations are as follows:

Equilibrium equation:

a. Thiem's method

Non-equilibrium equations:

b. Theis' standard curve analysis method
c. Jacob's straight line analysis method
d. Recovery method

To apply these methods, the following assumptions must be established:

(a) Aquifer is distributed horizontally having the same thickness and isometric characteristics. The aquifer's permeability coefficient (also transmissibility constant) and storage coefficient are constant throughout.

(b) The groundwater flow in the aquifer is unidirectional, steady or unsteady conditions and Darcy's law is applicable to the flow. Thus, the vertical component of the flow is negligible compared to its horizontal component. In a well, the aquifer yields water through its entire thickness, i.e., the well is perfectly drilled.

In addition to the above assumptions, the following assumptions must be established for the non-equilibrium methods:

(c) The aquifer thickness under groundwater pumping is practically the same as its primary thickness (thickness before pumping starts).

In an unconfined aquifer, the water table drawdown by pumping is very small compared to the aquifer thickness(at most 20 to 30 percent of the thickness).

In a confined aquifer, no free water table occurs.

(d) An aquifer does not receive any water supply from the impermeable strata that are sandwiching it or from surface water sources, such as rivers, lakes and ponds. The groundwater does not receive any effect from rivers, rainwater, tides and pumping of adjacent wells.

(e) The well diameter is infinitesimal.

3.4 MAJOR WELL TEST EQUIPMENT

The major equipment used for the well tests is listed in Table H.1.

4. SELECTION OF DRILLING POINTS

The exact drilling points is determined, taking account of following points of view:

a) To define the potentiality of shallow groundwater resources within the area where existing water supply facilities are not found.

b) To examine the possibility of deep groundwater development at higher part and/or dense settlement area.

c) To clear the typical relationship between occurrence of aquifer and geology in the study area.

d) To consider the possibility of the water supply development based upon the social factors, such as electrification, settlement structure and other infrastructure.

The description of each drilling point selected are given as below:

(80 m deep well)

Br.1: Shallow groundwater investigations at lowland of Lake Muhazi basin which has higher lake water table in the Study Area.

Br.2: Shallow groundwater investigations on broad gentle slope of the fan where no existing water supply facility and social increase of population by migration are found. Western portion of Lake Nasho basin.

Br.3: Shallow groundwater investigations at the weathered zone of granite on the shore of Lake Sake where Electrification is completed.

(150 m deep well)

Br.4: Investigation of the potentiality of deep groundwater developments in densely inhabited area at higher part. Following points are considered to select the location:

- Existing electric facilities are found
- Fracture zone of fault may run

Br.5: Deep groundwater investigation at hard rock area of southern parts of the area (Rusumo) where quartzite widely occurs. The point is upper part of the existing water supply facilities which is not functioned at present.

The drilling points are outlined as Table below with their location, geology and site of geophysical prospecting.

Outline of Test Well

Description Well No.	Location	Well Type	Site of Geophysical Prospecting	Geology
No.1	SE of Lake Muhazi, Muhazi Kayonza	80m Depth	EP-3	Weathered schist overlain by Alluvium
No.2	W of Lake Nasho, Gashiru, Rukira	80m Depth	EP-22	Alluvial fan deposits
No.3	Shore of Lake Sake, Rakama, Sake	80m Depth	EP-13	Weathered granite
No.4	Rurenge, Kabarondo	150m Depth	EP-9	Fracture zone of schist interbedded with sandstone/ quartzite
No.5	Nganda, Rusumo	150m Depth	EP-21	Quartzite

5. CIRCUMSTANCES OF THE WELL TESTS

The well tests were scheduled to be conducted during a period from December 1989 through March 1990. However, it took a long time to repair the large size air compressor that was provided by MINITRAPEE ... the air compressor was needed for the air hammer drilling system to drill deep wells. Thus, the original schedule was substantially delayed. The well tests were rescheduled to conduct the shallow well test (Nos. Br.1, 2 and 3) during the first year and the deep well tests (Nos. Br.4 and 5) during the second year.

The circumstances of the first year and second year well tests were as follows:

The first Year Well Test (December 1989 through March 1990):

After confirming the selected test boring sites, checking and adjusting equipment, and preparing the plan of operation, boring of No. Br.1 began early January 1990 and was followed by the boring of Nos. Br.3 and 2. The mud water method was applied for drilling these three test wells. Except for No. Br.2, the test well boring proceeded smoothly.

No. Br.2 site was covered by large pieces of quartzite to the depth of G.L. -0.4 m at No. Br.2-1 and to G.L. -1.9m at No. Br.2-2. Thus, it was impossible to attach a counter-weight to the tricorn bit of the drilling equipment. The bore holes (Nos. Br.2-1 and Br.2-2) made by applying the equipment weight were bent excessively. As a result, further drilling was halted.(Note: Nos. Br.2-1 and Br.2-2 are located very close to each other).

The well drilling team waited for MINITRAPEE to repair the large size air compressor, but the repair work took longer than anticipated.

A new Br.2 was drilled to the northwest of the originally planned site. A series of well tests were carried out there.

The Second Year Well Test (June through September 1990):

After repairs to the air compressor were made and the boring equipment was adjusted, No. Br.4 boring got underway at the beginning of July 1990. The air hammer method was applied to the test well drilling. The drilling progressed 10 to 25 m a day. Due to the capacity of the drilling equipment and to prevent well failure, an 8 1/4 inch diameter hole was drilled to a depth of between 130 and 150 m.

The boring of Br.5 started after the completion of No. Br.4's drilling. At the depth of 74 from the ground surface, hard rock was encountered and the drilling speed slowed down to less than 1 m a day. After discussing the situation with the counterpart team, the Study team halted the drilling of Br.5-1 at the depth of 78 m.

By taking into account the area topography, spring locations, the existing topographic map, and the purposes of the well drilling (deep wells), a new sight for No. Br.5-2 was selected and the drilling commenced August 20, 1990. As previously expected, fractured rock was reached and, as the ground was soft, it was easy to bore the hole deeper than 80 m using the air hammer method. A confirmed aquifer having a water pressure of G.L. -17m (from the ground surface) was found between the G.L. -40 to -75 m strata.

Due to the application of the air hammer method in the soft ground and the existence of a great amount of groundwater, well caving occurred and it became impossible to continue the well drilling either by the air hammer method or the mud water method.

As the well caving progressed, the shape of the well became extremely deformed. Thus, the Study Team concluded that No. Br.5-2 was unsuitable as a test well for examining the hydrogeological conditions of the area.

A new well, No. Br.5-3, was carefully drilled using the mud water method at a location 50 m away from No. Br.5-2. At a depth of approximately 100 m below the ground surface the drill hit hard quartzite and the drilling was stopped at a depth of 104.5 m below the ground surface and the hole was cleaned for well testing.

Nos. Br.5-2 and Br.5-3 sites were selected for the following reasons:

i) By taking into account the water table (G.L. -43 m) found at No. Br.5-1 and the ground elevation of EL 1,480 m at No. Br.5 (original location), locations having ground elevations of G.L. -1,480 were thought to be suitable for finding groundwater tables at G.L. -80 m.

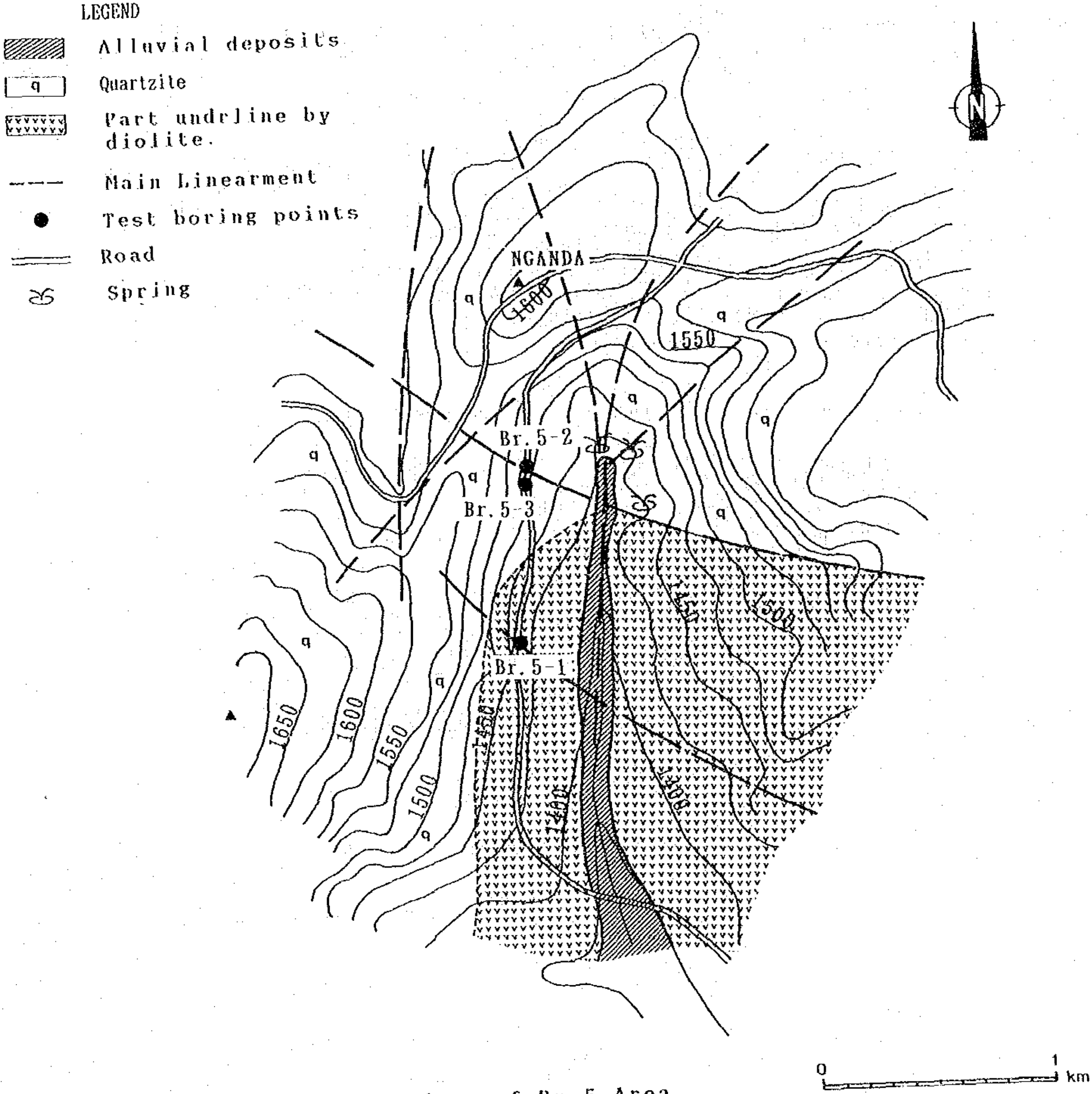
ii) From the findings at No. Br.5-1 drilling site, distribution of a low relative resistivity zone found by geo-electrical prospecting and as a result of area reconnaissance, a distribution of a diorite skill was detected in the vicinity of the stream in the southeastern part of the selected area. Well drilling must avoid the diorite distribution.

iii) New well drilling sites should be located on a high fracture zone (based on lineament) that have sufficient size, higher elevation catchment area.

iv) New well drilling sites must show a sign of the existence of groundwater judging from spring distribution conditions and area vegetation.

v) New well drilling sites must be easily accessible by the boring equipment.

At the request of MINITRAPEE, No. Br.5-3 was preserved as a future test well and No. Br.5-2 was restored and equipped with a hand pump to supply water to area residents.



Geology of Br-5 Area

6. THEMES OF SAND THE ATTENTION TO BE PAID TO WELL DRILLING WORK

By taking into consideration the capacity of the drilling machine provided by MINITRAPEE, strong support from highly experienced engineers is essential for drilling a well deeper than 100 m using the air hammer method. By installing a sub-receiver tank of 2 to 3 m3 capacity on the large size air compressor, the removal of slime will be easier and safe deep-well drilling will be possible.

With the present equipment and tools, the deepest limit of well drilling by using the air hammer method is about 100 m.

Well drilling in the extra-hard rock formation area and the plutonic rock rubble distributed area that were confirmed at No. Br.5-1 and Br.5-2 drilling sites, well drilling seems infeasible considering the present technical level and the economic outlook.

In a bedrock distributed area it is important to develop wells in the fracture zone only after evaluating aerial photographs of the area and making a careful survey of area vegetation.

As the No. Br.5-2 well drilling revealed, drilling in a fracture zone by the air hammer method progresses slowly because of the back pressure (pressure difference between the groundwater head and the pressure acting on the drilling bit). Further, the bit disturbs the aquifer in the fractured soft strata greatly. The limit of the back pressure must be 3 to 4 kg/cm2.

For actual well drilling vice test well drilling, it is not necessary to drill deeper than the aquifer. Thus, the aquifer may not be greatly disturbed. But, there is no guarantee that the aquifer will not be disturbed. Aquifer disturbance may be prevented by installing double or triple casings, but this may present problems for drilling work efficiency and might possibly entail high drilling costs.

For these reasons and for drilling safety, it would be desirable to apply the mud water method when drilling wells in the fracture zone.

The following is a summary of the test well drilling:

i) When deep wells are drilled more than 100 m using MINITRAPEE's drilling machine, it is hard to maintain the safety of the drilling work depending upon the geological conditions and on the difficulty of mobilizing a large size air compressor.

ii) In the quartzite zone that is widely distributed in the Rusumo area, extra hard rock may be encountered when drilling at a depth of around 100 m. Considering the present technical level and the economic outlook it would be unrealistic to drill a 150 m deep well in the area.

iii) For groundwater development in the quartzite area, it is of prime importance to find the fracture zones by conducting preliminary surveys. Careful application of the mud water rotary drilling method is absolutely essential when drilling wells in the fracture zones.

7. TEST RESULTS

The results of the machine boring, including the well logging, are listed in the Annex. The geological structures and drilling are summarized below:

i) No. Br.1 Site:

The site is located to the southeast of Lake Muhazi. The upper horizon is mainly made up of clay of the alluvial epoch. The strata confirmed by test well drilling are as follows:

GL -17.0 to -22.5 m : Mainly clay with small amounts of sand mix. Weathered gravel was occasionally found.

GL -22.5 to -28.0 m : Heavily weathered schist layer. Mixture of clay, sand and gravel.

GL -28.0 to -64.0 m : Schist layer. 10 to 20 m fractures and soft portions were occasionally found below GL -40.0 m.

GL -64.0 to -83.0 m : Rock became harder and harder. No fissure was found.

The heavily weathered layer up to GL -28.0 m was drilled by using a 10 5/8 inch diameter wing bit. An 8 inch diameter casing was installed to prevent well caving. A tip-type tricorn bit of 8 1/2 inch diameter was used for drilling below GL -28.0 m.

ii) No. Br.2 Site:

The site is located on the west side of Nasho Lake. As previously described, drilling was impossible at the originally selected drilling site because of the existence of hard boulders in the upper layer. Thus, a new site for No. Br.2 drilling was selected northwest of the original site.

The results of the No. Br.2 drilling are as follows:

GL 0.0 to -22.1 m : Composed of clay, sandy clay, gravel mixed sandy clay and gravel mixed clayey sand.

GL -22.1 to -23.9 m : Drilling speed slowed down because of the existence of quartzite boulders and cobblestones.

GL -23.9 to -81.0 m : Composition of schist and micaceous schist. Rock became harder as boring progressed deeper.

A 10 5/8 inch diameter wing bit was used to drill the upper alluvial layer. An 8 1/2 inch diameter tip-type tricorn bit was used to drill to a deeper level than the quartzite boulder zone.

The drilling speed was 0.7 cm/min. in the quartzite boulder zone under a 3 ton bit pressure. In the schist and micaceous schist, the drilling speed was 2 to 3 cm/min. under a 1.8 to 2.5 ton bit pressure.

iii) No. Br.3 Site:

The site is located east of Sake Lake. The boring test results are as follows:

GL 0.0 to -15.0 m : Mainly clay mixed sand

GL -15.0 to -40.0 m : Granite. Became harder as drilling progressed deeper.

GL -40.0 to -81.0 m : Alternate hard and soft strata. The drilling speed was approximately 3 cm/min. in the hard stratum and about 5 cm/min. in the soft stratum.

Well developed fissures and a soft portion were found between GL -63.5 m and -69.2 m. The drilling speed and bit pressure varied significantly in this section.

Drilling conditions were quite different from those in ordinary granite.

A 10 5/8 in diameter wing bit was used up to GL -18.0 m and a 9 inch diameter guide casing was installed. The deeper portion was drilled using an 8 1/2 inch diameter tip-type tricorn bit suitable for drilling hard rock.

Judging from the drilling results, it is thought that well drilling in the granite zone of the Sake area may be possible if a tricorn bit is used.

iv) No. Br.4 Site:

The boring test results are as follows:

GL 0.0 to -6.0 m : Gravel mixed clayey soil

GL 6.0 to -22.0 m : Highly weathered schist. The rock was extremely soft.

GL -22.0 to -41.0 m : Weathered schist. A 20 to 50 cm thick quartzite schist layer was found below GL-33 m.

The well was drilled by using a 14 1/2 diameter wing bit up to GL -3.0 m and a 12 inch diameter casing was installed. For further drilling, a 10 5/8 inch diameter tricorn bit was used up to GL -22.0 m and a 9 inch diameter guide casing was installed. Below GL -22.0 m, the well was drilled to the depth of GL -130 m using an 8 1/2 inch diameter air hammer. Drilling to the depth of GL -150 m was accomplished by using a 6 1/4 diameter air hammer.

v) No. Br.5 Site:

No. Br.5-1:

The top weathered layer reached to the depth of GL -37.5 m. It consisted mainly of schist and quartzite schist intercalating a very thin layer of quartzite. The layer between GL -37.5 to 43.0 m was diorite. Fissures were found, but the deeper portion was very hard, fresh rock.

A guide hole was drilled through the boulder and cobblestone layer by an 8 1/2 inch diameter air hammer and the loosened material was removed manually. Then, a 14 1/2 diameter wing bit was used. But, a 12 inch diameter casing could not be installed. Thus, the 8 1/2 air hammer was again used to drill up to GL -13 m. The hole was reamed by using a 10 5/8 inch diameter tricorn bit and a 9 inch diameter guide casing was installed up to GL -12.0 m.

Further drilling was made by using the 8 1/2 inch diameter air hammer up to GL -78.0 m.

No. Br.5-2:

Weathering was progressed to GL -74.0 m. It was believed to be a fractured fault zone. The ground was composed of alternate layers of soft (extremely weathered) rock and quartzite (lightly weathered).

The drilling was carried out in the same manner as for No. Br.5-1. A guide hole was drilled by an 8 1/2 inch diameter air hammer followed by a 14 1/2 wing bit. The hole was reamed by a 10 5/8 inch tricorn bit. Two casings (12 inches and 9 inches in diameter) were installed to depths of GL -3.0 m and GL -12.0 m respectively. The well was further drilled to GL -88 m.

No. Br.5-3:

The geological structure of the site was almost the same as that for No. Br.5-2. The site was thought to be located on a fractured fault zone. Sandy schist was predominant. The fracture reached to GL -99.3 m. The portions that contained quartzite schist or quartzite were comparatively hard.

Below the fracture, comparatively new quartzite is distributed. Its hardness increased in proportion to the depth. Quartzite boulders and cobblestones distributed in the 1.4 m thick surface layer were cut and crushed by an 8 1/2 air hammer; the loosened material was manually removed. The hole was reamed by a 14 1/2 inch wing bit after which a 12 inch diameter casing was installed to GL -30 m. The hole was further drilled by the 8 1/2 air hammer to GL -15.0 m and then reamed by injecting mud water using a 10 5/8 inch tricorn bit to GL -16.0 m. A 9 inch casing was installed in the hole. Further drilling was made by using an 8 1/2 inch tip-type hard rock tricorn bit. After the bit reached GL -99.3 m, the drilling speed became less than 1.0 m a day. After discussing the situation with the counterpart team, the Study Team halted the drilling at a depth of GL -104.5 m.

8. WELL LOGGING RESULT

Generally, the borehole was cleaned out by pressure washing, before attempting geo-physical logging. The boring rods were taken out in steps. Geophysical logging results (see Fig. H.3"Geological Columnar") have been compared with the Drilling Logs, obtained from the geological slime at every borehole. A discussion on the test results are being included here. All the logging depths, shown in this discussion, are the depths below ground level.

The resistivity of weathered formations varies from 30 to 700 ohm meter, where as the schist formations have a high resistivity from 400 to 1,200 ohm-meter. The mixed strata have a medium value. The plots and the corresponding drilling log have good correlations.

SP measurements were not correct due to interference from an underground 0.1 Hz leakage current. Observation values of the plot is shown in Fig. H.3.

- BR-1 Borehole

Logging depth : 0 to 83 m
Logging method : Relative resistance S.P., Gamma ray

Due to the effect of the temporary casings, no variation of the relative resistance was observed up to the ground level of -28 m. At the boundary zone of clay and schist layers and a weathered rock layer (ground levels (GL) of approximately -30 m and -53 through -60 m), variations of relative resistance were observed. Thus, it is assumed that aquifers exist in the variable relative resistance zones.

- BR-2 Borehole

Logging depth : 0 to -81 m
Logging method : Relative resistance S.P., Gamma ray

At the boundary zone of clay and schist layers (GL -28 through -28 m), variations of the relative resistance were seen. Significant variations were also seen within schist layers between GL -60 m through Gl -64 m. According to the agreement with the drilling data, it is believed that a crack zone (aquifer) is developed in the schist layer.

- BR-3 Borehole

Logging depth : 0 to -81 m
Logging method : Relative resistance S.P., Gamma ray

In the granite of Gl -64 m through -75 m, variations of relative resistance were observed. It is assumed that cracks were made and an aquifer is developed in that zone.

- BR-4 Borehole

Logging depth : 0 to -150 m
Logging method : Relative resistance S.P., Gamma ray

Variations of relative resistance were observed in the schist layer of groundwater at the depths of GL -63.2 m, -68.7 m, -80.6 m, -85.0 m and -90.9 m respectively, it is believed that many groundwater flows exist in the crack zones.

- <u>BR-5-1 Borehole</u>

Logging depth : 0 to -78 m
Logging method : Relative resistance S.P., Gamma ray

The ground was formed of a uniform schist layer and no variation of relative resistance was seen. By taking into consideration the drilling data, it is thought that no aquifer exists in that layer.

- <u>BR-5-2 Borehole</u>

Logging depth : 0 to -86 m
Logging method : Relative resistance S.P., Gamma ray

Significant amounts of water occurred at the depths of GL -34 m, -43 m, -62 m, and -70 m during the borehole drilling. Slight variations of relative resistance were observed. Layers below GL -20 m can be thought to be aquifers. In particular, significant groundwater flows are thought to exist at the depths of GL -34 m, -43 m, -62 m, and -70 m respectively.

- <u>BR-5-3 Borehole</u>

Logging depth : 0 to -104 m
Logging method : Relative resistance S.P., Gamma ray

In the schist layers of GL -30 m through -45 m and GL -65 m through -75 m, variations of relative resistance were observed. By comparing the drilling data, it is assumed that cracks are made and aquifers are developed in those layers.

9. PUMPING TEST RESULTS

After confirming the existence of an aquifer by the test boring, the bored holes were finished into wells and the wells were used for the pumping tests.

Two types of pumping tests were conducted. One was the interval pumping test; the other was the continuous pumping test.

i) Interval Pumping Test Results

The interval pumping tests were made by changing the pump discharge four or five times. For each discharge the pump was continuously operated until the water level was stabilized. The changing water level during the pump operation was recorded.

From the obtained data, the relationship between the pump discharge and the stabilized water level were plotted on logarithmic paper and the breaking point of the straight line was considered as the critical pumping amount.

The obtained critical pumping amount of each well is as follows:

No. Br.1 :	210 l/min.
No. Br.2 :	250 l/min.
No. Br.3 :	100 l/min.
No. Br.4 :	15 l/min.
No. Br.5 :	170 l/min.

ii) Continuous Pumping Test Results

Pumping under a constant discharge was continued until the water level was stabilized. During the pumping period, the changing water level, i.e., drawdown, was recorded.

After the pump was stopped, the recovering water level was also recorded.

The obtained data were analyzed by using non-equilibrium equations, i.e., the Jacob's straight line analysis method and the recovery method.

The results of the analyses are as follows:

(1) Muhagi Area

$Q=14.4\ m^3/h=4.0X10^{-3}\ m^3/sec$

$r=0.106\ m$

a. Jacob Method

$\Delta s=9.6\ m$

$t_0=8.4\ sec$

$$T=\frac{2.3Q}{4\pi\Delta s}=\frac{0.183Q}{\Delta s}=\frac{0.183\times 4X10^{-3}}{9.6}=7.63X10^{-5}\ m^2/sec$$

$$S=\frac{2.25Tt_0}{r^2}=\frac{2.25X7.63X10^{-5}X8.4}{0.0112}=1.29X10^{-1}$$

b. Recovery Method

$\Delta s=3.6\ m$

$$T=\frac{2.3\ Q}{4\pi\Delta s}=\frac{0.183X4X10^{-3}}{3.6}=2.03X10^{-4}\ m^2/sec$$

(2) Nasho Area(Br.2)

$Q=27.0\ m^3/h=7.5X10^{-3}\ m^3/sec$

$r=0.106\ m$

a. Jacob Method

$t_0=22.8\ sec$

$$T=\frac{2.3Q}{4\pi\Delta s}=\frac{0.183Q}{\Delta s}=\frac{0.183X7.5X10^{-3}}{4.75}=2.89X10^{-4}\ m^2/sec$$

$$S=\frac{2.25Tt_0}{r^2}=\frac{2.25X2.89X10^{-4}\ X22.8}{0.0112}=1.32$$

b. Recovery Method

$\Delta s=2.35m$

$$T=\frac{2.3\ Q}{4\pi\Delta s}=\frac{0.183X7.5X10^{-3}}{2.35}=5.84X10^{-4}\ m^2/sec$$

(3) Sake Area(Br.3)

$Q=4.50\ m^3/h=1.25X10^{-3}\ m^3/sec$

$r=0.106\ m$

a. Jacob Method

$\Delta s = 7.0$ m

$t_0 = 66.0$ sec

$$T = \frac{2.3Q}{4\pi\Delta s} = \frac{0.183Q}{\Delta s} = \frac{0.183 X 1.25 X 10^{-3}}{7.00} = 3.27 X 10^{-5} \text{ m}^2/\text{sec}$$

$$S = \frac{2.25 T t_0}{r^2} = \frac{2.25 X 3.27 X 10^{-5} X 66.0}{0.0112} = 4.34 X 10^{-1}$$

b. Recovery Method

$\Delta s = 10.6$m

$$T = \frac{2.3\ Q}{4\pi\Delta s} = \frac{0.183 X 1.25 X 10^{-3}}{10.6} = 2.15 X 10^{-5} \text{ m}^2/\text{sec}$$

(4) Kabarond Area (Br.4)

$Q = 15.0$ m^3/h $= 2.50 X 10^{-4}$ m^3/sec

$r = 0.106$ m

a. Jacob Method

$\Delta s = 3.8$ m

$t_0 = 25.8$ sec

$$T = \frac{2.3Q}{4\pi\Delta s} = \frac{0.183Q}{\Delta s} = \frac{0.183 X 2.50 X 10^{-4}}{3.80} = 1.20 X 10^{-5} \text{ m}^2/\text{sec}$$

$$S = \frac{2.25 T t_0}{r^2} = \frac{2.25 X 1.20 X 10^{-5} X 25.8}{0.0112} = 6.22 X 10^{-2}$$

b. Recovery Method

$\Delta s = 3.15$m

$$T = \frac{2.3\ Q}{4\pi\Delta s} = \frac{0.183 X 2.50 X 10^{-4}}{3.15} = 1.45 X 10^{-5} \text{ m}^2/\text{sec}$$

(5) Rusmo Area (Br.5)

$Q = 150$ l/min$= 2.50 X 10^{-3}$ m^3/sec

$r = 0.106$ m

a. Jacob Method

$\Delta s = 6.2$ m

$t_0 = 10.2$ sec

$$T = \frac{2.3Q}{4\pi\Delta s} = \frac{0.183Q}{\Delta s} = \frac{0.183X2.50X10^{-3}}{6.20} = 7.38X10^{-5}\ m^2/sec$$

$$S = \frac{2.25Tt_0}{r^2} = \frac{2.25X7.38X10^{-5}X10.2}{0.0112} = 1.51X10^{-1}$$

. Recovery Method

$\Delta s = 7.7$ m

$$T = \frac{2.3\ Q}{4\pi\Delta s} = \frac{0.183X2.50X10^{-3}}{7.70} = 5.94X10^{-5}\ m^2/sec$$

where, Q: pump discharge (m3/sec)
r: radium of well (m)
T: transmissibility coefficient (m3/sec)
S: storage coefficient
To: time intercept on the zero-drawdown axis (obtained from graph)
s: drawdown difference per log cycle of time(m)

The results of pumping-test analysis are outlined as follows:

Coefficient of Aquifer

Location	Thickness of Aquifer (m)	Transmissivility(m2/sec)		Permeability(m/sec)		Storativity
		Jacob	Recovery	Jacob	Recovery	Jacob
Br. 1	21. 1	7. 63 E-5	2. 03 E-4	3. 62 E-6	9. 62 E-6	1. 29 E-1
Br. 2	20. 9	2. 89 E-4	5. 84 E-4	1. 38 E-5	2. 79 E-5	1. 32
Br. 3	12. 0	3. 27 E-5	2. 15 E-5	2. 73 E-6	1. 79 E-6	4. 34 E-1
Br. 4	32. 0	1. 20 E-5	1. 45 E-5	3. 75 E-7	4. 53 E-7	6. 22 E-2
Br. 5-3	19. 1	7. 38 E-5	5. 94 E-5	3. 86 E-6	3. 11 E-6	1. 51 E-1

10. CONCLUSION OF WELL TESTS AND RECOMMENDATION FOR WELL CONSTRUCTION

From the results of the shallow well tests conducted during fiscal year 1989 and the deep well tests conducted during fiscal year 1990, the conclusion of the well tests and recommendations for well construction can be summarized as follows:

i) In the alluvial planes developed along rivers and lakes in the Study Area, the existence of groundwater was confirmed in shallow strata.

According to the boring results of the Phase I project, impermeable bedrock is widely distributed in the areas dominated by schist that was formed of mud.

In these areas, the possibility of the existence of groundwater is small even in the low elevation areas.

ii) It is very difficult to select suitable areas for groundwater development in schist or alternatives of schist and quartzite distributed areas. In these areas, it is necessary to select fissure zones or fractured fault areas.

Without selecting a suitable well drilling site, pumping of necessary amounts of water from a well is impossible even if the existence of groundwater is observed in the well.

iii) In the quartzite distributed area in the southern part of the Study Area, extra-hard rock, such as quartzite diorite, occurs at the elevation of approximately 100 m from the ground surface. In view of the present boring technique level in Rwanda and the economy of well construction, it is not recommendable to bore wells having depths of more than 100 m from the ground surface for the Phase III project.

iv) For the development of deep groundwater, it is of most importance to find fractured fault areas during the preliminary field survey. Thus, from a hydrogeological viewpoint, it is extremely effective to survey and evaluate the details of lineament, mud rock and spring distributions during the project planning stage.

For the Phase III project, it is believed to be appropriate to detect groundwater by conducting the survey and evaluation in the manner described and select deep well construction sites in the mountainous areas within the project area.

v) By taking into consideration MINITRAPEE's present equipment and technical level, there would be problems with safety and equipment mobilization for constructing more than 100 m deep wells. For the Phase III project, it is recommendable to construct wells that are less than 100 m deep.

It would be appropriate to apply the mud water drilling method to drill wells at the fractured fault zone in the mountainous areas for simplifying the checking of groundwater and the maintenance of the drilled hole.

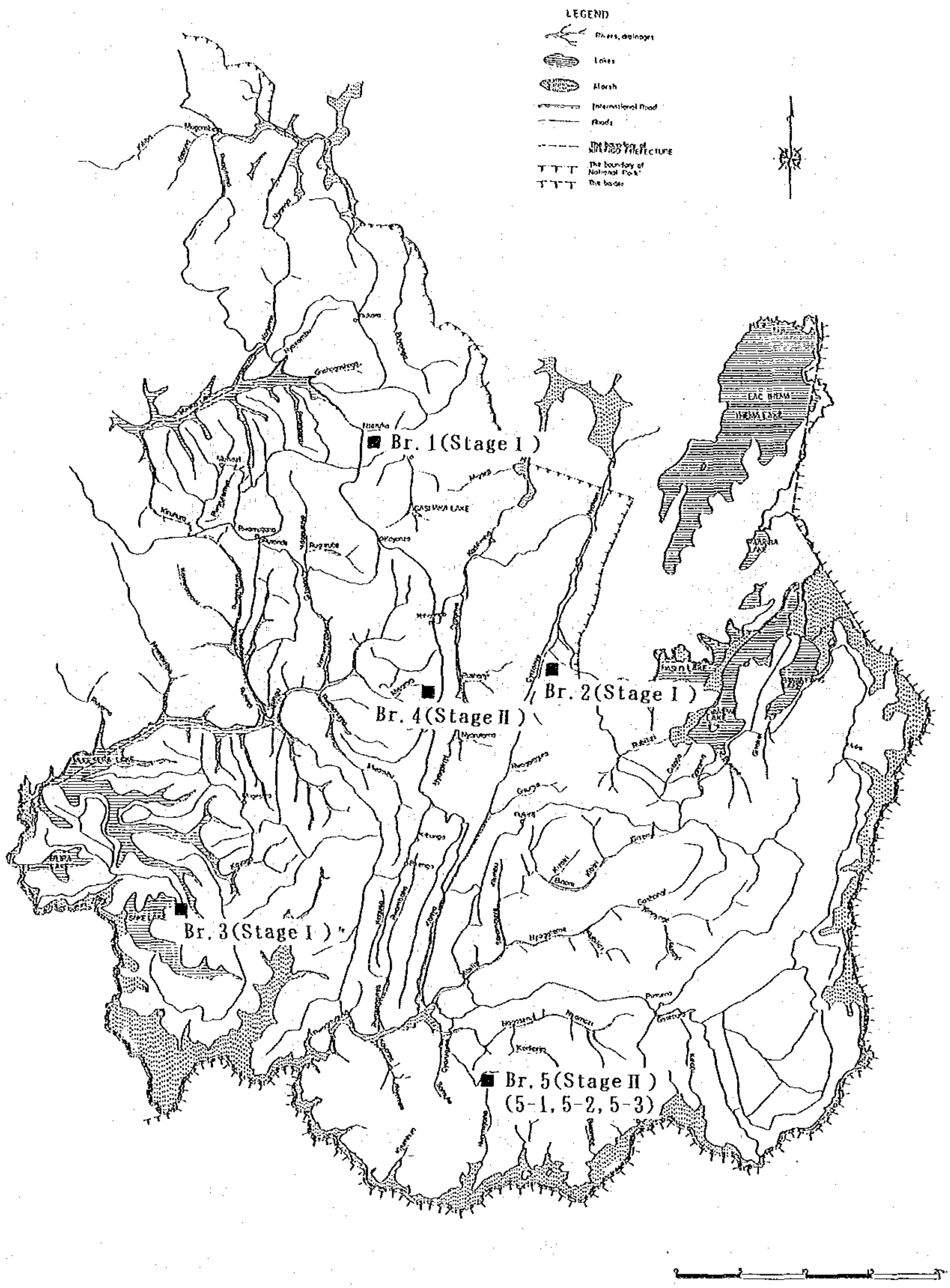
vi) For the final section of well drilling sites it is very important to effectively apply the surface prospecting methods, such as the geo-electrical prospecting and magnetic field prospecting methods, the techniques of which were transferred to the counterpart team during the field survey periods by the Study Team.

Furthermore, the survey data obtained together with the well drilling data should be clarified and retained for future use.

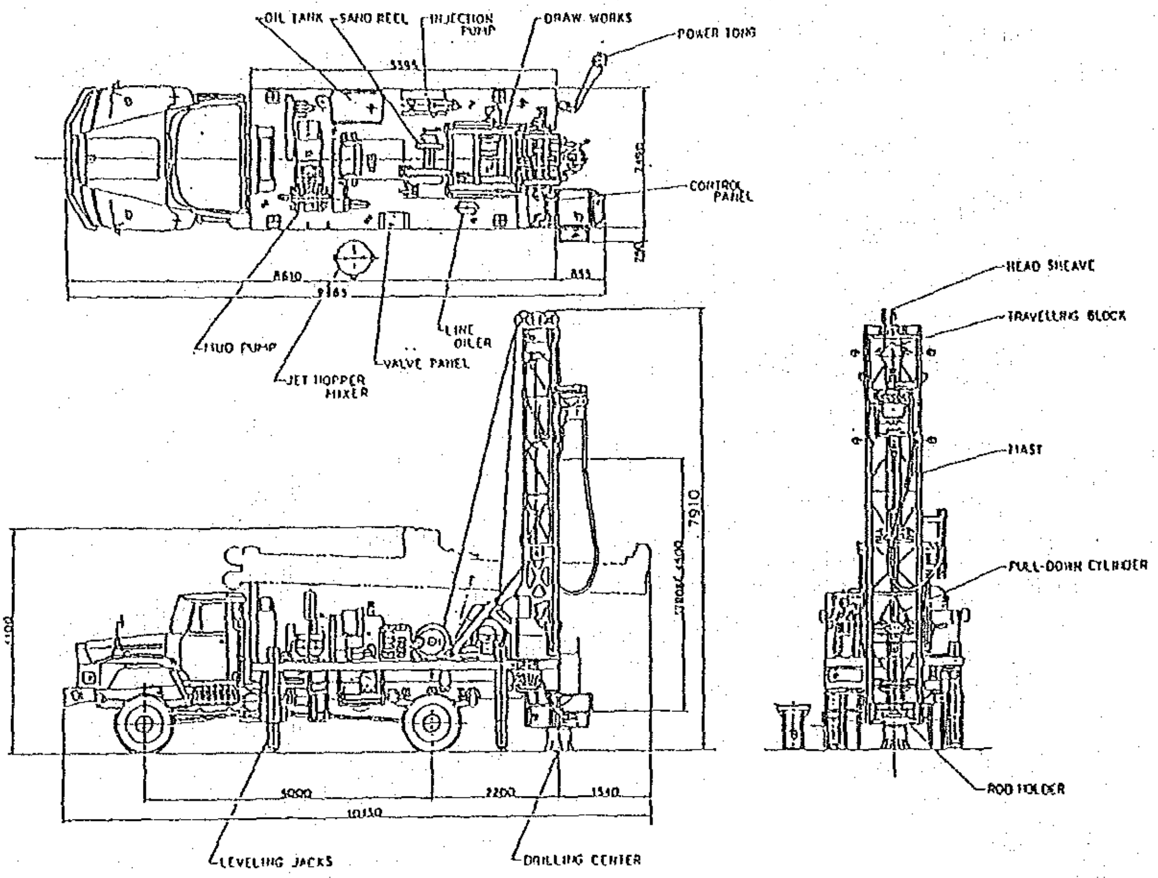
Table H.1

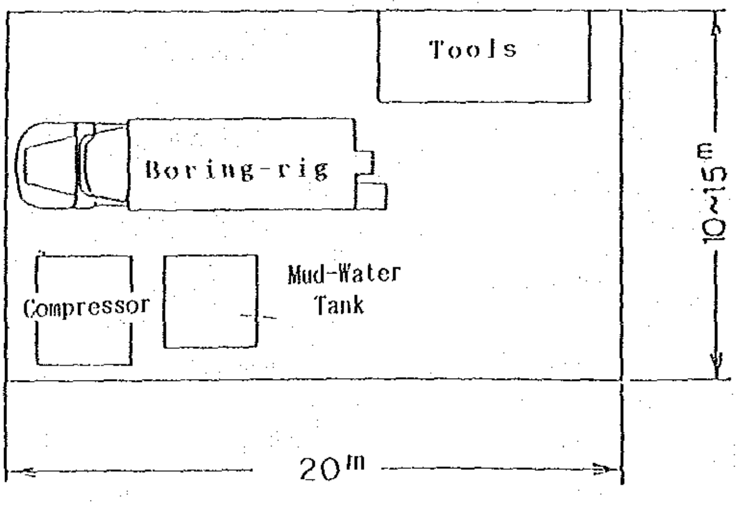
List of Equipment Used for Well Tests

Purpose	Equipment Name	Model No.	Description
Machine boring	Power swivel type drill	FSW-ST	120.7mm dia., 100m shaft length
	Mud water pump	MG-25	600 liters/min. with 25kg/cm2 pressure
	Injection pump	MS903	90 liters/min. with 35kg/cm2 pressure
	Jet hopper mixer	JHM 80W	Tank capacity 60 liters, nozzle dia. 25mm
	Down-the-hole drill	DD 6C-1	Bit size 6 & 8.5 in dia., length 1,270mm, weight 95kg
	Air compressor	PDSH 700	Air pressure11.5kg/cm2 Capacity 300 m3/min.
	Tricorn bit		10"5/8 & 8"1/2 in dia.
	Wing bit		14"1/2 & 10"5/8in dia.
Well logging	Chief logger	3433	Resistivity 20k ohm, Spontaneous radiation 20k cps Spontaneous potential 2,000mv
	Combination probe	349S	Resistivity Spontaneous potential
	Well thermometer	EST-3	Groundwater temp.
	Submersible pump & motor	SU	Pump dia. 85mm 200V, 50Hz, 3,000rpm
	Compressor Pumping test	PDS 125	Air pressure 7.0kg/cm2 Capacity 3.5m3/min.
	Triangle Notch		
	Water level gage		String length 200m



Location of Test Boring Points


OIL TANK
SAND REEL
INJECTION PUMP
DRAW WORKS
POWER TONG
5595
2450
CONTROL PANEL
250
8610
855
9165
MUD PUMP
JET HOPPER MIXER
VALVE PANEL
LINE OILER
HEAD SHEAVE
TRAVELLING BLOCK
MAST
PULL-DOWN CYLINDER
ROD HOLDER
7910
STROKE 4400
4100
5000
2200
1510
10330
LEVELING JACKS
DRILLING CENTER

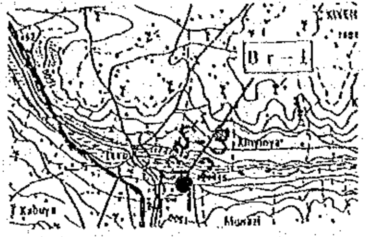

Tools
Boring-rig
Compressor
Mud-Water Tank
10~15 m
20 m

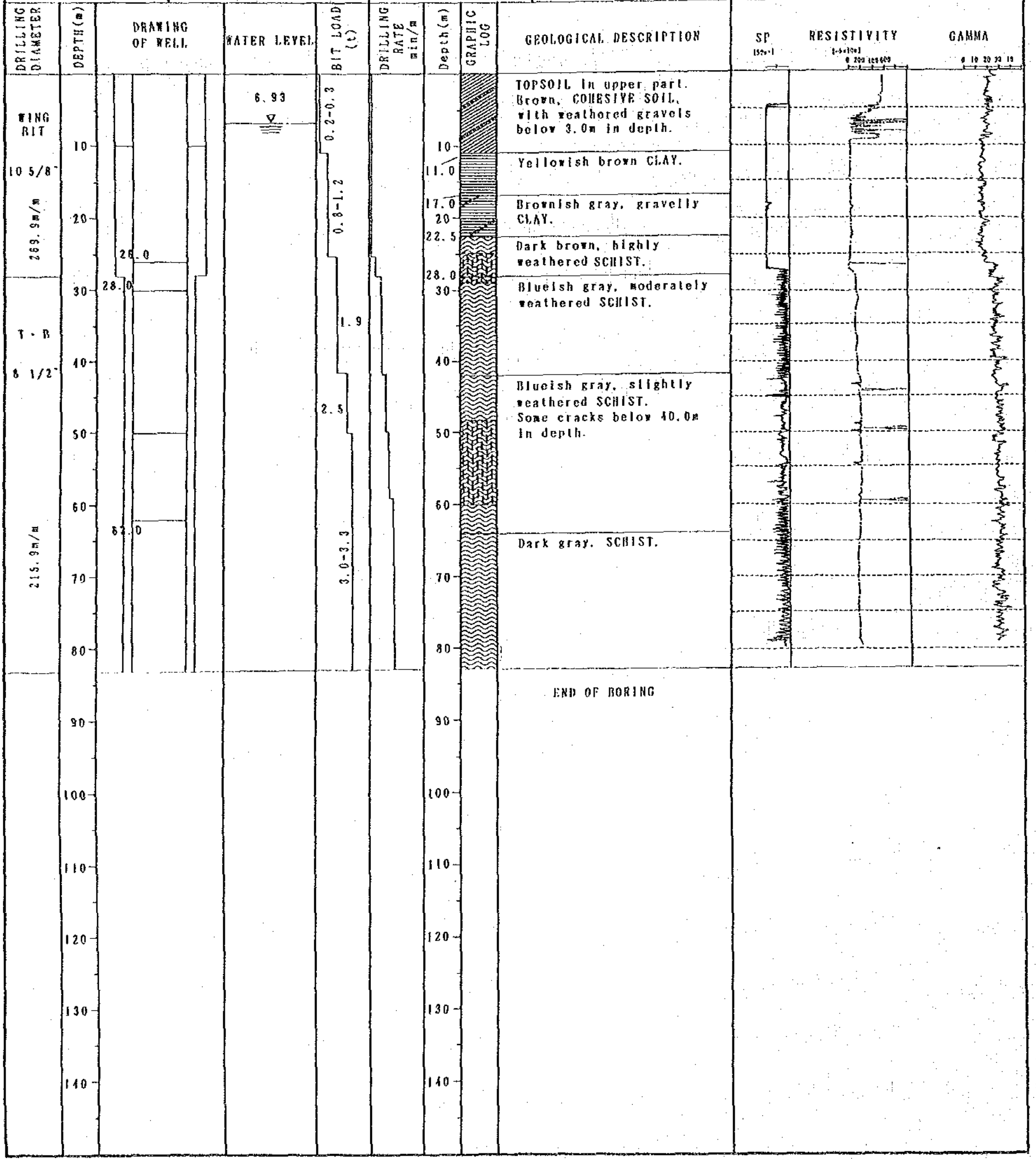
Boring Columnar and Logging Data (Phase Ⅲ)

DRILLING LOG

B・H・NO.	Br-1	WELL CASING DEPTH	83m
LOCATION	MUHAZI AREA	SCREEN DEPTH	26-30.0m 50-62.0m
DRILLING DEPTH	83.0m	WELL CASING SCREEN SIZE	6" OD170 ID150 m/m
DRILLING DIAMETER	215.9m/m	DISCHANGE CAPACITY	
COMMENCED ON	90-Jan-8	STATIC WATER LEVEL	6.93m
COMPLETED ON	90-Jan-16	DYNAMIC WATER LEVEL	

LOCATION





TOPSOIL in upper part. Brown, COHESIVE SOIL, with weathered gravels below 3.0m in depth.

Yellowish brown CLAY.

Brownish gray, gravelly CLAY.

Dark brown, highly weathered SCHIST.

Blueish gray, moderately weathered SCHIST.

Blueish gray, slightly weathered SCHIST. Some cracks below 40.0m in depth.

Dark gray, SCHIST.

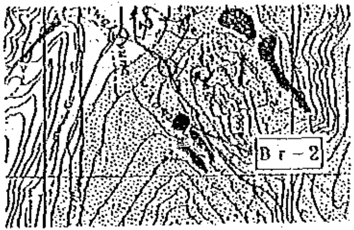
END OF BORING

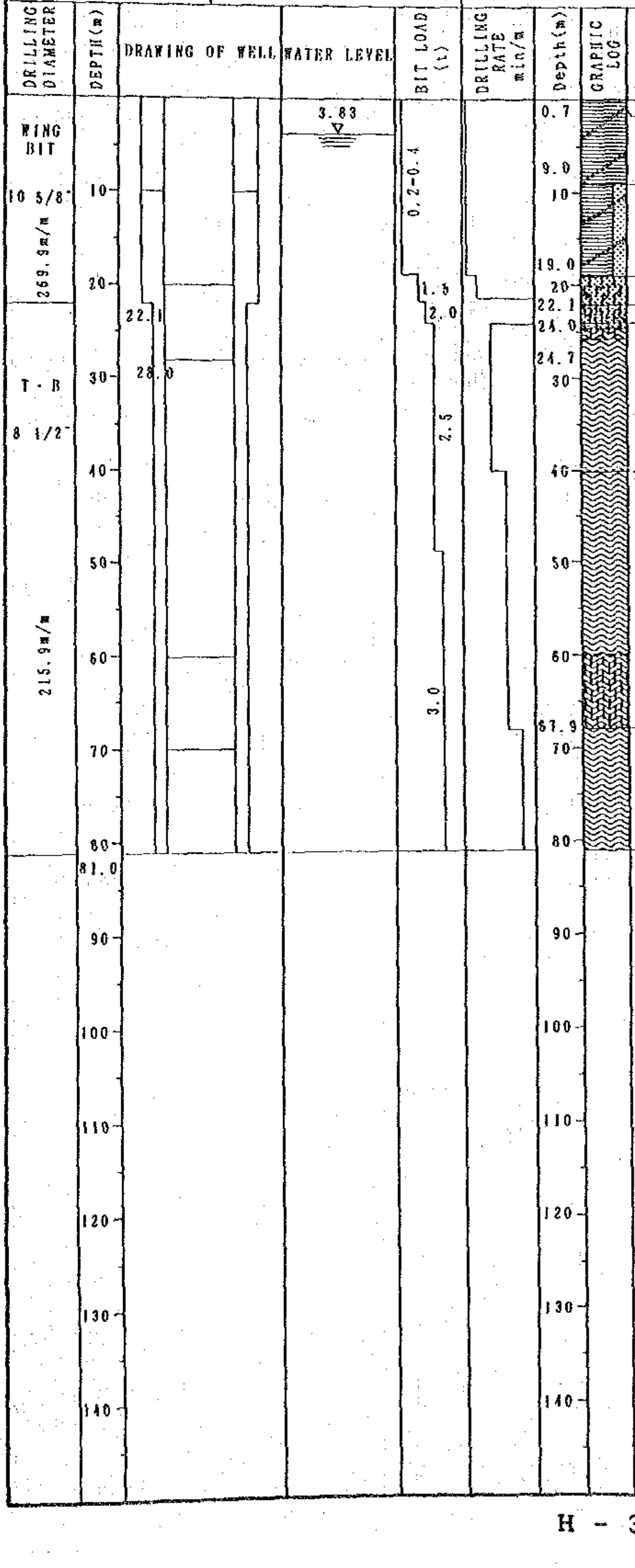
Fig H.3
(2)

DRILLING LOG

B・H・NO.	Br-2	WELL CASING DEPTH	81m
LOCATION	NASHO AREA	SCREEN DEPTH	20.0-28.0m 60.0-68.0m
DRILLING DEPTH	81.0m	WELL CASING SCREEN SIZE	6" OD170 m/m ID150
DRILLING DIAMETER	215.9m/m	DISCHANGE CAPACITY	
COMMENCED ON	90-Feb-2	STATIC WATER LEVEL	3.83m
COMPLETED ON	90-Feb-9	DYNAMIC WATER LEVEL	

LOCATION





GEOLOGICAL DESCRIPTION

TOPSOIL

Dark gray Sandy CLAY.

Gray, Sandy CLAY, with gravels.

Gravelly SAND.

COBBLE&BOULDERS

SAND intervence between 24.0 to 24.70m in depth.

Highly to moderately weathered SCHIST.

Moderately weathered SCHIST.

Cracks between 60.2 to 63.0m in depth.

Slightly weathered Quartze SCHIST.

Fresh Quartze SCHIST.

END OF BORING

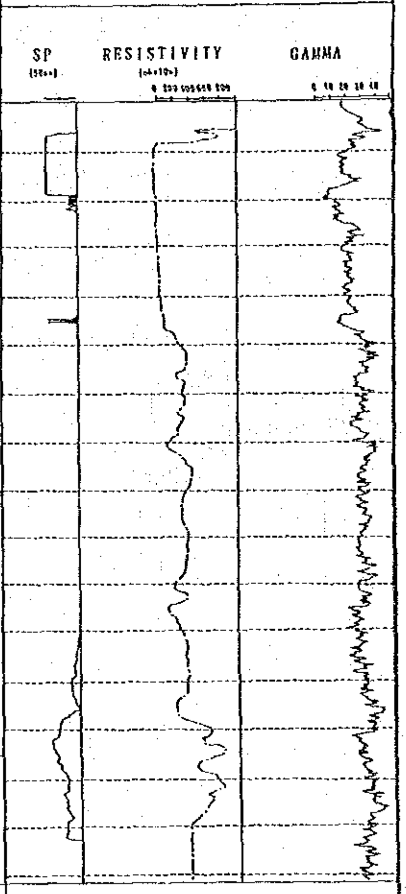
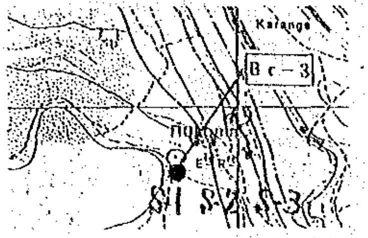


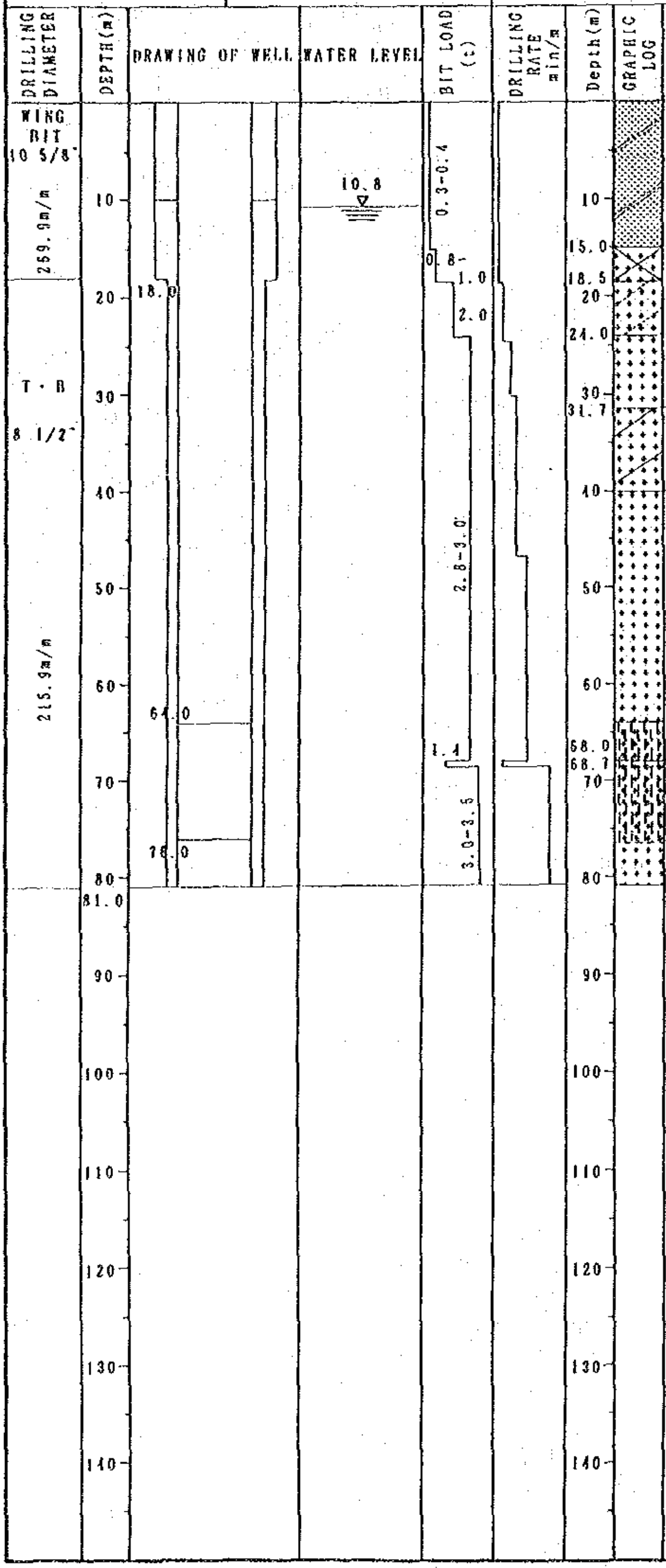
Fig. H.3 (3)

DRILLING LOG

B · H · NO.	Br-3	WELL CASING DEPTH	81m
LOCATION	SAKE AREA	SCREEN DEPTH	64.0-76.0m
DRILLING DEPTH	81m	WELL CASING SCREEN SIZE	
DRILLING DIAMETER	215.9m	DISCHARGE CAPACITY	6" OD170 ID150 m/m
COMMENCED ON	90-Jan-24	STATIC WATER LEVEL	10.8m
COMPLETED ON	90-Jan-31	DYNAMIC WATER LEVEL	

LOCATION





GEOLOGICAL DESCRIPTION
Yellowish brown. Medium to coarse SAND. with some fines.
Completely weathered to highly weathered GRANITE. Brownish colour.
Partly weathered GRANITE. Dark gray colour.
Moderately weathered GRANITE.
Moderately weathered to slightly weathered GRANITE.
Completely to highly weathered GRANITE
Slightly weathered to fresh GRANITE.

END OF BORING

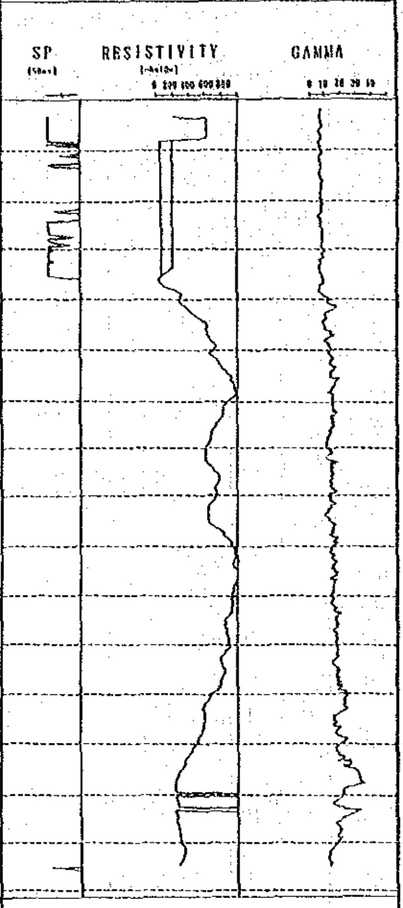
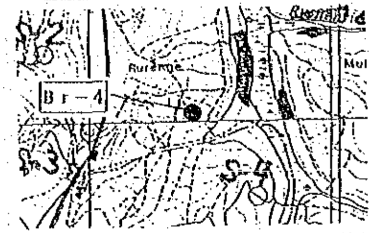


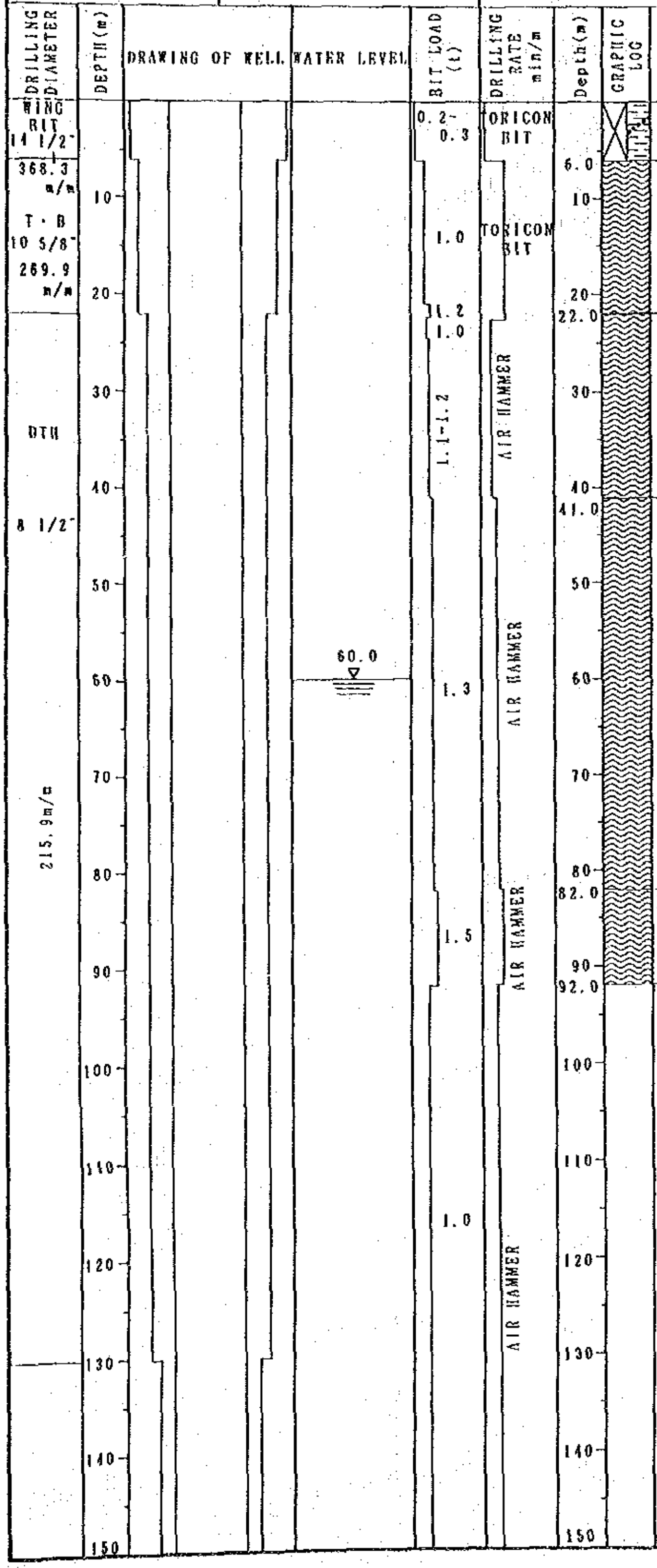
Fig. H.3
(4)

DRILLING LOG

B・H・NO.	Br-4	WELL CASING DEPTH	130m
LOCATION	KABARONDO AREA	SCREEN DEPTH	62.0-74.0m 78.0-94.0m
DRILLING DEPTH	150m	WELL CASING SCREEN SIZE	6"
DRILLING DIAMETER	158.15m	DISCHANGE CAPACITY	
COMMENCED ON	90-Jul-11	STATIC WATER LEVEL	60.0m
COMPLETED ON	90-Jul-25	DYNAMIC WATER LEVEL	

LOCATION





GEOLOGICAL DESCRIPTION

Brownish gray TOPSOIL with fine Gravels.

Dark gray. Moderately weathored to highly weathered Soft SCHIST.

Dark gray. Moderately weathered SCHIST.

Quartz SCHIST Inetrvens below 33.0m in depth.

Thickness of Quartz SCHIST were 20 to 50cm Earch

Dark gray. Slightly weathered SCHIST. Quartz SCHIST & Quartzite Intervens as an Alternating Structure

Alternating Bed of Dark gray SCHIST & Yellowish White Quartzite.

Dark gray. Moderately weathered SCHIST.

Trace of MICA.

END OF BORING

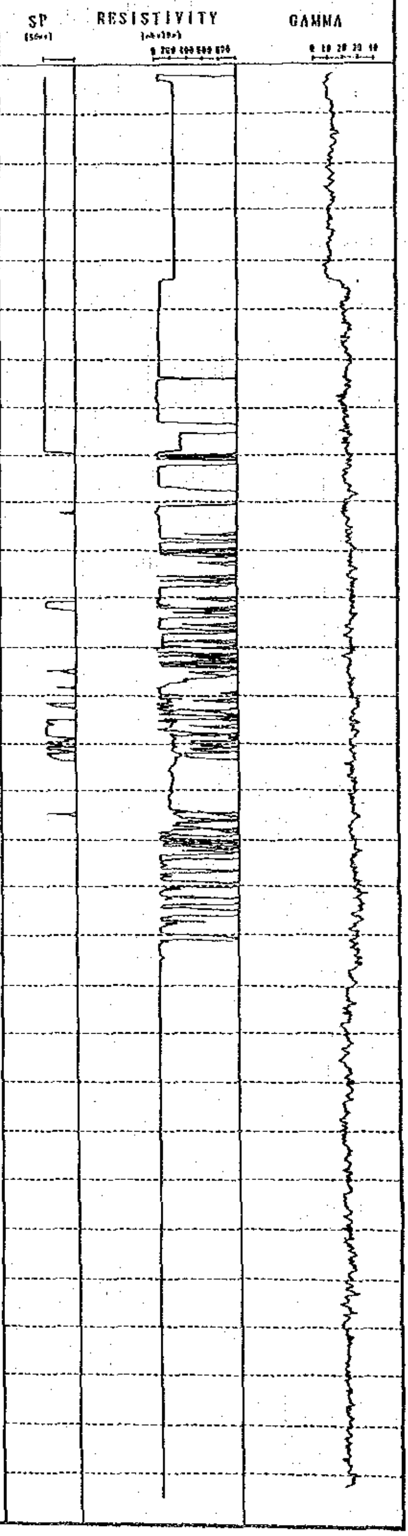
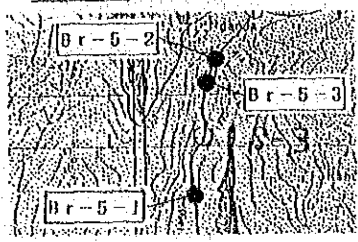


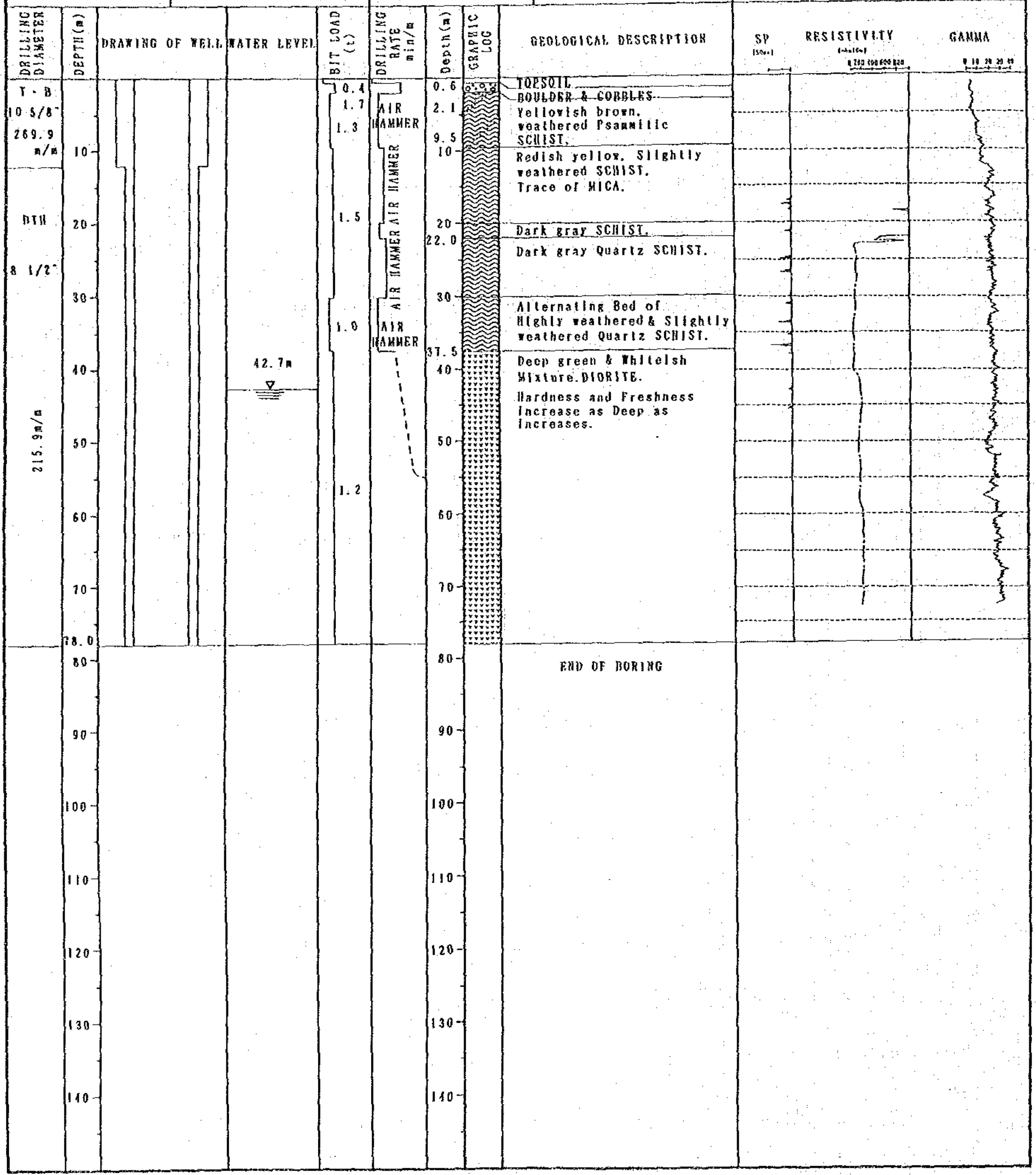
Fig. H.3
(5)

DRILLING LOG

B · H · NO.	Br-5-1	WELL CASING DEPTH	
LOCATION		SCREEN DEPTH	
DRILLING DEPTH	78m	WELL CASING SCREEN SIZE	
DRILLING DIAMETER	215.9m/m	DISCHANGE CAPACITY	
COMMENCED ON		STATIC WATER LEVEL	42.7m
COMPLETED ON		DYNAMIC WATER LEVEL	

LOCATION





GEOLOGICAL DESCRIPTION

TOPSOIL

BOULDER & COBBLES

Yellowish brown, weathered Psammitic SCHIST.

Redish yellow, Slightly weathered SCHIST. Trace of MICA.

Dark gray SCHIST.

Dark gray Quartz SCHIST.

Alternating Bed of Highly weathered & Slightly weathered Quartz SCHIST.

Deep green & Whiteish Mixture.DIORITE.

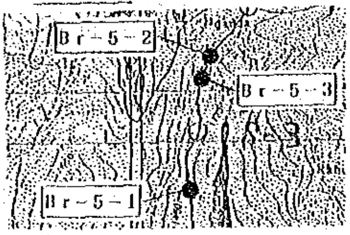
Hardness and Freshness Increase as Deep as Increases.

END OF BORING

DRILLING LOG

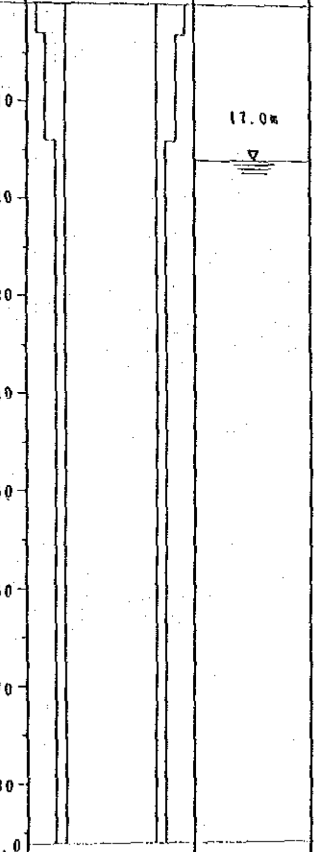
B・H・NO.	Br-5-2	WELL CASING DEPTH	
LOCATION		SCREEN DEPTH	
DRILLING DEPTH	86m	WELL CASING SCREEN SIZE	
DRILLING DIAMETER	215.9m/m	DISCHANGE CAPACITY	
COMMENCED ON		STATIC WATER LEVEL	17.0m
COMPLETED ON		DYNAMIC WATER LEVEL	

LOCATION



DRILLING DIAMETER	DEPTH(m)	BIT LOAD (t)	DRILLING RATE min/m	Depth(m)	GEOLOGICAL DESCRIPTION
WING BIT 14 1/2"		1.2	AIR HAMMER	1.7	BOULDER & COBBLES
		1.0			Redish brown, Highly to Moderately weathered SCHIST.
T・B 10 5/8"	10			9.0	Quartzite.
			AIR HAMMER	10	Yellowish brown Sandstone or/and Psammitic SCHIST.
	20			16.0	Redish brown Psammitic SCHIST, with Some MICA. Very Soft as Clay at 22.0m in depth.
8 1/2"	30			27.3	Yellowish brown & Redish brown, Alternating Bed of Sandstone and Psammitic SCHIST.
	40	1.5		37.5	Dark gray to Light gray, Quartz SCHIST.
215.9m/m	50		AIR HAMMER	42.0	Alternating Bed of Highly to Completely weathered SCHIST and Moderately Quartz SCHIST. Thicknoss of Completely weathered SCHIST Is 10 to 30m.
	60			62.5	Bluish gray, Highly weathered SCHIST.
	70			65.0	Alternating Bed of Completely weathered SCHIST as Clay & Moderately weathered Quartz SCHIST.
				74.0	Quartz Schist.
	80	1.2		80	Moderately weathered Quartz SCHIST.
	86.0				END OF BORING
	90			90	
	100			100	
	110			110	
	120			120	
	130			130	
	140			140	

DRAWING OF WELL / WATER LEVEL



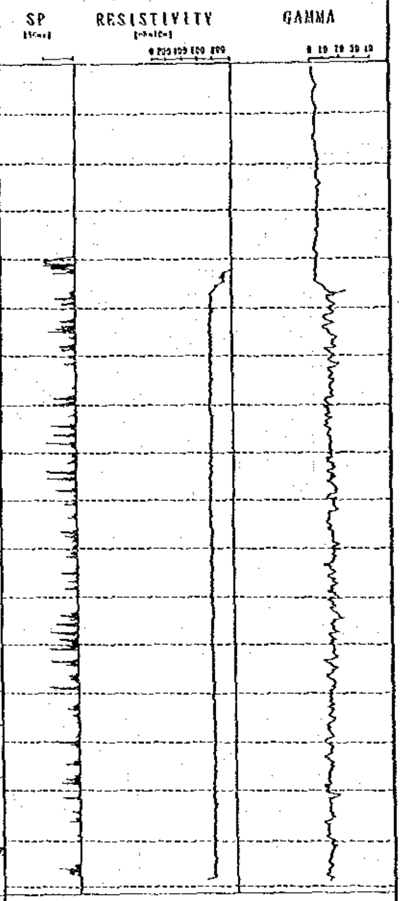
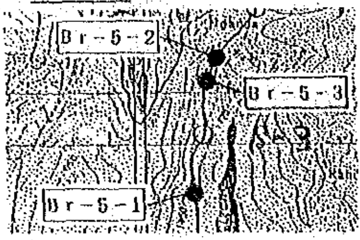


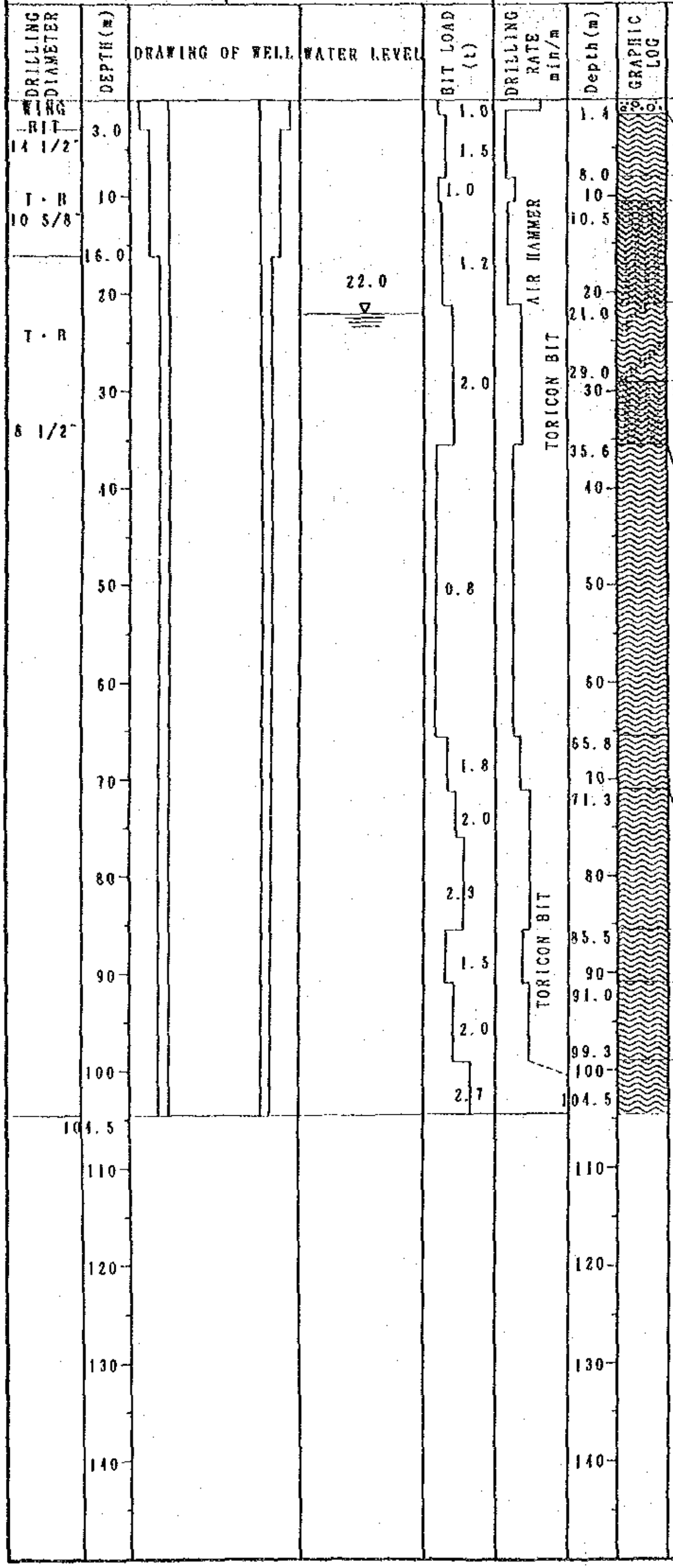
Fig. H.3 (7)

DRILLING LOG

B・H・NO.	Br-5-3	WELL CASING DEPTH	
LOCATION		SCREEN DEPTH	
DRILLING DEPTH	104.5m	WELL CASING SCREEN SIZE	
DRILLING DIAMETER	215.9m/m	DISCHANGE CAPACITY	
COMMENCED ON		STATIC WATER LEVEL	22.0m
COMPLETED ON		DYNAMIC WATER LEVEL	

LOCATION





GEOLOGICAL DESCRIPTION

1.4	BOULDER & COBBLES
8.0	Redish brown, Highly to Moderately weathored SCHIST.
10.5	Quartzite.
21.0	Yellowish brown Sandstone or/and Psammitic SCHIST.
29.0	Redish brown, Psammitic SCHIST, with some MICA.
35.6	Yellowish brown, Alternating Bed of Sandstone and Psammitic SCHIST.
65.8	Yellowish brown, Highly to Completely weathered SCHIST.
71.3	Alternating Bed of Highly to Completely weathered SCHIST Slightly weathered Quartz SCHIST.
85.5	Moderately weathered Quartz SCHIST. Brownish gray Colore. Moderately weathered Quartz SCHIST.
91.0	Light brownish gray Highly weathered SCHIST.
99.3	Dark gray, Slightly weatered SCHIST. Quartzite Intervenes.
104.5	Fresh. Quartzite.

END OF BORING

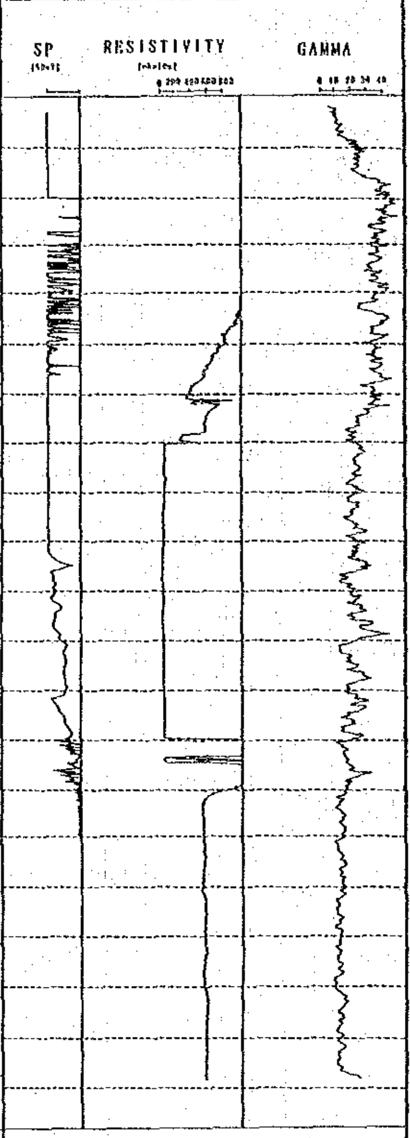
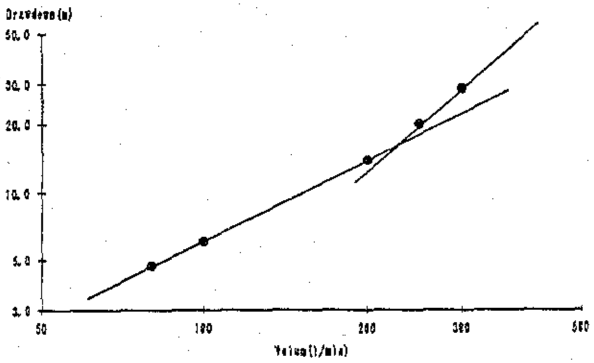
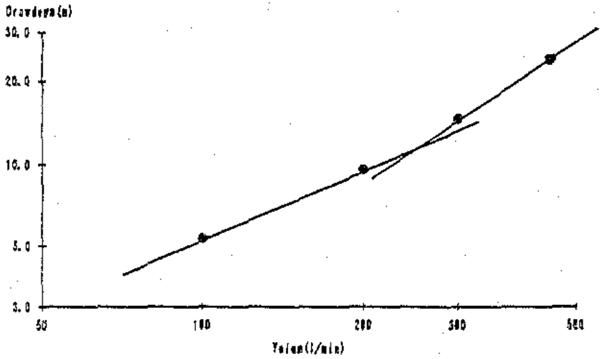


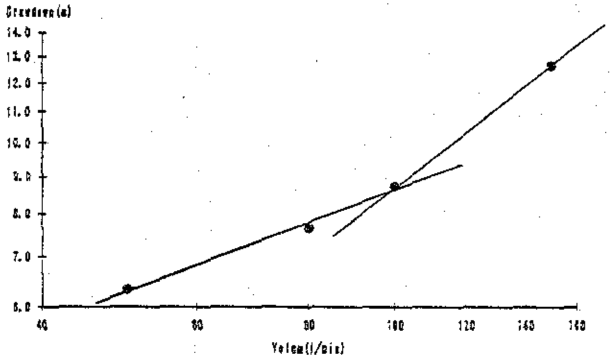
Fig. H.4

Table Result of Step Drawdown Test

Br-1			Br-2			Br-3		
Volume (l/min)	Water Level(m)	Drawdown (m)	Volume (l/min)	Water Level(m)	Drawdown (m)	Volume (l/min)	Water Level(m)	Drawdown (m)
-	6.45		-	3.25		-	10.25	
80	11.15	4.70	100	8.57	5.32	50	16.58	6.33
100	12.53	6.08	200	12.85	9.60	80	17.88	7.63
200	20.45	14.00	300	17.85	14.60	100	18.95	8.70
250	26.76	20.31	450	23.10	19.85	150	22.85	12.60
300	35.42	28.97						


Step Drawdown Test (logQ - logSw Courve) Br-1


Step Drawdown Test (logQ - logSw Courve) Br-2


Step Drawdown Test (logQ - logSw Courve) Br-3

APPENDIX I

HYDROGEOLOGY

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HYDROGEOLOGY

1. GENERAL

The results of the geoelectrical prospecting, test boring, and each area's hydrogeological examination are summarized in the previous section. By referencing the hydrogeological survey results obtained by the Feasibility Study conducted in 1985, the results of the Phase I Project, and by clarifying the results of the field survey, the hydrogeological conditions in the Study Area are examined below.

2. SUMMARY OF PREVIOUS DATA

Except for the 1985 Feasibility Study report, the boring/water quality data of the Phase I Project and other simple survey summary reports, no hydrogeological data of the Study Area was available. Thus, the summary of previous data is outlined based on the 1985 Feasibility Study report(geological columnar of F/S in Phase I stage are given in Fig.I.1.) and Phase I project's boring data(see Fig. I.2).

2.1 HYDROGEOLOGICAL CLASSIFICATION

In view of the bedrock geology and water use conditions, the hydrogeological environment of the Study Area can be classified into the two areas suitable for shallow well sites (less than 30 m in depth) and deep well sites (more than 30 m in depth).

Water Source Category	Symbols	Characteristics of Aquifer	Rock Type of Aquifer	Remarks
Shallow wells (under 30m in depth)	S1	unconfined	quartzite	fulluvial deposits
Shallow wells (under 30m in depth)	S2	unconfined	quartzite	abundant boulders
Deep wells (over 30m in depth)	D1	confined	quartzite	dominant schist
Deep wells (over 30m in depth)	D2	confined	quartzite	dominant quartzite
Deep wells (over 30m in depth)	D3	confined	granitic	extensive joint system weathered zone

The mountainous areas higher than elevation of 1,500 m are classified as "deeper groundwater distribution areas". In these areas the groundwater levels are deeper than those of the above mentioned deep wells and are considered to be unsuitable for well construction because drilling wells deeper than those drilled for the Phase I project would be required.

It was previously believed that it would be impossible to specify a spring distributed area, but, from spring-water use conditions, Rutonde Commune and its surrounding area are now considered to have many springs.

2.2 CHARACTERISTICS OF AQUIFERS

Groundwater development was mainly made in the alluvial and diluvial strata areas for the Phase I project and the examinations of aquifer characteristics were made accordingly.

Following is a summary of the examinations:

(Result of Phase I Study)

Classification of Aquifer	Geology	WT (m-GL)	Thickness (m)
SHALLOW GROUNDWATER (not deeper than GL-30m of groundwater table)			
. in Alluvial Deposits	Gravel, Sand, Sand/Clay	0 - 20	<20
. in Debris & Weathered Materials at Low	Granular Granite, Coarse Weathered & Fracture Zone (schist/quartzite)	15<	25-45
DEEP GROUNDWATER (deeper than GL-0m of groundwater table)			
. in Debris & Weathered Materials at Slope	Granular Granite, Coarse Weathered & Fracture Zone (schist/quartzite)	50<	-
. in Weathered Materials at Slope	Fracture Rocks (quartzite)	50<	-

2.3 AQUIFERS' HYDRAULIC CONSTANTS

For the 1985 Feasibility Study, pumping tests were conducted in Test Boring No.1 and No.2.

According to the Phase I project's well data, the permeability coefficients were calculated from the aquifers' thicknesses and pump discharge amounts. The calculation results are shown in Table I.1. In general, the permeability coefficients of the alluvial planes are;

1 x 10-3 to 3 x 10-3 cm/sec and

the storage coefficients are in the range of;

0.1 to 0.5.

These values are considered to be appropriate for unconfined aquifers.

3. HYDROGEOLOGICAL CHARACTERISTICS

3.1 BASIC CONCEPT OF CONSIDERATION

Groundwater is found in aquifers formed by rainfall which flow or stay in permeable zones. The nature of underground therefore, largely determined the availability of groundwater.

The Study Area is mainly underline by highly consolidated Precambrian formations, granitic rocks and unconsolidated Quaternary deposits. Weathered rock zone in upper and unconsolidated Quaternary deposits therefore, are mainly considered to be aquifers in the Study Area. Unaltered parts of the Pre-cambrian formations and granitic rocks are estimated hydrogeological basement (aquiclude), except fracture zone and joint in tensile zone of faults/folds.

According to the geological condition of the Study Area, basic concept of relationship between occurrence of aquifers and detailed geological types in the Area are examined and the relationship are basically indicated as following Table:

Relationship Between Aquifers and Geology

Geological Type	Description
Alluvial Deposits	Formation that transmit or yield shallow groundwater within a few quantities where underline by massive basal rocks and/or yield groundwater in appreciable quantities where underline by fracture basal rock, except finer material deposits which have low permeability. However, groundwater in swampy lands are stagnant and deoxidized circumstance of groundwater is widely found.
Talus Sediments	Formation that recharge or transmit in upper parts and/or shallow groundwater in lower parts within a little quantities.
Weathered Soft Rocks	Mainly formations of impervious materials of pelitic schist that obstruct the groundwater flow, except or Schist coarser weathered materials which is aquifers.

(cont.)

Geological Type	Description
Weathered Rock Zone	Formations that recharge or transmit in of Quartzite/Sandstone higher parts and/or yield groundwater in and Granitic Rock relatively lower portions within some quantities except massive unaltered parts.
Unaltered Massive	Aquiclude except fracture zone of faults Rock in hard rock (e.g. quartzite, sandstone, granite) and joints in tensile zone of folds.

The relationship between occurrence of aquifers and geology types are also presented on the geological cross sections of Hydrogeological Map, accompanied with estimated groundwater table.

4. CONDITIONS OF SPRING WATER

The spring condition survey results obtained by the Feasibility Study conducted in 1985 by JICA, the communes' spring-water use survey data and by clarifying the results of the field check, are examined.

Each commune's spring-water use conditions and water yield rate per unit area are summarized in the following Table, referring to the existing discharge records of the F/S and communes' spring-water survey data:

Spring-water use Conditions of Each Commune

COMMUNE	AREA (Km2)	DAILY YIELD (m3/d)	UNIT YIELD (m3/d/km2)
BIRENGA	263.6	361	1.4
RUKIRA	253.2	962	3.8
RUSUMO	788.8	1,129	1.4
KABARONDO	160.3	845	5.3
KAYONZA	190.0	247	1.3
RUTONDE	93.7	1,758	18.8
SAKE	146.1	1,498	10.3
MUGESERA	144.1	2,717	18.9
KIGARAMA	273.3	1,448	5.3
MUHAZI	91.6	95	1.0
RUKARA	261.9	147	0.6

For the spring-water survey mentioned above, the springs can be mainly found in the foot slope of the crack hard rock and the schist mountainous areas, mainly underline by impervious formations;i.e. schist, phyllite and sericite. Geologically, cluttered weathered portions of the alternation of schist/ quartzite and quartzite are found and the areas are considered to have a high potential for spring water resources.

Generally, existing discharge records of spring water conflict with observations which mostly indicates lower capacities than those of existing data. Based on the some field checks during June to October, spring conditions in the Study Area are outlined as below:

- As the topography of plateau-like hills within the Study Area(the Kibungo Prefecture), the catchment areas of streams and springs are relatively very small. Consequently, the quantities of spring water are considered to be a smaller amount and more unsettled, as compared with another prefectures of Rwanda.

- The high production areas of spring water are scattered on Rutonde(the southern low lying lands of Muhazi Lake), Sake/Mugesera/Kigarama(western/ northern lower parts of broad high lands) and Rukira/Rusumo(lower portions of broad hard rock mountainous areas)communes.

- Most of the springs discharged water in a relatively small range from 1 to 30 lit/min(1 m3 to 40 m3/day) with heavy fluctuations except a few springs of over 100 m3/day yields which are water sources of existing supply systems. A few springs do not exit/flow throughout the year.

- Many small springs are generally scattered in broad area within the Study area.

- The spring water qualities are suitable for drinking purpose with EC(electric conductivity) values in a range from 100 to 450 S/cm, as mentioned in Appendix D.

Based on the present environment of spring water, it is considered that remaining high potential areas of spring water development for Phase III are Mugesera/Sake/Rusumo Communes. Thus, for establishing a water supply plan in these areas, the first priority should be given to the development of spring-water.

The existing water use data are compiled as in "Data Book".

The unit yield of spring water in each Secteur which is estimated from the existing water use data is given in Fig. I.3. The field observations during the Study of Phase III are given in Table I.2 and locations are presented in Fig. I.4. High potential parts of spring-water development within the Study Area are given in "Groundwater Development Potential Map".

5. HYDROGEOLOGICAL CLASSIFICATION OF THE STUDY AREA

5.1 OUTLINE OF HYDROGEOLOGICAL CONDITIONS

The bedrock geology of the Study Area is composed of schist, quartzite, sandstone, their alternate layers and granite. The general geological structure has many north-south lineaments, from west to east slopes, and NNE-SSW direction fault and fold axes.

The groundwater flow is controlled by the lineaments, slopes and the fault and fold axes. The flow of NNW-SSW direction is predominant.

In the hill area, narrow and long ridges are well developed in a NNE-SSW direction.

Corresponding to the above topographical and geological environments, the Study Area's hydrogeological characteristics can be summarized as follows:

- In general, the groundwater is recharged in the ridge areas and flow down along the slopes into the alluvial lowlands. Therefore, the flow of groundwater along the bedrock geological structure is only to water in very deep ground. Most of the groundwater in the Study Area exists in shallow strata and flows along the ground surface.

- The permeation and flow of the groundwater are greatly influenced by the degree of the bedrock's weathering condition. Thus, the movement of the groundwater is limited to the relatively small ridge-valley range.

- Except for some fissured areas, good quality aquifers are believed to be limited to the alluvial planes and their small lowland fringes, no large aquifer development is expected.

- However, groundwater at many alluvial swampy lands is also stagnant and the deoxidized condition of groundwater may be observed with high contents of divalent Fe/Mn ions.

- In view of the aquifers' characteristics, the groundwater in the Study Area is believed to circulate only in several year cycles.

5.2 HYDROGEOLOGICAL GROUP IN THE STUDY AREA

Based on the bedrock geology and geo-morphological setting, the Study Area can be classified into six(6) hydrogeological groups as below:

(A) : Alluvial Area
(Q) : Quartzite Area
(SQ): Alternation Area of Schist and Quartzite
(S) : Schist Area
(Gn): Gneissoes Granite Area
(Gr): Massive Granite Area

In addition, Alluvial Area(A) is further divided into two(2) categories, mainly referring to groundwater conditions of Phase I well;

Alluvial land	coarser deposits generally are found on higher part than swampy lands and only short periodic water logged. Groundwater may flow to downward.
Alluvial swampy land ...	finer deposits are found and long term water logged throughout year. Groundwater is generally stagnant and deoxidized circumstance of groundwater may occurs with high contents of divalent Fe/Mn ions.

The distribution of each hydrogeological group is presented in "HYDROGEOLOGICAL MAP" with typical cross sections.

5.3 CHARACTERISTICS OF THE GROUP

From the 1985 Feasibility Study's geoelectrical prospecting results and this Study's geoelectrical prospecting results, the depths of the unaltered bedrocks that are considered as impermeable strata and are classified as listed in the following Table.

Geological Group	Depth of Unaltered Rock from Surface (m)		
	Lower Slope	Middle Slope	Upper Slope or Ridge
(A	30>		)
Q	65	40	40
SQ	60	40	40
S	60	45	30
Gn	40	55	55
Gr	a few (m)	10>	10>

5.4 HYDROGEOLOGICAL FEATURE WITHIN THE STUDY AREA

Hydro-geologically, the Study Area is classified into five(5) types of region as follows, based upon the characteristics of geological groups and their spatial distributions, and geo-morphological classification. Characteristics of the types are given as follows:

Mostly pelitic schist and a few sandstone quartzite, accompanied with many slender alluvial lands. ("S"+"A")

Mainly impervious area that obstruct the groundwater flow and low permeability, except alluvial lands and/or coarser weathered parts which is small aquifers.

Quartzite on ridge areas and schist/alternation of schist & quartzite on sloping to bottom area with narrow alluvial lands. ("SQ"+"A")

Recharge or transmit in higher parts and/or yield groundwater in relatively lower portions and bottom alluvial lands within some quantities except massive unaltered parts and a large pelitic schist area. A few springs in quartzite area are found.

Quartzite on ridge and steep sloping area, and alluvial lands on lower parts. ("Q"+"A")

A large area of recharge or transmit in higher parts and/or yield groundwater in sloping area, lower portions and alluvial lands within some quantities except massive unaltered parts. A few springs in quartzite area are found.

Mostly gneissoes granite around main lakes and some schist on higher part, accompanied with small alluvial lands. ("Gn"+"A")

Transmit in several parts and/or yields groundwater around lakes/main streams and alluvial lands within some quantities except massive unaltered parts and pelitic schist area.

Massive flesh granite on gentle lands and few alluvial land. ("Gr")

Aquiclude except fracture zone of faults and joint in tensile zone. Only deeper groundwater is expected.

6. CHARACTERISTICS OF AQUIFERS

6.1 UNDER-GROUND GEOLOGY AND GROUNDWATER CHARACTERISTICS

Geological cross sections of the Area (see "Hydrogeological Map") show sow shape relief with straight dip of Pre-cambrian stratum, except granitic rock areas where are relatively gentle. Drainage system generally follows geological structures,such as NS strike and main faults/fold axis of NNE-SSW trend.

According to the above geo-morphological/geological conditions, following characteristics of groundwater hydrology in the Study Area is estimated.

- Basically groundwater flows in transmit horizons of upper weathered/unconsolidated zones. Groundwater flow therefore is limited in small section, forward to streams and/or relatively lower parts.

- Aquifers which is suitable to be developed, are generally found on alluvial lands and their surrounding areas at limited extent. Therefore many small scale aquifers are developed along stream lines.

- Continuance of aquifers are not expected in the Study area and narrow/small aquifers of discontinuity are scattered.

The above characteristics of limited discontinuity aquifers are supported by existence of small scale springs on higher part and Changeable spring-water volume throughout year, confirmed by field check and hearing survey.

Conditions and classification of the aquifers in the Study Area can be judged from the above-mentioned characteristics of hydrogeology and aquifers. Based upon geoelectric survey and Phase I survey/construction information, the aquifers' classification of Phase I Study Stage is modified as below;

Classification of Aquifer	Geology	WT (m-GL)	Thickness (m)
SHALLOW GROUNDWATER (not deeper than GL-50 m of GWT)			
Ia :in Alluvial Deposits	Gravel, Sand, Sand/Clay	0 - 20	< 20
Ib :in Debris & Weathered Materials at Low	Granular Granite, Coarse Weathered & Fracture Zone (schist/quartzite)	15 <	25-45
DEEP GROUNDWATER (deeper than GL-50 m of GWT)			
IIa:in Debris & Weathered Materials at Slope	Granular Granite, Coarse Weathered & Fracture Zone (schist/quartzite)	50 <	20 <
IIb:in Weathered Materials at Slope	Fracture Rocks (quartzite)	50 <	20 <
LOW PERMEABLE HORIZON			
IIIa:in Weathered Materials	Fine to Medium Weathered Rock (Mainly schist)		
IIIa:in Unaltered Basal Rock	Massive Rocks (schist, quartzite, granite)		

6.2 HYDROGEOLOGICAL PARAMETERS

Hydrogeological parameters in the Study Area were analyzed, based upon existing data, information and field pumping tests during this Study period. The results of these analyses and Information of Phase I are outlined in Table below and details are given in " Pumping Test Result " of Appendix H.

SUMMARY OF HYDROGEOLOGICAL PARAMETER

Site/Location	Aquifer	Thickness (m)	Trans-missibility [T](m2/day)	Storativity [S]	Permeability [K] (cm/sec)	Note
PHASE I DATA						
No.1 Test Well	Alluvial Sand &	14.1	22.2	9.25E-02	1.82E-03	Jacob Method
	Gravel	14.1	34.2		2.81E-03	Recovery Method
No.5 Test Well	Alluvial Sand &	6.2	8.3	4.55E-01	1.55E-03	Jacob Method
	Gravel (Clay)					
Constructed Well						
Zone I	Alluvial Clay,				3.19E-03	
Zone II	Sand & Gravel,				3.36E-03	Average Data
Zone III	and Weathered				2.40E-03	
Zone IV	Schist & Quatzite				2.00E-03	
PHASE III DATA						
Br.1 Test Well	Alluvial C,S & G	21.1	6.6	1.14E-03	3.62E-04	Jacob Method
	+ Weathered Schist	21.1	17.5		9.62E-04	Recovery Method
Br.2 Test Well	- do -	20.9	25.0	5.34E-03	1.38E-03	Jacob Method
		20.9	50.5		2.79E-03	Recovery Method
Br.3 Test Well	Weathered Granit	12.0	2.8	4.34E-01	2.73E-04	Jacob Method
		12.0	1.9		1.79E-04	Recovery Method
Br.4 Test Well	Alternation of	32.0	1.0	6.22E-02	3.75E-05	
	Schist/Quartzite	32.0	1.3		4.53E-05	
Br.5-3	Fracture zone of	19.1	6.4	1.15E-01	3.86E-04	
Test Well	Quartzite	19.1	5.1		3.11E-04	

Through the analysis and examination above, the hydrogeological parameter of the Study Area is considered to be as a follow:

	Transmissibility [T](m2/day)	Permeability [k](cm/sec)	Storativity [S]
Alluvial Deposits	10 - 35	5 x 10E-4 - 1 x 10E-3	1 x 10E-1 - 1.5
Weathered Schist/Quartzite	5 - 20	1 x 10E-3	5 x 10E-2
Weathered & Fractured Granite	1 - 3	1 x 10E-4	5 x 10E-1

7. CLASSIFICATION OF GROUNDWATER DEVELOPMENT POTENTIALITY

Based on the hydrogeological classification in the Study Area mentioned above, the potentiality of groundwater development is examined and following eight(8) classifications are established:

Sa: Suitable for a shallow groundwater development with lower limitations of both quantity and quality

Yield shallow groundwater is expected in relatively lower portions within enough quantities. Groundwater table is estimated as not deeper than 50 m deep from ground surface. Springs may be found on upper parts within the area.

Sb: Moderately suitable for a shallow groundwater development with low limitation of quantity but high limitation of quality

Yield shallow groundwater is expected within much quantities but deoxidized circumstance of groundwater with high contents of divalent Fe/Mn ions widely occurs. Careful determination of well location is therefore strongly required through detail topographical/geological examinations. Groundwater table is estimated as not deeper than 50 m deep from ground surface.

Sc: Moderately suitable for a groundwater development with high limitation of drilling work

Yield groundwater is expected within some quantities at lower parts and lands mainly underline by cracked hard rocks(quartzite). Groundwater table is considered to be 30 m to 100 m deep from surface. However, a few well constructions within the areas are considered to be costly and harder works on account of extremely hard rock formations. Careful determination of well locations should be conducted, using aero-photo interpretation, geoelectric prosection and field investigation.

Sd: Marginally suitable for a shallow groundwater development with limitations of quantity

Yield shallow groundwater is expected in relatively lower portions along the lake shore mainly underline by granitic rocks. However, the quantities are considered to be marginal for the groundwater development. Location of wells therefore should be carefully determined through detail geological survey/exploitation on account of occurrence of some impervious areas that obstruct the groundwater flow and low permeability. Groundwater table is estimated as not deeper than 50 m deep from ground surface.

M : Marginally suitable for shallow groundwater development and moderately suitable for a deep groundwater development

Yield shallow/deep groundwater is expected at limited extent. Then location of wells should be carefully determined through detail geophysical exploitation. Geologically, quartzite is dominant. In addition, a few well constructions within the areas are considered to be costly and harder works because of extremely hard rock formations(quartzite/ diorite). Groundwater table is considered to be 50 m to 150 m deep from ground surface. A few springs within some quantities are considered to be found in the area.

Da: Moderately suitable for a deep groundwater development

Yield deep groundwater is expected but location of wells should be carefully determined through detail geophysical exploitation on account of some impervious areas that obstruct the groundwater flow and low permeability, being found. Geologically, alternation of schist and quartzite is dominant. Groundwater table is considered to be 50 m to 150 m deep from surface.

Db: Marginally suitable for a deep groundwater development

Yield deep groundwater is expected with some constraints. Careful determination of well location is therefore strongly required through detail geophysical exploitation. Geologically, granitic rock is dominant. Groundwater table is similar to that of "Da".

N : Non-suitable for groundwater development

Groundwater development is not proposed at this project stage because of the deep groundwater table of 150 m and the high development cost.

The conceptions of the relationship between Well locations and under-ground conditions are given in Fig. I.5, which also shows typical groundwater environments.

8. HYDROGEOLOGICAL CHARACTERISTICS OF EACH BASIN

The Study Area is divided into eleven (11) drainage basins (see Appendix C). Each basin has different hydrogeological conditions. The schematic cross sections of the basins are presented in Fig. I.6. On the basis of above hydrogeological classification, the features of each basin are generally as follows:

A Basin : Gneissoes granite on northern lowland and schist/quartzite on southern higher part, accompanied with small alluvial lands.

Transmit and/or yields groundwater only around main streams and alluvial lands within some quantities except massive unaltered parts and pelitic schist area of southern high lands. Deeper groundwater is estimated to be available on north lowland.

B Basin : Mostly gneissoes granite around Muhazi Lake and some schist on eastern slightly higher parts, accompanied with small alluvial lands.

Yields groundwater around lake/main streams and alluvial lands within some quantities except massive unaltered parts. Influent stream of groundwater from Muhazi Lake is estimated on account of the highest lake water table of Muhazi Lake in the Study Area.

C Basin : Quartzite/sandstone on ridge and sloping areas, and schist on alluvial lands/bottom areas with gentle to flat landform.

Recharge or transmit in higher parts and/or yield groundwater in relatively lower portions and alluvial lands within some quantities except massive unaltered parts and a large pelitic schist area on gentle to flat bottom.

D Basin : Gneissoes granite, covered with alluvial fan deposits, around eastern lakes and quartzite/schist or diorite on western to southern higher parts, accompanied with small alluvial lands.

Yields groundwater around lakes/main streams and a few areas of alluvial fan within some quantities except massive unaltered parts. Effluent streams of groundwater to lake is estimated because of the higher mountainous area surrounding lakes.

<u>E Basin</u> : Pelitic schist and a few sandstone/quartzite beds accompanied with many slender alluvial lands.

Mainly impervious area that obstruct the groundwater flow and low permeability, except alluvial lands, and debris & coarser weathered parts of sloping area which is small aquifers at lower sections. The aquifers are considered to be narrow/small, discontinuity and scattered.

<u>F Basin</u> : Mostly gneissoes granite is found around Mugesera and Sake Lakes, and schist/quartzite on eastern higher parts accompanied with small alluvial lands.

Transmit in limited parts and/or yields groundwater around lakes/main streams and alluvial lands within some quantities except massive unaltered parts and higher pelitic schist area.

<u>G Basin</u> : Pelitic schist with a few sandstone/quartzite beds, accompanied with swampy alluvial lands in center.

Mainly impervious area that obstruct the groundwater flow, except alluvial lands and debris & coarser weathered parts of sloping area where narrow/small aquifers of discontinuity are developed at lower parts.

<u>H Basin</u> : Quartzite on ridge and steep sloping area, schist on rolling lands/lower slope areas with more gentle landform and alluvial lands on lower parts/bottoms.

A large area of recharge or transmit in higher parts and/or yield groundwater in sloping area, lower portions and alluvial lands within some quantities except massive unaltered parts. A few springs in quartzite area are found.

<u>I Basin</u> : Quartzite on ridge and steep sloping area, schist/quartzite/diorite on lower slope areas and alluvial lands on lower parts/bottoms.

Recharge or transmit in higher parts and/or yield groundwater in sloping area, lower portions and alluvial lands within some quantities except unaltered parts. A few springs in sloping area are found.

J Basin : Massive flesh granite on gentle lands is dominant. In northern sections, quartzite and schist are found, and a few alluvial lands occur.

Aquiclude except fracture zone of faults and joints in tensile zone and north quartzite/schist areas where small aquifers are developed. Only deeper groundwater is expected on granite area.

K Basin : Same as "I Basin"

9. EXAMINATION OF SUSTAINED GROUNDWATER DEVELOPMENT

Groundwater development possibility is examined for rural water projects based upon the water balance simulation and the results of geological survey/pumping test.

The examination of groundwater development possibility will be carried out by the following two methods:

- Hydrological method ; to clarify the hydrological cycle by mean of water balance.
- Hydraulic method ; to assure pumping possibility.

9.1 HYDROLOGICAL METHOD

The hydrological method is to study the groundwater recharge compared to precipitation based on the simulation result.

Recharge for proposed water source area is outlined as follows:

- Northern portion of the Area(Drainage Basins A and B)

Annual rainfall	1,018 mm p.a.
Rate of recharge	16 %
Groundwater recharge	115 million m3 p.a., 305,000 m3/km2 p.a.