7.1.3 Electrical logging:

No. 1 - No. 3 holes were studied by electrical logging to determine the detailed conditions and characteristics of each layer.

7.1.4 Results, Considerations:

An outline of the drilling log and the groundwater potential is as shown in FIG. VII - 2.

No. 1: The main geological component of this place is welded tuff, while weathered material is located with non-weathered material.

According to the specific residency, it is difficult to determine the aquiferous layer. The strainer is 170-240 m of wheathered welded tuff.

No. 2: The ground condition consists of small and medium sand with pumice up to about 90 m depth.

The low specific residency at 120-140 m may result from the presence of impermable stratum. No sample material was available for this failure at 64-194 m.

Basalt layer with pumice and sand exists under 194 m. The strainer is set at 240-280 m and weathered.

No. 3: The main material is basalt up to 230 m and limestone exists under this level.

According to the specific residency, 120-140 m, 220-260 m are thought to have a low permeability. The material is assumed to be weathered basalt of 140-150 m 170-190 m, and weathered limestone of 260-270 m.

Strainers are installed for the limestone layer.

7.2 Pumping Test:

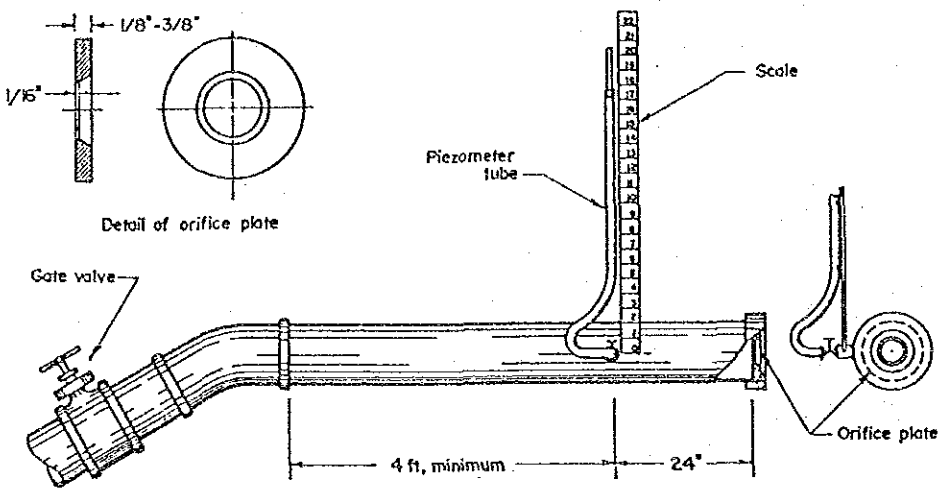
Pumping tests for evaluation of the hydraulic condition were performed at No. 1, 2, 3.

Physical features of the test equipment are as follows:

- Pump :

According to the data of existing wells, the discharge is approx. 5-60 l/s., so that capacities of 10 l/s, 20 l/s and 60 l/s are expected.

Circular orifices are adapted to measure the pumping rate as follows:



Essential details of the circular orifice weir commonly used for measuring pumping rates when pumping by means of a turbine pump. Discharge pipe must be level.

- Water level

Static and dynamic water level is measured by the air line method as follows:

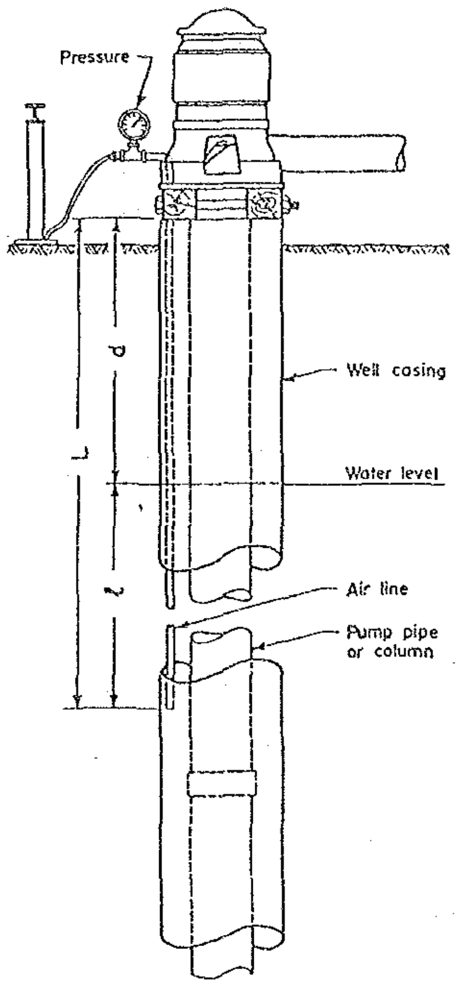
d = L-1

where

d is depth to water, in ft

L is depth to bottom of air line, in ft

l is pressure head, in ft, represented by a column of water of height equal to the submerged length of the air line.



Typical installation for measuring water levels by air-line method.

7.2.1 Results and Calculations

The results of the pumping test were analyzed to be nosteady radial flow without vertical movement constant discharge, as follows:

(1) Nº 1

a) Physical Features:

- Total depth	305 m
- Diameter of casing	0-220 m ø 300 m
	220-300 m ø 200 m
- Pump installation level	215 m
- Static water level	99.46 m
- Dynamic water level	190.53 m
- Drawdown	91.07 m

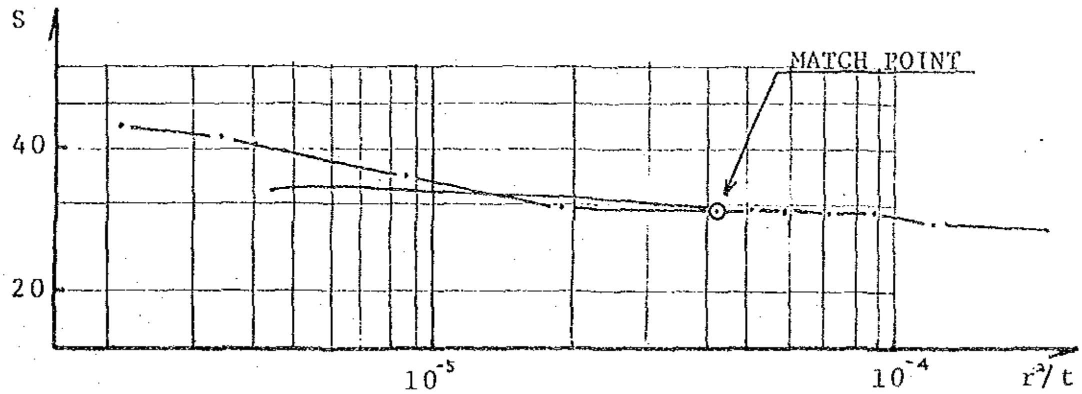
b) Curve matching method by Theis

The relationship between the radial distance, time, drawdown and the data curve are as follows,

$S - r^2/t$

r	r	t(sec)	r^2/t	S
0.1	0.01	0		23.20
		30	2.2×10^{-4}	26.40
		80	1.25×10^{-4}	27.80
		110	9.1×10^{-5}	28.50
		140	7.1×10^{-5}	28.50
		200	5×10^{-5}	28.50
		240	4.2×10^{-5}	29.51
		540	1.9×10^{-5}	28.50
		1,140	8.8×10^{-5}	35.53
		2,940	3.4×10^{-6}	41.16
		4,740	2.1×10^{-6}	43.93

$s - r^2/t$ Curve



The match point with the type curve is determined as follows:

$W(\ ) = 20, \quad = 9.0 \times 10^{-6}$

$S = 29.51, \ r^2/t = 4.2 \times 10^{-5}$

$$T = \frac{Q}{4\pi s} W(\ )$$

$$= \frac{6.3 \times 10^{-3}}{4 \times 3.14 \times 29.51} \quad 2.0 = 3.4 \times 10^{-4} \ (m^2/sec.)$$

$$S = \frac{4uTt}{r^2}$$

$$= \frac{4 \times 9 \times 10^{-6} \times 3.4 \times 10^{-4}}{4.2 \times 10^{-5}}$$

$$= 2.9 \times 10^{-4}$$

c) Straight-line solution by Jacob:

The relationship s - t is shown in following figure, and as 1 cycle t = 100 - 1,000, drawdown is made for s = 4

$$T = \frac{2.3\ Q}{4\ \Delta s}$$

$$= \frac{0.183\ Q}{\Delta s}$$

$$= \frac{0.183 \times 6.3 \times 10^{-3}}{4}$$

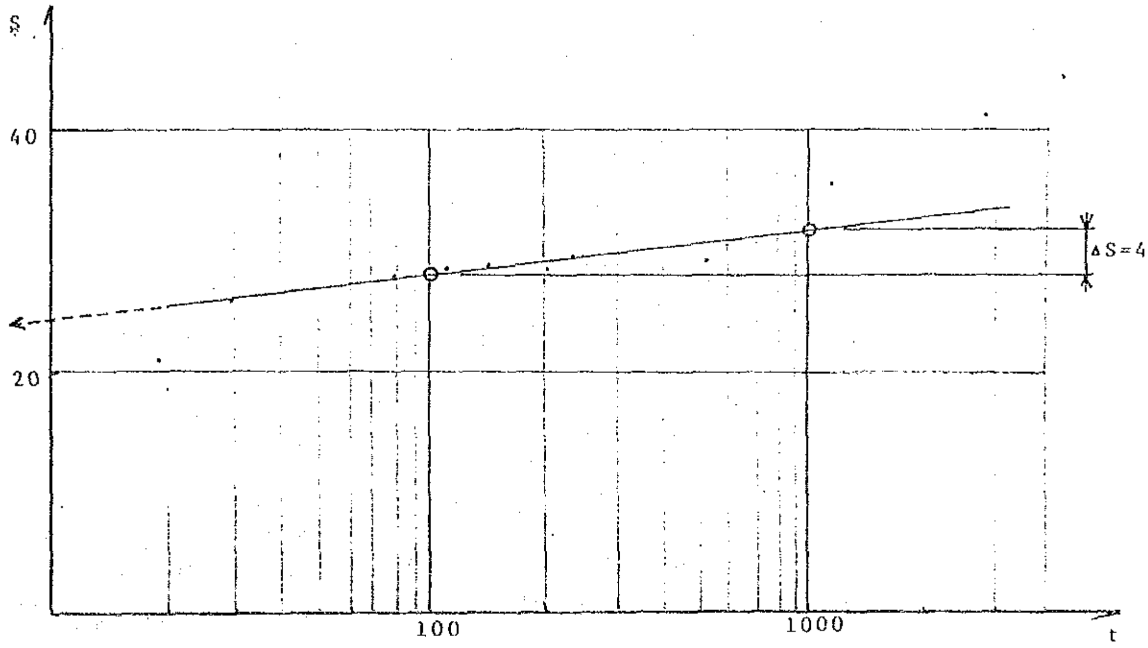
$$= 2.9 \times 10^{-4} \ (m^2/sec.)$$

$$S = \frac{2.25 \times T \times t_o}{r^2}$$

$$= \frac{2.25 \times 2.9 \times 10^{-4} \times 10^{-4}}{0.01}$$

$$= 6.5 \times 10^6$$

s - t Curve



d) Recovery Solution

The relationship between s - $\log_{10}$ t/t' is shown in following figure and table. The required point is found on the straight line which is given by data plotting.

s = 50, $\log_{10}$ t/t = 1.86

$$T = \frac{0.183 \times Q}{S} \log t/t'$$

$$= \frac{0.183 \times 6.3 \times 10^{-3}}{50} \times 1.86$$

$$= 4.3 \times 10^{-5} \ m^3/sec.$$

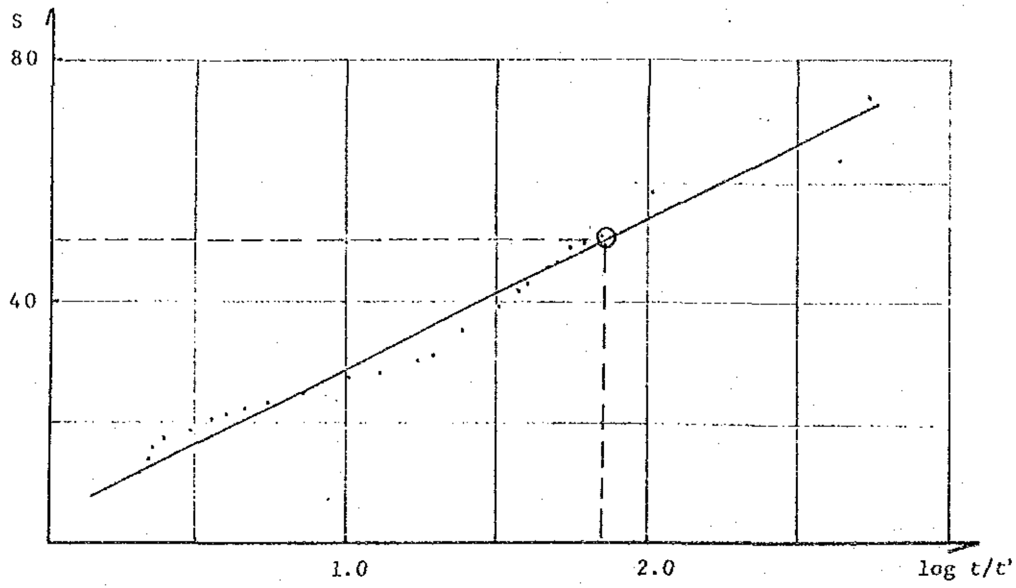
As a hydraulic coefficient, T.S. is analyzed by the described solutions and the coefficient of water conductivity calculated with a strainer length of 24 m, is as follows:

SOLUTION	TRANSMISSIVITY COEFFICIENT (T)	WATER CONDUCTIVITY (k) COEFFICIENT	STORAGE COEFFICIENT (S)
Thies	3.4×10^{-4}	1.4×10^{-5}	2.9×10^{-4}
Jacob	2.9×10^{-4}	1.2×10^{-5}	6.5×10^{-6}
Recovery	4.3×10^{-5}	1.8×10^{-6}	------

t	t'	S	t/t'	log t/t'
540	0	87.56		
541	1	73.50	541	2.73
545	5	58.73	109	2.04
548	8	51.00	69	1.84
550	10	48.19	55	1.74
552	12	45.38	46	1.66
555	15	41.86	37	1.57
558	18	38.35	31	1.49
563	23	35.54	24	1.39
568	28	32.02	20	1.31
573	33	30.61	17	1.24
583	43	28.51	13	1.13
593	53	27.80	11	1.05
600	60	27.10	10	1.00
630	90	24.99	7	0.85
660	120	23.58	6	0.74
690	150	22.88	5	0.66
720	180	21.48	4	0.60
750	210	20.77	3.6	0.55
780	240	20.07	3.2	0.51
810	270	18.66	3.0	0.48
840	300	17.96	2.8	0.45
870	330	17.96	2.6	0.42
900	360	17.26	2.5	0.39
930	390	15.15	2.4	0.38
960	420	15.15	2.3	0.36
990	450	13.74	2.2	0.34
1,050	510	11.63	2.1	0.31

From the above table, the S-log t/t' curve is drawn by plotting with S on the ordinate and log t/t' on the abscissa.

s-log t/t' Curve



(2) <u>No. 2</u>

a) Physical Features:

- Total depth	300 m	
- Diameter of casing	0 - 220 m	⌀300 mm
	200 - 300 mm	⌀200 mm
- Pump installation level	205 m	
- Static water level	GL - 95.81	
- Dynamic water level	GL - 117.01	
- Drawdown	21.2 m	

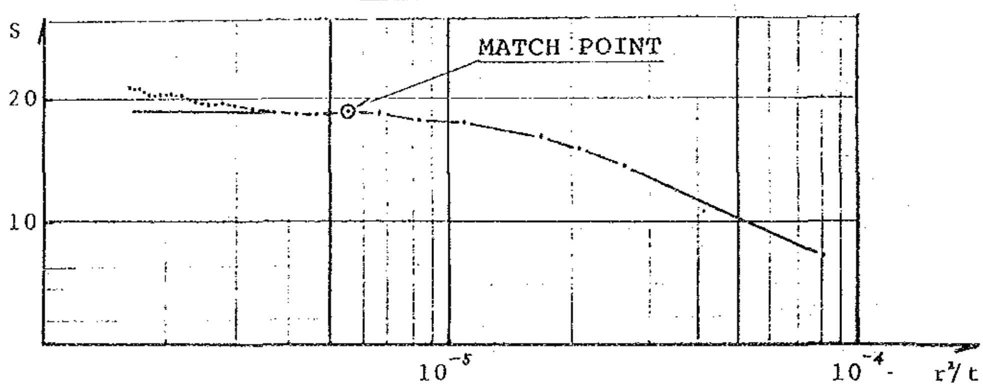
b) Curve-watching method by Theis

The relationship between the radial distance-time-drawdown and the data curve is as follows.

Table $S-r^2/t$

r	r^2	t (sec)	r^2/t	S	Remarks
0.1	0.01	120	8.3 x 10^{-5}	8.4	
		360	2.7 x "	13.5	
		480	2.1 x "	15.0	
		600	1.7 x "	16.1	
		900	1.1 x "	17.4	
		1,200	8.3 10^{-6}	17.9	
		1,500	6.7 x "	18.4	
		1,800	5.6 x "	18.8	
		2,100	4.7 x "	18.5	
		2,700	3.7 x "	18.4	
		3,000	3.3 x "	19.0	
		3,300	3.0 x "	19.4	
		3,600	2.8 x "	19.8	
		3,900	2.6 x "	19.6	
		4,200	2.4 x "	19.8	
		4,500	2.2 x "	20.3	
		4,800	2.1 x "	20.5	
		5,100	1.69 x "	20.3	
		5,400	1.85 x "	20.4	
		5.700	1.75 x "	21.1	
		6,000	1.66 x "	21.2	

$s - r^2/t$ Curve



The match point with type curve is found as follows:

W ( ) = 10.0, = 2.5 x 10^{-5}

S = 18.8, r^2/t = 5.6 x 10^{-6}

$$T = \frac{Q}{4 \pi s} W(\ )$$

$$= \frac{0.054}{4 \times 3.14 \times 18.8} \times 10 = 2.29 \times 10^{-3} \ m^2/sec$$

$$S = \frac{4 \ \ Tt}{r^2}$$

$$= \frac{4 \times 2.5 \times 10^{-5} \times 2.29 \times 10^{-3} \times 1}{5.6 \times 10^{-6}} = 1$$

$$= 0.041$$

c) Straight-line solution by Jacob:

The s-t relationship is shown in following, and as 1 cycle t = 300 to 3,000, a drawdown is made at s = 5.3

$$T = \frac{0.183 \ Q}{S}$$

$$= \frac{0.183 \times 0.054}{5.3}$$

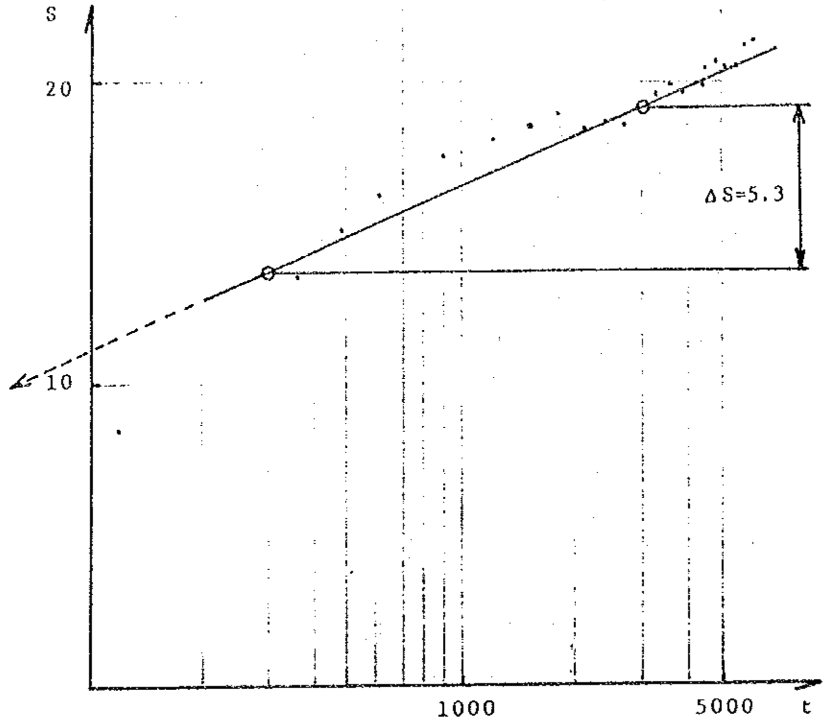
$$= 1.86 \times 10^{-3} \ m^2/sec$$

$$S = \frac{2.25 \times T \times t_0}{r^2}$$

$$= \frac{2.25 \times 1.86 \times 10^{-3} \times 0.86}{0.01}$$

$$= 0.36$$

s-t Curve



d) Recovery solution

The water table recovered in only 3 minutes.

The hydraulic coefficient analyzed by described solutions, and the coefficient of water conductivity calculated with a strainer length of 24 m are shown as follows:

Solution	Transmissivity coefficient (T)	Water conductivity coefficient (k)	Storage coefficient (s)
Theis	2.29×10^{-3}	9.5×10^{-5}	0.041
Jacob	1.86×10^{-3}	7.7×10^{-5}	0.36

(3) No. 3

a) Physical Features:

- Total depth — 300 m
- Diameter of casing — 0 - 220 = ø300 mm
  200 - 300 = ø200 mm

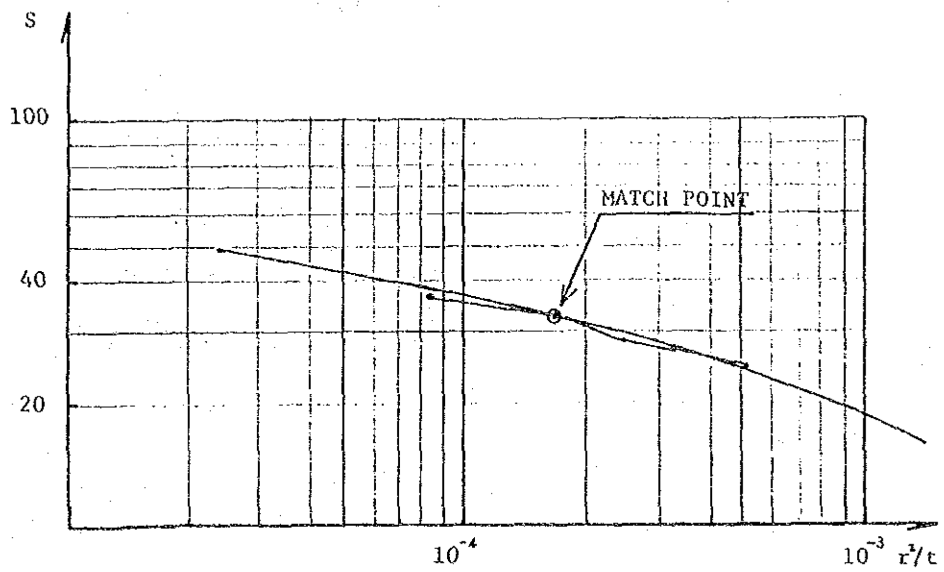
- Pump installation level — GL - 256 m
- Static water level — GL - 63.47 m
- Dynamic water level — GL - 240.86 m
- Drawdown — 177.39 m

b) Curve matching method by Theis

The relationship between the radial distance-time-drawdown and the data curve is as follows.

r	r^2	t	r^2/t	S
0.1	0.01	10	1×10^{-3}	18.52
		20	5×10^{-4}	24.14
		30	3.3×10^{-4}	26.95
		40	2.5×10^{-4}	2.36
		50	2×10^{-4}	31.17
		60	1.7×10^{-4}	32.58
		120	8.3×10^{-5}	35.28

s-r^2/t curve



The match point with the type curve is found as follows:

$W(u) = 4.1, \quad u = 1.2 \times 10^{-2}$

$s = 32.58, \quad r^2/t = 1.7 \times 10^{-4}$

$$T = \frac{Q}{4\pi s} W(u)$$

$$= \frac{12.62 \times 10^{-3}}{4 \times 3.14 \times 32.58} \times 4.1$$

$$= 1.3 \times 10^{-4} \ m^2/sec$$

$$S = \frac{4\ Tt}{r^2}$$

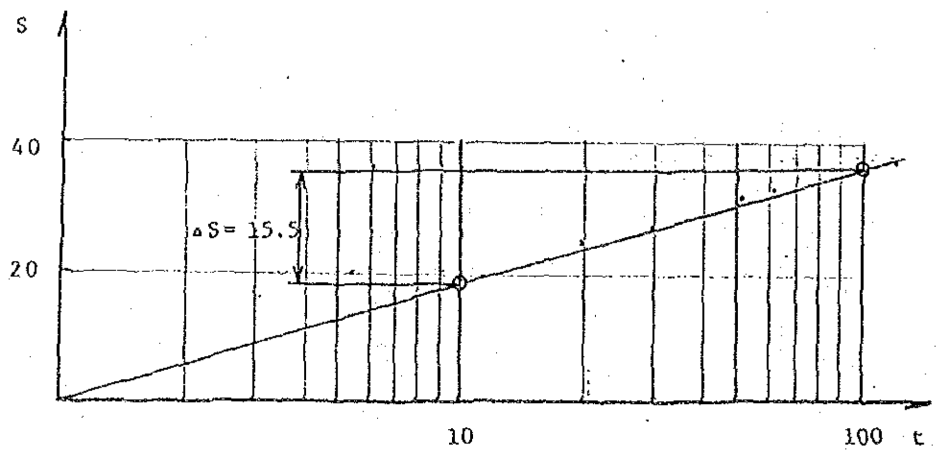
$$= \frac{4 \times 1.2 \times 10^{-2} \times 1.3 \times 10^{-4} \times 1}{1.7 \times 10^{-4}}$$

$$= 0.037$$

c) Straight line solution by Jacob

The relationship s-t is shown in FIG. and as 1/2 cycle, a drawdown is made at $\Delta s = 15.5$

s - t Curve



$$T = \frac{0.183\ Q}{\Delta s}$$

$$= \frac{0.183 \times 12.62 \times 10^{-3}}{15.5}$$

$$= 1.5 \times 10^{-4}\ m^2/sec$$

$$S = \frac{2.25 \times T \times to}{r^2}$$

$$= \frac{2.25 \times 1.5 \times 10^{-4} \times 1}{0.01}$$

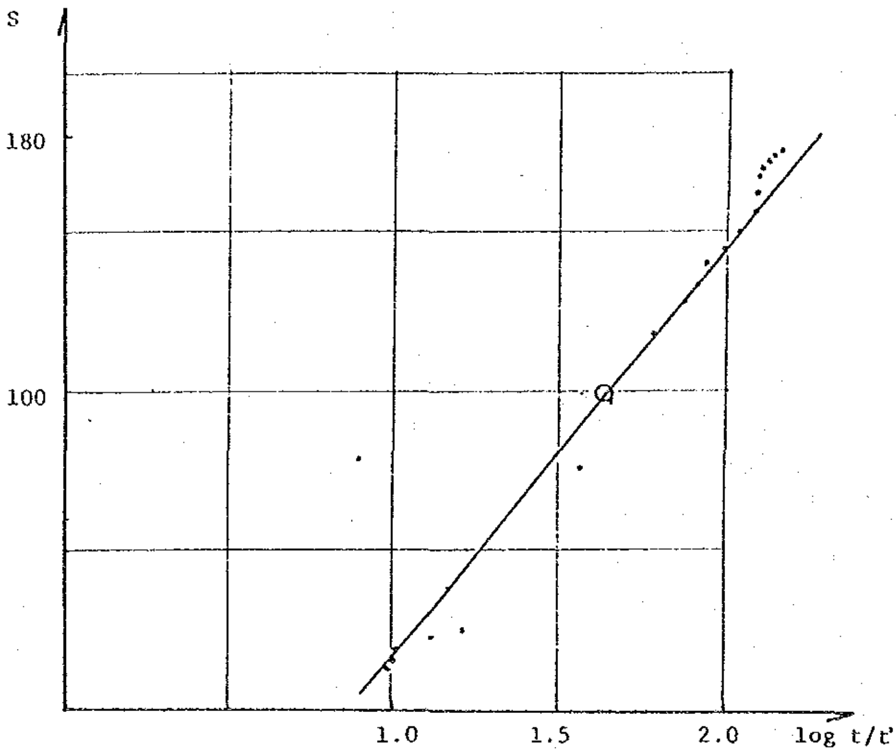
$$= 0.034$$

d) Recovery solution

The relationship between s-log t/t' is shown in following figure and table, and the point is found on the straight line which is outlined in the data plotting.

t (min.)	t' (min.)	S (m)	t/t'	log t/t'
4,560	0	177.39	-	-
4,590	30	176.67	163	2.185
4,591	31	175.29	148	2.170
4,592	32	174.58	143.5	2.157
4,593	33	170.36	139.2	2.144
4,594	34	166,15	135.1	2.131
4,595	35	162.63	131.3	2.118
4,596	36	15701	127.7	2.106
4,601	41	150.63	1212.2	2.050
4,606	436	145.76	100.1	2.000
4,611	51	140.14	90.4	1.956
4,616	56	134.51	82.4	1.916
4,620	60	129.59	77.0	1.886
4,635	75	118.34	61.8	1.791
4,660	100	97.26	46.6	1.668
4.680	120	76.17	39.0	1.591
4,860	300	25.13	16.2	1.209
4,920	360	22.53	13.7	1.136
4.980	420	19.03	11.9	1.976
5.040	460	16.23	10.9	1.037
5,100	520	13.93	9.8	0.991
5,160	580	12.23	8.9	0.949

s - log t/t' Curve



$S = 100 \ , \ \log t/t' = 1.65$

$$T = \frac{0.183 \times Q}{S} \log t/t'$$

$$= \frac{0.183 \times 12.63 \times 10^{-3}}{100} 1.65$$

$$= 3.8 \times 10^{-5} \ m^3/sec$$

The hydraulic coefficient T.S., is analyzed by the described solutions and coefficient for the water conductivity calculated with strainer length of 24 m and is shown as follows:

Solution	Transmissivity coefficient (T)	Water conductivity coefficient (k)	Storage coefficient (s)
Theis	1.3×10^{-4}	5.4×10^{-6}	0.037
Jacob	1.5×10^{-4}	6.2×10^{-6}	0.034
Recovery	3.8×10^{-5}	1.6×10^{6}	-

7.3 Results and Considerations

All analyzed results are shown in the following.

Well No.		Theis	Jacob	Recovery
1	T	3.4×10^{-4}	2.9×10^{-4}	4.3×10^{-5}
	S	2.9×10^{-4}	6.5×10^{-6}	-
	K	1.4×10^{-5}	1.2×10^{-5}	1.8×10^{-6}
2	T	2.3×10^{-3}	1.9×10^{-3}	-
	S	0.04	0.36	-
	K	9.5×10^{-5}	7.7×10^{-5}	-
3	T	1.3×10^{-4}	1.5×10^{-4}	3.8×10^{-5}
	S	0.037	0.034	-
	K	5.4×10^{-6}	6.25×10^{-6}	1.58×10^{-6}

No. 1 Discharge is 6.3 l/s and the drawdown is 0.9 m the capacity of yield aquifer. This is not enough for a production well because the amount of fractured welded tuff is not large.

No. 2 The discharge of 54 l/s and the drawdown of 2 m are good conditions for production wells.

However the storage coefficient of 0.04/0.36 is too large a value for a confined aquifer. The strainer position is at 230-238 m, 260-276 m.

No. 3 Discharge is only 2.84 l/s.

The position of strainer has the limestone as the object, but confirmation of this could not be made. A good aquifer is supposed exist at 350 - 400 m because the limestone site of a private cement company is about 200 m from here.

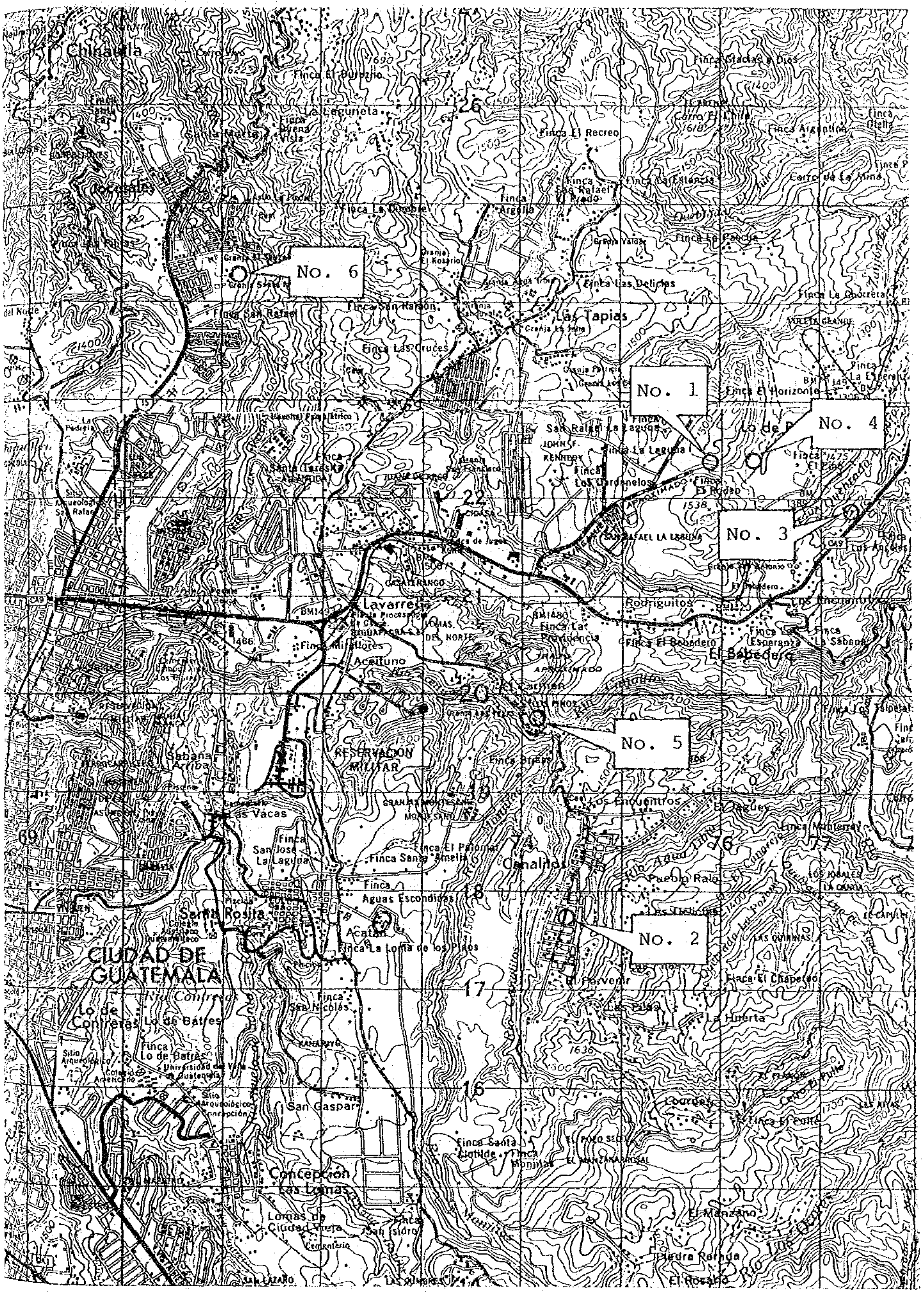


Fig.VII-1 TEST BORING SITE

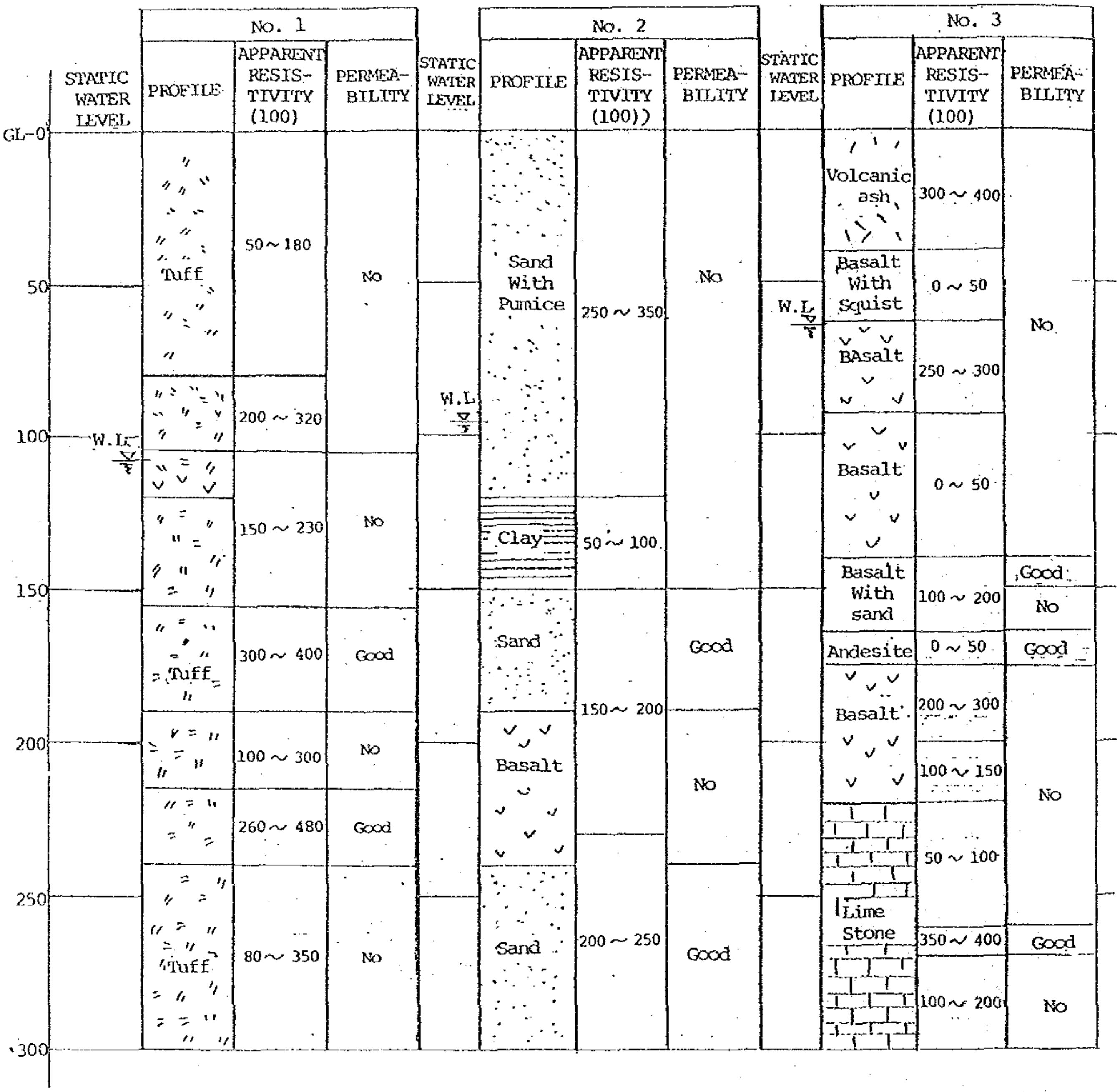


Fig. VII-2 GOUNDWATER POTENCIAL OF TEST BORING

FIG VII-3 DRILLING LOG TEST BORING N°1

NAME OF PROJECT: Guatemala City Ground Water Development Project — No. OF HOLE 1

LOCATION PINARES — BORE HOLE DIA 17-1/2" — DEPTH OF HOLE 305m

ELEVATION 1410 masl — DRILL MACHINE SKYTOP — OPERATOR DAHO

UNDER GROUND WATER TABLE GL-108.7m — NO. 1 — SUPERVISOR K.K

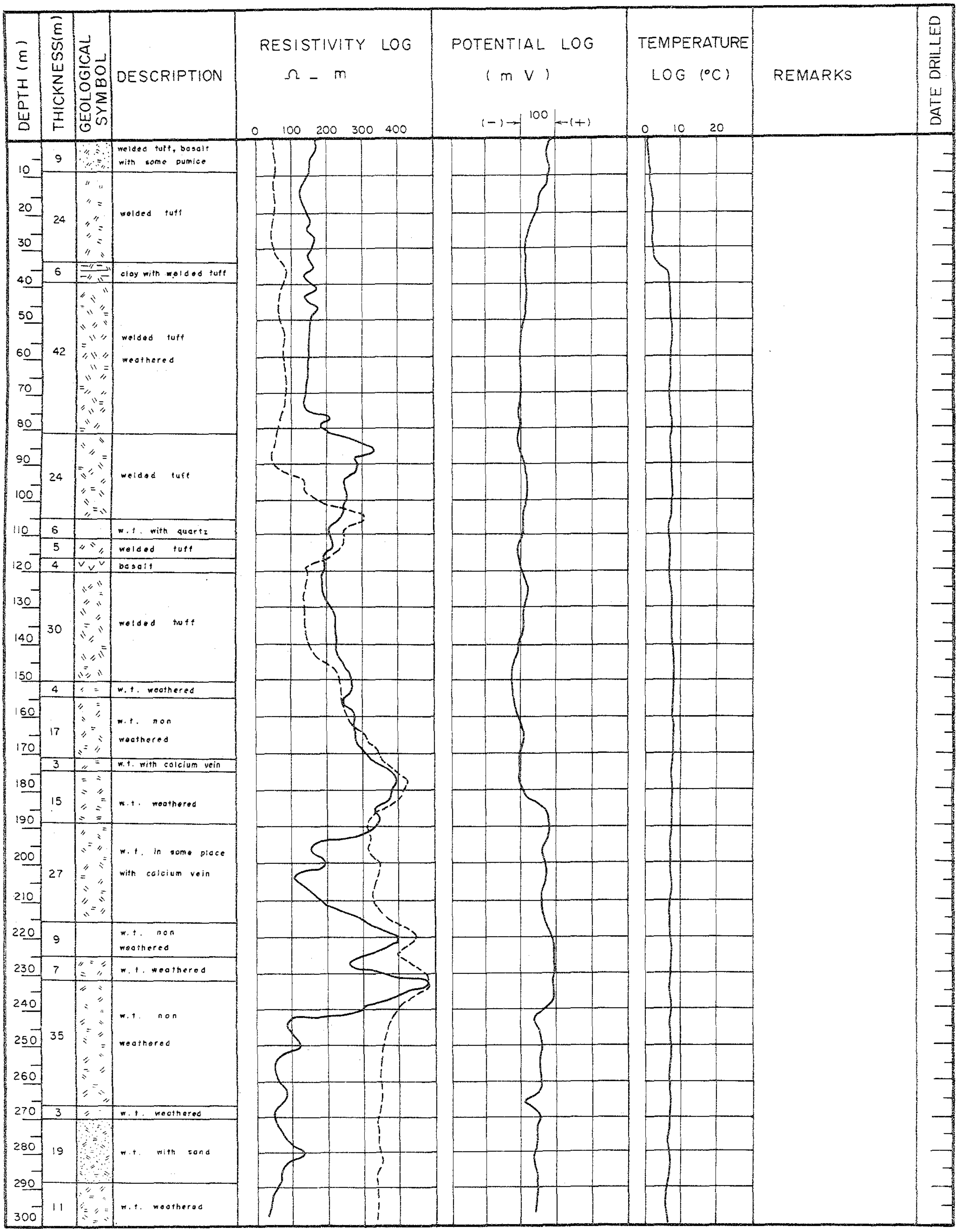


FIG VII-4 DRILLING LOG TEST BORING N°2

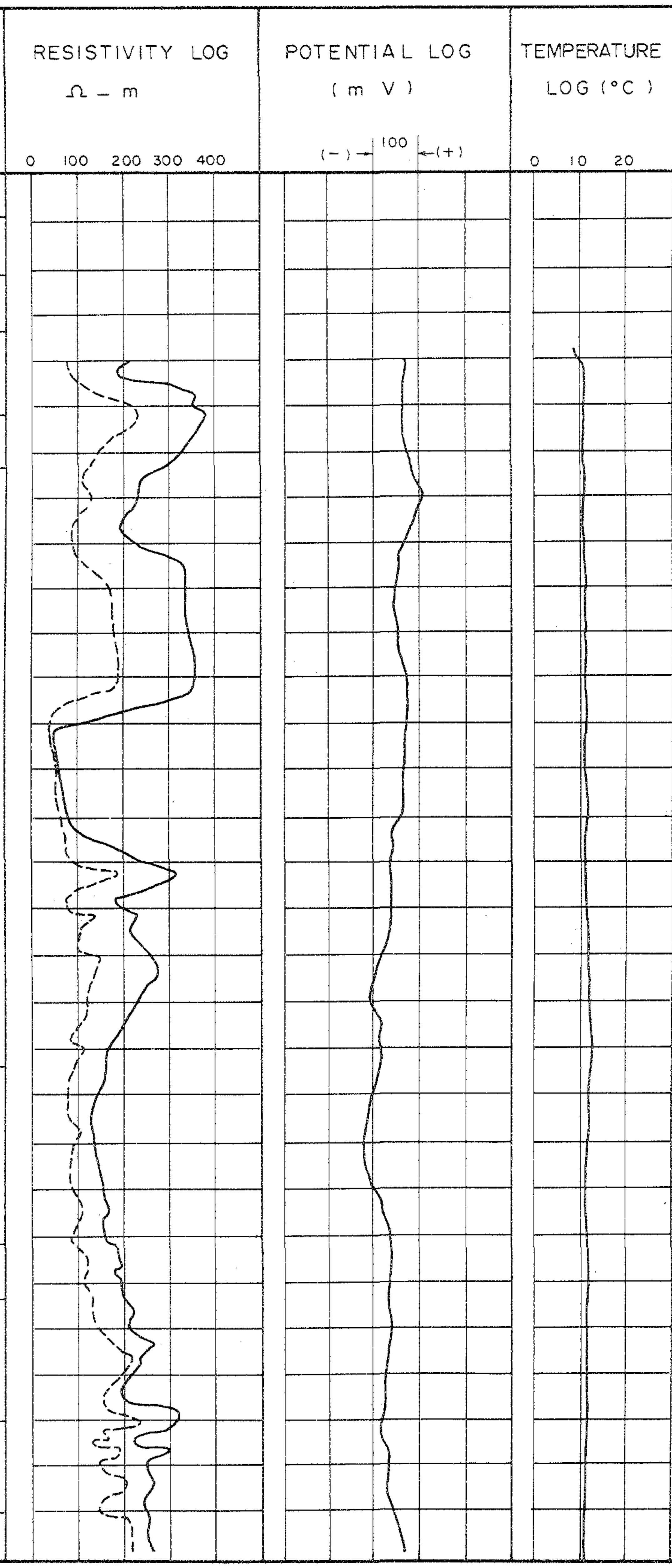
NAME OF PROJECT: Guatemala City Ground Water Development Project — NO. OF HOLE 2

LOCATION: CANALITOS — BORE HOLE DIA 17-1/2" — DEPTH OF HOLE 300 M

ELEVATION 1537 masl — DRILL MACHINE SKY TOP — OPERATOR DAHO

UNDER GROUND WATER TABLE GL-95.8 m — NO. 2 — SUPERVISOR K·K

DEPTH (m)	THICKNESS (m)	DESCRIPTION	REMARKS
0–9	9	medium sand with pumice	
9–21	12	pumice with fine sand	
21–33	12	fine sand with basalt and pumice	
33–51	18	medium sand with pumice and basalt	
51–63	12	fine sand with pumice	
63–223	160	There aren't samples May be sand with gravel and pumice	Clay stratum (approx. 120–145 m)
223–261	38	weathered basalt	
261–273	12	basalt with pumice	
273–300	27	sand with gravel and basalt	
	20	basalt	
	10	medium sand	



DATE DRILLED

FIG VII-5 DRILLING LOG TEST BORING N°3

NAME OF PROJECT: Guatemala City Ground Water Development Project — NO. OF HOLE 3

LOCATION Km 13 — BORE HOLE DIA 17-1/2" — DEPTH OF HOLE·300 m

ELEVATION 1285 masl — DRILL MACHINE SKYTOP — OPERATOR DAHO

UNDER GROUND WATER TABLE GL-63 m — NO. 3 — SUPERVISOR K·K

THICKNESS (m)	DESCRIPTION
3	volcanic ash
12	volcanic ash with pumice
3	pumice with sand
12	volcanic ash
9	fine sand
3	fine sand with pumice
9	fine sand
9	basalt with calcite and squist
6	weathered basalt with coarse sand
24	weathered basalt with calcite and quarte
6	basalt
6	consolidated clay with basalt
21	basalt with calcite vein
6	basalt with sand, and calcite
12	coarse sand with basalt and calcite
14	weathered basalt with calcite
6	coarse sand w/ basalt
6	basalt with sand
3	basalt with calcite
3	basalt with andesite
18	andesite
15	basalt
9	basalt with calcite
10	medium sand
9	coarse sand with calcite
65	limestone

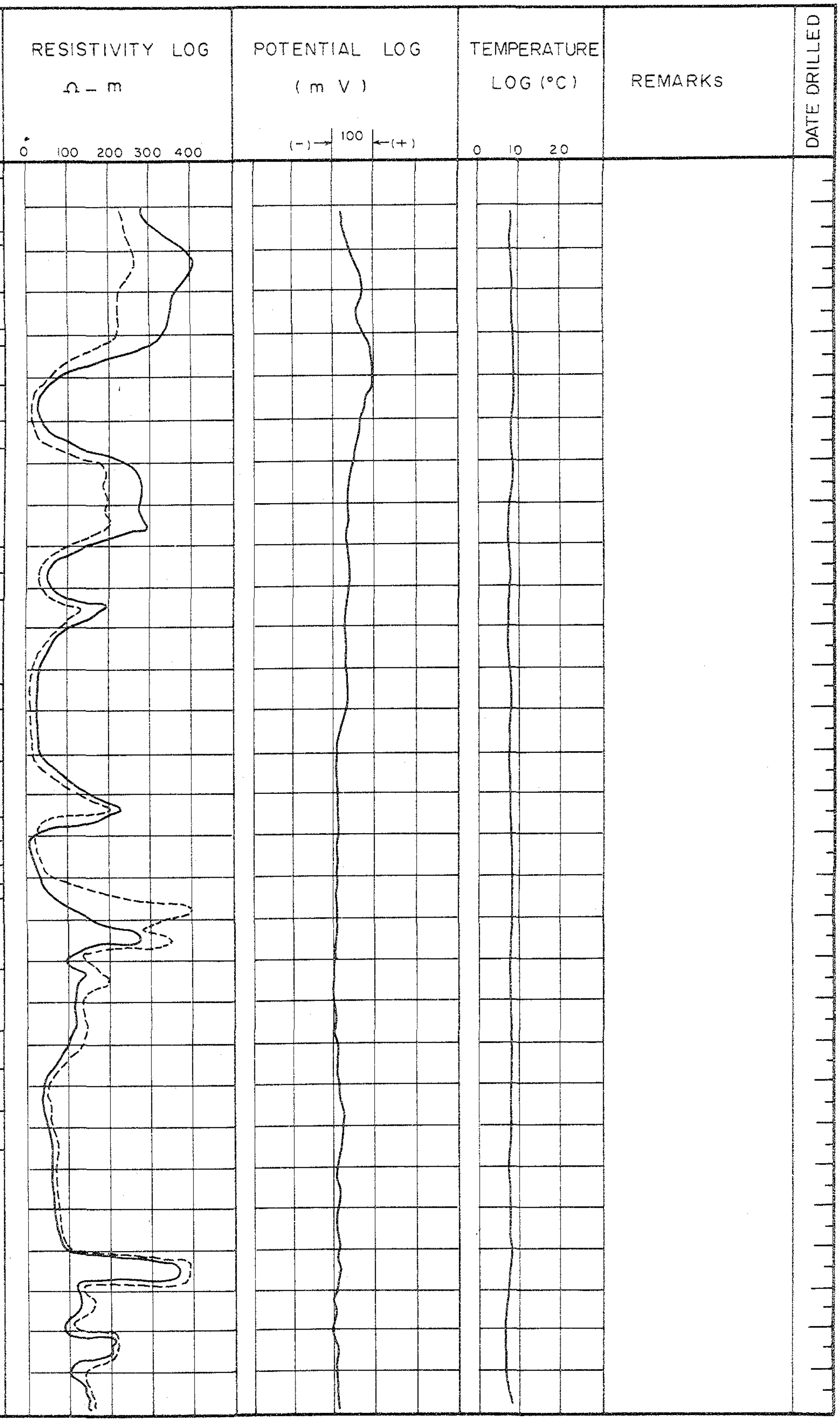


FIG VII-6 DRILLING LOG TEST BORING N°4

NAME OF PROJECT: Guatemala City Ground Water Development Prolect

NO. OF HOLE 4

LOCATION PINARES

BORE HOLE DIA 12-1/4"

DEPTH OF HOLE 220 M

ELEVATION 1410 masl

DRILL MACHINE INGERSOLL-RAND NO. 4

OPERATOR DAHO

UNDER GROUND WATER TABLE GL-110m

SUPERVISOR K·K

THICKNESS (m)	DESCRIPTION
9	volcanic ash with some welded tuff
9	welded tuff with calcite
6	welded tuff with volcanic ash
6	welded tuff with calcite
3	w.t. weathered
3	w.t. weathered with sand
6	w.t. with calcite
12	welded tuff weathered
12	welded tuff
6	welded tuff with calcite
6	sand with w.t.
12	welded tuff weathered
24	welded tuff with sand and some calcite
6	medim sand with w.t.
9	medium sand with andesite and w.t.
3	w.t. weathered
6	fine sand
12	fine sand with wedded tuff
12	medium sand with basalt andesite and limestone
3	limestone and basalt
12	medium sand with limestone
3	limestone with basalt
3	limestone
26	medium sand with limestone

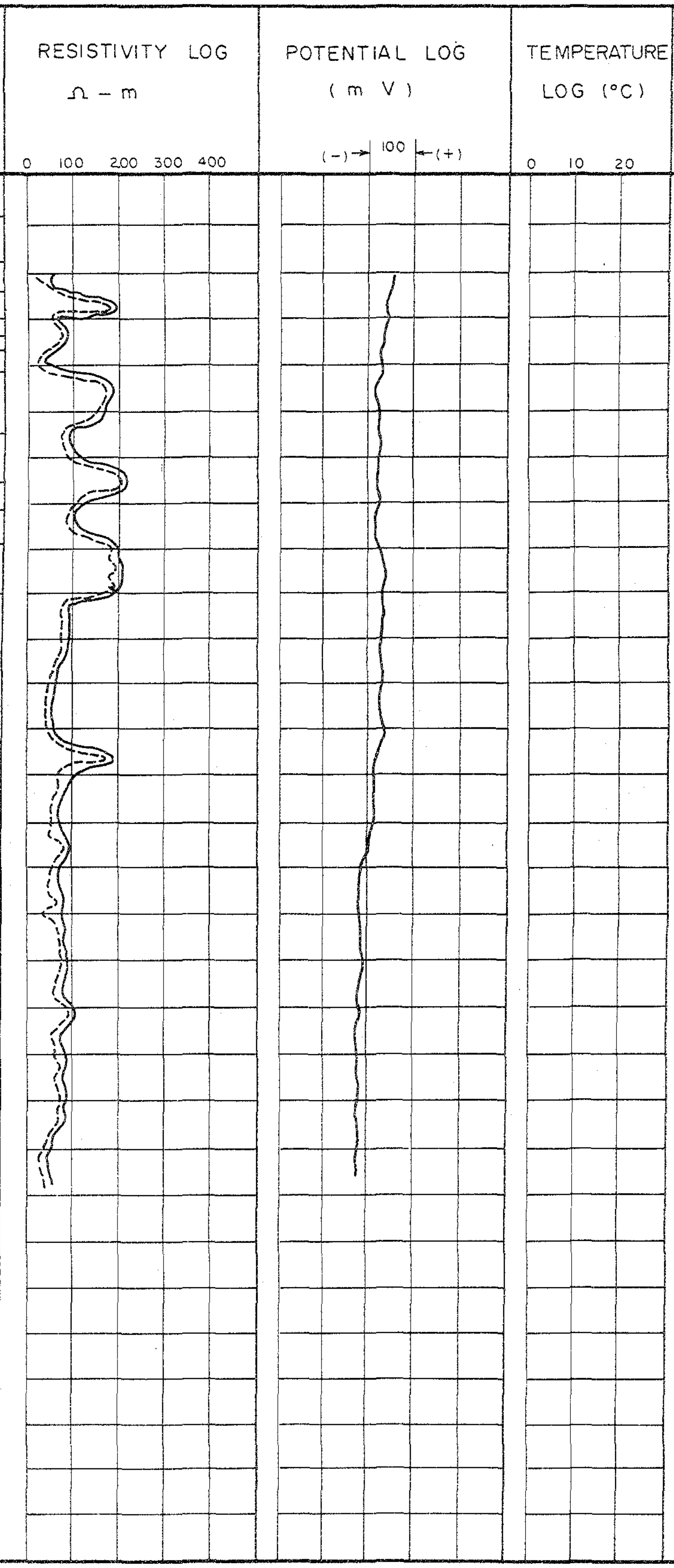


FIG VII-7 DRILLING LOG TEST BORING No 5

NAME OF PROJECT : Guatemala City Ground Water Development Project

NO. OF HOLE 5

LOCATION CANALITOS

BORE HOLE DIA 12 - 1/4"

DEPTH OF HOLE 120 m

ELEVATION 1381 masl

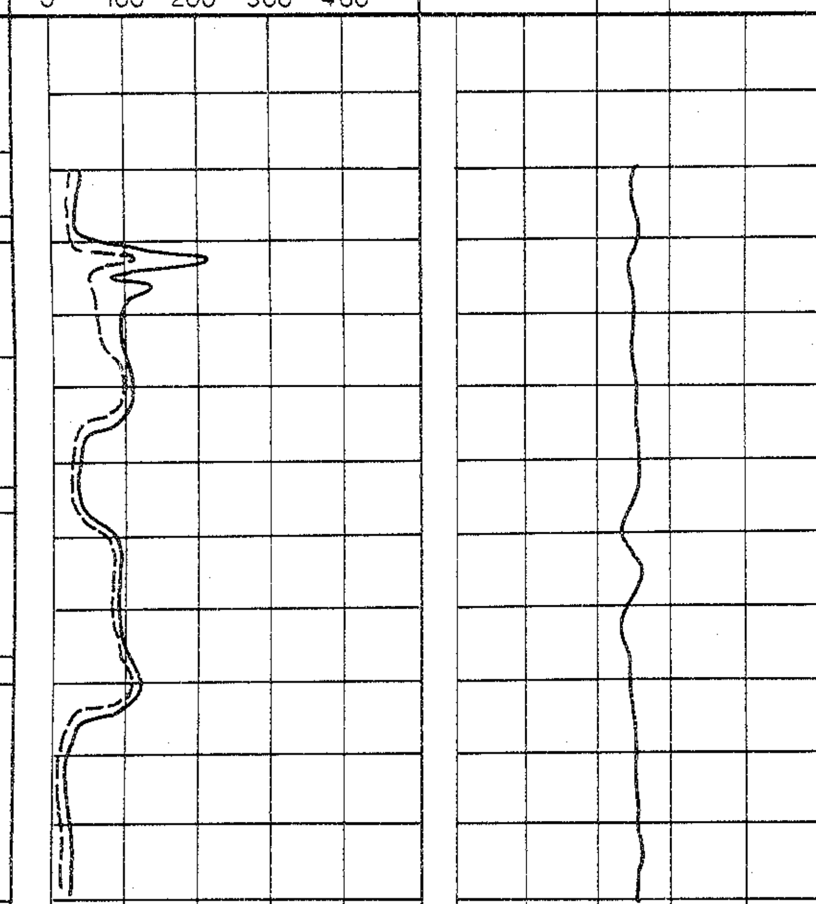
DRILL MACHINE INGERSOLL-RAND NO. 5

OPERATOR DAHO

UNDER GROUND WATER TABLE GL – 7 m

SUPERVISOR K.K

DEPTH (m)	THICKNESS (m)	GEOLOGICAL SYMBOL	DESCRIPTION	RESISTIVITY LOG Ω – m (0 100 200 300 400)	POTENTIAL LOG (mV) (–)→ 100 ←(+)	TEMPERATURE LOG (°C) (0 10 20)	REMARKS	DATE DRILLED
0–18	18		fine sand with gravel					
18–27	9		pumice with fine sand					
27–30	3		pumice					
30–45	15		fine sand					
45–63	18		fine sand with gravel					
63–66	3		pumice					
66–87	21		pumice with medium sand					
87–90	3		sand with gravel					
90–120	30		fine sand					



CHAPTER VIII

WATER BALANCE

8.1 Free Aquifers (First Type)

8.1.1 Area Evaluation

For the purpose of evaluating the water balance in the Study area, recharge and circulation areas (north, south and east sectors) have been defined as shown in FIG. IV-2), TABLE IV-4 considering:

a) river basins;

b) structural boundaries given by the faults of Mixco, Santa Catarina Pinula and Teocinte/Palencia at the west, center and the east of the study area, respectively (see FIG. III-2); and

c) geological boundary of granite intrusives in the north of the study area.

8.1.2 Method of Evaluation

In order to estimate the underground runoff, the concept of resources susceptible to runoff (R) has been used. This simply expresses the difference between the annual recharge by rainfall (P) and the water losses by evapotranspiration (E).

$$R = P - E$$

where,

R: Runoff (mm)
P: Rainfall (mm)
E: Evapotranspiration (mm)

The resources susceptible to runoff represent the availability for surface runoff (Qs), for underground runoff (Qg), as well as the volume which determines the main water consumption (Qc).

$$R = Qs + Qg + Qc$$

8.1.3 Rainfall (P)

Annual rainfall is estimated on the basis of meteorological data observed over the 15 years from 1970 through 1984. The annual precipitation for each river basin as given in TABLE IV-3 was derived from FIG. IV-2. Basin rainfall amounts expressed in m^3/year were converted to m^3/sec. For example, annual rainfall for basin N-1 is 86.82 km^2 (area) x 1072 mm/year (annual rainfall) : 93.07 km^3 = 93.07 x $10^6 m^3$/year. This is subsequently converted to m^3/sec:

$$365 \text{ days} \times 86{,}400 \text{ sec} = 31.536 \times 10^6 \text{ sec}$$

$$93.07 \times 10^6 m^3/\text{year} \quad 31.536 \times 10^6 \text{sec/year} = 2.95\ m^3/\text{sec}$$

Rainfall amounts for each basin were so converted in the above manner.

8.1.4 Evapotranspiration (E)

Evapotranspiration rate was computed using the average value 724 mm/year determined in section 4.1.3. If basin N-1 is again used as an example:

$$86.82\ km^2 \text{ (area)} \times 0.724 \text{ mm/year (evapotranspiration)}$$
$$= 62.857\ km^3 = 62.867 \times 10^6 m^3/\text{year}$$

$$62.875 \times 10^6 m^3/\text{year} - 31.536 \times 10^6 \text{sec/year} = 1.98\ m^3/\text{sec}$$

This calculation was performed for evapotranspiration of each basin.

8.1.5 Surface Runoff (Qs)

Surface runoff values indicated in section 4.2 of 5.42 l/sec/km^2 in the northern sector, 7.2 l/sec/km^2 in the southern sector and 9 l/sec/km^2 *in the eastern sector were utilized in calculating the surface runoff for* each basin.

In other words surface runoff for basin N-1 was calculated as follows:

$$86.82\ km^2 \times 0.0054\ m^3/sec/km = 0.468\ m^3/sec = 0.47\ m^3/sec$$

As a further example, that for basin S-I was calculated as follows:

$$119.16\ km^2 \times 0.0072\ m^3/sec\ km = 0.857\ m^3/sec = 0.86\ m^3/sec$$

This calculation was repeated for each basin.

8.1.6 Basin Reserve

Basin reserve = P - E - Qs

8.1.7 Safe Yield of Groundwater

On the basis of "8.1.8 Actual Pumping Volume," the safe yield of groundwater for the subject Study was determined at 40% of basin reserve.

8.1.8 Actual Pumping Volume

The actual discharge being pumped by EMPAGUA in the northern sector is 30% of potential pumpable amount. In the southern sector the ratio is 49.1%.

The total actual volume pumped in the northern sector in relation to total pumpable discharge was subsequently assumed at 30% for EMPAGUA and 30% for other sources, while ratios in the sourthern sector were estimated as 49% for EMPAGUA and 30% for other sources.

Actual pumping volumes are as shown in the TABLE below:

(from 1983 EMPAGUA data)

		EMPAGUA: Pumpable discharge	Others Pumpable discharge	Total	Actual discharge being pumped	Actual discharge/ potential discharge
		1/sec	1/sec	1/sec	1/sec	%
	N - I		51.04	51.04		
North	N - II	264.04	355.34	619.38	79.2	30.0
	N - III	261.33	419.63	680.96	78.4	30.0
		527.37	926.01	1,351.38	157.6	
	S - I		292.70	292.70		
	S - II	939.42	287.04	1,226.46	461.60	49.1
South	S - III		180.77	180.77		
		939.42	760.51	1,699.93	461.60	

8.1.9 Water Balance

TABLE VIII-1 shows the free aquifer and the water balance for this area, as calculated from the various data already described.

As a result at this the groundwater availability for the northern sector is estimated at 0.44 m^3/sec and that for the eastern sector at 1,13 m^3/sec, giving a total at 2.14 m^3/sec.

TABLE VIII-1

SUMMARY OF WATER BALANCE

Basin		Area	Annual Rainfal (P)		Evapotrans-piration (E)	Total Runoff (R)	Surface Runoff (Qs)	Basin Reserve	Safe Yield of Groundwater Basin	Actual Pumping Volume (Qc)	Groundwater Availability
		(km^2)	(mm)	(m^3/s)	(m^3/s)	(m^3/s)	(m^3/s)	(m^3/s)	(m^3/s)	(m^3/s)	(m^3/s)
Northern Area	N-I	86.82	1,072	2.95	1.98	0.97	0.47	0.50	0.20	0.01	0.19
	N-II	96.34	1,240	3.79	2.20	1.59	0.52	1.07	0.43	0.18	0.25
	N-III	56.90	1,248	2.25	1.30	0.95	0.31	0.64	0.26	0.13 (0.07)*	0.13
	Sub-Total	240.06	1,130	8.97	5.48	3.51	1.30	2.21	0.89	0.32	0.57
Southern Area	S-I	119.16	1,141	4.31	2.72	1.59	0.86	0.73	0.29	0.09	0.20
	S-II	73.05	1.144	2.65	1.67	0.98	0.52	0.46	0.18	0.15 (0.45)*	0.03
	S-III	125.93	1,114	4.45	2.88	1.57	0.91	0.66	0.26	0.05	0.21
	Sub-Total	318.14	1.131	11.41	7.27	4.14	2.29	1.85	0.73	0.29	0.44
Eastern Area	E-III	82.88	950	2.50	1.89	0.61	0.75	-0.14	-	-	-
	E-IV	17.00	1,023	0.55	0.39	0.16	0.15	0.01	0	0.01	0.06
	E-V	46.87	1,118	1.66	1.07	0.59	0.42	0.17	0.07	0.01	0.06
	E-VI	80.55	1,091	2.79	1.84	0.95	0.72	0.23	0.09	0	0.09
	E-VII	209.48	1,382	9.18	4.78	4.40	1.89	2.51	1.00	0.02	0.98
	Sub-Total	436.78	1,204	16.68	9.97	6.71	3.93	2.78	1.16	0.03	1.13
	Total	994.98	1,198	37.08	22.72	14.36	7.52	6.84	2.78	0.64	2.14

* The quantities indicated in parentheses are thought to result from the lower aquifer, and were excluded form the calculateion for the actual pumping valume.

8.2 Lower Aquifers (Second Type)

8.2.1 Lower Aquifer Catchment Conditions

According to the data of the Ojo de Agua #1 (No. 139) bore (EL 1300 m, depth 274 m) in the southern block, there is fractured Andesite at depths of below 110 m, with crack seepage from this producing astesian flow. In addition, the majority of the nearby deep bores No. 138 through No. 146 also have artesian flow, with the results of pumping tests showing extremely large values between 50 l/sec and 189 l/sec. The elevations of the bore heads were between EL 1240 m and EL 1320 m. Subsurface geological conditions are unclear but are assumed to be the same as for No. 139 with seepage from Fractured andesite (possibly a confined aquifer). Furthermore, the deep well of the Project 4-3 (No. 2) bore (EL 1467 m, depth 247 m) in the northern sector, had fractured limestone below a depth of 115 m with the water level at a depth of 167 m (EL 1300 m). The pump-up volume was relatively great at 63 l/sec, thus suggesting groundwater having the nature of a lower aquifer. Moreover, despite this well being about 18 km from the deep wells in the southern and northern sectors, there was practially no difference in the water head near EL 1300 m for all, therefore indicating the presence of a lower aquifer. The Test Well #2 bore (EL 1536.9 m, depth 300 m) in the eastern sector became fractured andesite at depths below 240 m (EL 1296), while pump-up of 50 l/sec or more was possible nearby. The water level of this bore indicated 95.81 m and is thought to be that of the top part of an free aquifer, indicating the presence of both free and lower aquifers for this sector.

8.2.2 Estimated Storage

In general, lower aquifers contained in water-bearing layers in monocline and basin structures are thought to be non-flowing, in all but special cases, with measurement of the discharge being difficult. Lower aquifers such as these have recharge proportional to the amount of water taken from them. This recharge is from higher places that are not covered by impermeable strata, and is often regulated by large-scale geological formations extending outside the object region.

The lower aquifer for this sector has water-bearing layers consisting of fractured Cretaceous coal-shale and basalt, as well as Tertiary volcanic lava and welded tuff, etc. These fractured strata are dominated by the faults within the sector and are thought to have a high permeability. Points where they intersect are thought to be extremely promising. At the present stage, a detailed geological study has yet to be performed and it is therefore impossible to pinpoint these positions. A further survey is therefore desirable.

As explained earlier, results of prior test borings give an estimated water head for the lower aquifer, near EL 1300 m, and indicate a general productive potential of 60 l/sec. Because of this, it is necessary for the object of future lower aquifer prospecting to be the fractured layers in the previously described rock below EL 1300 m.

The lower aquifer in this area requires further investigation to determine whether it is a lower aquifer or not.

Estimating the storage for this aquifer of this sector was calculated from the landform and the surface geology, and involved the following assumptions. Object area: Following the block divisions of the free aquifer.

Probability of existence in basements at EL 1300 m:	North; 50%, East, South; 30%
Probability of existence in basement fracture zone:	10%
Fracture porosity:	30%
Fracture zone:	50 m
Pump-up possible probability:	30%

The results of calculation are given in TABLE VIII-2.

However,

(1) The probability of existance in the basement fracture zone was estimated on the basis of results of the boring core checks such as those by RQD (crack frequency index) and electric logging, but the lack of data at the present stage led to 10% being judged from the geological characteristics over the greater area.

(2) The fracture porosity was set at 30% on the basis of the 10^{-2} - 10^{-4} coefficient of permability for the metanorphic rock and igneons rock cracks from the standpoint of soil engineering.

TABLE VIII-2

Storage Capacity of Lower Aquifer

Vasin	Area km^2	Deep m	Basement probability %	Fracture Zone probability %	Fracture Prosity %	Storage m^3
N-I	86.82	50	50	10	30	65.12×10^6
N-II	96.34	50	50	10	30	72.25×10^6
N-III	56.90	50	50	10	30	42.66×10^6
Sub-total	240,06	50	50	10	30	180.03×10^6
S-I	119.16	50	30	10	30	53.61×10^6
S-II	73.06	50	30	10	30	32.87×10^6
S-III	125.93	50	30	10	30	56.66×10^6
Sub-total	318.14	50	30	10	30	143.14×10^6
E-III	82.88	50	30	10	30	37.30×10^6
E-IV	17.0	50	30	10	30	7.65×10^6
E-V	46.87	50	30	10	30	21.08×10^6
E-VI	80.55	50	30	10	30	36.25×10^6
E-VII	209.48	50	30	10	30	94.26×10^6
Sub-total	436.78	50	30	10	30	196.54×10^6
Total	994.98	50				519.43×10^6

Here, if the pump-up possible probability is assumed to be 30%, then the storage capacity is $54.0 \times 10^6 m^3$ for the northern sector, $42.94 \times 10^6 m^3$ for the southern sector, and $58.96 \times 10^6 m^3$ for the eastern sector.

8.2.3 Estimated Discharge

In general, recharge to lower aquifers first occurs when pump-up is performed, and this recharge is from the recharge area (where there are outcrops of rock forming water-bearing layers) in the land behind. There are therefore usually no problems with the discharge as long as excessive pump-up is not performed. However, excessive pump-up large volumes will bring about either local or temporary lowering of the groundwater level, and may lead to disasters such as ground subsidence. This local lowering of the groundwater level occurs when the pump-up volume at a certain point, exceeds the recharge or rather, the discharge that is possible within the water-bearing layer. Predicting the discharge therefore provides a guide for pump-up. In general, the discharge can be estimated from the coefficient of permeability for the water-bearing layer. The permeabilities of Test Wells No. 1, No. 2 and No. 3, were used to estimate the discharges as shown in TABLE VIII-3.

TABLE VIII-3 Estimation of Flow Movement Capacity

	Section Type (B . H)		K	ø	Q (m^3/sec)
When K of No. 2 bore is used	Andesite (Fractured) 2500 m x 50 m	T J	9.45×10^{-5} 7.75×10^{-5}	0.05	0.597 0.485
When K of No. 1 bore is used	Welded Tuff (Non-fractured?) 2500 m x 50 m	T J	1.40×10^{-5} 1.20×10^{-5}	0.03	0.042 0.036
When K of No. 3 bore is used	Limestone (Non-fractured?) 2500 m x 50 m	T J	5.40×10^{-6} 6.25×10^{-6}	0.03	0.021 0.024

Where: Discharge $Qg = B \cdot H \times K \times ø$

B: Width (2.5 km)
H: Depth (50 m)
K: Permeability Coefficient
ø: Gradient

T: non-equilibrium Theis-type curve analysis

J: non-equilibrium Jacob-type straight-line analysis

This is to say that the discharge Q can be used to revise the pump-up potential from wells at 2.5 km intervals. However, one problem with this table are the extreme differences between the discharge of No. 2 bore and the others and are assumed to be due to the following reasons. First at all, the movement of water within the lower aquifer in a sector such as this having many faults and fracture zones, is thought to follow the lines formed by these. Of those wells within this sector, the pump-up volume of those thought to be supplied by the lower aquifer is large at 50 l/sec - 180 l/sec, and without any lowering of the groundwater level. This fact indicates the high possibility that these wells are being supplied by the fracture zones. However, the pump-up volume of the previously-mentioned No. 2 bore is 50 l/sec, but those of No. 1 and No. 3 were both about 6 l/sec. The No. 1 bore has a high possibility of being a fracture zone but the No. 3 has a high possibility of not being one, or of being one of small scale and low density if it is. It was therefore judged satisfactory to use the value of the No. 2 bore as the discharge for this sector.

8.3 Points of Difference Between Interim Report (March 1986) and Draft Final Report

As the result of a comprehensive investigation into the results of a survey of the existing materials and the results of the various geophysical surveys that were performed, it was clarified that there is a lower aquifer in this area, and that it has the nature of both a free aquifer and a confirmed aquifer.

There was no distinction made between these two types of aquifers in the Interim Report. The following is an explanation of the differences that occur between this report and the Interim Report.

(1) The values for the rainfall in the southern part of the northern area were revised for the values of the annual rainfall in the respective recharge areas on the basis of the isothetal map of annual precipitation.

(2) In the summary water balance in the Interim Report, the actual pumping volume was arrived at through subtraction from the total of the free aquifer and the lower eraquifer.

However, waht was clearly perceived as the lower aquifer was excluded this time from the actual pumping volume. Because of this, the groundwater availability as free aquifer changed from 0.604 to 0.57 m/sec for the northern sector, from 0.073 to 0.44 m^3/sec for the sourthern sector, and from 0.982 to 0.98 m^3/sec for the eastern sector, thereby changing the total from 1.657 to 2.14 m^3/sec.

(3) In the Interim Report, the actual pump-up volume was subtracted from the pump-up potential as a result of the pump-up test.

However, trial calculations were performed using the actual pump-up data from EMPAGUA for the five-year period from 1980 to 1984. Furthermore, a pump-up volume of 30% arrived at on the basis of this data, was sused for those wells where the actual pump-up volumes were not known.

(4) There was no emphasis on the lower aquifer in the Interim Report but as a result of re-investigation, it was considered that there is a lower aquifer present in the fractured basement at an elevation of 1,300 meters. The storage and the discharge are therefore estimated accordingly. The pump-up volume of the lower aquifer and the free aquifer can be considered differenct, with the pump-up volume of the lower aquifer being 40 l/sec., and that of the free aquifer being in the range of 10-15 l/sec.

CHAPTER IX

DEVELOPMENT PLAN

Results of the subject survey in the envisioned Project area of 815 km^2 indicated groundwater presence in the form of an free aquifer in Quaternary sediments (pyroclastics, ash, etc.) centering on Guatemala City, and a lower aquifer in fractured zones of Tertiary and Cretaceous basements (volcanic lava and limestone).

The free aquifer consists of seepage water, and is governed by the basin and graben formations. Where basement is shallow, groundwater level is shallow and where basement is dup, groundwater level is also deep. Groundwater pumping potential is greatest at the certer of basin and graben formations where water collection is most concentrated.

The presence of the lower aquifer is confirmed by the artesian flowing well of Ojo de Agua in the south and the well at Project 3-4 in the north. Water head of the lower aquifer is assumed at around EL 1,300 m.

Groundwater development to date in the Study area has consisted primarily of drafting from the free aquifer. However, availability from the said free aquifer is considered inadequate to meet demand requirements. Against this backgroud, the subject survey was implemented to identify areas of optimum groundwater potential, the nature of the aquifer to be tapped, pump-up volume, well depth, etc.

9.1 Favorable Area for Groundwater Development

On the basis of hinterland recharge area and basin structure, the Study area is broadly divided into three free aquifer catchments: northern sector, southern sector and eastern sector. The water balance in each of these sectors is discussed in chapter 8, and summarized in the TABLE below.

	A Effective storage capacity m^3/s	B Current pump-up	C=(A-B) Remaining pump-up potential
northern sector	0.89	0.32	0.57
southern sector	0.73	0.29	0.44
eastern sector	1.16	0.03	1.13
Total	2.78	0.64	2.14

As can be seen from the above, pump-up of 0.44 m^3/sec is possible in the southern sector. However, in the vicinity of Guatemala City, drop in water level has been observed and it is not recommended that further groundwater be pumped in this area. As a result, the only portions of this sector where groundwater may be developed are in the east and west, i.e. situated at a distance from metropolitan zones.

New pump-up volume of 0.57 m^3/sec is possible in the northern sector. However, as numerous wells have already been constructed in and around Guatemala City, only the north portin of the northern sector has remaining development potential.

Groundwater in the eastern sector is largely undeveloped, and 1.13 m^3/sec of pump-up volume is anticipated. Results of electric prospecting and evaluation of groundwater level data indicate that the most promising development potential is in the central portion of east-west trending and in the northwestern portion of the said sector.

As the above indicated water balances are those for an entire sector, it should be noted that heavy extraction of groundwater at one point may reduce possible pump-up at another point. In other words, drafting of groundwater from the upstream portion of an artery would result in reduction of availability downstream. Also, potential pump-up at a specific well cannot physically exceed the hinterland recharge volume. These factors must be taken into consideration in the wellfield site selection.

The water head of lower aquifer in the Study area is estimated at EL 1300 m. Said lower aquifer is contained within basements, and is considered extractable from heavily fractured andesite, welded tuff and investor in particular. Storage capacity and pump-up potential of lower aquifers in the Study area is as indicated below (see Chapter 8).

	Storage Capacity	Available Pump-up Volume
Northern Sector	$180 \times 10^6 m^3$	$54 \times 10^6 m^3$
Southern Sector	143 x "	43 x "
Eastern Sector	196 x "	59 x "
Total	519 x "	156 x "

Expressed as liters per second, the above potential pump-up volumes are 1.71 m^3/sec in the northern sector, 1.36 m^3/sec in the southern sector and 1.86 m^3/sec in the eastern sector.

9.2 Groundwater Development Areas

Groundwater availability in the various sectors of the Study area is as described in the previous section. However, optimum areas for groundwater development are further delimited by such factors as degree of construction ease (topography, access roads, etc.) and proximity to existing water supply facilities. Particulary in the case of the subject Project, which is intended for prompt implementation, proximity to existing facilities is a major consideration.

On this basis, and as indicated in FIGURE IX-1, blocks I, II, III, IV, V and VIII in the eastern sector and blocks VI and VII in the northern sector were selected as optimal for development. These blocks are comparatively close to existing treatment plant facilities, and the pump-up volume of this area is estimated to be as in the following table.

	Area Km²	Groundwater availability (free aquifer) m³/sec	Favorable area for ground water develoment	Object groundwater for development	Area Km²	Estimated pump-up volume: Free aquifer m³/sec	Estimated pump-up volume: Lower* aquifer m³/sec
N-I	86.82	0.19					
N-II	96.34	0.25	o	VII	7.0	0.018	0.284
				VI	3.5	0.009	0.568
N-III	56.90	0.13	o	VI	3.5	0.004	
				II	6.0	0.014	0.358
E-IV	17.00	0.06					
E-V	46.87	0.06	o	IV	4.0	0.005	0.336
E-VI	80.55	0.09					
E-VII	209.48	0.98	o	I	10.0	0.047	0.492
				III	7.0	0.033	0.284
				V	5.0	0.023	0.245
				VIII	4.0	0.019	0.254

* (1) The pump-up volume of lower aquifer was taken as 30% of the discharge to the area.

(2) This discharge ws regarded as being cirde-shaped for the object area for development, and with inflow from half the circumference. The discharge of 0.597 m^3/sec for the 2.5 km length calculated in 8.2.3, was taken as the base for the calculation of the discharge for the half-circle.

9.2.1 Block I (Eastern Sector)

This block is situated at the southern portion of the eastern sector basin formation. Electrical prospecting and groundwater level data imply the presence of a groundwater artery extending along the approximately 2 km wide graben oriented SW - NE. Quaternary sediments (ash. pyroclastic, etc.) in the area are 150 - 250 m thick. Water Level of the free aquifer is 70 - 120 m. Free aquifer is assumed to flow into the graben from the southwest.

Test well No. 2 indicates lower aquifer below EL 1300 m. Furthermore, the above discussed graben formation suggests basement fracturing, from which may be concluded the presence of a good aquifer.

Consequently, development of both the free (47 l/sec) and lower (492 l/sec) aquifers in this block is considered possible. Nevertheless, drafting from the deep, lower aquifer is desirable as extraction from the free aquifer would result in reduced pump-up at points further downstream on the groundwater artery.

For extraction from the free aquifer, a well depth of less than 200 m would be sufficient. However, well depth requirements for tapping into the lower aquifer are governed by ground elevation and thickness of Quaternary sediments. At EL 1500 m, roughly 300 m well depth is necessary. At over EL 1500 m increased well depth is required, and consequently siting of wells at such elevations should be avoided where possible.

9.2.2 Block II (Eastern Sector)

This block is situated at the northwest portion of the eastern sector basin formation. Results of electrical prospecting and evaluation of groundwater level data imply the presence of an underground basin formation approximately 4 km in diameter, with groundwater outflow to the southeast. The basin is considered as being fed with free aquifer from the north and west. Although the thickness of Quaternary deposits (same as for Block I) has not been conclusively identified, it is estimated at 150 - 300 m on the basis of evident geological characteristics of the vicinity. Free aquifer level depth is considered to be 70 to 120 m. Although the presence of a lower aquifer has not as yet been confirmed, the existence of north - south and east -west systems of faulting in the area lead to the conclusion that fracturing of the basement is extensive, and lower aquifer below EL 1300 m in basement rock may be expected.

Consequently, potential is present in this block for development of both lower (358 l/sec) and free (14 l/sec). However, since free aquifer is not large volume, development of the lower aquifer is preferable.

A well depth of 300 m would be required to extract from the lower aquifer.

9.2.3 Block III (Eastern Sector)

This block is situated in the eastern portion of the basin formation comprising the eastern sector. On the basis of electrical prospecting results and evaluation of groundwater level data, it is assumed that an underground trough extends east-west and northeastward with groundwater outflow to the northeast. Inflow into the trough is free aquifer from blocks I and II, and from highlands to the south. Although the thickness of Quaternary deposits (same composition as for blocks I and II above) forming the free aquifer has not been confirmed, relatively low ground elevation (1400 m±) of the area syggests a thickness of 150 -250 m. Free aquifer level depth is estimated at 100 - 150 m.

A north - south fault is present in the eastern portion of the block and corresponds to an extension of the northeast - southwest underground trough formation in block I discussed above and of the east - west faults in block II. Extensive fracture of basement is accordingly anticipated. Presence of a lower aquifer is considered likely.

Development of both the lower (284 l/sec) and free (33 l/sec) aquifers in this block would be desirable. Particularly, as the free aquifer lies downstream of other areas in the eastern sector, the effective water volume is assumed to be high.

A well depth of 200 m would be necessary to tap the free aguifer, and a depth of 300 m would be required to extract from the lower aquifer.

9.2.4 Block IV (Eastern Sector)

This block is situated outside the northeastern boundary of the eastern sector basin formation. Results of electric prospecting evaluation of the groundwater level and those of Test #1 indicate that the basement lies at a relatively shallow depth in Block IV, and is thought to be an upheaval block overall. The main recharge area of the free aquifer is thought to be the relatively small-scale mountainous region to the north. Although the aquifer flows down from this region, the recharge volume is small. Despite the fact that Test #1 confirmed the presence of an lower aquifers in this sector, the pump-up potential is very small at around 6 l/sec, and leads to the conclusion that the (limestone) basement is a block with minor cracking.

Because of this, the implementation of detailed geological surveys is necessary to confirm the presence of the lower aquifer prior to implementation of test boring for the development of Block IV.

9.2.5 Block V (Eastern Sector)

This block is situated on the northeastern boundary of the eastern sector basin formation and its geological structure shows it belongs to the eastern graben part of the fault running north-south. This also appears in the landform as a steep cliff extending north-south, and for which the eastern side is about 100 m lower with an elevation of around 1,200 m. The free aquifer of this block is downstream from Block III and is thought to be formed from inflow from the hilly region to the south, and from part of the western-side lower aquifer that resurfaces from below EL 1300 m along the north-south criff. Test well No. 3 boring indicated a depth at 240 m for the thickness of the Quarternary sediments in this block, and a depth of 50 m for the level of the free aquifer. As yet, the presence of a lower aquifer remains unconfirmed for this block but further surveys are necessary since the landform conditions indicate the possibility that the water head may differ from that mentioned above.,

On the basis of area ratio, the free aquifer volume of sites to be development in block 5 in estimated at 23 l/sec. However, if the inflow into block 5 from upstream blocks I, II and III mentioned above is included, the volume increases to 94 l/sec. Furthermore, as elevation is less than 1,300 m outflow from the lower aquifer must also be considered.

From these results it is concluded that the free aquifer should be the object of development in this block. It is desirable that test boring be implemented for above the goundwater artery, and that a bore depth of between 250 m and 300 m would be appropriate.

9.2.6 Block VI (Northern Sector)

This block is situated on the northern margin of the northern basin formation of this sector, and is a plateau with an elevation of around 1400 m. However, the landform interrupted by river systems running north-south. These is a fairly wide distribution for the limestone outcrops that constitute the basement in this block and the Quarternary sediments are no more than thinly deposited sediments in a basin. Results of the Project 4.3 boring for this block indicate that the lower equifer has a water head at EL 1300 m, and that the pump-up volume is 63 l/sec. Geologically speaking, the block contains the north-south fault and fissure zones concentrating in the northeast-southwest directions to provide conditions that suggest the existence of a lower aquifer.

Development for this block should therefore be implemented with the lower aquifer (568 l/sec) as the object.

A depth of 250 m is the desirable depth for test borings. This is considered necessary even at points lower than EL 1300 m since the groundwater level is thought to fall with the elevation.

9.2.7 Block VII (Northern Sector)

This block is situated in the north of the northern sector basin formation. The landform is a plateau with an elevation of around EL 1400 m, with an andesite formation of EL 1600 m to the western side. Overall, the elevation decreases to the northeast where there is river development. The thickness of the Quarternary sediments has not been confirmed but it is estimated to be below 100 m from the results of electric prospecting. Supply to the free aquifer of this block is from the western highlands mentioned above, and also from the south but it is thought that the pump-up volume of individual wells is extremely small due to discontinuities caused by the interrupt of the northeast-southwest rivers mentioned above. In this block, water is pumped up from the lower aquifer in a valley, and is used as water for utilization by a brewery. This suggests the presence of a lower aquifer. Geologically, the block is one where northeast-southwest fissures develop, thus indicating the strong possibility of the presence of a lower aquifer.

Development at this block should therefore take the lower aquifer as the object, with a minimum test boring depth of 250 m being necessary as it was for Block VI.

9.2.8 Block VIII (Eastern Sector)

This block lies outside the southwestern edge of the eastern sector basin. Geologically, it comprises a subsided zone.

According to the boring log for well No. 21, water level is 50m from ground level. The free aquifer comprises 213m of Quaternary deposits to EL 1,300m. Water level at other wells in the block ranges from 11m to 50m, and pump-up is considered as from the free aquifer.

On the basis of electrical prospecting results for SE-29 and SE-30, basement is assumed at 400m depth from the surface.

Consequently, if pump-up is aimed at the lower aquifer, well depth would have to be in excess of 400m. Accordingly, the free aquifer is to be tapped.

However, as the free aquifer has generally limited water storage capacity, wells should be as intersection of high porosity (such as intersection points of faults, etc.) to maximize pump-up potential.

9.3 Conclusion

The following table summarizes the object aquifer for development, the necessary boring depth and the pump-up volume per boring, for each block.

Sector	Object Block	Object Groundwater for Development		Bore Depth		Estimated Pump-up Volume	
		Free aquifer	Lower aquifer	Free aquifer (m)	Lower aquifer (m)	Free aquifer (l/sec)	Lower aquifer (l/sec)
Eastern	I	o	o	200	300	10 - 15	40
	II		o	-	"	-	40
	III	o	o	200	"	10 - 15	40
	IV	x	o	-	"	-	10
	V	o	?	250 - 300	-	15	-
	VIII	o	?	250 - 300	-	10 - 15	-
Northern	VI	x	o	-	250 more	-	40
	VII	x	o	-	"	-	40

However, the estimated pump-up volume was set at 10-15 l/sec since the maximum pump-up volume of existing wells only averages 10 l/sec for free aquifers. In the case of confined aquifers, the performance of existing wells where the groundwater level is below EL 1300 m, varies greatly between 3 l/sec and 189 l/sec, with some being thought due to other than lower aquifers. Nevertheless, at the present stage, accurate determination is difficult because of the lack of geological profiles for each well. The average pump-up volume per bore was therefore set at 40 l/sec. Results of Test well Nos. 1 and 3 gave 10 l/sec for Block IV of the eastern sector.

9.4 Topics for Future Investigation

As has been explained in the preceding, this survey clarified the conditions of groundwater catchment and the nature of groundwater in the Project Area and of the blocks currently in urgent need of development, selected five blocks of the eastern sector and two blocks of the northern sector. The bodies of groundwater that form the object for development are free aquifers within Quarternary sediments and having their water level at a depth of around 50 m - 120 m, and a lower aquifer in fractured basement and having a water head near EL 1300 m.

However, the results of a survey of existing data and the conclusions described above merely serve to provide a general outline of the groundwater stored in this region, and leave the following topics that should be clarified through future investigation and survey.

(1) The structure of the basement is unknown because the depth and state of distribution of the basement remains unclear. This means that the free aquifer arteries (trough and basin formations) for which pump-up is most effective, are still unknown.

(2) The thickness of the Quarternary sediments has not been clarified and so the catchment conditions for the effective free aquifer are not precise.

(3) Except for those places where the groundwater level is currently known, no precise distinction can be made between the free aquifers and lower aquifers. Because of this there is the possibility that the two may have been mixed for the areas covered by this survey.

(4) The estimated water heads of the free aquifers cannot be said to be precise since they were made on the basis of data for only three or four place. A much greater number of data will be necessary. Furthermore, the recharge area, basement conditions, conditions for sloping ground and lowlands with an elevation below EL 1300 m and the locations of fault fractures all require confirmation and/or elucidation in the future.

(5) A pump-up test was performed for the lower aquifer at the Test #2 bore, but not for the free aquifer. Reinvestigation is therefore necessary in areas where utilization of the free aquifer is intended.

(6) The lower aquifer anticipated in the southern sector was excluded from this survey for the Urgent Development Plan. This was because it occurs in lowland having an elevation of less than EL 1300 m, because results of a gravity survey suggest a large falling basin formation, because the thickness of Quarternary sediments has not been confirmed although their presence has, and because lowering of the groundwater level (for the free aquifer) is presently occurring in some parts. Accordingly, it is necessary that the geological structure and hydraulic mechanism of this area be elucidated prior to the implementation of development for this region.

Each of these problems were factors contributing to the inadequate elucidation of the geological structure in this region. Consequently, effective development cannot be expected to occur in the future unless the following surveys are urgently implemented.

(1) Detailed geological surveys: These should include detailed surveys of the basement in the region and the distribution, direction, slope, thickness, faults, fissures and other characteristics of the Quarternary sediments, and therefore enable the geological structure to be clarified.

(2) Physical Prospecting: Gravity surveys should be implemented to clarify the underground structure of the basement in the region, and also determine the position and depth of basin and trough formations.

(3) Test boring: Core borings and electric logging should be implemented at representative locations in order to determine the depth of the basement and the thickness of the Quarternary sediments and provide reference data for the above surveys.

(4) Core sampling, Pump-up tests: Pump-up tests should be performed for test wells and the depths for which there is water seepage. Pump-up tests should be performed for both the free and lower aquifers and used as data for the calculation of the pump-up volume.

(5) Comprehensive Analysis: A comprehensive investigation should be performed and include existing data as well as the results already obtained. The purpose of this is to determine the catchment conditions for the groundwater in this region and to propose the most effective development and utilization plan.

FIG VII-8 DRILLING LOG TEST BORING N°6

NAME OF PROJECT: Guatemala City Ground Water Development Project — NO. OF HOLE 6

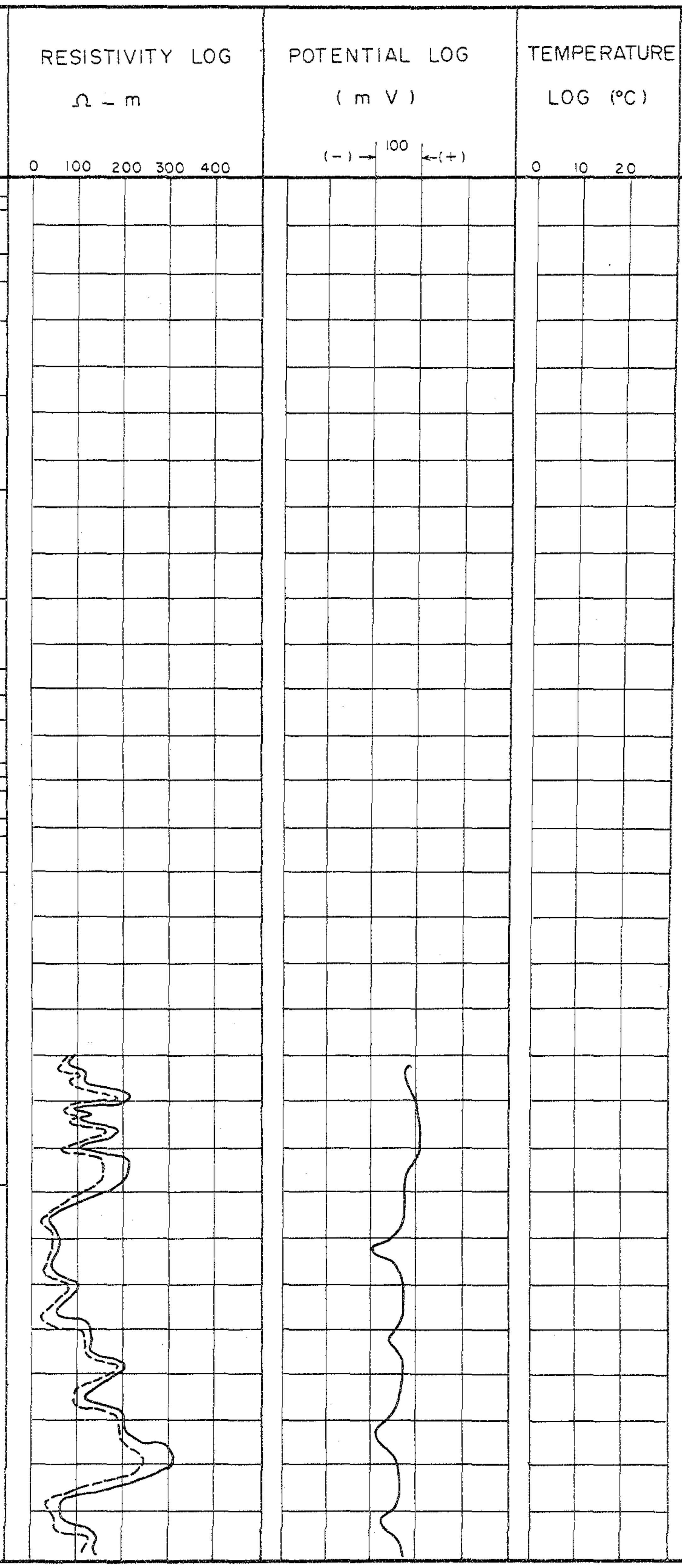
LOCATION PROYECJ04-4 — BORE HOLE DIA 12-1/4" — DEPTH OF HOLE 350m

ELEVATION 1452 masl — DRILL MACHINE INGERSOLL-RAND — OPERATOR DAHO

UNDER GROUND WATER TABLE GL-170m — NO. 6 — SUPERVISOR K·K

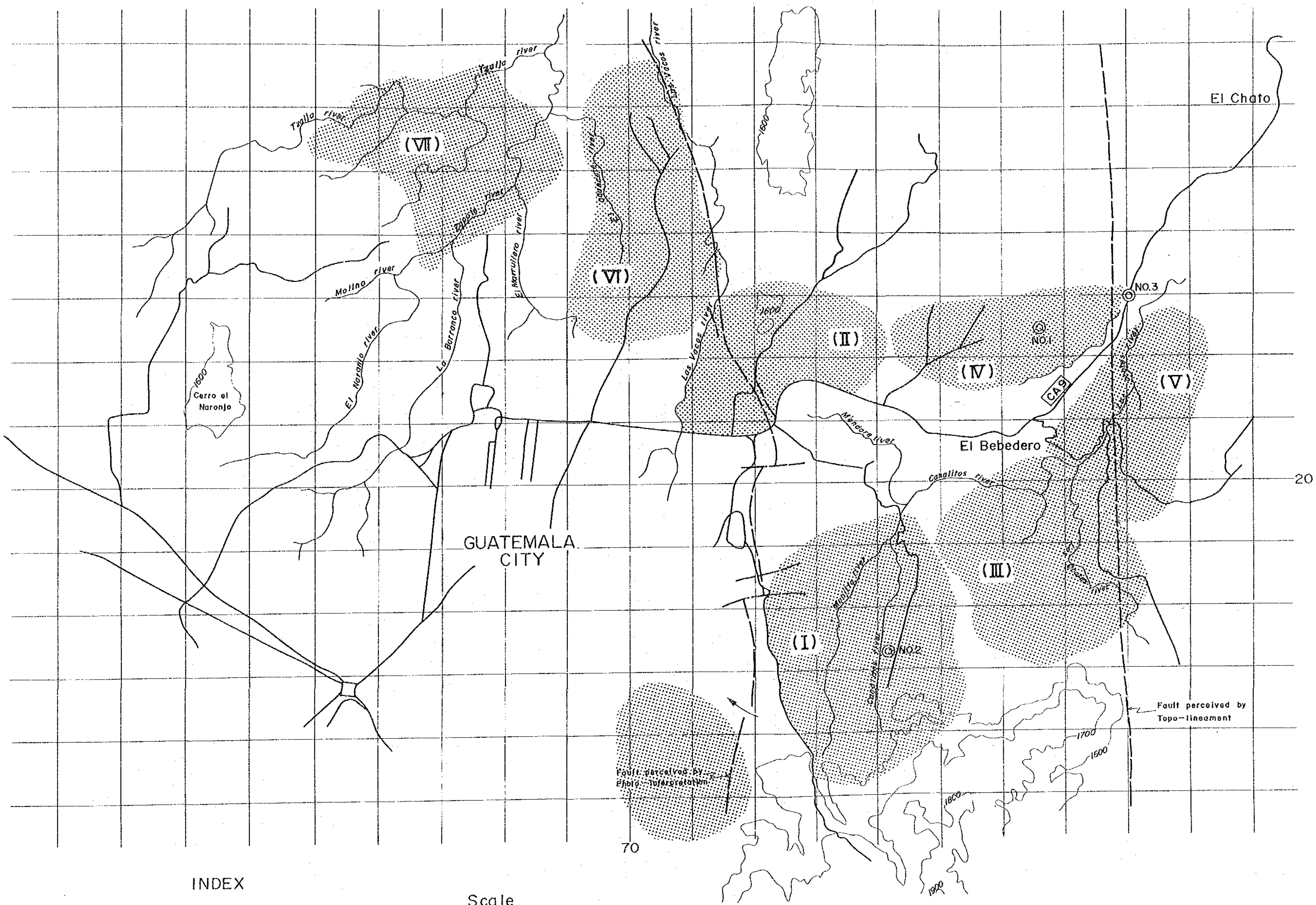
THICKNESS (m)	DESCRIPTION
3	volcanic ash with sand
3	pumice with fine sand
9	gravel with fine sand and pumice
6	fine sand with gravel and pumice
9	gravel with pumice
15	pumice with sand and weathered basalt
21	pumice with fine sand
24	fine sand with weathered basalt
15	fine sand with weathered basalt
6	fine sand with pumice and basalt
6	coarse sand
9	pumice with medium sand
3	pumice with basalt
3	pumice with calcite
6	pumice with basalt
3	fine sand with pumice
9	pumice with basalt
69	pumice
131	limestone

DEPTH (m): 10, 20, 30, 40, 50, 60, 70, 80, 90, 100, 110, 120, 130, 140, 150, 160, 170, 180, 190, 200, 210, 220, 230, 240, 250, 260, 270, 280, 290, 300



REMARKS

DATE DRILLED



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(I) Groundwater Development area

◎ NO.2 Site of Test Boring

Scale 0 — 3km

FIG. IX-1 RECOMMENDED WATER DEVELOPMENT AREA

JICA