Ticuantepe (1 well)

Main water-bearing formations : TQps(M) and QvM

Sc : 391 m^3/day/m (272 l/min./m)

T : 477 m^2/day (3.31 X 10^{-1} m^2/min)

As mentioned in "Test Well Drilling and Pumping Test", the test well JI-1 has revealed the existence of a formation somewhat different from the commonly known Middle Las Sierras Group, which has very high specific capacity value of 19,464 m^3/day/m (1,088 gpm/ft). Based on its confirmed thickness, more than 220 meters, and its lithological characteristics, the formation is considered to be one of the initial volcanics of the Las Sierras Group, as shown in Fig. 4.6.1. However, this presumed hydrogeological structure of the area shall be revised by detailed surveys in the future. Therefore, the specific capacity value obtained from test well JI-1 is eliminated from the iso-value line map of specific capacity (Fig. 4.8.3).

As for existence of Tertiary formations, it is presented in the cross section of Fig. 4.1.8 and 4.1.9.

4.8.4 Groundwater occurrence

(1) Areal features of groundwater occurrence

1) Western sub-area (Los Brasiles Valley)

As mentioned before, the principal water-bearing formations in the sub-area consist of the alluvial deposits, the Quaternary pyroclastic materials and the Middle Las Sierras Group. Groundwater occurrence is basically influenced by the NNW-SSE fault systems of the Mateare Fault Scarp and the shape of the top surface of the Tertiary formations regarded as hydrogeologically impermeable basal layers (Fig. 4.8.2).

The shape of the groundwater table in the sub-area is as shown in Fig. 4.8.1, and it is controlled by the topographical and geological conditions mentioned above. The groundwater in the sub-area is generally unconfined. Test well JI-5 was drilled through the Middle Las Sierras Group of the principal water-bearing formation into the El Salto formation, and daily fluctuations of groundwater level in the borehole was not observed (Fig. 4.8.5).

2) Managua central sub-area

This sub-area has a good recharge condition from the topographical, geological and vegetation viewpoints. The catchment area of rainfall is about 237 square kilometers. The principal water bearing formation is the Middle Las Sierras Group, and main aquifers consist of fractured zones, weathered zones and local beds of porous scoria with rock fragments in the formation. Groundwater generally exists in these unconfined aquifers, and perched water and confined aquifer were also partially found.

Groundwater discharge for industrial and domestic uses in the sub-area has been increasing. As shown in Fig. 4.8.1, the shape of the groundwater table is topographically similar to the top surface of the Tertiary formation (Fig. 4.8.2), although depression areas more likely correspond with the heavy pumping areas. The water table of Lake Asososca has been continuously decreasing at an annual average of 30 centimeters, due to excessive discharge.

In recent years, the water table of Lake Asososca has been about 3 meters lower than that of Lake Managua. Lake Asososca's water is apt to be polluted by the drainage of an oil refinery located between the two lakes. In this Study, an optimum discharge to avoid water pollution is recommended based on the results of the water balance analysis.

3) Eastern sub-area

This geohydrolic sub-area has the highest potential for groundwater development in the Study Area due to its topographical, hydrological and geological conditions.

This sub-area can be divided into the groundwater recharge district, and groundwater storage and runoff district. Further, the former is sub-divided into two hydrological basins: Ticuantepe upstream and Masaya Caldera basins.

The Ticuantepe upstream basin has a rainfall catchment area of 82 square kilometers. Most of the rainfall on the mountainous area of the Sierra de Managua flows down to canyons in the form of direct runoff. A part of this direct runoff infiltrates into the ground through the Masaya Group Volcanics and becomes important water sources of this geohydrolic sub-area.

Masaya Caldera basin has a rainfall catchment area of 213 square kilometers. A greater part of the rainfall in the mountainous area of the Sierra de Carazo flows into Masaya Caldera as direct runoff of intermittent rivers. A lot of the surface water and groundwater in the Caldera infiltrate into the submerged valley through the northern wall of the Caldera and become important water sources of this geohydrolic sub-area (Fig. 4.8.6).

The submerged valley mentioned above resulted from the erosion of the Las Sierras Group followed by the eruption of the Masaya Group Volcanoes; thus it also contains lava and pyroclastic materials of the Masaya Group volcanics. Its depth along the center line is around 100 meters in the south and 150 meters in the north, and the width is 4 kilometers in the south and 8 kilometers in the north. As shown in hydrogeological map (Fig. 4.1.7) and hydrogeological cross sections (Fig. 4.1.8 and 4.1.12), the development of this submerged valley is estimated to have been influenced by the two active fault systems of NS and NE-SW directions. Many of the volcanic cones and collapse composite crater in Veracruz can be found in a submerged valley, and their volcanic chains are mainly influenced by the NS fault system.

As previously mentioned, many springs can be found in the Las Mercedes shore. These springs are influenced by the different lithological characteristics of the Masaya Group Volcanics (highly permeable) and the alluvial deposits (relatively low permeability, see Fig. 4.8.3). Total discharge of these springs amounts to 1.3 m^3/second (February 1992), with the San Rafael spring group having the highest discharge of 0.8 m^3/second which is nearly equal to the yield of the Carlos Fonseca well field (0.79 m^3/second).

As shown in Fig. 4.8.6, the groundwater table in the sub-area is affected by topographical and geological conditions, and the submerged valley and fault systems. Further, the Figure also clearly shows the groundwater flow mechanism in this geohydrolic sub-area. Fig. 4.8.5 shows the fluctuation in groundwater table in boreholes drilled in this Study, and was used as a basis in determining that most observed groundwater are unconfined, while the rest are perched and confined.

Fig. 4.8.7 and Table 4.8.5 represent the comparison between initial and present well conditions of the Carlos Fonseca well field. Both evidently show that wells in the field are spaced too closely, thereby resulting in interferences which largely deteriorate the specific capacity of the wells. A decrease in static water level, between 7.5 and 0.5 meters, is also estimated.

According to Table 4.8.5, average deterioration of specific capacity of the wells is 66.21% and average drawdown in the 9 pumped wells is 28.27 meters. Since the yield capacity of the field amounts to about 74,000 m^3 per day, daily yield of 74,000 m^3 may be theoretically covered by 8 wells (specific capacity: 27-30 m^3/hour/m, drawdown : 15-20 meters), if wells are properly spaced.

Table 4.8.6 represents the radius of influence of the 8 wells in Carlos Fonseca, using the Theis's formula under the following assumed conditions.

$S = QW(u)/4\ T$ $\qquad$ $U = r^2S/4\ T$

Where, S: drawdown (0.1 m)

Q: pumping rate (5,000 m^3/day)

S: storage coefficient (0.10 and 0.15)

t: time since pumping start (2 days)

T: coefficient of transmissivity (T = 1.22Sc. original)

W(u): well function (u is obtained from the table function)

r: radius of influence (at s = 0.1m)

As shown in Table 4.8.6 and Fig. 4.8.7, it is evident that well spacing is not appropriate.

(2) Groundwater flow mechanism

In this Study, analyses of chemical components and tritium concentration of the representative water samples were conducted to investigate the groundwater flow mechanism and to evaluate the potential of groundwater development in the Study area.

1) Areal features of chemical component in water samples

The results of the analyses were converted into the Trilineal and Stiff patterns diagrams, as shown in Fig. 4.7.1 and 4.7.2, and they are explained in Section 4.7.1.

These Figures refer to the water samples taken in low zones such77`asSabana Grande and Managua, where the aquifer and ion elements have changed. These results are correlated with recharge cycle in the hydrogeological catchment area mentioned in the section on groundwater occurrence.

2) General features of tritium concentration

In order to estimate the groundwater age and to consider the groundwater flow mechanism, 7 water samples were taken to Japan for radio-isotope (H_3) analysis. The results are shown in Table 4.8.7.

Determining the tritrium concentration (TU) is useful in estimating the age of the groundwater.

Tritium is a radioactive isotope of hydrogen, having a life of 12.3 years. The occurrence of tritium in the hydrological cycle is possible both naturally and artificially. Tritium is produced naturally in the earth's atmosphere by the interaction of cosmic-ray-produced neutrons with nitrogen.

Until 1952, the average natural tritium content in precipitation world-wide was in the range of about 5-20TU. Upon the onset of large scale atmospheric testing of thermonuclear bombs in 1952, the tritium contents in precipitation rose sharply, reaching a maximum of about 80,000TU in some localities in 1962-63 which is a concentration, over a thousand times greater than the amount prior to nuclear bomb testings. With restrictions on atmospheric testing, tritium contents have been declining, but still remain in larger concentrations than those naturally produced. Tritium is widely used for groundwater dating in the following contexts:

(a) Very low tritium concentrations, around the level of detectability, shows water properties principally characterizing the pre-bomb period, while relatively high tritium concentrations indicate the opposite.

(b) For more precise tritium dating, the changes in rainfall regime must be taken into account.

Assuming that piston flow occurs, the dating of water can be achieved by applying the following equation of decay.

$$\ln(A) = \ln(B) - t/th^{*} \ln(2)$$

where,

A : Tritium concentration in sample
B : Tritium concentration in precipitation (t years earlier)
t : Age of the water
th: Half-life of tritium (12.262 years)

Fig. 4.8.8 shows the integrated record of tritium in precipitation at Madison, Wisconsin (U.S.A). Tritium in precipitation at Madison was about 8-10 units prior to 1953, reached a peak of over 4,500 TU during 1962, and declined to 20-30 TU by 1982. Although there is no long-term tritium measurement station in Nicaragua, the tritium in precipitation at Managua was assumed to be similar to that at Madison.

Assuming that groundwater movement in an aquifer follows the piston flow, a decay curve of tritium units in the groundwater of the Study Area can be drawn by using the above equation to estimate the groundwater age (see Fig. 4.8.9).

3) Groundwater flow mechanism

Fig. 4.8.6 shows the groundwater flow mechanism in the Study area, which was prepared comprehensively from topographical, hydrological and hydrogeological viewpoints.

This Figure plus the area features of the chemical components in water samples, and the general features of tritium concentration served as bases for the considerations on groundwater flow mechanism in the Study area, which are summarized as follows:

(a) The water of Lakes Masaya and Asososca seems to be supplied mainly from lateral recharge of groundwate in the Middle Las Sierras Group, flowing at a circulation rate of 35 to 45 years.

(b) It can be also estimated that the groundwater of Ticuantepe and southwestern part of Veracruz has a flow mechanism which is similar to the waters of Lakes Masaya and Asososca.

(c) Assuming that the water of the pool in IRENA and Río Mocuana springs are mainly supplied by lateral recharge of groundwater from Masaya Caldera flowing through a submerged valley widely distributed with the Masaya Group Volcanics and fractured zones influenced by the NNE-SSW fault system, the circulation rates are estimated to be about 8.5 and 4.0 years, respectively (Fig. 4.8.6 and Fig. 4.8.9).

(d) As shown in Fig. 4.8.6, the groundwater at Sabana Grande well field is supplied by lateral recharges from Masaya Caldera and the foot of the Sierras de Managua consisting of the Middle Las Sierras Group. Therefore, its tritium concentration shows a relatively low value (1.29 TU) compared with that of IRENA and Río Mocuana springs.

(e) As a result of the above mentioned consideration, the groundwater stored in the Middle Las Sierras Group is evaluated to have low renewal characteristics, while the groundwater stored in the Masaya Group Volcanics has high renewal characteristics.

Assuming that the transitional distance of groundwater between Masaya Caldera (recharge area) and springs (discharge area) is about 14 km, the groundwater flow rate is 9.6 m/day (14,000 m/4 years) to 4.5 m/day (14,000 m/8.5 years). On the other hand, assuming that the transitional distance of groundwater discharged in Lakes Masaya and Asososca is about 10 km, the flow rate of groundwater is estimated to be 0.78 m/day (circulation rate: 35 years) to 0.61 m/day (circulation rate: 45 years).

These groundwater flow rates can be used for the many groundwater basins throughout the world that are composed of younger volcanic rocks.

Table 4.8.1 EXISTING WELL RECORD(1)

Geohydrolic Area : Western sub-area(Los Brasiles Valley)

Well No.	Elevation (m)	Drilled Depth (m)	Screen Position Top(GL-m)	Screen Position Bottom(GL-m)	Screen length(m)	Aquifer	Pumping Test Record Discharge (Q: m³/h)	S.W.L (GL-m)	D.W.L (GL-m)	Sc(Q/s) (m³/h/m)	T (m²/day)	Remarks
INAA 1	——	134	74.9	121.6	25	Qal, QvH&QvP	114	53.34	59.43	18.92	554	
INAA 2	——	125				Qal, QvH&QvP	114	53.34	65.07	9.72	285	
INAA 3	——	——	80.5	128.3	24.4	Qal, QvH&QvP	——	——	——	13.40	392	
INAA 6 「4294 PAS1-9」	142	213.41	113	210	91	Qal, QvH&QvP	213.83	95.12	97.81	79.50	2,327	
PB-02	——	152				Qal, QvH&QvP	250	——	——	47.44	1,389	
PB-04	——	122	49	120	63	Qal, QvH&QvP	250	40.23	49.23	27.81	814	
PB-05	——	152				Qal, QvH&QvP	250	——	——	17.61	516	
PB-07	——	122				Qal, QvH&QvP	250	——	——	22.35	654	
PB-08	——	122	67	102	34	Qal, QvH&QvP	250	33.53	44.83	22.12	648	
PB-09	——	122	63	133	67	Qal, QvH&QvP	——	——	——	33.09	969	
61	——	——				Qal, QvH&QvP	——	——	——	16.70	489	
										28.06	821	Average of 11 wells
5042 IA-89 (240)	——	173.74	134	171	37	TQps(M)	3.86	128.02	128.71	5.40	158	
Pas 6-1 INAA-61	342	305	125	301.8	140.2	TQps(M)	178	108.82	142.40	5.30	155	
										5.35	157	Average of 2 wells

Table 4.8.1 EXISTING WELL RECORD(2)

Geohydrolic Area : Managua Central sub-area (Asososca-Ticomo Volcanoes well field ①)

Well No.	Elevation (m)	Drilled Depth (m)	Screen Position Top(GL-m)	Screen Position Bottom(GL-m)	Screen length(m)	Aquifer	Pumping Test Record Discharge ($Q: m^3/h$)	S.W.L (GL-m)	D.W.L (GL-m)	Sc(Q/s) ($m^3/h/m$)	T (m^2/day)	Remarks
PPA-3A	47.38	82.30				TQps(M)	161	6.52	15.94	17.09	500	
T4857 1A89	—	60.96	33.53	57.91	24.38	TQps(M)	136	17.07	23.22	22.04	645	
PPA-14	—	76.20	—	—		TQps(M)	129.9	20.94	32.20	11.50	340	
UNIDAS-13 (4882)	—	56				TQps(M)	165	19.80	26.50	24.62	720	
UNIDAS-5	—	61				TQps(M)	515	4.87	15.77	47.25	1,383	
PPA-15A	61	42	23.8	42.0	18.2	TQps(M)	32	22.86	41.06	2.25	66	
UNIDAS-31	—	45				TQps(M)	18	27.10	32.00	3.67	107	
PPA-16W	80	67				TQps(M)	102	28.96	32.24	31.16	912	
T5203 1A-90	80	45	28.96	44.20	15.24	TQps(M)	114	27.73	28.18	(249.00)	(7,290)	Eliminated from average
5080 PB-2-1	90.36	183	70	180	79	TQps(M)	342	50.90	61.37	32.66	956	
PPA-M2	145.39	198				TQps(M)	33	106.40	107.55	28.87	845	
PPA-3A	47.38	82				TQps(M)	161	6.52	15.94	17.06	500	
4294 PAS6-2 (INAA-63)	147	235	125	225	88	TQps(M)	91	105.76	113.46	11.79	345	
PAS6-10 (INAA-58)	195	247	183	271	88	TQps(M)	91	161.59	169.85	10.99	322	
INAA-43						TQps(M)	88	159.84	168.95	9.66	282	

Table 4.8.1 EXISTING WELL RECORD(3)

Geohydrolic Area : Managua Central sub-area (Asososca-Ticomo Volcanoes well field ②)

Well No.	Elevation (m)	Drilled Depth (m)	Screen Position Top(GL-m)	Screen Position Bottom(GL-m)	Screen length(m)	Aquifer	Pumping Test Record Discharge (Q: m³/h)	S.W.L (GL-m)	D.W.L (GL-m)	Sc(Q/s) (m³/h/m)	T (m²/day)	Remarks
INAA-44	——	259	183	253	42.4	TQps(M)	113	152.59	163.71	10.16	297	
INAA-45	——	289	174	286.5	91.4	TQps(M)	145	151.07	158.56	19.36	566	
PAS3-1 (INAA-85)	250	335	207	332	114	TQps(M)	45	19.51	22.05	17.88	524	
INAA-59	——	283	216	277	39.6	TQps(M)	74	160.32	173.10	5.79	169	
1640 PPC-88	480	356.6	262	356.6	76.3	TQps(M)	79.45	247.5	——	6.90	200	
										17.40	509	Average of 19 wells

Table 4.8.1 EXISTING WELL RECORD(4)

Geohydrolic Area : Managua Central sub-area (Managua Central well field ①)

Well No.	Elevation (m)	Drilled Depth (m)	Screen Position Top(GL-m)	Screen Position Bottom(GL-m)	Screen length(m)	Aquifer	Pumping Test Record Discharge (Q:m³/h)	S.W.L (GL-m)	D.W.L (GL-m)	Sc(Q/s) (m³/h/m)	T (m²/day)	Remarks
PB-5-1	63	154	35.1	139	80	TQps(M)	230	28.96	32.94	66.09	1,935	
PB-5-2 INAA-7	59	183	42.7	180	134	TQps(M)	227	22.25	40.72	12.31	360	
INAA-8	——	183	42.7	88.4	45.7	TQps(M)	186	23.88	38.28	12.92	378	
INAA-53	——	152	76.2	97.5	18	TQps(M)	102	61.57	96.13	2.95	86	
4980 PA5-12	86	244				TQps(M)	227	60.96	72.90	19.01	556	
4679 1A-88	——	189	30.48	179.23	145.7	TQps(M)	136	12.80	35.61	5.97	175	
PB-5-3 (INAA-9)	57.4	152.4	40.0	128	70	TQps(M)	267 (140	20.06 18.29	34.02 24.51	19.13 21.53	560 630)	
4249 PB-5-4	66.60	152	70.5	149	50.4	TQps(M)	204	18.29	57.02	5.65	165	
INAA-54	——	213	70.1	80.7	7.6	TQps(M)	116	39.93	47.79	14.76	432	
4294 PA-88	117.40	155	73.1	155	79	TQps(M)	182	54.88	59.60	38.47	1,126	
4699 1A-88	321.00	274	182.9	252.7	70	TQps(M)	68	175.00	178.10	21.98	644	
UNIDAS-17	——	76				TQps(M)	202	10.7	42.7	6.30	184	
5184 1A-90	——	152	24.38	——	——	TQps(M)	137	10.97	27.38	9.18	269	
UNIDAS-21	——	71				TQps(M)	125	9.15	26.04	7.40	216	
UNIDAS-19	——	108				TQps(M)	82	13.70	40.15	3.10	91	
INAA-32 (UNIDAS-43)	——	181				TQps(M)	102	81.40	89.02	13.40	392	

Table 4.8.1 EXISTING WELL RECORD(5)

Geohydrolic Area : Managua Central sub-area (Managua Central well field ②)

Well No.	Elevation (m)	Drilled Depth (m)	Screen Position Top(GL-m)	Screen Position Bottom(GL-m)	Screen length(m)	Aquifer	Pumping Test Record Discharge ($Q: m^3/h$)	S.W.L (GL-m)	D.W.L (GL-m)	Sc(Q/s) ($m^3/h/m$)	T (m^2/day)	Remarks
INAA-33	——	——				TQps(M)	97	85.34	102.10	5.81	170	
INAA-34	——	——				TQps(M)	146	81.85	87.90	24.13	706	
INAA-35 (UNIDAS-8)	——	204	115.8	137.2	12	TQps(M)	98	85.94	104.48	5.28	154	
UNIDAS-22	——	61				TQps(M)	68	32.00	36.57	14.90	436	
4952 1A-89	60	76	27.43	73.15	39.64	TQps(M)	36	21.30	31.13	3.69	108	
INAA-11 (A-56)	70	213	48.8	210.3	146.3	TQps(M)	227	22.74	49.05	8.63	253	
UNIDAS-89	——	155				TQps(M)	68	——	——	12.74	373	
INAA-41	——	——				TQps(M)	82	50.59	63.52	6.34	185	
INAA-42	——	——				TQps(M)	43	49.46	79.25	1.44	42	
INAA-38	——	243	143	152	9	TQps(M)	86	96.75	134.23	2.29	67	
INAA-37 (UNIDAS-88)	——	171				TQps(M)	38	79.00	79.49	79.00	2,313	
PAS-6-8 T-4294	245.8	335	207	326	119	TQps(M)	163	161.60	167.11	29.65	868	
PAS-8-1 (INAA-51)	130.0	213	85	207	121.9	TQps(M)	204	61.28	72.46	18.03	528	
UNIDAS-70	——	137				TQps(M)	20	85.30	98.30	1.57	46	
PAS-8-7 (4294)	190	244				TQps(M)	159	94.19	144.68	3.17	93	
3489 1A-84	——	152				TQps(M)	144	79.25	100.66	5.33	156	

Table 4.8.1 EXISTING WELL RECORD(6)

Geohydrolic Area : Managua Central sub-area (Managua Central well field ③)

Well No.	Elevation (m)	Drilled Depth (m)	Screen Position Top(GL-m)	Screen Position Bottom(GL-m)	Screen length(m)	Aquifer	Pumping Test Record Discharge (Q:m³/h)	S.W.L (GL-m)	D.W.L (GL-m)	Sc(Q/s) (m³/h/m)	T (m²/day)	Remarks
INAA-12 (PB-9-8)	72	213	51.8	61	9.1	TQps(M)	214	33.65	43.15	22.57	661	
INAA-39 (PAS-10-6)	125	280.5	82.3	180	88.7	TQps(M)	216	59.45	83.64	8.9	261	
INAA-48	——	183	134	179	26	TQps(M)	77	84.11	105.34	3.62	106	
PAS-85 4980	170	305	186	302	116	TQps(M)	136	103.70	144.42	3.34	98	
5397 1A-90	255	183	122	180	58	TQps(M)	6	106.68	174.04	(0.08)	(2.34)	Eliminated from average
UNIDAS-122	——	91				TQps(M)	138	12.30	32.49	6.85	200	
5376 1A-91	56	122	30.5	117.3	76.1	TQps(M)	36.3	15.24	31.13	3.69	108	
1783 1A-76	——	122	76.2	118.9	30.5	TQps(M)	91	13.11	37.49	3.72	109	
5158 1A-90	75	91	39.6	88.4	48.8	TQps(M)	49	32.00	50.34	2.67	78	
PB-9-10 4294	80	189	61	140	49	TQps(M)	227	30.05	45.66	21.39	626	
UNIDAS-66	——	85				TQps(M)	——	53.30	——	22.30	653	
2673 1A-85	95	152.4	45.7	134	82.3	TQps(M)	193.3	34.1	56.73	8.54	250	
INAA-65	——	——				TQps(M)	97	152.69	160.99	11.69	342	
INAA-52	——	280	85.3	277.6	158.5	TQps(M)	151	65.97	78.76	11.81	345	
INAA-50	——	198				TQps(M)	72	134.72	179.83	1.60	47	
INAA-49 (PAS-84)	213	299	155	295	131	TQps(M)	127	131.37	140.03	14.67	429	

Table 4.8.1 EXISTING WELL RECORD(7)

Geohydrolic Area : Managua Central sub-area (Managua Central well field ④)												
Well No.	Elevation (m)	Drilled Depth (m)	Screen Position		Aquifer	Pumping Test Record					Remarks
			Top(GL-m)	Bottom(GL-m)		Discharge (Q:m³/h)	S.W.L (GL-m)	D.W.L (GL-m)	Sc(Q/s) (m³/h/m)	T (m²/day)	
			Screen length(m)								
									13.36	391	Average of 47 wells
									14.52	425	Average of ManaguaCentral sub-area 66 wells

Table 4.8.1 EXISTING WELL RECORD(8)

Geohydrolic Area : Eastern sub-area (western area of Sabana Grande & Carlos Fonseca) ①

Well No.	Elevation (m)	Drilled Depth (m)	Screen Position Top(GL-m)	Screen Position Bottom(GL-m)	Screen length(m)	Aquifer	Pumping Test Record Discharge (Q:m³/h)	S.W.L (GL-m)	D.W.L (GL-m)	Sc(Q/s) (m³/h/m)	T (m²/day)	Remarks
UNIDAS 37	——	76				TQps(M)	59	35.00	41.10	9.70	284	
UNIDAS 38	——	173				TQps(M)	141	28.00	35.60	18.53	542	
1208 4d-78	——	131				TQps(M)	554	9.75	28.95	28.85	844	
4294 pa.10-1	(INAA-28) 90	244	70.1	240.8	134	TQps(M)	182	58.83	70.66	15.38	450	
INAA-30 (SG-4)	70.5	244				TQps(M)	164	24.10	32.26	20.10	588	
INAA-27 (SG-1)	110.5	283	133.5	264.4	40.8	TQps(M)	159	47.99	62.13	11.23	329	
INAA-28 (SG-2)	106.5	244	70.1	240.8	134.1	TQps(M)	169	60.68	75.41	11.47	336	
INAA-29 (SG-3)	88.5	308	85.3	277	185	TQps(M)	159	52.03	79.83	5.72	167	
										15.12	443	Average of 8 wells

Table 4.8.1 EXISTING WELL RECORD(9)

Geohydrolic Area : Eastern sub-area (Sabana Grande - Carlos Fonseca - Cofredia) ②

Well No.	Elevation (m)	Drilled Depth (m)	Screen Position Top(GL-m)	Screen Position Bottom(GL-m)	Screen length(m)	Aquifer	Pumping Test Record Discharge (Q: m³/h)	S.W.L (GL-m)	D.W.L (GL-m)	Sc(Q/s) (m³/h/m)	T (m²/day)	Remarks
INAA-31 (SG-5)	68.5	198	27.4	134.0	88.3	QvM&TQps(M)	354	17.07	32.07	23.62	692	
SG-7	75.2	273				QvM&TQps(M)	271	20.81	25.47	48.73	1,426	
UNIDAS-61	———	55				QvM	28	17.70	21.30	7.70	225	
UNIDAS-62	———	56				QvM	41	21.30	22.70	28.60	837	
UNIDAS-58	———	219				QvM&TQps(M)	137	9.50	10.10	227.80	6,670	
UNIDAS-52	———	169				QvM&TQps(M)	227	6.70	7.46	298.80	8,749	
4718 1A-88	———	79	27.4	76.2	48.8	QvM	114	9.14	13.00	29.40	861	
4786 5E-88	———	76	27.4	73.1	42.7	QvM	159	20.87	22.87	79.5	2,328	
INAA-17 (CF-1)	64.59	151	47.8	151.5	96.3	QvM&TQps(M)	216	13.72	19.32	38.55	1,129	
INAA-18 (CF-2)	62.04	152	33.5	147.8	62.6	QvM&TQps(M)	300	10.67	25.76	19.88	582	
INAA-19 (CF-3)	62.05	110	42.1	104.5	42.7	QvM	463	10.67	25.66	30.87	904	
INAA-20 (CF-4)	61.97	108	38.1	103.6	45.7	QvM	382	10.36	16.46	62.64	1,834	
INAA-21 (CF-5)	61.87	152	33.5	148.1	51.8	QvM&TQps(M)	404	10.67	20.82	39.83	1,166	
INAA-22 (CF-6)	62.09	104	34.4	101.5	47.2	QvM	375	8.64	19.72	33.50	981	
INAA-24 (CF-8)	61.82	104	37.2	71.6	19.8	QvM	463	9.60	25.76	28.57	836	
										66.53	1,948	Average of 15 wells

Table 4.8.1 EXISTING WELL RECORD(10)

Geohydrolic Area : Eastern sub-area (Las Mercedes-Carlos Fonseca) ③

Well No.	Elevation (m)	Drilled Depth (m)	Screen Position Top(GL-m)	Screen Position Bottom(GL-m)	Screen length(m)	Aquifer	Pumping Test Record Discharge (Q: m³/h)	S.W.L (GL-m)	D.W.L (GL-m)	Sc(Q/s) (m³/h/m)	T (m²/day)	Remarks
INAA-14 (CF-9)	76.27	183	61.0	179.8	82.3	Qal(&QvM)	93	30.63	48.16	5.29	155	
INAA-15 (CF-12)	——	130	45.7	112.8	32.0	Qal(&QvM)	——	20.89	——	3.02	88	
UNIDAS-49	——	37				Qal(&QvM)	79	3.00	27.53	3.22	94	
UNIDAS-54	——	36				Qal(&QvM)	4	3.30	3.61	12.70	372	
UNIDAS-55	——	42				Qal(&QvM)	34	7.90	32.18	1.40	41	
4718 2B-88	——	69	39.62	59.44	15.25	Qal(&QvM)	159	4.57	18.18	11.67	341	
4745 3C-88	52	61	21.3	64.0	39.6	Qal(&QvM)	139	12.49	22.22	16.34	478	
										7.66	224	Average of 7 wells

Table 4.8.1 EXISTING WELL RECORD(11)

Geohydrolic Area : Eastern sub-area (Veracruz-Ticuantepe) ④

Well No.	Elevation (m)	Drilled Depth (m)	Screen Position Top(GL-m)	Screen Position Bottom(GL-m)	Screen length(m)	Aquifer	Pumping Test Record Discharge (Q:m³/h)	S.W.L (GL-m)	D.W.L (GL-m)	Sc(Q/s) (m³/h/m)	T (m²/day)	Remarks
UNIDAS-76	139	92.6				QvM	107	41.72	46.72	21.40	626	
UNIDAS-85						TQps(M) (Sheared zone)				45.80	1,341	Veracruz Valley
UNIDAS-121	—	62.0				QvM	214.3	25.22	26.63	152.30	4,459	Average Sc : 61.10
UNIDAS-108						QvM				24.90	729	
UNIDAS-93						QvM&TQps(M)				16.30	477	Ticuantepe
B-2-74 INAA-72	—	122.0	69	114	45	QvM&TQps(M)	121	62.22	67.71	22.00	644	
D-2-85 INAA-71	—	152.5	62	107	45	QvM&TQps(M)	92	54.29	68.17	14.00	409	Average Sc : 15.23
N-3-89 INAA-76	—	97.6				QvM&TQps(M)	204.4	48.80	69.79	9.70	284	
J-1-85 INAA-69	—	187.9	102	159	57	TQps(M)	—	80.83	—	7.23	211	
N-1-84 INAA-74	—	152.5	108	159	51	TQps(M)	129.45	67.71	85.71	7.19	210	Average Sc : 8.03
N-2-89 INAA-75	—	97.6	75.3	89.7	14.4	TQps(M)	204.39	48.80	69.97	9.65	282	

Table 4.8.1 EXISTING WELL RECORD(12)

Geohydrolic Area : San Rafael del Sur

Well No.	Elevation (m)	Drilled Depth (m)	Screen Position Top(GL-m)	Screen Position Bottom(GL-m)	Screen length(m)	Aquifer	Pumping Test Record Discharge (Q: m³/h)	S.W.L (GL-m)	D.W.L (GL-m)	Sc(Q/s) (m³/h/m)	T (m²/day)	Remarks
2		21.3				Quatemany deposits and Oligocene Masachap F.	13.63	2.13	11.74	1.42	41.5	
3		21.3				Ditto	19.31	6.25	7.77	12.67	370.9	
D-1		18.6				Ditto	12.49	7.01	9.75	4.55	133.2	
D-2		18.6				Ditto	9.08	7.32	10.67	2.68	78.5	
D-3		21.9				Ditto	6.81	10.18	12.68	2.56	74.9	
		20.3					12.26	6.59	10.52	4.78	140	Average of 5 wells
1		90.2				Mainly Oligocene Masachapa Formation	4.32	4.57	24.08	0.22	6.5	
I-1		109.7				Ditto	5.68	5.27	45.59	0.15	4.4	
		100.0					5.00	4.42	34.83	0.19	5.5	Average of 2 wells
7		71.6				Mainly Eocene Brito Formation	6.81	18.90	24.38	1.24	36.4	

Table 4.8.2 AQUIFER CHARACTERISTICS OF THE TQps(M)

Well Conditions	No. of Test well Drilling		
	JI-1	JI-4	JI-5
Scoria bed (fall/flow) (m)	45.72 ★1	C/C	C/C
Ash bed (fall/flow) (m)	74.67 ★1	C/C	C/C
Other pyroclastic flow (m)	9.14 ★1 (porous lava)	C/C	C/C
Weathered agglomerate with fossil soil (m)	27.43 ★1	28.10	36.50 ★2
Fractured agglomerate (?) (m)	—	48.50	37.75
Total screen length (m)	84.12	71.00	54.00
Static water level (GL-m)	104.24	94.28	100.18
Pumping water level (GL-m)	105.00	106.17	102.01
Constant discharge (m^3/day)	1,482.51	1,471.68	1,471.68
Specific capacity (m^3/day/m)	19,464.48	123.77	804.19
Transmissivity (m^2/day)			

(C/C: Could not confirm)

★1 These lithofacies are estimated to be an initial volcanics of the Las Sierras Group.

★2 Including basal layers of coarse sandstone and fine conglomerate on top surface of the El Salto Formation.

Table 4.8.3 CORRELATION BETWEEN RESISTIVITY AND LITHOFACIES IN THE STUDY AREA

INFORMATINO	LITHOFACIES	Grade humidity (ohm/m)			Remarks
		Dry	Capillary Wet	Saturate	
Alluvium Deposits with Quaternary Pyroclastic Materials	Clayey bed	45 - 90			
	Sandy bed	60 - 800		8 - 25	
	Gravelly bed		100 - 200	- 25	
	Pumice or Scoria		100 - 200	- 25	
Masaya Group Volcanics	Pyroclastic fall deposits (mainly Scoria)	170 - 880			
	Pyroclastic flow	90 - 120		25 - 50	
	Lava flow (Brecciated)	100 - 200		10 - 20	Affected by hydrothermal solution
	Lava flow (compact)		270 - 500	25 - 200	
Upper Las Sierras Group	Alternatione of pyroclastics	250 - 700			
Middle Las Sierras Group	Massive and compact agglomerate with tuffbreccia and tuff	110 - 400	40 - 60		
	Weathered tuffbreccia with fossil soil and pyroclastic plow			10 - 80	
El Salto Formation	Low consolidated tuffaceous sandstone and siltstone			1 - 25	Affected by hydrothermal solution
Brito Formation (?)	Sandstone and shale			57 - 456	

Table 4.8.4 Result of Electrical Prospecting (1) (Schlumberger's)

Prospecting		Geologic division of resistivity														Elevation (m)	
NO.	depth (m)	I layer		II layer		III layer		IV layer		V layer		VI layer		VII layer			
		m～m	ρ-a	m～m	ρ-a	m～m	ρ-a	m～m	ρ-a	m～m	ρ-a	m～m	ρ-a	m～m	ρ-a	GL	Base
S- 1	400	0～3	14	3～ 7	122	7～ 20	55	20～135	23	135～400	1.3					58	-77
S- 2	400	0～7.4	12	7.4～32	35	32～180	15	180～300	5	300～400	L< 5					48	-252
S- 3	500	0～3	140	3～16	70	16～ 18	9	18～140	20	140～170	4	170～270	28	270～500	1	72	-198
S- 4	500	0～6	102	6～18	189	18～160	126	160～320	68	320～500	14					160	-160
S- 5	400	0～3.1	78	3.1～13.5	702	13.5～ 66	120	66～360	28	360～400	210					100	-260
S- 6	500	0～7	15	7～41	45	41～ 60	23	60～165	8	165～370	10	370～500	190			50	-320
S- 7	400	0～2.8	41	2.8～35	96	35～240	24	24～350	10	350～400	57					80	-270
S- 8	500	0～5	88	5～26	108	26～ 41	700	41～130	408	130～170	3	170～500	3			148	-22
S- 9	750	0～6	70	6～25	130	25～ 52	87	52～ 84	161	84～160	69	160～320	17	320～750	153	110	-50
S-10	750	0～6	113	6～9.6	61	9.6～ 27	142	27～ 86	116	86～170	29	170～500	7	500～750	133	140	-30
S-11	750	0～6	82	6～42	410	42～130	137	130～450	24	450～750	456					170	+40
S-12	500	0～5	206	5～13.5	833	13.5～ 68	313	68～160	78	160～400	16	400～500	H			175	+15
S-13	750	0～4.5	158	4.5～9	53	9～ 39	158	39～150	40	150～410	10	410～750	990			240	+90
S-14	400	0～6	33	6～14	18	14～ 49	72	49～ 86	39	86～160	117	160～290	63	290～400	9	50	-240
S-15	750	0～4.5	56	4.5～5.8	224	5.8～ 36	149	36～180	223	180～260	96	260～440	96	440～750	19	210	-50
S-16	750	0～6	87	6～7.2	261	7.2～ 72	140	72～340	210	340～480	210	480～750	23			260	-80
S-17	750	0～4	103	4～19	412	19～ 66	176	66～280	59	280～370	59	370～750	10			200	-80
S-18	750	0～5	120	5～26	180	26～170	120	170～220	180	220～370	60	370～750	3			160	-210
S-19	400	0～6	1000	6～19	176	19～ 33	528	33～ 45	226	45～ 98	528	98～320	105	320～400	6	160	-160
S-20	750	0～6	65	6～7.4	325	7.4～ 19	604	19～ 80	151	80～140	50	140～470	27	470～750	8	202	+62
S-21	500	0～4.6	136	4.6～60	253	60～180	63	180～500	9							175	-5

Table 4.8.4 Result of Electrical Prospecting (2) (Schlumberger's)

Prospecting		Geologic division of resistivity														Elevation (m)	
NO.	depth (m)	I layer		II layer		III layer		IV layer		V layer		VI layer		VII layer			
		m~m	ρ-a	m~m	ρ-a	m~m	ρ-a	m~m	ρ-a	m~m	ρ-a	m~m	ρ-a	m~m	ρ-a	GL	Base
S-22	750	0~6	171	6~7.6	513	7.6~64	220	64~370	31	370~750	3					99	-271
S-23	750	0~6	69	6~9	12	9~56	10	56~150	12	150~195	4	195~330	12	330~750	4	70	-260
S-24	500	0~5	133	5~8	399	8~42	100	42~140	25	140~330	31	330~500	13			74	-256
S-25	500	0~3	30	3~12	13	12~62	30	62~80	16	80~130	24	130~360	6	360~500	5	58	-302
S-26	750	0~3	22	3~12	44	12~24	36	24~70	44	70~130	22	130~195	18	195~750	4	80	-115
S-27	750	0~6	128	6~15	156	15~43	52	43~145	13	145~250	16	250~350	7	350~750	21	85	-165
S-28	750	0~3	110	3~7.4	220	7.4~31	1246	31~240	415	240~750	13					110	-130
S-29	750	0~6	29	6~74	54	74~280	18	280~750	4							215	-65
S-30	750	0~5	50	5~32	117	32~160	50	160~750	9							128	-32
S-31	500	0~5	35	5~6.4	105	6.4~18	57	18~34	63	34~70	42	72~135	78	135~500	20	78	-57
S-32	500	0~4	58	4~8.2	232	8.2~35	58	35~120	15	120~380	6	380~500	L< 6			71	-49
S-33	750	0~4	64	4~23	119	23~54	97	54~88	119	88~165	40	165~750	10			200	+35

Table 4.8.5 COMPARISON OF ORIGINAL AND ACTUAL WELL'S CONDITIONS IN CARLOS FONSECA W/F

Well's No.	Original (a)		Actual (b)		Deteriorate $\frac{a-b}{a}$ (%)	Actual Drawdown (14/10/92) (m)
	Sc: $m^3/h/m$	Date of test	Sc: $m^3/h/m$	Date of tet		
No. 1	38.51	10. 7.73	3.19	11. 9.91	91.72	31.94
No. 2	19.89	19. 9.74	11.92	?. 5.82	40.07	33.75
No. 3	30.84	7.10.73	10.93	18.11.91	64.56	31.74
No. 4	64.80	17. 4.75	21.15	?. 5.82	67.36	—
No. 5	39.85	19. 9.73	15.27	?. 5.82	61.65	23.26
No. 6	33.52	23. 3.74	8.28	27.11.91	75.30	24.12
No. 7	13.41	18. 3.74	6.85	?. 5.82	48.92	30.66
No. 8	28.53	1. 7.76	8.22	18.11.91	71.19	—
No.12	5.81	?. 5.82	3.02	27.11.91	48.02	25.80
No.13	4.39	?. 5.82	3.81	18.11.91	13.21	18.72
No.15	14.15	28.10.82	6.58	27. 8.91	53.50	34.42
Average	26.69	(293.62)	9.02	(99.22)	66.21	28.27

* Average specific capacity of 8 wells drilled in 1973-1976 is $32.67m^3/h/m$(original).

Table 4.8.6 Radius of influence(r) of Carlos Fonseca well field

Well NO.	Date of P.Test	S c (m³/h/m)	T (m²/day)	T (m²/h)	Q (m³/day)	s (m)	t (h)	W (u)	u	S	r (m)	remark
NO－1	19/9/73	38.50	1127.28	46.97	5000	0.1	48	0.283	0.88	0.10	282	
										0.15	230	
NO－2	19/9/74	19.89	582.37	24.26	5000	0.1	48	0.146	1.18	0.10	234	
										0.15	191	
NO－3	7/10/73	30.84	902.99	37.62	5000	0.1	48	0.227	1.0	0.10	269	
										0.15	219	
NO－4	17/4/75	64.80	1897.34	79.06	5000	0.1	48	0.477	0.62	0.10	307	
										0.15	250	
NO－5	19/9/73	39.85	1166.81	48.62	5000	0.1	48	0.293	0.85	0.10	282	
										0.15	230	
NO－6	28/3/74	33.52	981.46	40.89	5000	0.1	48	0.246	0.95	0.10	273	
										0.15	223	
NO－7	18/3/74	13.41	392.64	16.36	5000	0.1	48	0.099	1.49	0.10	153	
										0.15	125	
NO－8	1/7/76	28.53	835.36	34.81	5000	0.1	48	0.21	1.03	0.10	262	
										0.15	214	

$s = QW(u)/4\pi T$

$u = r^2 S/4tT$

s : drawdown
Q : pumping rate
W(u) : well function
S : coefficient of storage
r : radius of inflence
t : time since pumping started
T : coefficient of transmissibility

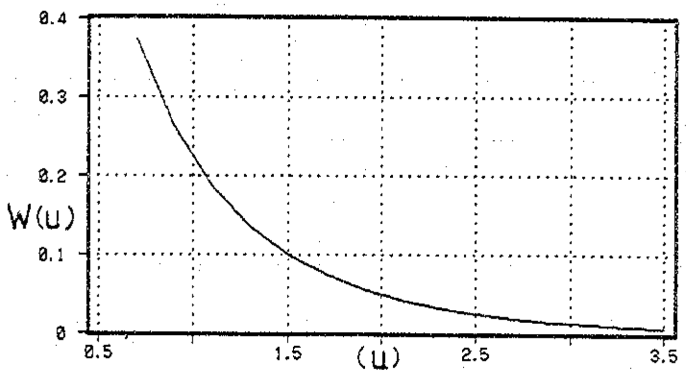


Table 4.8.7 TRITIUM CONCENTRATION

Sample No.	Sampling Place	Sampling Date	Principal Water-Beating Formation	Tritium Units
JI-T-1	Laguna de Masaya	1992 June	TQps (M) and TQpl	2.46 (±0.25)
JI-T-2	Laduna de Asososca	1992 June	TQps (M)	1.78 (±0.24)
JI-T-3	IRENA (Spring)	1992 March	QvM and TQps(M)	1.51 (±0.20)
JI-T-4	Ticuantepe (Well)	1992 June	TQps (M) and QvM	1.13 (±0.21)
JI-T-5	Veracruz (INAA's No.70 well)	1992 March	TQps (M) and QvM	1.17 (±0.21)
JI-T-6	Rio Mocuana (Spring)	1992 March	QvM and TQps(M)	1.96 (±0.23)
JI-T-7	Sabana Grande (INAA's No. 5 well)	1992 March	QvM and TQps(M)	1.29 (±0.21)

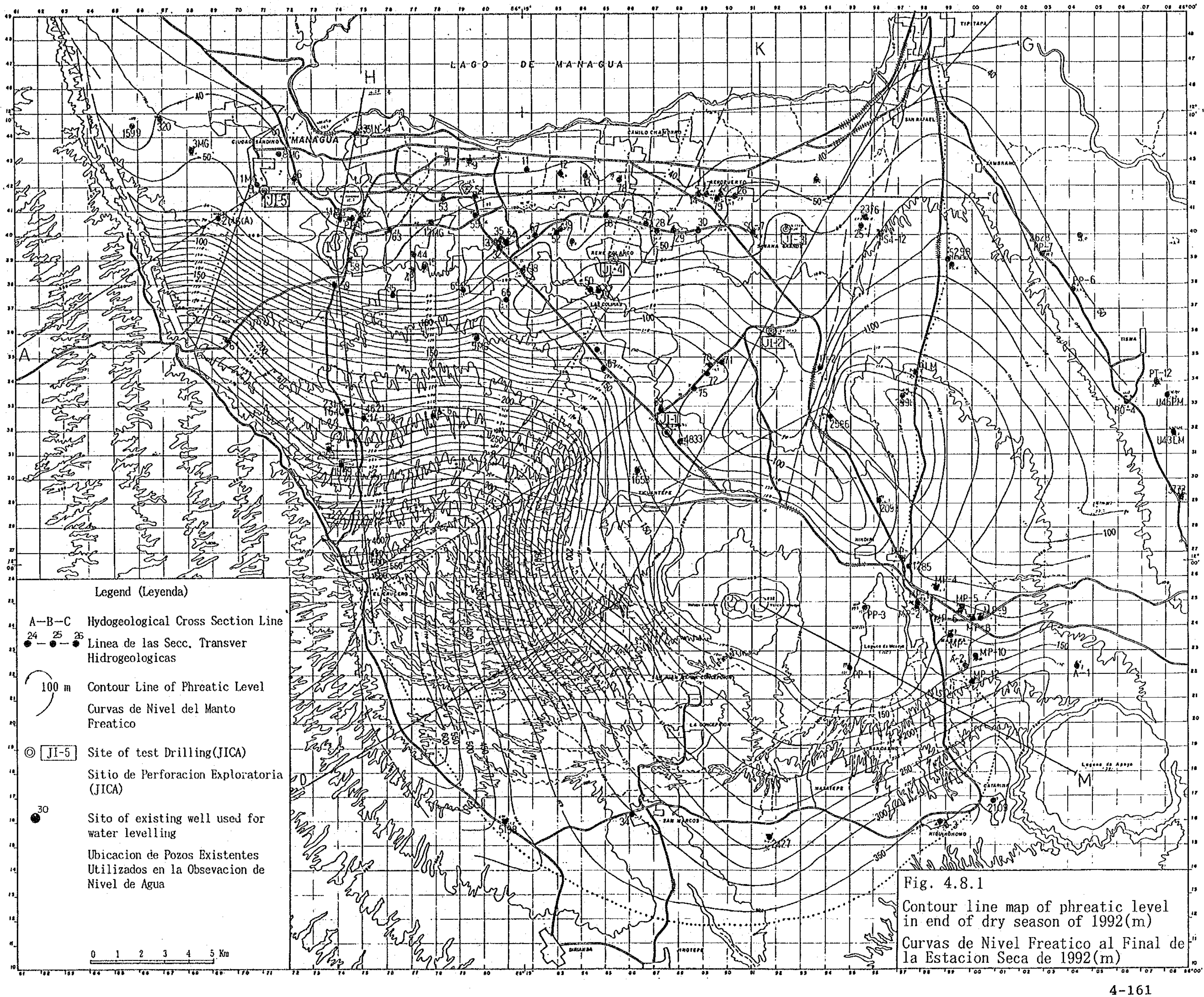


Fig. 4.8.1

Contour line map of phreatic level in end of dry season of 1992(m)

Curvas de Nivel Freatico al Final de la Estacion Seca de 1992(m)

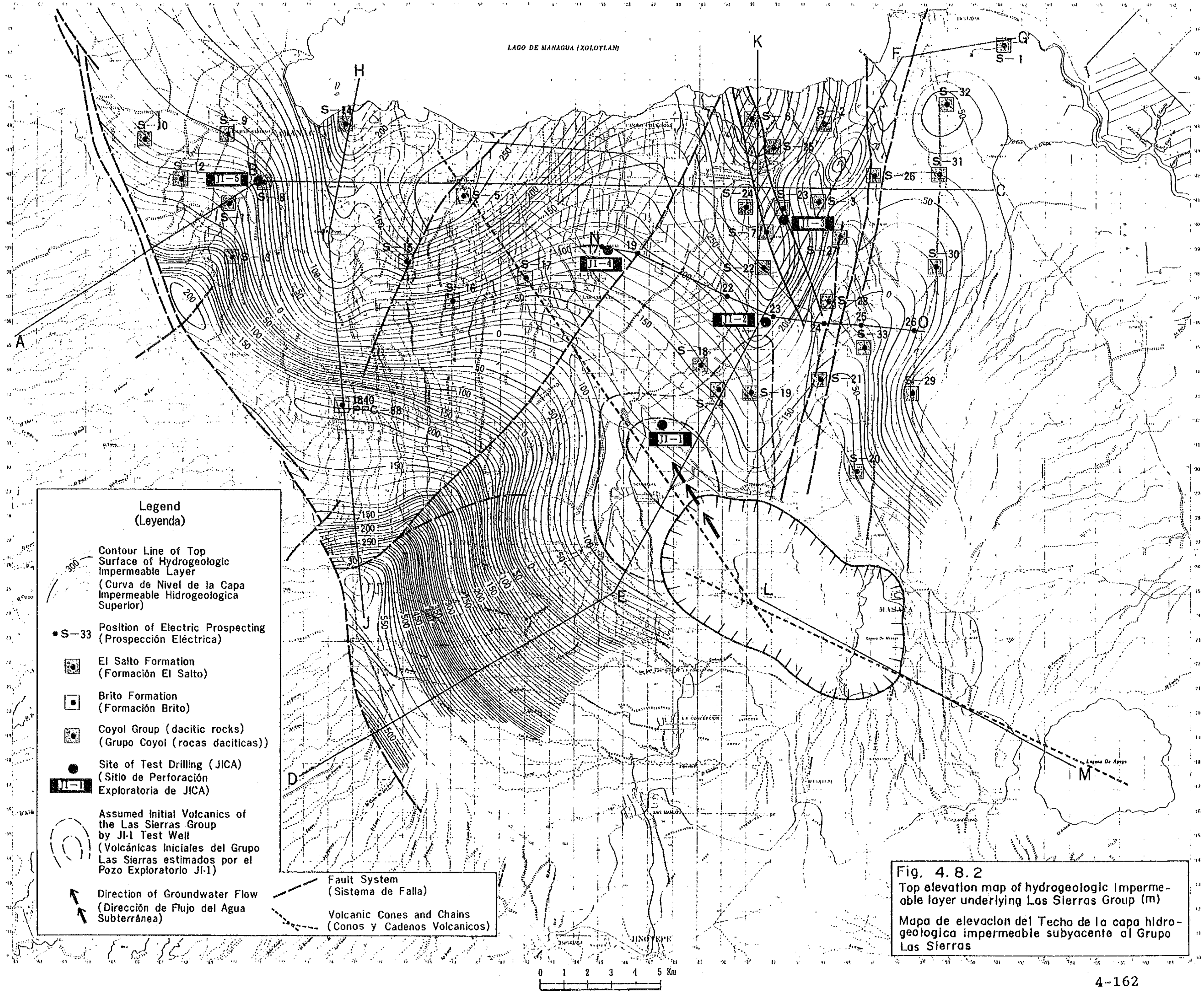


Fig. 4.8.2
Top elevation map of hydrogeologic Impermeable layer underlying Las Sierras Group (m)
Mapa de elevacion del Techo de la capa hidrogeologica impermeable subyacente al Grupo Las Sierras

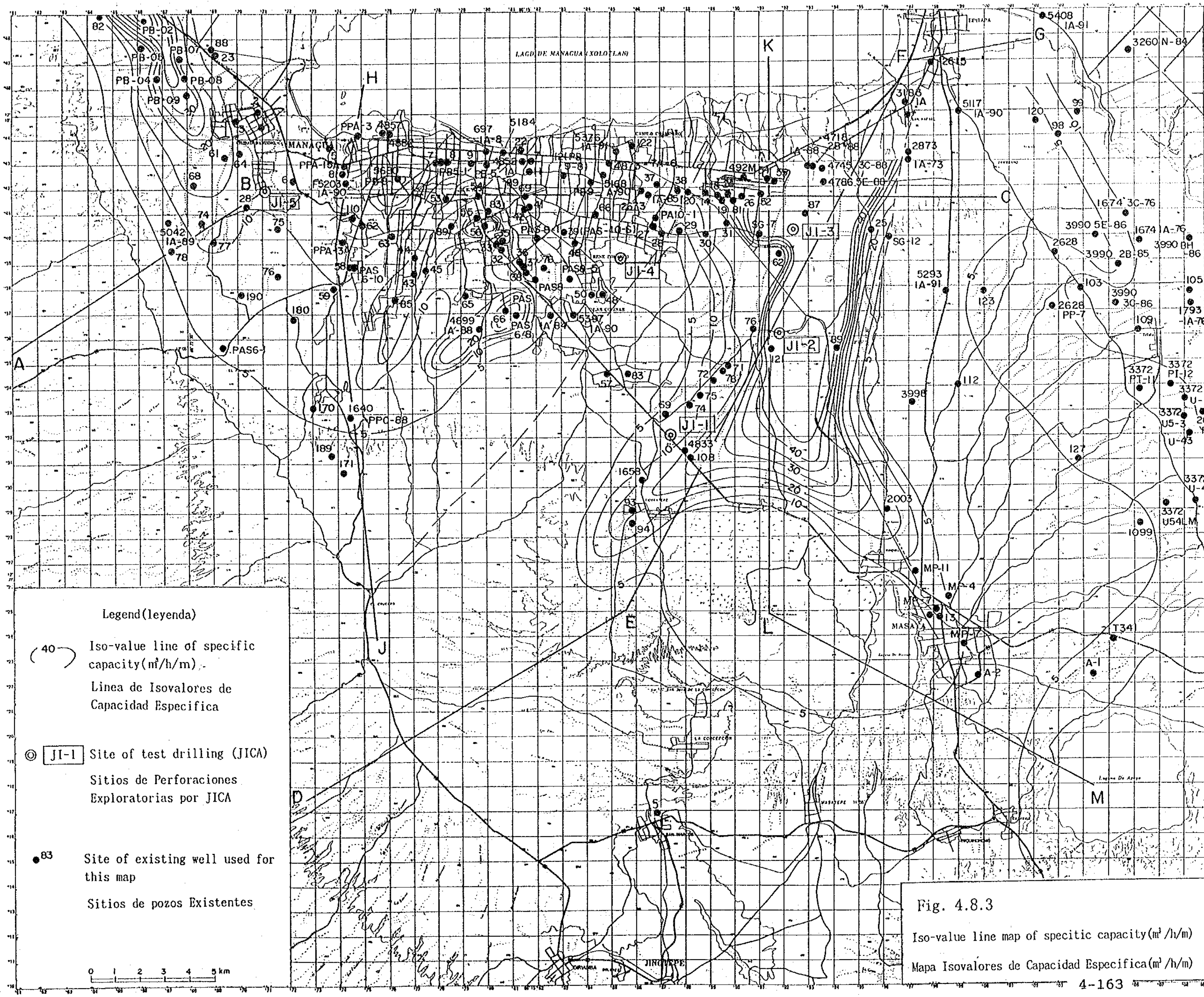


Fig. 4.8.3

Iso-value line map of specitic capacity(m³/h/m)

Mapa Isovalores de Capacidad Especifica(m³/h/m)

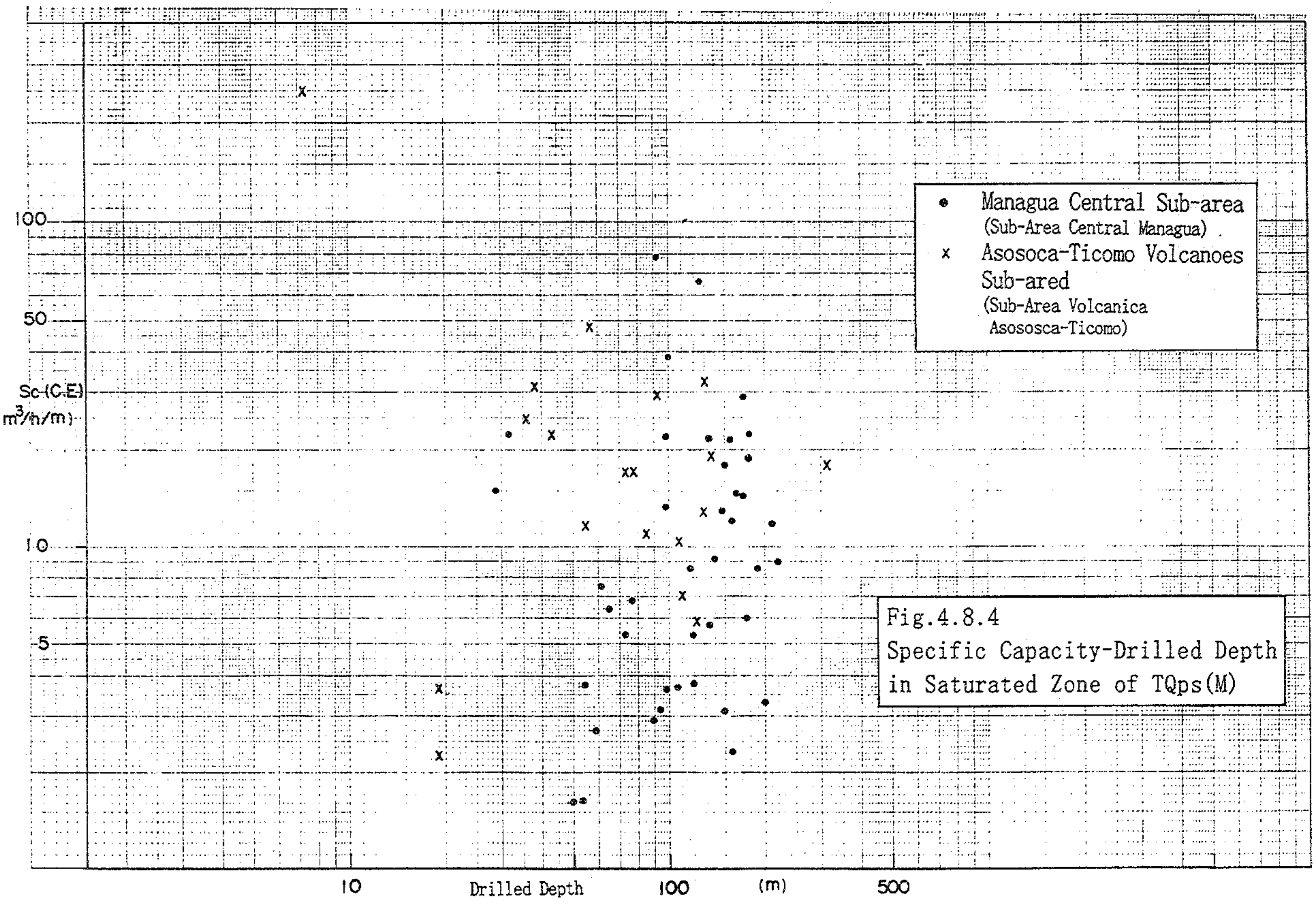


Fig.4.8.4
Specific Capacity-Drilled Depth in Saturated Zone of TQps(M)

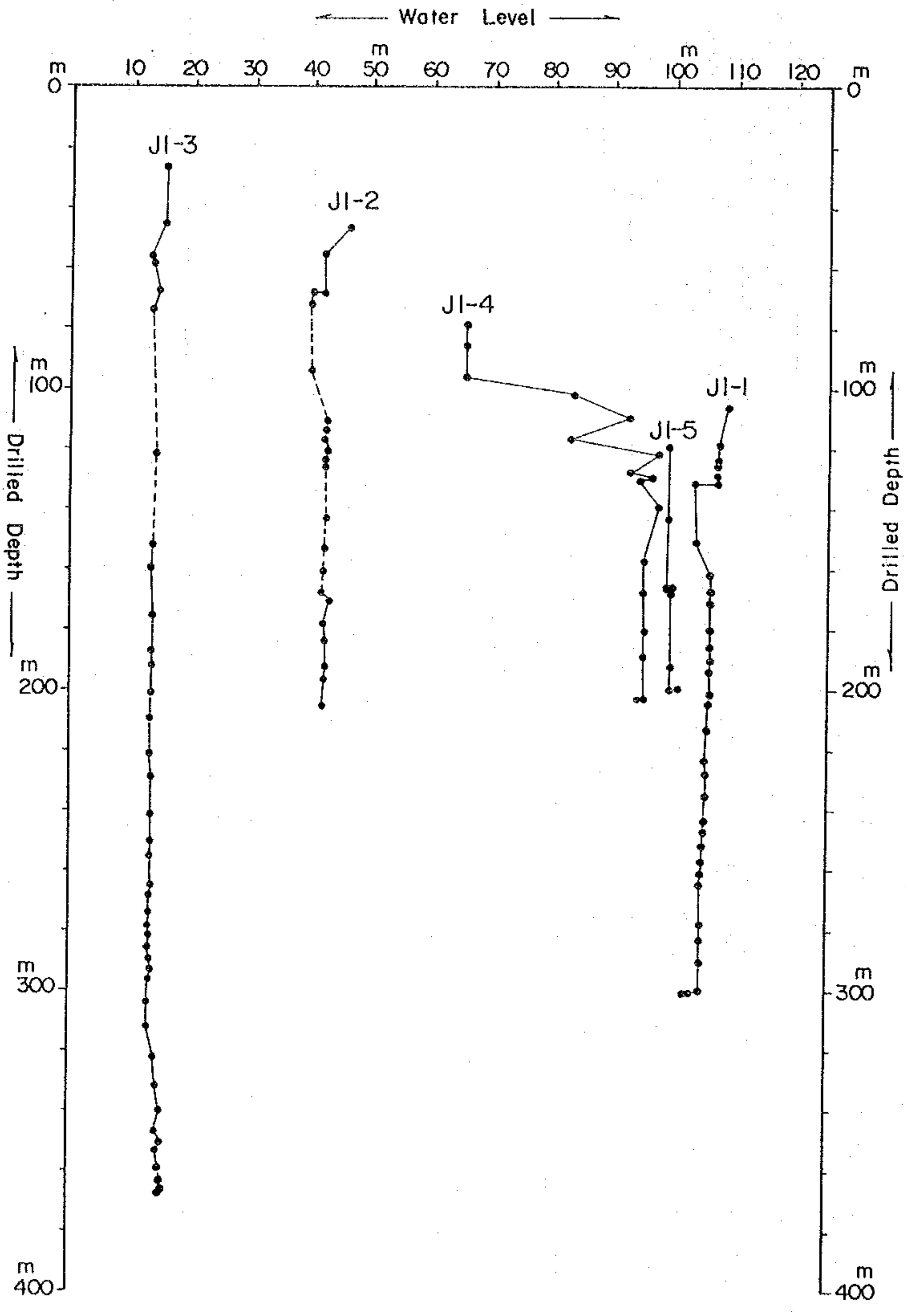


Fig. 4·8·5 Fluctuations of groundwater level

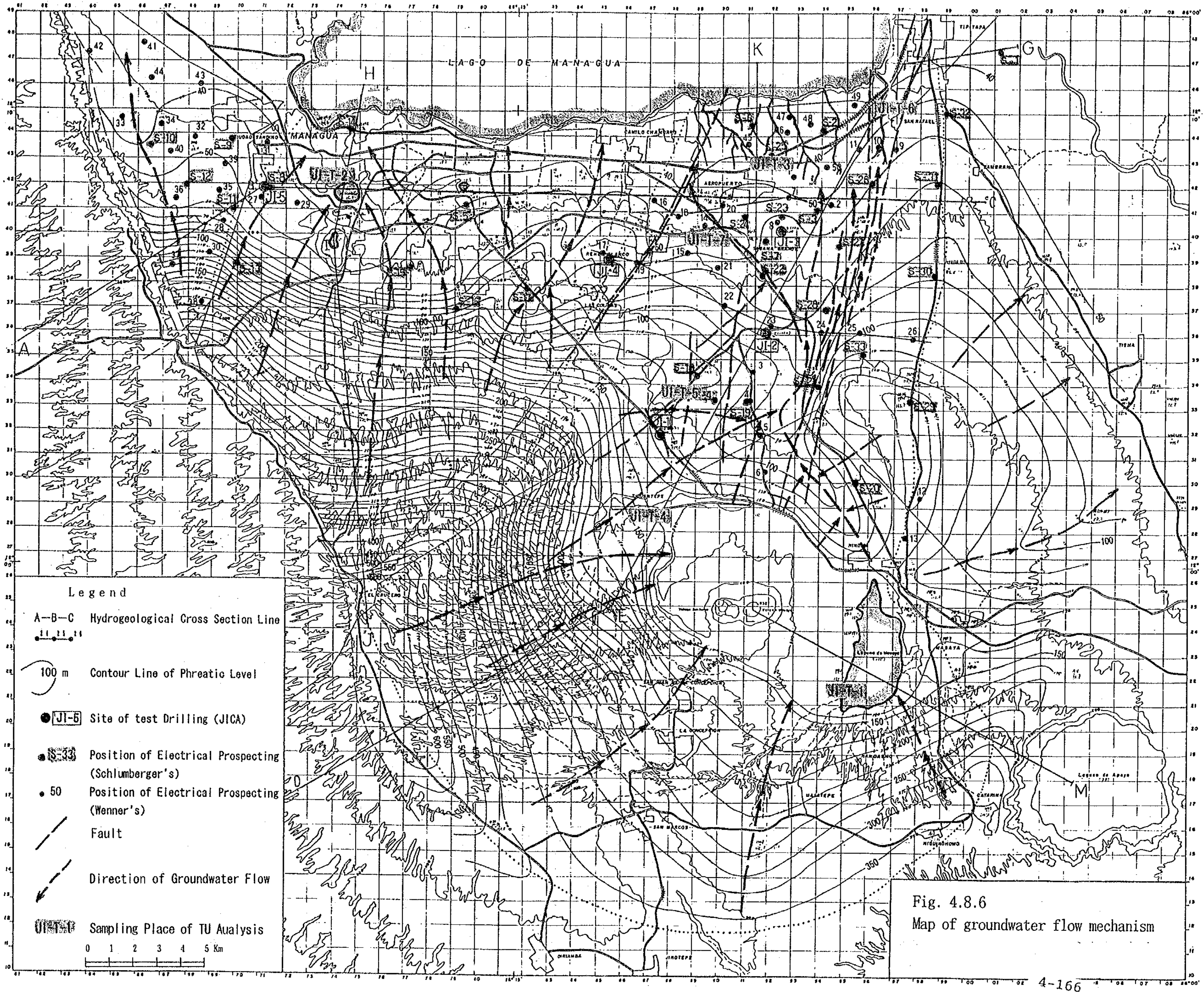


Fig. 4.8.6
Map of groundwater flow mechanism

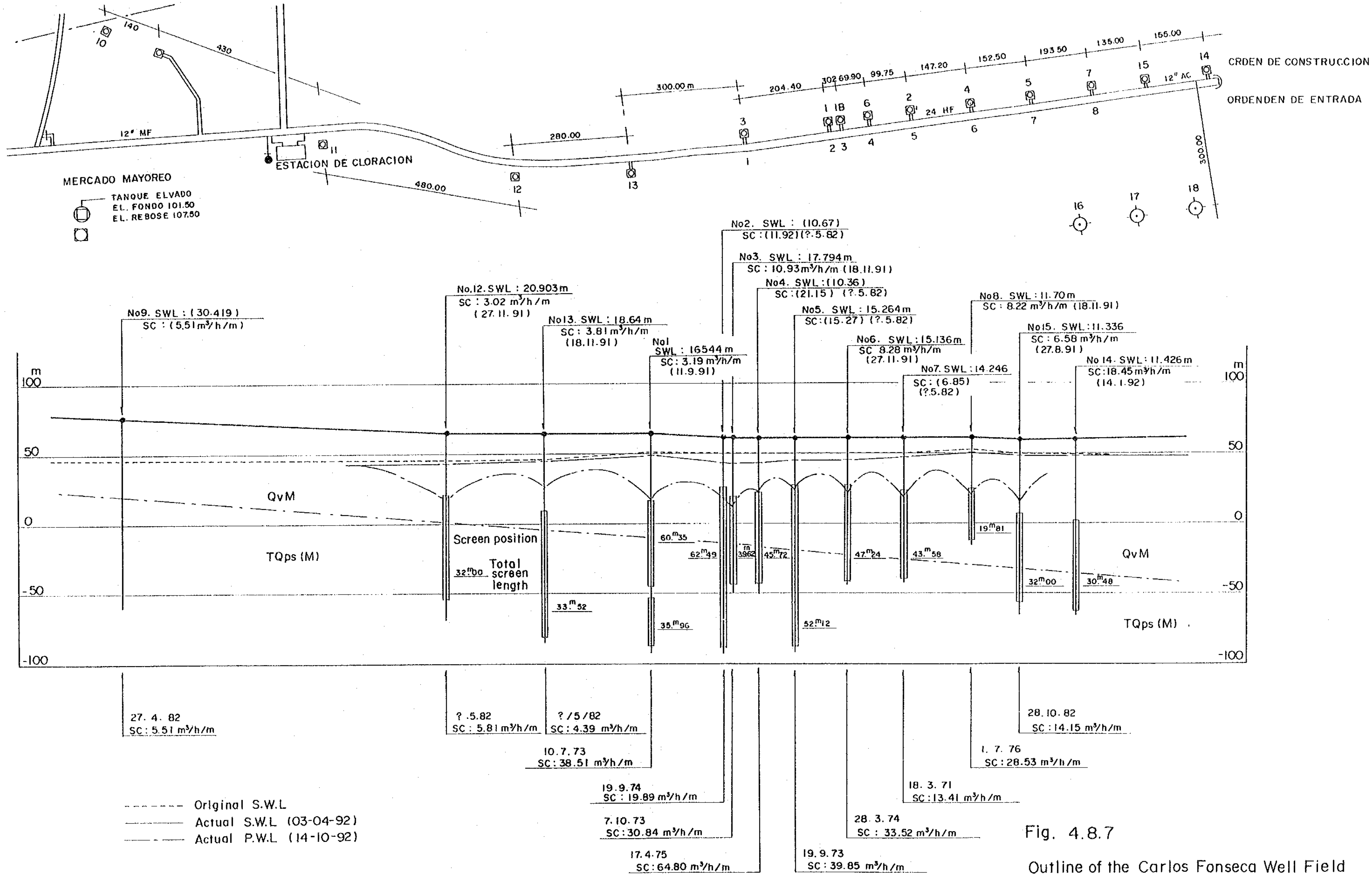


Fig. 4.8.7

Outline of the Carlos Fonseca Well Field

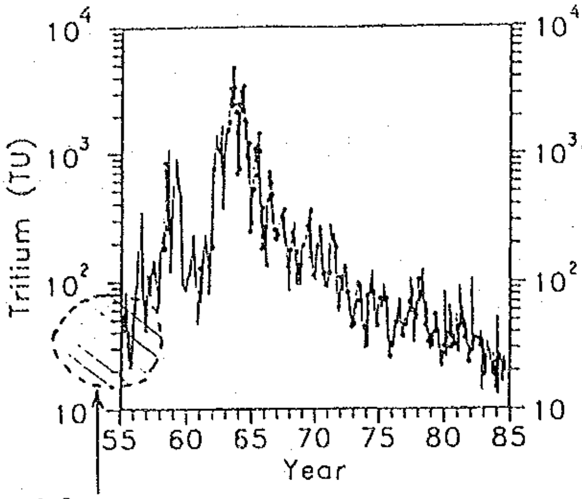
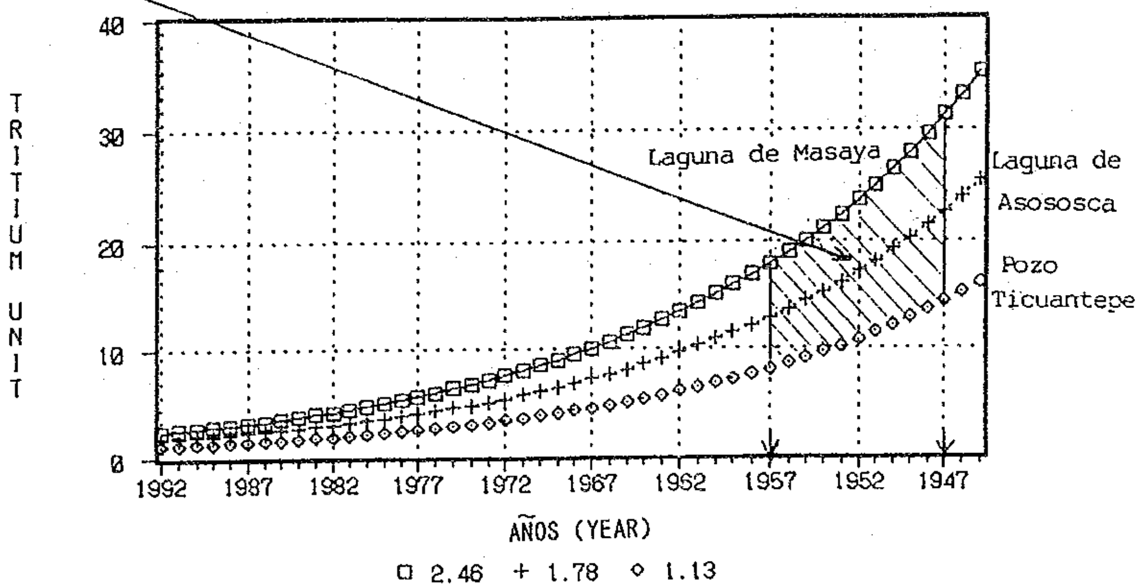
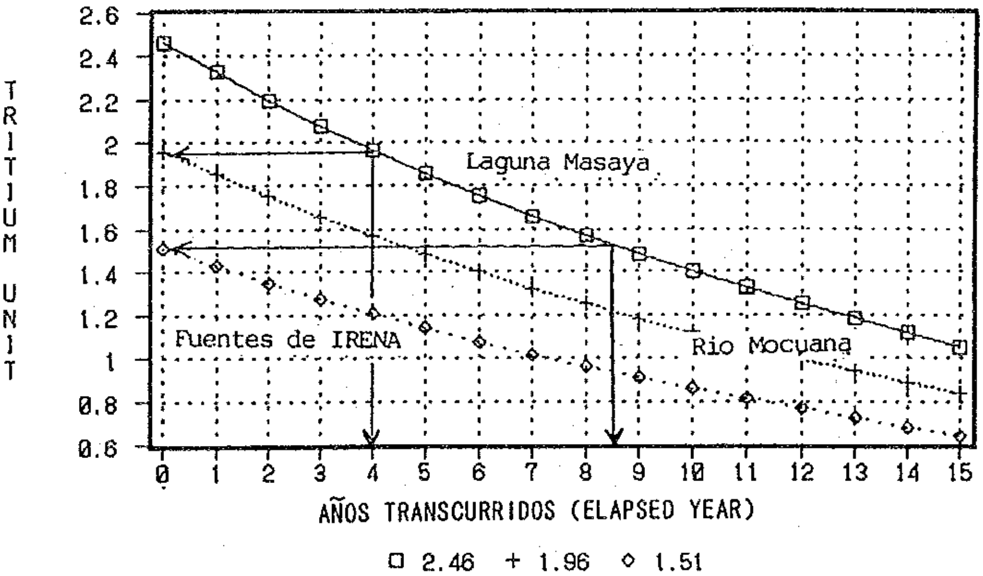


Fig. 4.8.8
Registros sintetizado de Tritio en las Precipitaciones de Madison Wisconsin .

Fig. 4.8.8 Synthesized record of tritium in precipitation at Madison, Wisconsin. Points indicate actual measurements at Madison.

Fig. 4.8.9 Historia de la unidad Tritio .
Fig. 4.8.9 HISTORY OF TRITIUM UNIT





4.9 Database

Information collected and surveyed on the meteorological, hydrogeological and water quality sectors have been arranged in a data base system in the computer.

The data base system mainly consists of two soft wares "Lotus-123" and "dbase III".

The summary of the input data is as follows:

(1) Meteorology

- Monthly temperature
- Monthly rainfall
- Monthly evaporation
- Monthly relative humidity
- Monthly velocity

(2) Well Inventory

(3) Water Quality

A part of the well inventory is attached in Data Book.

CHAPTER 5 EVALUATION OF GROUNDWATER

5.1 General

In order to evaluate the groundwater development scale, it is important to quantitatively evaluate the possible development amount based on regional hydrogeological condition.

"Storage" and "Yield" are terms generally used in groundwater potential evaluations. "Storage" refers to the total capacity of groundwater in the aquifer, and "Yield" refers to the amount of groundwater extracted, i.e., the former corresponds to "Static" and the latter to "Dynamic".

In the case of groundwater development, "Yield" has to be discussed because groundwater has already been extracted in the target area through pumping equipments, and due to the importance of evaluating the development "Yield" which varies due to changes in groundwater draw-down.

The term permissible groundwater development amount used herein generally refers to the "Safe yield of groundwater basin", and the three following terms are usually discussed in relation to the term.

- Sustained yield

This term is defined as groundwater amount continuously extracted from the groundwater basin.

- Mining yield

This term is defined based on the idea that groundwater is an irreplaceable resource like oil and natural gas. Since groundwater in this case is found in closed, non-leaky, confined aquifer, continuous extraction is not possible.

- Critical Water Level

This word is basically similar to the term "Safe Yield", and is based on the idea that is only focused on pumping draw-down. Critical water level is the level corresponding to the safety yield.

How to determine the "Safety Yield" is still a matter to be discussed, and the following four factors are normally involved in its regulation.

(a) Recharge factor: Safety yield should not over use the recharge cycle (Recharge factor).

(b) Pumping cost should be less than the cost of other alternative water supplies (Economic factor).

(c) Draw down by pumping should not cause the water quality to deteriorate (Water Quality factor).

(d) Extraction of groundwater should not be a violation of the water rights.

The following table summarizes the safety yield factors.

Safety Yield	Sustained Yield	<———>	Mining Yield
Groundwater Characteristics	Unconfined	<———>	Confined
Circulation	Rapid	<———>	Slow
Renewal	Renewed	<———>	Old
Criteria	Hydrogeological Balance	<———> (Water Rights, Water Quality)	Economic Risk

By considering these factors, it is concluded, therefore, that "Safety yield" should be used as "permissive yield" as it refers to the permissive standard in environmental pollution instead of a safety standard for natural conditions.

"Permissive yield" is defined as a socioeconomical category tolerated by the residents in consideration of the pumping risks and benefits.

Given this viewpoint, the following factors should be considered in the discussion on "groundwater management" in Managua City.

a) Macro-factors such as hydrogeological structure, rechargable potential, and water balance;

b) Critical factors such as the intrusion of the water of Lake Managua into Lake Asososca and other wells;

c) The intrusion of industrial waste water into Lake Asososca.

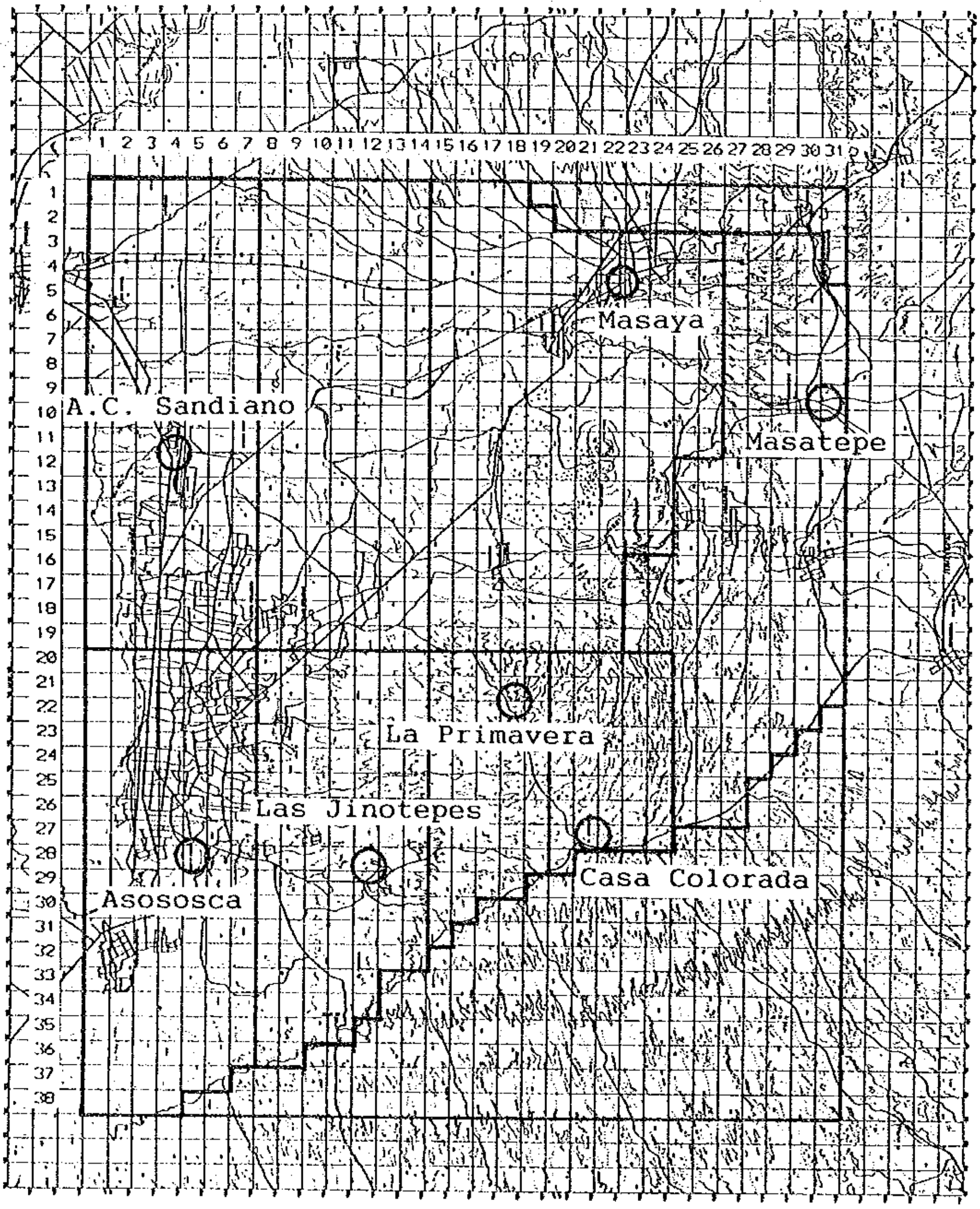
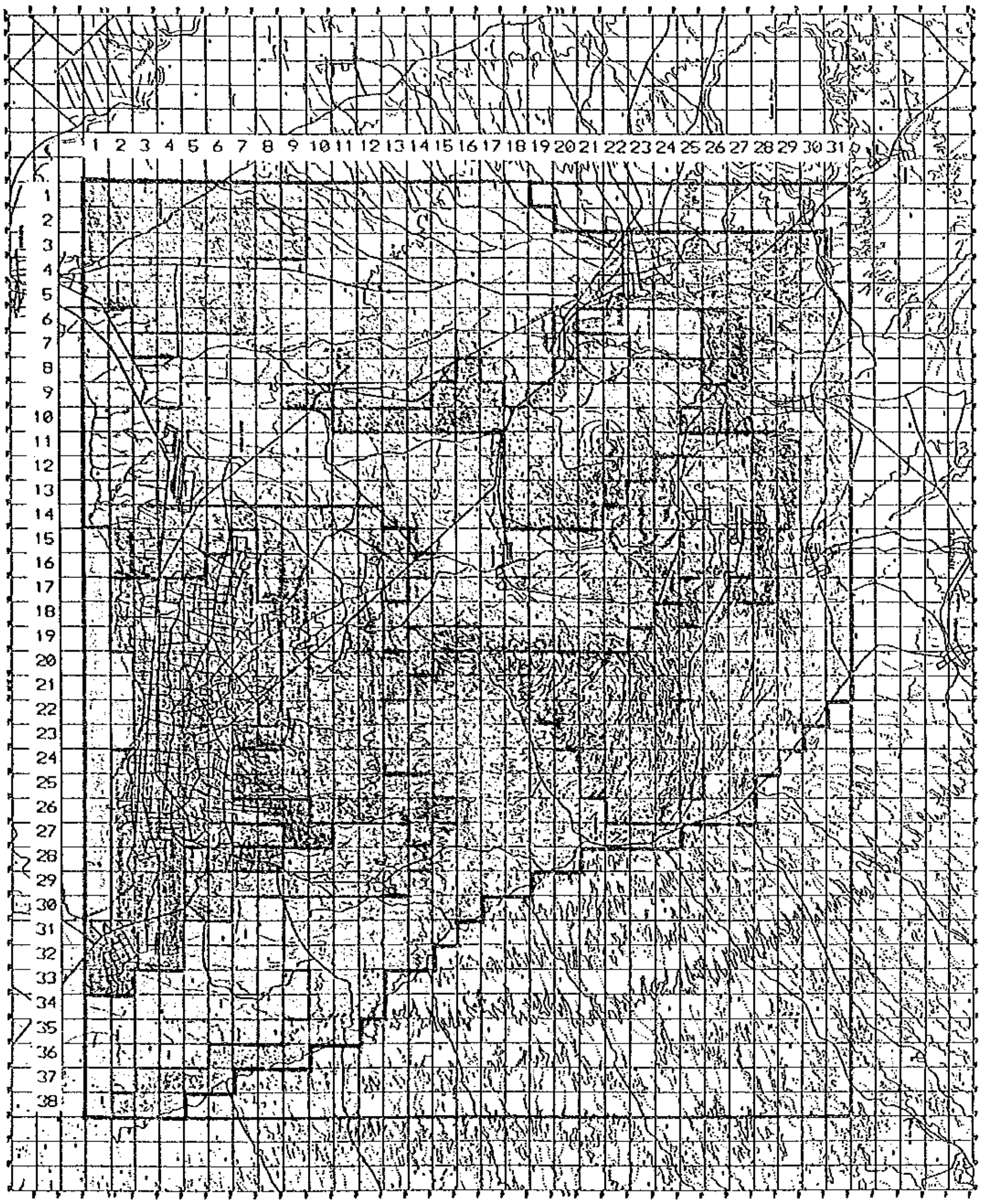


Fig. 5.2.1 Rainfall Block



Water area
Urban area
Qal
QvH
QvP, QvA, QvM
TQps(S,M), TQpl

Fig. 5.2.2 Recharge Block

5.2 Water Balance

5.2.1 Areal Rainfall and Recharge ratio

The evaluation of "recharge" is essential in groundwater potential evaluation. Various factors, i.e., land use and cover, geology, landslope, rainfall intensity, evapotranspiration, etc., have to be considered for the evaluation. However, there are some constraints in the data required for the verification of groundwater movement affected by rainfall and runoff condition.

In order to estimate areal recharge condition in the Study Area, annual rainfall and recharge ratios were used in 1km x 1km meshes applied in the model simulation to be discussed in the next section.
Point rainfall was directly employed to estimate areal rainfall. Fig. 5.2.1 shows the meteorological stations discussed in Section 3.2. in blocks. Because there is no station between the Airport and Masaya stations, the simple average of the annual rainfall of both stations was used.

The recharge ratio of the annual rainfall observed in previous studies was introduced in the report "Field and Modeling Studies of Groundwater Contamination of Laguna Asososca, Managua, Nicaragua", by David Norman Bethune in 1991.
This report compared several methods in order to estimate steady-state groundwater recharge, and a 22-30 % average annual rainfall is suggested due to topographic elevation.

"CUARTA ETAPA DEL PLAN MAESTRO DE AGUA POTABLE PARA MANAGUA", by HIDROTECNIA, 1988 conducted a water balance survey in the Sabana Grande-Cofradia-Veracruz area. As a result, three levels of recharge ratio, 15-20 % for the rainy year, 10-15% for normal year and 5-10 % for the dry year, were applied in the groundwater evaluation due to rainy conditions.

On the other hand, the relation between geological classification and infiltration was estimated in the Study "CUARTA ETAPA DEL PLAN MAESTRO DE AGUA POTABLE PARA MANAGUA" as 20 % in Qal, 50 % in Qvh, 35 % in Qvm, 15 % in Tps and Tpos.

In consideration of the above ideas, the Study Area was classified into the following 6 blocks and given recharge (infiltration) ratios based on the hydrogeological map shown in Fig 4.1.7 and the calibration discussed in the next section.

Class	Recharge ratio(%)
Water area	0
Urban area	10
Qal	20
QvH	40
QvP,QvA,QvM (flat area)	25
(steep area)	20
TQps(S,M),TQpl (flat area)	15
(steep area)	10

Fig. 5.2.2 shows the distribution of recharge ratio.

The ratio for the mountainous area was reduced 5 and less than original value because the steep slope has a higher runoff ratio and because the water that floods the flat area can be evaporated and used for recharge.

Recharge in Masaya and Asososca lakes and the spring zone in Sabana Grande, lowland area is neglected because evaporation from open water surfaces and evapotranspiration from swamps or wet areas are considered to be higher than the rainfall amount in the annual water balance.
The method used for recharge estimation is still very rough in this stage and has to be considered along with future monitoring data.

5.2.2 Water balance

A rough estimate of the water balance in the Study Area can be calculated based on the recharge ratio discussed above, annual rainfall and the pumping discharge discussed in Chapter 3.2-4.

Western sub-area (I) includes Ciudad Sandino and surrounding area; Managua central sub-area (II) covers the central part of Managua City; and the eastern-sub area (III) extends from Sabana Grande-Cofradia to the southern edge of the Study Area.

The annual rainfall and recharge ratios were calculated according to the mesh concept above mentioned. Tha annual rainfall calculation arrived at a 50% probability, a ratio corresponding to the average annual rainfall mentioned in Section 3.2.

The results of the calculation are shown below.

Annual Water balance

Hydrogeological Basin	I	II	III
Area(km^2)	54	237	499
Annual Rainfall (mm)	1151	1211	1289
Ratio(%)	18.0	18.1	21.0
Annual Groundwater Recharge (million m^3)	11.19	51.95	135.07
Annual Groundwater Potential (million m^3)	8.9	41.6	108.0
Pumping Discharge in 1991 (million m^3)	3.1	69.5	39.2
Balance	5.8	-27.9	68.8

The simple averages of annual rainfall (mm) and recharge ratio (%) calculated for each basin were used. According to the probability analysis in Section 3.2, the 5-year non-exceedable probability rainfall value corrsponds to around 80% of the average rainfall, therefore, the estimated potential amount is tentatively calculated according to this percentage.

The results indicate the following values:

(a) The results clearly indicate over-pumping in basin II even with the pumping discharge in 1991.

Around 27 million m^3 must be subtracted from the total pumping discharge to stabilize the hydrological cycle.

(b) Basin I was estimated to have a groundwater potential of around 6 million m^3.

(c) Basin III is expected to have agroundwater development potential of almost 70 million m^3.

5.3 Groundwater Modeling

A groundwater flow model for confined aquifer systems in the Study Area is constructed based on hydrogeological analysis. This modeling activity is undertaken to predict future groundwater movement and specifically to:

(a) Describe the hydrogeological conditions that led to heavy decline in groundwater head; and

(b) To estimate the movement of groundwater resulting from alternative schemes of future aquifer utilization or regulation.

5.3.1 General

Because groundwater is essentially an invisible resource, studies on groundwater movement under natural and artificial conditions require modeling techniques. Several types of models have been developed and used for this purpose. These models may be subdivided into four major categories; porous media models, miscellaneous analog models, electrical analog models, and digital computer models for numerical solution of aquifer flow equations.

In recent years, digital computer models have gained wider acceptance as they foster more efficient groundwater resource management. These tools have considerable capability to aid decision-making in relation to the various uses of both actual and potential groundwater systems.

Flow models consist of a set of differential equations that are known to govern the flow of groundwater.

Reliability of prediction using a groundwater model depends on how well the model approximates the field situation. As natural aquifer systems are inherently complex and uncertain, construction of the model is always required in the making of assumptions and simplifications. It is very important to keep this awareness about the model, even though sophisticated numerical techniques and high-speed computers have already been developed.

5.3.2 Groundwater Flow model

(1) Model Concept

The digital model used for the Study is a quasi three-dimensional model (Q3P). Its basic concept is that water in the main confined aquifer is supplied by lateral flow through the aquifer and by a vertical flow through the aquitard from overlying phreatic aquifer.

Groundwater flow in a groundwater basin is naturally three dimensional. But if the draw down of piezometric heads by groundwater discharge is small, the groundwater flow can be treated as lateral in two dimensions. This is because vertical flow such as leakage through confining layers and squeeze from clayey layers are negligible.

On the other hand, large draw down of the piezometric heads makes the groundwater flow pattern more complicated and three-dimensional. The three-dimensional model is thus the best suited to simulate groundwater flow. It is difficult, however, to simulate a three dimensional groundwater flow given the complexity of the structure of a groundwater basin, the inadequacies of input data, and the limitations of numerical solution techniques and memory capacity of a computer. Therefore, the quasi three-dimensional model has been developed and widely used for practical purposes.

(2) Groundwater Flow Equation

Neglecting the vertical flow component in the main confined aquifer and the horizontal flow component in aquitard, the basic equation of the motion of the system is expressed as follows.

$$T\left(\frac{\partial^2 h}{\partial x^2}+\frac{\partial^2 h}{\partial y^2}\right)=S\frac{\partial h}{\partial t}+W(x,y,t) \qquad (5.1)$$

Where,

T	:	transmissivity, L^2/T
S	:	storage coefficient, dimensionless
h	:	hydraulic head, L
t	:	time, T
x,y	:	spatial coordinates, L
W(x,y,t)	:	volume flux per unit area, L/T.

W(X,Y,t) can be expressed as:

$$W(x,y,t)= Qd(x,y,t)+k'/b'(h-H) \qquad (5.2)$$

where,

Qd(x,y,t)	:	the rate of withdrawal or recharge, L/T
k'	:	the permeability of the confining layer (aquitard), L
b	:	the thickness of the confining layer (aquitard), L
H	:	the phreatic water level , L

The second term on the right hand side of Equation (5.2) is the leakage through confining layer from phreatic aquifer defined by Hantush and Jacob (1955).

Equation (5.1) and (5.2) can be solved by the finite-difference method or finite-element method. A schematic cross section of the quasi three-dimensional groundwater model is illustrated in Figure 5.3.1.

This study employed the finite-element approximation using rectangular elements to simulate the groundwater basin model. Figure 5.3.2 shows the conventional procedure in Q3P model.

(3) Required Input Data and Output Data

The required input data for the Q3P model are as follows:

for model framework

Element data
Node data
Boundary conditions
Model control card

for hydrogeological settings

Transmissivity
Storage coefficient
Aquitard thickness
Aquitard permeability
Phreatic water level
Initial piezometric heads
Direct recharge data

for groundwater use

Discharge data

The output data from the model are:

- Piezometric heads distribution in each time step
- Changes of piezometric heads at specified nodes
- Water balance components in specified area

(4) Model Assumption

The model assumes that hydrogeologic parameters such as transmissivity, storage coefficient and leakage are not affected by changes in piezometric heads. Also the model needs to assume that those parameters and boundary conditions do not change over time. Additionally, the leakage from aquitard is neglected in this model because direct recharge is applied here.

In order to conduct a model simulation analysis, "recharge", "pumping discharge", and "aquifer parameters" have to be considered with actual field condition.

5.3.3 Boundary Condition and Model Parameters

A model frame work was prepared based on the hydrogeological evaluation discussed in Section 4.8.

Principal concepts on modeling are summarized below: Fig. 5.3.3 and 5.3.4 show the finite-element grid and boundary conditions.

(a) 1 km x 1 km mesh of topographical map (scale 1:50,000) is used for unit element.

(b) The model area is the whole Study Area, however, Ciudad Sandino is omitted due to the cpu memory size (see Fig.5.2.1).

(c) Unconfined aquifer by direct recharge is applied on the model. Depth of aquitard and its leakage is neglected as mentioned in Model Assumption.

(d) As shown in Fig. 5.3.4, boundary conditions in watershed are composed of flow divide and constant head.
Watershed on western and southern mountains is considered as flow divided boundary. In case of western watershed, this boundary is very clear for this condition, however, southern boundary in Carazo Area is complicated because there is a possibility that groundwater flows to the east.

(e) As mentioned in the section on groundwater level, the water level of Managua Lake varies by rainfall, evaporation and groundwater recharge. For simplification, the water level of this lake was assumed as constant. When calibration was performed, a constant head was used based on the April values in these 20 years. And the average of these 10 years was used for future prediction.

(f) Spring zone is also considered as constant head boundary.

(g) The mount in the groundwater in the eastern boundary is considered as the moving boundary of the flow from Masaya Lake and the pumping zone in the Tisma irrigation field.

Therefore, model parameters (storage coefficient or transmissivity) are modified even as dummy values for calibration.

(h) Calibration (calculation steps) took 20 years, starting from 1972. Initial head in 1972 is considered for the 1992 groundwater table made by steady states calibration.

5.3.4 Aquifer parameters

(1) Storage coefficient

A 10% storage coefficient was basically adopted and the Sabana Grande area and the area around lake Asososca were given 20% and 15%, respectively, because the storage coefficient of the unconfined aquifer in the Study Area is geologically estimated at 5 - 20%. Fig. 5.3.5 shows the representative specific yield range.

(2) Transmissivity

Transmissivity is based on the specific capacity map shown in Fig. 4.8.3, and converted by the following formula:

$$T = 1.22 \times 24 \times Sc$$

Additionally, the following points will be considered to modify the parameters.

(a) The Sabana Grande area shows high potentials of transmissivity estimated at a minimum of 1500 m^2/day, and a higher value can be found along the fault system running through Volcano Masay - Mocuana river.

(b) The surrounding area of Lake Asososca is also considered to show high transmissivity. The following studies were conducted for the model analysis in the area.

- "BALANCE HIDROLOGICO DE LA LAGUNA DE ASOSOSCA" by UNIVERSIDAD NACIONAL AUTONOMA DE NICARAGUA, 1989

Water balance is determined by the water level in the dry season of 1963-1978. Potential transmissivity in this area was calculated at 2400-6600 m^2/day.

- "FIELD AND MODELING STUDIES OF GROUNDWATER CONTAMINATION OF LAGUNA ASOSOSCA, MANAGUA, NICARAGUA"
  by David Norman bethune, 1991

  A two dimensional steady-state groundwater flow modeling was conducted. Hydraulic conductivity was 0.07-4.0 m/day in the mountainous zone and 10-400 downstream.

(c) According to the Sc Map, high transmissivity can not be expected from the center of central Managua, between Lake Tiscapa and west of the Airport.

(d) Sabana Grande low land area has low transmissivity on the Specific Capacity Map. However, many springs producing swamps and wet zones can be found in the area, except for Mocuana river. Therefore, a high value should be adopted in order to conduct calibration.

(e) The eastern boundary will be tried to form the existing water table with high storage coefficients. However, high coefficients were basically used for unconfined aquifer, therefore, transmissivity will be modified in order to form the existing condition.

Typical K values for consolidated and unconsolidated aquifers are shown in Fig. 5.3.5.

5.3.5 Calibration

The objective of calibration is to review the reality of "the model" by "the parameters" provided from described comprehensive hydrogeological analysis.

This inspection is practically based on researched water level, pumping discharge and estimated recharge. Hydraulic parameters are to be modified under this trial and the most appropriate is to be selected.

(1) Steady and Non-steady states simulation

Calibration was initially carried out in steady-states conditions to identify the initial head and other parameters of the model. The simulated piezometric heads were observed at selected points as shown in Fig. 5.3.6. The condition given here is based on the 1972 data of the survey on pumping discharge and rainfall, and the calculation steps covered 20 years.

On the other hand, the information on groundwater tables in some parts of the Study Area were estimated by Hazen and Sawer in 1971 and based on the "PROYECT DE INVESTIGACIONES DE AGUAS SUBTERRANEAS EN LA REGION DEL PACIFICO", NACIONES UNIDAS conducted in 1972.

In comparison with these maps and the 1992 groundwater table prepared in this Study, the appropriate groundwater table in 1972 was considered to have been prepared by trial and error. This work was performed until the change in the piezometric head was made negligibly small.

A non-steady state simulation was carried out from 1972-1992 to review the decline in piezometric heads due to increased pumping discharge in the center of Managua City. The calculation steps covered 20 periods, wherein a step is equivalent to 1 year(365 days), from 1972-1992.

(2) Results of calibration

Fig 5.3.7 and 5.3.8 show the final distributions of storage coefficient and transmissivity.

Storage condition was determined by the trial results of 5% - 20%. The transmissivity ratios in Sabana Grande area, Lake Asososca area were increased to around 10000 m^2/day along with the estimated fractured zones.

Higher values are given to form the eastern boundary condition, and the values on the one-line element N-S were changed to 15000 because the storage coefficient is higher in the whole area and is not enough to change the water table to the actual condition. Therefore, the eastern condition was made by using dummy parameters and necessitated the use of other works, too.
High values of 12000 m^2/day was given to Lake Masaya, the Volcanic area and the S-N zone from this area to Mocuana River. Detailed hydrogeological condition of this zone is mentioned in Section 3.8. Additionally, the same value was given to the surrounding area of the test drilling site JICA-1, located North of Ticuantepe, because the pumping test results confirmed high potentiality.