Layer	Thickness (m)	Resistivity (ohm-m)
1st Layer	10-120	28-1,400
2nd Layer	20-400	10-50
3rd Layer	>50	<10
4th Layer		>100

The 2nd layer is considered as expected aquifer.

2) Boring Test

Eleven (11) wells including four (4) test wells (J-C to J-F) and seven (7) observation wells (J-3 to J-9) were drilled in the whole area of Pampa del Tamarugal. The well locations were set on the TEM survey lines in principle as shown in Fig. 2.16.

The results of the boring tests are summarized in Table 2.5. The table shows borehole depth, dimensions of casing and screen pipes, geological features of the identified aquifers and resistivity of well logging, compared with that of TEM survey. For columnar sections of the 11 wells, see Fig. 2.19 and Fig. 2.20.

Further, pumping tests including step drawdown test, constant discharge test and recovery test were executed for the above 11 wells.

The results of the pumping tests are summarized in Table 2.6. The table shows pumping data by constant test, aquifer constants and well capacity.

2.3.5 Aquifer

1) Configuration of Aquifer

Location and size of the aquifers were estimated based on 11 boring tests of JICA and three (3) boring tests of ENAP.

Geological profiles and cross sections of the aquifers are shown in Fig. 2.19 and Fig. 2.20 respectively. For their location, see Fig. 2.18.

The aquifers exist in Altos de Pica Formation. Altos de Pica Formation consists of the units of Q_1, Q_2, Q_3 and Q_4 of which the aquifers appear in the units of Q_3 and Q_4. These units are underlain by thick impermeable clayey beds of Q_2.

The unit Q_4 consisting of sand and gravel with mud is distributed over the whole aquifer area. On the other hand, the unit Q_3 consisting of sand and gravel is limited in the area from Huara to Salar de Bellavista. No impermeable layers are identified between the units of Q_3 and Q_4.

The aquifer area is enclosed by the following boundaries:

To the north	:	watershed of Aroma River Basin.
To the south	:	Cerro Gordo.
To the east	:	mountain foot of Andes. This border is formed by the faults running on the west of Pica and Tarapacá.
To the west	:	eastern edge of the coastal mountains. This border is formed by faults.

For location of the aquifer area, see Fig. 2.21.

Length of the aquifer in the north-south direction is approximately 130 km. On the other hand, the width in the east-west direction is 13 km to 46 km, averaging 30 km.

Thickness of the aquifers increases toward south from about 80 m at the northern fringe to 200 m at Salar de Pintados.

Thickness, width and level of the aquifers are summarized below.

Area	Thickness (m)	Width (km)	Top Level* (m. BGL)	Base Level* (m. BGL)
Zapiga/Dolores	80	13-17	10	90
Negreiros	70	15	20	90
Huara	60	15-19	50	110
Humberstone	155	27	30-40	180-200
Pozo Almonte	225	26	20-30	240-260
Pintados	200	30-37	10-30	220
Bellavista	110	30-46	10-60	120-170

* : Level below ground surface

2) Hydrogeological Characteristics of Aquifer

The aquifers of Pampa del Tamarugal exist in the units of Q_3 and Q_4 of Altos de Pica Formation. Q_3 consists of sand and gravel. Q_4 is composed of sand and gravel which are mixed with mud and in some places, intercalated with mud layers.

Q_3 and Q_4 are hydraulically regarded as one (1) body although their geological compositions are different. No impermeable layers are identified between Q_3 and Q_4.

Hydrogeological characteristics of the aquifers including specific yield, transmissibility and permeability are evaluated based on the pumping tests of JICA along with the previous pumping tests.

The results of JICA pumping tests by area are summarized as follows.

Area	Well No.	Specific Yield (l/sec/m)	Transmissibility (m^3/day/m)	Permeability (cm/sec)
Dolores	J-3	0.73	113.81	2.20×10^{-3}
Negreiros	J-4	2.22	271.08	5.22×10^{-3}
Huara	J-C	0.09	8.29	1.23×10^{-4}
	J-D	3.47	1506.17	1.81×10^{-2}
Pozo Almonte	J-5	8.33	769.61	8.23×10^{-3}
	J-E	6.77	644.33	7.31×10^{-3}
Canchones	J-6	0.26	21.63	3.20×10^{-4}
	J-7	2.72	383.83	5.30×10^{-3}
Pintados	J-8	2.18	376.27	5.18×10^{-3}
Bellavista	J-9	1.92	266.06	3.54×10^{-3}
	J-F	1.65	86.81	9.57×10^{-4}
Average		2.76	404.35	5.13×10^{-3}

The results of the previous pumping tests are summarized in Table 2.7.

Specific yield and transmissibility of both tests are in well agreement. The average specific yield and transmissibility of the whole aquifer area by two (2) pumping tests are compared as follows.

	Average Specific Yield (l/s/m)	Average Transmissibility (m^3/day/m)
JICA Test	2.76	404
Previous Test	2.27	547

However, the permeability of the two (2) pumping tests are much different.

In this report, the average specific yield and transmissibility of each aquifer area are estimated by averaging all the data of the two (2) pumping tests. However, the average permeability of each aquifer area is estimated based on the JICA pumping tests, considering reliability of the data.

The results are summarized below:

Aquifer Area	Specific Yield (l/s/m)	Transmissibility ($m^3/d/m$)	Permeability (cm/s)
Zapiga/Dolores/Negreiros	0.94	202	4×10^{-3}
Huara	2.91	702	9×10^{-3}
Pozo Almonte/Canchones/Pintados	3.41	826	5×10^{-3}
Oficina Victoria/Bellavista	1.46	205	2×10^{-3}
Whole Area	2.37	502	5×10^{-3}

3) Estimated Groundwater Storage

The total groundwater storage of the aquifers in Pampa del Tamarugal is estimated to be 26,900 million m^3 with the following break-down by zone.

Zone	Geological Section	Storage (10^6 m^3)	Included Communities
1	A-A' to B-B'	3,638	Dolores, Negreiros
2	B-B' to C-C'	886	
3	C-C' to D-D'	867	
4	D-D' to E-E'	1,057	Huara
5	E-E' to F-F'	2,077	Baquedano, Humberstone
6	F-F' to G-G'	1,116	Pozo Almonte
7	G-G' to H-H'	2,031	
8	H-H' to I-I'	4,405	La Tirana, Huayca
9	I-I' to J-J'	2,373	Canchones
10	J-J' to K-K'	3,411	Pintados
11	K-K' to L-L'	3,398	Oficina Victoria
12	L-L' to Southern End	1,624	Cerro Gordo
Total		26,908	

In this estimation, the effective porosity of the aquifers is assumed to be 30%.

For location of the above sections, see Fig. 2.18.

2.3.6 Groundwater Level and Quality

1) Existing Groundwater Extraction

The existing groundwater extraction from the aquifers of Pampa del Tamarugal was estimated, based on the interviews to the users which was conducted in this study. The results are summarized below.

Water Use	Extracting Quantity (l/s)
Domestic Use	660.65*
Irrigation Use	0.35
Mining Use	35.00
Total	696.00

* Includes the military water use.

The above quantity excludes the groundwater extraction in Pica and Matilla area, and upstream river valleys which are located outside the aquifers of Pampa del Tamarugal.

2) Existing Groundwater Level

Static groundwater level of the Pampa del Tamarugal has periodically been observed for approximately 40 wells by DGA since 1981. In addition to this, static water level of 160 wells were observed by this study in October to November, 1993.

(1) Depth of water level (m, BGL): water level below ground surface.

The contour map of the depth of water level is shown in Fig. 2.22.

The depth is shallow in the central to western part of the aquifers, especially in Salar de Pintados and Salar de Bellavista. The depth increases toward east because the eastern part of the aquifers is covered by thick Fan Deposits.

Depth of the water level by region is summarized as follows.

Region	Depth of Water Level (m.BGL)
Zapiga, Dolores and Negreiros	10 - 50 m
Huara to Pozo Almonte	20 - 50 m
Salar de Pintados	10 m
Salar de Bellavista	< 15 m

(2) Water Level (m. MSL) : water level above mean sea level.

The water level of the aquifers gradually becomes lower toward south from 1,150 m. MSL at Zapiga to 909 m. MSL at Salar de Bellavista. The gradient of water level is approximately 2/1000.

Historical change of the water level is very small. Average draw-down of water level of the whole aquifer area during the period of 1985 to 1993 was not more than 0.6 m, equivalent to 0.07 m/year.

No seasonal change of the water level is recognized.

The existing groundwater extraction at Canchones causes no significant draw-down of the water level in the surrounding areas.

Groundwater level in Pica area is approximately 60 m higher than that of Pampa flat areas. This is because the aquifer of Pica area is independent from that of Pampa flat areas.

(3) Water Quality

There is no difference between shallow well and deep well in regard to water quality except Salar de Pintados and Salar de Bellavista areas. Then the water quality data of shallow and deep wells are treated collectively.

Groundwater in some areas of Pampa del Tamarugal is contaminated by TDS, Cl, As, B, Mn, Fe and Cd. The water contaminated areas are delineated as shown in Fig. 2.23 (1) to Fig. 2.23 (7).

The following water quality standards for drinking water is adopted as the criteria for delineation of the water contaminated areas.

TDS : 1,000 mg/l, Cl : 250 mg/l, As : 0.05 mg/l, Mn : 0.1 mg/l, Fe : 0.3 mg/l, Cd : 0.01 mg/l.

There is no standard for B at present time. In this report, 5 mg/l is adopted, considering that B of 5 mg/l is allowed in the water supply of Antofagasta.

In general, the groundwater in the western part of the aquifers is contaminated, especially in the downstream areas of Aroma and Tarapacá rivers, and in Salar de Pintados and Salar de Bellavista areas.

The groundwater quality in the downstream areas of Sagasca River is good although the river water is much contaminated by the wastewater of the mining.

However, treatment of Mn and Fe is technically and financially easy in general. Hence, the potential aquifer area for the development of drinking water can be delineated as shown in Fig. 2.23 (8) by disregarding the limitation of Mn and Fe.

2.4 Salar del Huasco Basin

2.4.1 General Features of Basin

The Basin covers a closed drainage area of 1,712 km^2. The water is collected by the Collacagua River originating from the Andes Mountains with an elevation of 4,000 m to 5,000 m. Precipitation of the Basin varies according to its altitude. The average annual precipitation ranges from 100 mm in the Huasco lake area to 250 mm in the highest mountain areas. All the surface water infiltrates into underground recharging the groundwater of Salar del Huasco. No surface water flows out from the Basin.

Salar del Huasco (Huasco Salt Lake) is located at an altitude of approximately 3,800 m. It covers a total area of 29 km^2 of which surface water area was 2 km^2 in December, 1993. The remaining 27 km^2 is wet land. Water depth of the Salar (lake) is less than 20 cm.

There is no existing water use in the Basin.

For location of the Basin, see Fig. 2.14.

2.4.2 Surface Water

1) Surface Water Run-off

Yearly rainfall of the Basin ranges from 100 mm in the lake area to 250 mm in the mountain peaks, averaging 158 mm. Run-off coefficient of the Basin is estimated at 0.094 based on the formula established in Section 2.3.2.

Then, average yearly run-off of the Basin is estimated to be 25,513 x $10^3 m^3$/year (= 809 l/s). This is considered as the amount of groundwater recharge of the Basin.

2) Surface Water Quality

Water quality of the Collacagua River is good except the parameters of As and Fe. The concentration of As and Fe are shown below.

	As (mg/l)	Fe (mg/l)
Observed Water Quality	0.103	2.856
Permissible Limit	0.05	0.30

2.4.3 Hydrogeology of Salar del Huasco

Geology of the Salar del Huasco Basin is classified into five (5) units as described below.

(1) Recent Deposits

Recent Deposits are thin consolidated sediments consisting of fan deposits, eolian deposits, and alluvial deposits. The permeability of the Deposits is low as a whole because the deposits contain abundant clay, silt and fine-grained volcanic ash.

(2) Pastillos Formation

Pastillos Formation is divided into two (2) units of upper and lower. The lower unit is composed of scarcely welded volcanic ash and mud flow deposits which contain abundant lapilli and pumice. The upper unit is composed of dacitic tuff intercalated with silstone and diatomite. It is also weakly welded.

The permeability of the formation is low.

(3) Volcanic Rocks

Volcanic Rocks are composed of andesitic and dacitic lava flows and pyroclastic rocks which form strata volcanoes and lava domes. Joints and fissures are well developed in the rocks. However, significant aquifers are not contained in the Volcanic Rocks.

(4) Collacagua Formation

Collacagua Formation is made up of coarse-grained alluvial deposits of high permeability. It is divided into three (3) units of upper, middle and lower. Upper and middle units are much permeable. However, the lower one is relatively less permeable since it occasionally contains pyroclastics and is compacted as a whole.

(5) Huasco Ignimbrite

Joints and fissures are well developed in the rocks. It is considered permeable to a certain extent. However, it is usually difficult to strike the aquifer by drilling.

From the above discussions and considerations, it is concluded that prospective aquifers exist only in Collacagua Formation.

Geological map of Salar del Huasco is shown in Fig. 2.24.

2.4.4 Geological Survey

Electromagnetic surveys and boring tests were conducted in this study for the plains extending over the lower reaches of Collacagua River to supplement the existing geological data.

1) Electromagnetic (TEM) Survey

The TEM surveys were conducted for five (5) stations set on one (1) survey line. Location of the survey line and stations are shown in Fig. 2.24.

The geoelectric profile along the survey line was prepared based on the observed apparent resistivity curves at the respective stations. It is shown in Fig. 2.24.

Geology of the survey area is classified into six (6) layers in terms of apparent resistivity. The resistivity of each layer is as follows.

Layer	Resistivity (ohm-m)	Layer	Resistivity (ohm-m)
1st Layer	>350	4th Layer	11-12
2nd Layer	55-90	5th Layer	14-42
3rd Layer	190	6th Layer	3-7

The 2nd, 4th and 5th layers are considered as expected aquifers.

2) Boring Test

One (1) test well (J-G) and one (1) observation well (J-10) were drilled in the locations as shown in Fig. 2.24.

The results of the boring tests are summarized in Table 2.8. The table shows borehole depth, dimensions of casing and screen pipes, geological features of the identified aquifers and resistivity of well logging, compared with that of TEM survey. For columnar sections of the above two (2) wells, see Fig. 2.25 and Fig. 2.26.

Further, pumping tests including step drawdown test, constant discharge test and recovery test were performed for the above two (2) wells.

The results of the pumping tests are summarized in Table 2.9. The table shows pumping data by constant test, aquifer constants and well capacity.

2.4.5 Aquifer

1) Configuration of Aquifer

Location and size of the aquifers of Salar del Huasco were estimated based on the JICA boring tests along with the previous data.

The aquifers existing in the Collacagua Formation extend from the southern fringe of Salar toward north to approximately 6 km north of Peña Blanca. They are bordered by Quaternary to Tertiary Volcanic Rocks both to the north and south, and by faults both to the east and west. The distance in the north-south direction is 30 km. The width in the east-west direction decreases toward north. The total area is approximately 190 km^2.

However, the aquifer in the Salar area can not be developed due to environmental and water quality problems. Hence, the aquifers other than in Salar area are considered as prospective ones. The length is 20 km and width is 4.5 to 7.0 km. Then, the area of the prospective aquifers comes to 126 km^2. For location of the prospective aquifers, see Fig. 2.24.

The geological profile and cross sections of the aquifers are shown in Fig. 2.25 and Fig. 2.26.

Thickness of the prospective aquifers increases toward south from 130 m in the northern end to 210 m in the southern end, averaging 170 m.

2) Hydrogeological Characteristics of Aquifer

The prospective aquifers are mainly composed of gravel intercalated with mud, and salt crust and lime. The aquifer constants including specific yield, transmissibility and permeability are estimated based on the pumping tests of JICA.

The average aquifer constants are estimated as follows.

Specific Yield : 0.99 l/sec/m, Transmissibility : 174 m^3/day/m
Permeability : 2.60×10^{-3} cm/sec

The above specific yield and transmissibility show a normal value. However, the permeability is a little smaller than that usually expected in sand and gravel beds.

3) Estimated Groundwater Storage

The total groundwater storage in the prospective aquifers is estimated to be 465 million m^3. In this estimation, effective porosity of the aquifers was assumed as 30% on an average. The above storage excludes the aquifers in the Salar area.

2.4.6 Groundwater Level and Quality

1) Existing Groundwater Level

The existing groundwater level is shallow. The depth of groundwater level measured from the ground surface is in the range of 6.0 and 27.0 m, averaging 16.0 m.

2) Groundwater Quality

Groundwater quality analysis was done for the two (2) JICA wells and two (2) springs existing in the fringe area of Salar. See, Fig. 2.24 for the location of JICA wells and Supporting Report B, Fig. B-IV, 1.1 for the location of springs.

The water quality is good as a whole. Contents of all the water quality elements except Mn, Fe and As are within the standards of drinking water.

Mn is 0.61 - 1.40 mg/l, about 10 times of the standard value (0.10 mg/l).

Fe is 4.30 - 18.00 mg/l, very large compared to the standard value of 0.30 mg/l.

As with a high concentration (0.460 mg/l) was observed in one (1) JICA well (J-10). This is equivalent to about 10 times of the standard value (0.050 mg/l). As at all the other locations are not higher than the standard.

Table 2.1 Surface Water Quality (Lluta River)
<Calidad de Agua Superficial (Rio Lluta)>

River	Location	As (mg/l)	B (mg/l)	Fe (mg/l)	Cl (mg/l)	SO_4 (mg/l)	pH
Caracarani	Huamapalca	0.120	3.23	1.17	165	285	7.80
Azufre	Huamapalca	1.246	19.05	61.94	1,377	2,111	2.11
Caracarani	Alcerreca	0.140	5.81	4.79	219	305	5.72
Colpitas	Alcerreca	0.465	21.55	1.41	545	223	7.53
Lluta	Alcerreca	0.209	9.85	4.83	309	284	6.28
Lluta	Tocontasi	0.305	10.69	3.82	323	310	6.89
Lluta	Poconchile	0.173	11.17	----	411	373	7.05
Lluta	Panamericana	0.124	16.84	2.37	704	751	7.43
Permissible Limit		0.05		0.30	250	250	6.0-8.5

Table 2.2 Surface Water Quality (Upstream Tributaries) (Observed in June, 1993)
<Calidad de Agua Tributarios (Curso Superior) (Observado en Jun 1993)>

River	Flow Rate		As		B		Fe	
	(l/s)	(%)	(mg/l)	(%)	(mg/l)	(%)<3	(mg/l)	(%)
Caracarani	394	28.2	0.085	5.2	2.30	6.3	0.26	1.2
Azufre	76	5.4	4.308	51.1	25.72	13.5	82.24	75.0
East Tributaries	334	23.9	0.112	5.8	0.23	0.5	2.75	11.0
Cascavillane	(82)	(5.8)	(0.421)	(5.4)	(0.48)	(0.3)	(10.30)	(10.1)
Others <1	(252)	(18.1)	(0.012)	(0.4)	(0.15)	(0.2)	(0.30)	(0.9)
Colpitas	231	16.6	0.981	35.3	13.28	21.2	2.38	6.6
Upper Colpitas	(211)	(15.1)	(1.058)	(34.8)	(14.10)	(20.6)	(2.54)	(6.4)
Upper Allane	(20)	(1.4)	(0.175)	(0.5)	(4.74)	(0.6)	(0.74)	(0.2)
Putre & Others <2	360	25.8	0.045	2.6	1.22	3.0	1.43	6.2
Total / Average	1,395	100.0	0.460	100.0	4.77	43.5	6.19	100.0
Lluta (at Chapisca)	1,184		0.270		12.22	100.0	2.55	
Permissible Limit			0.05				0.30	

Note: <1 Others: Teleschuno, Guancarane and Chuquiananta
<2 Others: Aroma and Socoroma
<3 B (%) : Percentage to Lluta (at Chapisca)
Average : Weighted average of all tributaries

Table 2.3 Result of Boring Test (Lower Lluta Valley)

< Resultado de Perforación (Curso Bajo del Valle de Lluta)>

Well No.	Bore hole Depth (m)	Casing Pipe		Screen Pipe		Geological Conditions of Aquifer			Geophysical Characteristics of Aquifer			
									Well Logging			TEM
		Size (inches)	Total Length (m)	Position (m)	Total Length (m)	Lithology	Formation	Period	Spontaneous Potential (mv)	Resistivity (ohm-m)	Gamma Ray (cps)	Resistivity (ohm-m)
J-A	150	8-5/8"	108.01	59.93 to 101.98	42.05	Sand, Sandy to clayey gravel	Fluvial Deposit	Quaternary	985-1025	15-30	50-70	12-26
J-B	200.4	8-5/8"	126.00	60.05 to 90.10	72.12	Clayey gravel, Sand	Fluvial Deposit	Quaternary	-8.2 to -8.4	15-30	25-50	17-26
				102.10 to 144.17		Fissured Ignimbrite	Oxaya Formation	Tertiary	-8.3 to -8.4	15-30	35-75	17-26
J-1	145	5-1/2"	85.00	31.00 to 91.00	60.00	Gravel, Sandy gravel	Fluvial Deposit	Quaternary	925-935	22-32	50-110	11-23
J-2	225	5-1/2"	136.00	64.02 to 154.01	89.99	Silty to sandy gravel	Fluvial Deposit	Quaternary	1060-1100	20-30	50-100	17-30

Table 2.4 **Result of Pumping Test (Lower Lluta Valley)**

< Resultado de Prueba de Bombeo (Curso Bajo del Valle de Lluta)>

Well No.	Pumping Data (from Constant Test)					Aquifer Constants			Well Capacity	
	Static Water Level (m)	Pumping Rate (l/s)	Dynamic Water Level (m)	Drawdown (m)	Specific Yield (l/s/m)	Transmissibility (m3/d/m)	Storage Coefficient	Permeability (cm/sec)	Critical Discharge (l/s)	Safe Yield (l/s)
J-A	9.82	15.30	74.51	64.69	0.24	22.72	8.54E-04	6.25E-04	15.30	7.50
J-B	34.56	18.90	65.19	30.63	0.62	310.44	4.72E-04	4.98E-03	20.30	13.00
J-1	21.69	4.40	24.75	3.06	1.44	368.06	6.62E-06	7.01E-03	4.40<	2.25
J-2	35.02	4.92	41.78	6.76	0.73	149.69	6.60E-06	1.93E-03	3.85	2.25

Table 2.5 (1) Result of Boring Test (Pampa del Tamarugal)

< Resultado de Prueba de Sondaje (Pampa del Tamarugal) >

Sheet No.1

Well No.	Bore hole Depth (m)	Casing Pipe Size (inches)	Casing Pipe Total Length (m)	Screen Pipe Position (m)	Screen Pipe Total Length (m)	Geological Conditions of Aquifer: Lithology	Altos de Pica Formation	Period	Geophysical Data: Well Logging Resistivity (ohm-m)	TEM Resistivity (ohm-m)
J-C	209	8-5/8"	131.99	43.01-73.01	78.01	clayey gravel,	Q4	Quaternary	10 - 20	13 - 23
				79.01-97.02		clayey sand	Q4		10 - 30	13 - 23
				163.02-192.99		sandy clay	Q2		10 - 30	13 - 23
J-D	210	8-5/8"	114.00	53.89-59.91	96.12	clayey gravel	Q4	Quaternary	10 - 20	7.9 -14
				71.91-89.93		clayey gravel	Q4		10 - 20	7.9 -14
				101.94-150.00		clayey gravel	Q3		10 - 25	7.9 -14
				156.00-162.00		clayey gravel	Q3		15 - 25	7.9 -14
				174.00-180.01		clayey gravel	Q2		15 - 20	7.9 -14
				186.01-198.02		clayey gravel	Q2		7 - 15	7.9 -14
J-E	250	8-5/8"	149.93	76.05-94.06	102.07	gravely clay	Q4	Quaternary	10 - 20	9.1 - 19
				106.60-118.00		gravely clay	Q3		10 - 20	9.1 - 19
				124.00-136.02		clayey gravel	Q3		10 - 20	9.1 - 19
				148.00-154.03		clayey gravel	Q3		10 - 20	9.1 - 19
				160.03-172.05		clayey gravel	Q3		10 - 25	9.1 - 19
				184.04-202.06		clayey gravel	Q3		12 - 30	9.1 - 19
				208.06-220.08		gravel	Q3		15 - 25	9.1 - 19
				232.08-244.09	1.00	clayey gravel	Q3		15 - 30	9.1 - 19
J-F	224	8-5/8"	119.85	52.98-73.98	105.01	gravely clay	Q4	Quaternary	20 - 70	7.3 - 16
				91.96-97.96		clayey sand	Q4		15 - 28	7.3 - 16
				103.96-133.96		gravely clay	Q3		12 - 30	7.3 - 16
				145.99-158.00		clayey sand	Q3		8 - 20	7.3 - 16
				163.99-169.99		sand	Q2		8 - 20	3.8 - 6.6
				182.00-194.00		sandy clay	Q2		8 - 20	3.8 - 6.6
				200.03-218.03		sandy clay	Q2		8 - 20	3.8 - 6.6
J-3	150	5-1/2"	92.74	45.61-81.53	59.86	sandy clay	Q4	Quaternary	20 - 40	-
				87.57-99.53		sandy clay	Q4		10 - 30	-
				132.83-144.83		sandy clay	Q2		15 - 31	-
J-4	150	5-1/2"	91.62	43.75-73.59	60.09	gravel	Q4	Quaternary	10 - 40	52 - 70
				79.61-85.61		clayey gravel	Q4		10 - 20	52 - 70
				97.67-115.72		clayey gravel	Q2		10 - 20	52 - 70
				138.92-144.94		conglomerate	Q2		15 - 25	52 - 70

Table 2.5 (2) Result of Boring Test (Pampa del Tamarugal)

< Resultado de Prueba de Sondaje (Pampa del Tamarugal) >

Sheet No.2

Well No.	Bore hole Depth (m)	Casing Pipe Size (inches)	Casing Pipe Total Length (m)	Screen Pipe Position (m)	Screen Pipe Total Length (m)	Geological Conditions of Aquifer: Lithology	Formation	Period	Geophysical Data: Well Logging Resistivity (ohm-m)	TEM Resistivity (ohm-m)
				103.12-109.13		clayey gravel	Q4		10 - 20	10 -17
				121.19-145.28		clayey gravel	Q4		10 - 30	10 - 17
J-5	300	5-1/2"	193.35	168.46-174.48	108.29	clayey gravel	Q3	Quaternary	15 - 30	10 - 17
				186.55-198.58		gravel	Q3		10 - 25	10 - 17
				204.61-246.71		clayey gravel	Q3		13 - 30	10 - 17
				264.82-282.46		sandy clay	Q2		10 - 20	0.1 - 7.5
				49.54-73.57		sandy gravel	Q4		25 - 40	10 - 19
				91.66-103.69		sandy gravel	Q3		30 - 35	10 - 19
J-6	200	5-1/2"	126.63	115.75-127.72	78.10	sandy gravel	Q3	Quaternary	30 - 35	10 - 19
				157.87-175.91		gravely clay	Q2		30 - 35	10 - 19
				181.94-193.97		clayey gravel	Q2		35 - 45	10 - 19
				55.79-61.76		sandy clay	Q4		13 - 18	7.4 - 9.5
				67.79-79.80		sandy clay	Q4		15 - 20	7.4 - 9.5
				109.95-139.81		gravely clay	Q3		15 - 21	7.4 - 9.5
J-7	210	5-1/2"	126.75	144.87-156.85	83.79	gravely clay	Q3	Quaternary	14 - 21	7.4 - 9.5
				167.94-179.96		gravely clay	Q3		13 - 20	7.4 - 9.5
				185.99-192.00		gravely clay	Q3		15 - 20	7.4 - 9.5
				198.03-203.97		clayey gravel	Q3		14 - 20	7.4 - 9.5
				53.12-65.13		clayey gravel	Q4		20 - 30	8.9 - 9.3
				75.13-81.10		gravely clay	Q4		12 - 25	8.9 - 9.3
				91.10-97.10		gravely clay	Q4		10 - 20	8.9 - 9.3
				112.42-118.44		gravely clay	Q4		10 - 22	8.9 - 9.3
J-8	210	5-1/2"	129.35	123.64-129.63	84.04	gravely clay	Q4	Quaternary	10 - 30	8.9 - 9.3
				135.63-141.66		clayey gravel	Q3		10 - 30	8.9 - 9.3
				146.66-152.66		clayey gravel	Q3		10 - 24	8.9 - 9.3
				157.73-163.71		fine gravel	Q3		15 - 33	8.9 - 9.3
				168.88-186.91		gravely clay	Q2		10 - 30	8.9 - 9.3
				191.97-203.98		sandy clay	Q2		11 - 30	8.9 - 9.3
				58.59-115.64		clayey gravel	Q4		5 - 20	-
J-9	172	5-1/2"	87.92	121.67-133.63	86.98	gravely clay	Q4	Quaternary	10 - 20	-
				144.87-156.84		sandy clay	Q3		10 - 30	-
				162.87-168.87		gypsum clay	Q2		15 - 45	-

Table 2.6 Result of Pumping Test (Pampa del Tamarugal)

< Resultado de Prueba de Bombeo (Pampa del Tamarugal) >

Well No.	Pumping Data (by Constant Test)					Aquifer Constants		Well Capacity	
	Static Water Level (m)	Pumping Rate (l/s)	Dynamic Water Level (m)	Drawdown (m)	Specific Yield (l/s/m)	Transmissibility (m3/d/m)	Permeability (cm/sec)	Critical Discharge (l/s)	Safe Yield (l/s)
J-C	52.03	2.25	75.75	23.72	0.09	8.29	1.23E-04	2.50	0.80
J-D	46.05	22.5	52.53	6.48	3.47	1506.17	1.81E-02	25.00<	10.00
J-E	13.73	27.00	17.72	3.99	6.77	644.33	7.31E-03	27.00<	50.00
J-F	57.00	20.00	69.15	12.15	1.65	86.81	9.57E-04	8.33	1.80
J-3	9.17	5.00	16.05	6.88	0.73	113.81	2.20E-03	5.00<	3.75
J-4	46.22	4.40	48.20	1.98	2.22	271.08	5.22E-03	4.00	0.30
J-5	29.08	5.00	29.68	0.60	8.33	769.61	8.23E-03	5.00<	2.00
J-6	14.04	4.04	29.70	15.66	0.26	21.63	3.20E-04	4.04<	5.00
J-7	7.94	5.00	9.78	1.84	2.72	383.83	5.30E-03	5.00<	10.00
J-8	37.99	3.34	39.52	1.53	2.18	376.27	5.18E-03	3.34<	29.00
J-9	13.97	5.00	16.57	2.60	1.92	266.06	3.54E-03	5.00<	3.50

Table 2.7 Previous Pumping Test

<Prueba de Bombeo Previo>

(Zapiga-Dolores-Negreiros Area)

BNA NO.	Discharge Rate (l/s)	Specific Yield (l/sec/m)	Transmissibility (m3/d/m)	Permeability (cm/sec)	Remarks
170	4.0	0.31			J
172	5.0	0.47			J
168	9.0	0.62			J
171	7.0	0.82			J
173	7.0	0.92			J
174	7.5	0.99			J
928	6.0	1.79	520	4.15E-02	C
925		1.21	164	1.89E-02	C
923	3.0	0.70	398	5.12E-02	C
922	3.0	0.89	135	1.30E-02	C
921	3.0	1.10	258	2.99E-02	C
941	1.0	0.24	53	3.06E-03	J
930	8.0	0.60	110	4.55E-03	J
927		0.15	23	1.75E-03	C
933	5.5	2.20	173	9.02E-03	J
Average		0.87	204	0.0192	

(Huara Area)

BNA NO.	Discharge Rate (l/s)	Specific Yield (l/sec/m)	Transmissibility (m3/d/m)	Permeability (cm/sec)	Remarks
190-6			1440		C
946	2.2	4.1	39	1.56E-04	J
949		4.0	935	3.37E-02	C
951	18.0	2.9	284	2.35E-02	J
Average		3.7	675	0.0191	

(Pica-Matilla Area)

BNA NO.	Discharge Rate (l/s)	Specific Yield (l/sec/m)	Transmissibility (m3/d/m)	Permeability (cm/sec)	Remarks
117-5	6.0	0.08			J
252-k	7.5	0.38			J
253-6	1.1	0.14			J
265-1	42.0	1.89			J
272-4	2.0	0.04			J
389-5	8.0	0.16	6	8.43E-05	J
390-9	1.0	0.04	312	1.39E-02	J
391 or 392			155		C
394-1	1.5	0.06			J
401-8			49		C
403-4	5.0	0.43			J
Average		0.36	130	6.99E-03	

(Pozo Almonte-Canchones-Pintados Area)

BNA NO.	Discharge Rate (l/s)	Specific Yield (l/sec/m)	Transmissibility (m3/d/m)	Permeability (cm/sec)	Remarks
129-9	36.0	5.14			J
130-2		1.66	47		C
131-0	60.0	3.82			J
132-9	30.0	2.61			J
136-1	3.8	0.40	9	8.51E-04	J
200-7	6.0	0.12			J
202-3	64.0	10.67			J
206-6	25.0	2.08			J
207-4	3.5	0.81	1094	1.06E-01	J
221-k	40.0	6.78			J
222-8	70.0	4.43	450		C
226-0	47.0	2.72			J
229-5	4.0	0.21			J
232-5	24.0	2.00			J
234-1			4280		C
240-6	20.0	3.33			J
357-7	120.0	5.36			J
366-6	120.0	4.72			J
415-8	9.3	3.10			J
421-2	5.5	2.75			J
423-9	70.0	1.37	920		C
955		4.46	915	2.52E-02	C
Average		3.26	1102	0.044	

(Oficina Victoria-Bellavista Area)

BNA NO.	Discharge Rate (l/s)	Specific Yield (l/sec/m)	Transmissibility (m3/d/m)	Permeability (cm/sec)	Remarks
432-b	25.0	1.51			J
445-k	26.0		420	1.39E-02	J
985		3.04	220		C
986		0.32	81		C
987		0.32	157		C
Average		1.30	219.5	0.014	

(TOTAL PAMPA AREA: except Pica-Matilla Area)

BNA NO.	Discharge Rate (l/s)	Specific Yield (l/sec/m)	Transmissibility (m3/d/m)	Permeability (cm/sec)	Remarks
Average		2.27	547	0.024	

(Note) C: Existing Data.
J: Estimated by the Study Team on the basis of existing test data

Table 2.8 Result of Boring Test (Salar del Huasco)

< Resultado de Prueba de Sondaje (Salar del Huasco)>

Well No.	Bore hole Depth (m)	Casing Pipe: Size (inches)	Casing Pipe: Total Length (m)	Screen Pipe: Position (m)	Screen Pipe: Total Length (m)	Geological Conditions of Aquifer: Lithology	Geological Conditions of Aquifer: Formation	Geological Conditions of Aquifer: Period	Geophysical Data: Well Logging Resistivity (ohm-m)	Geophysical Data: TEM Resistivity (ohm-m)
J-G	157	8-5/8"	96.03	30.81 -54.84	66.12	gravel clayey gravel	Collacagua (Qcm)	Quaternary	30 - 90	55 -90
				60.82 -102.91		clayey gravel sandy gravel			25 -90	55 -90
J-10	207	5-1/2"	116.70	39.02 -51.03	89.95	gravel	Collacagua (Qcu)	Quaternary	70 -300	-
				86.53 -146.51		clayey gravel	Collacagua (Qcm)		40 - 500	-
				161.81 -167.81		clayey gravel	Collacagua (Qcl)		25 -80	-
				172.83 -184.79		sandy mudstone clayey sandstone			40 - 80	-

Table 2.9 Result of Pumping Test (Salar del Huasco)

< Resultado de Prueba de Bombeo (Salar del Huasco) >

Well No.	Pumping Data (by Constant Test): Static Water Level (m)	Pumping Rate (l/s)	Dynamic Water Level (m)	Drawdown (m)	Specific Yield (l/s/m)	Aquifer Constants: Transmissibility (m3/d/m)	Permeability (cm/sec)	Well Capacity: Critical Discharge (l/s)	Safe Yield (l/s)
J-G	5.86	25.00	39.76	33.90	0.74	156.39	2.74E-03	25.00<	6.70
J-10	26.56	5.00	30.64	4.08	1.23	191.38	2.46E-03	5.00<	1.75

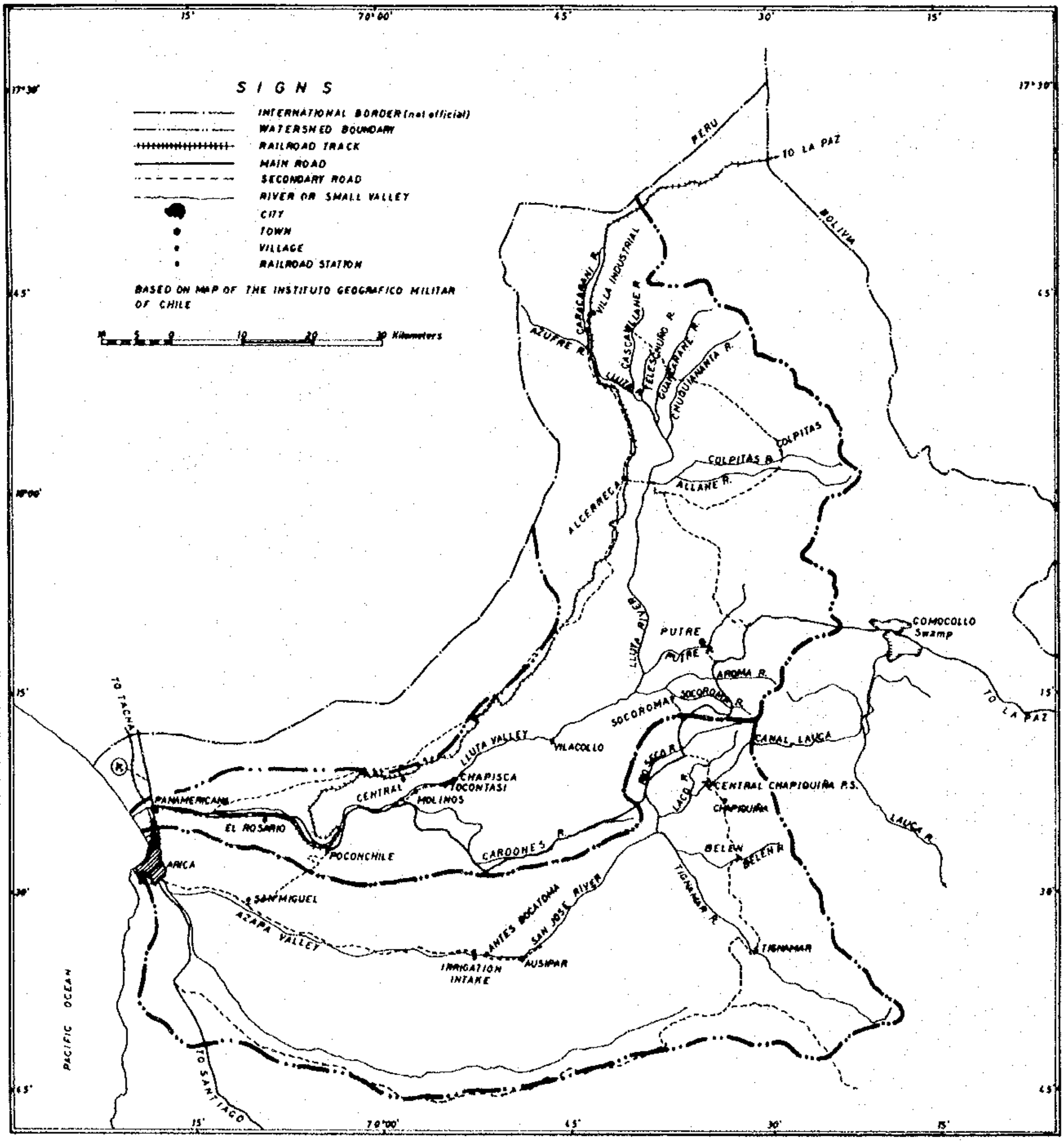


Fig. 2.1 River System of San José and Lluta River Basin

< Sistema Fluvial de las Cuencas de los Ríos San José y Lluta >

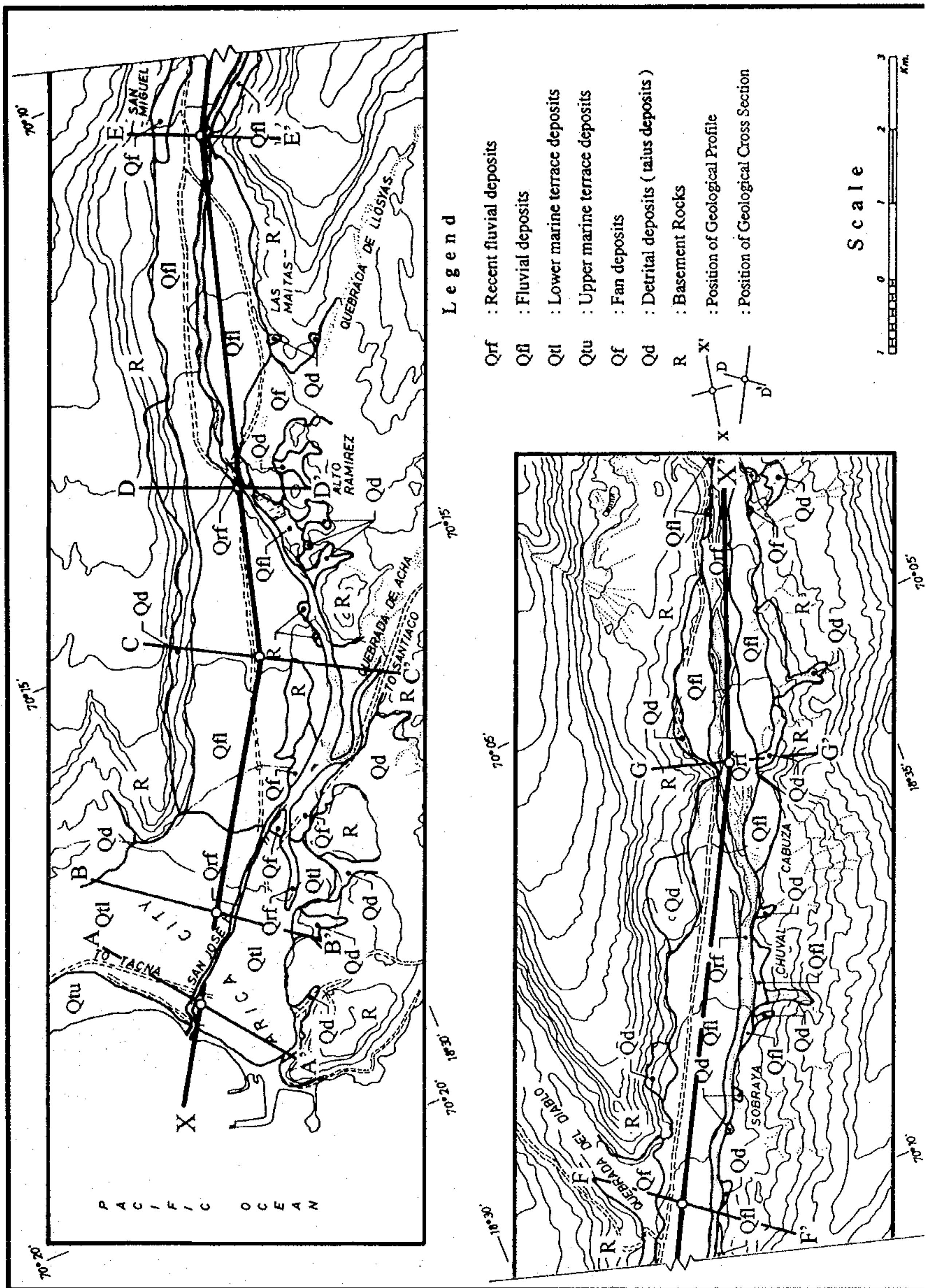


Fig. 2.2 Geological Map (Azapa Valley)

< Mapa Geológico (Valle de Azapa) >

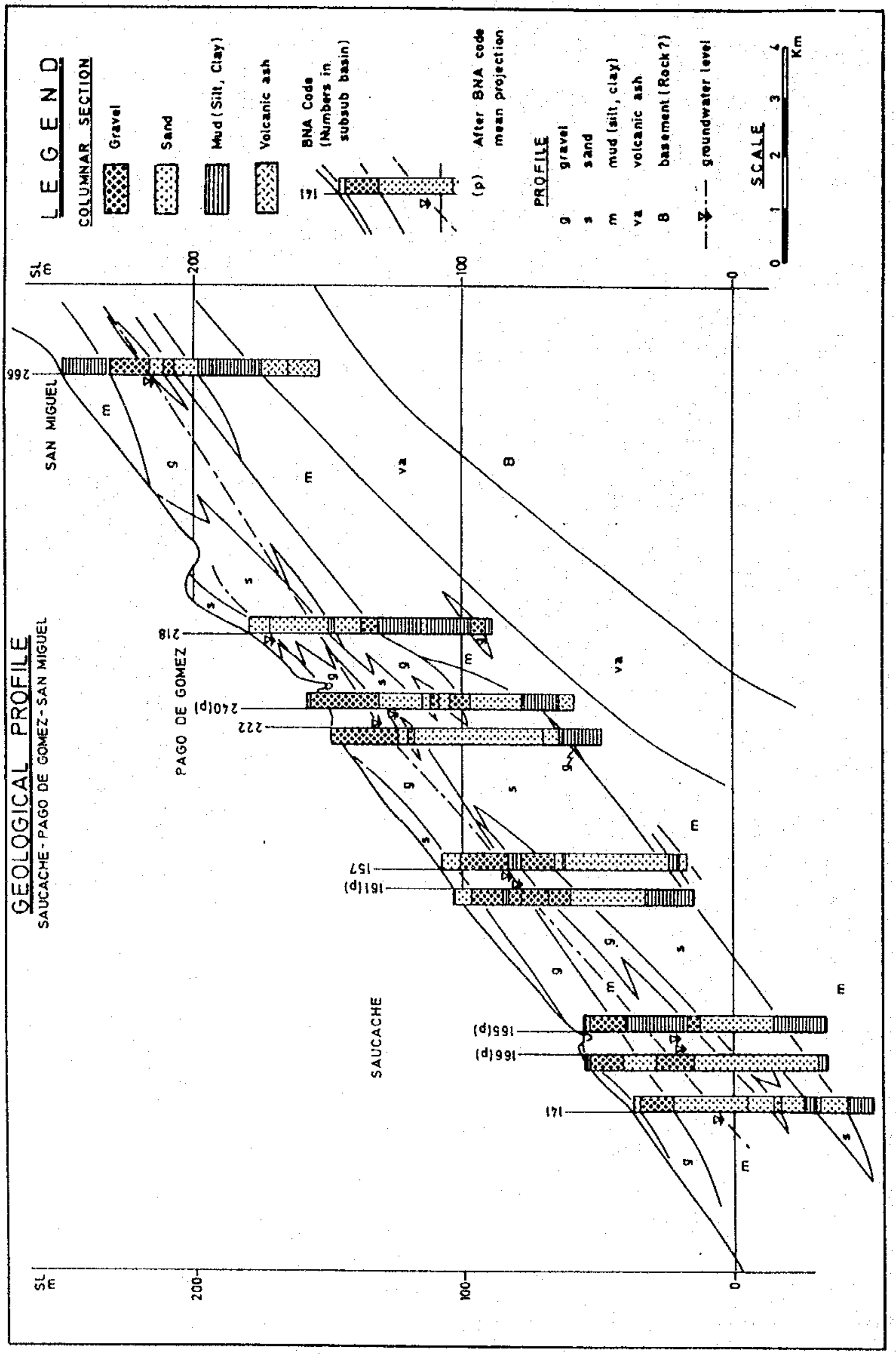


Fig. 2.3 Geological Profile (Azapa Valley)

< Perfil Geógico (Valle de Azapa)>

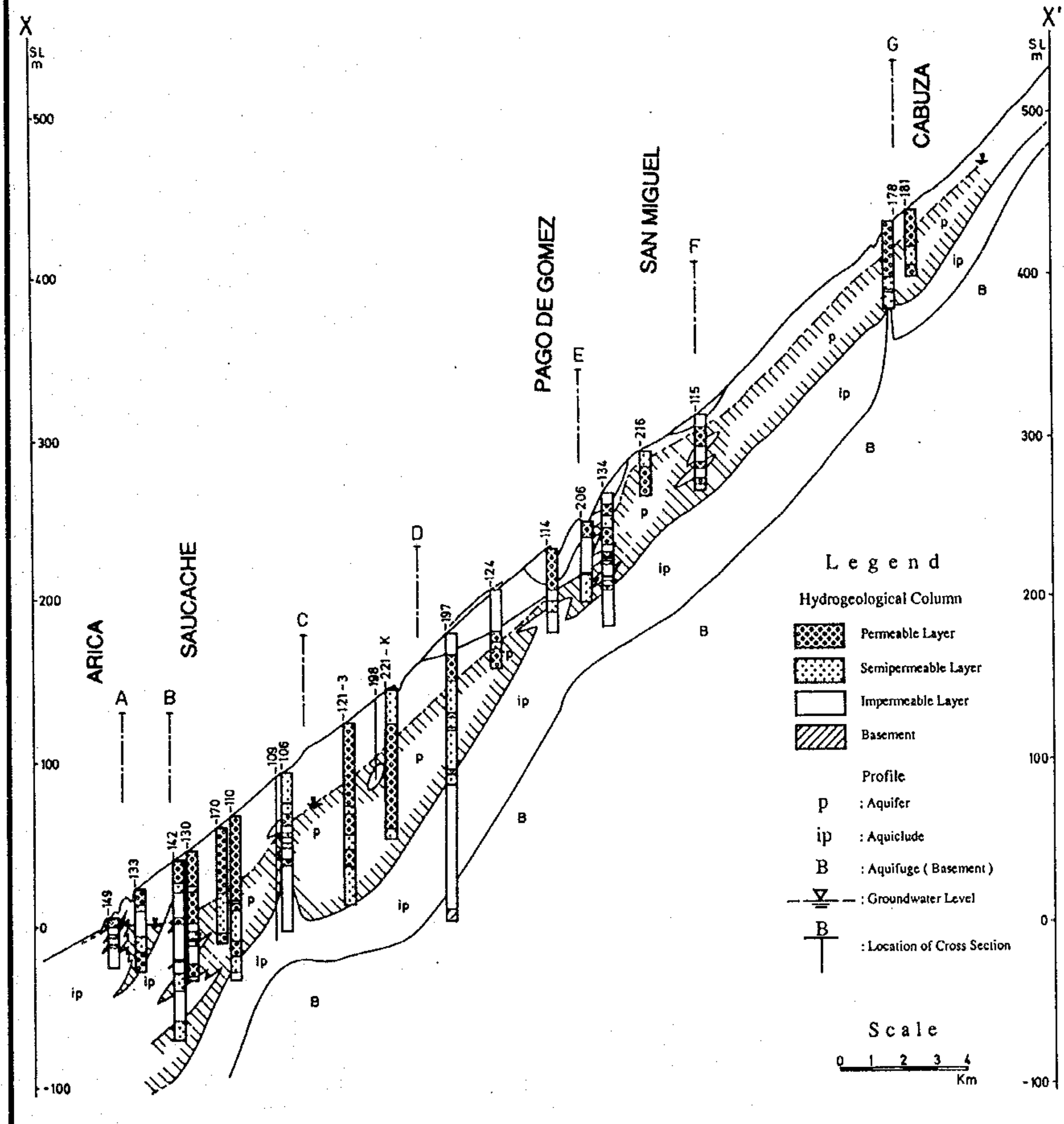


Fig. 2.4 Hydrogeological Profile (X - X')

< Perfil Hidrogeológico (X - X') >

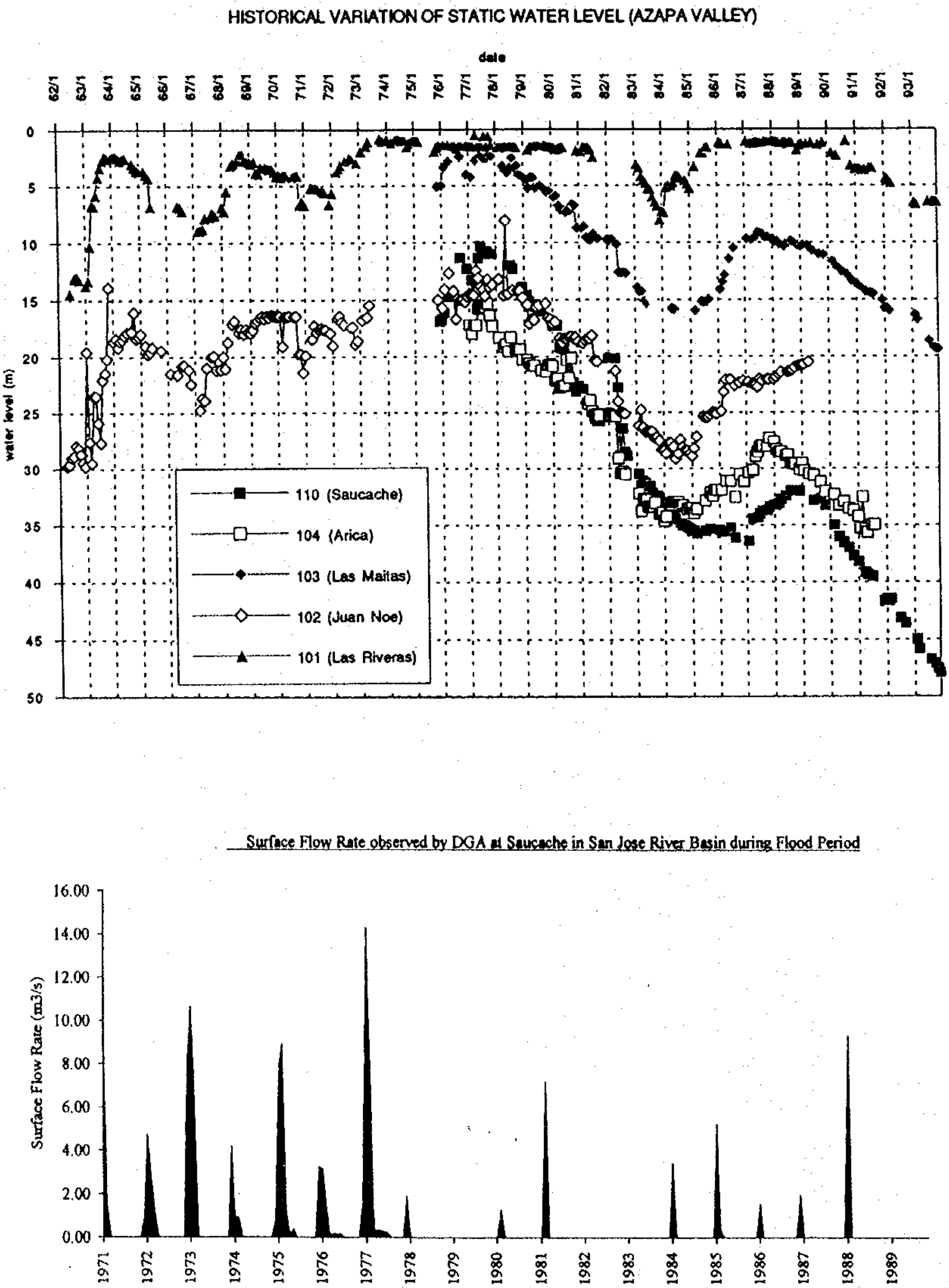


Fig. 2.5 Relation between Groundwater Level and Flood (Azapa Valley)

< Relación entre el Nivel Estático y Avenida (Valle de Azapa) >

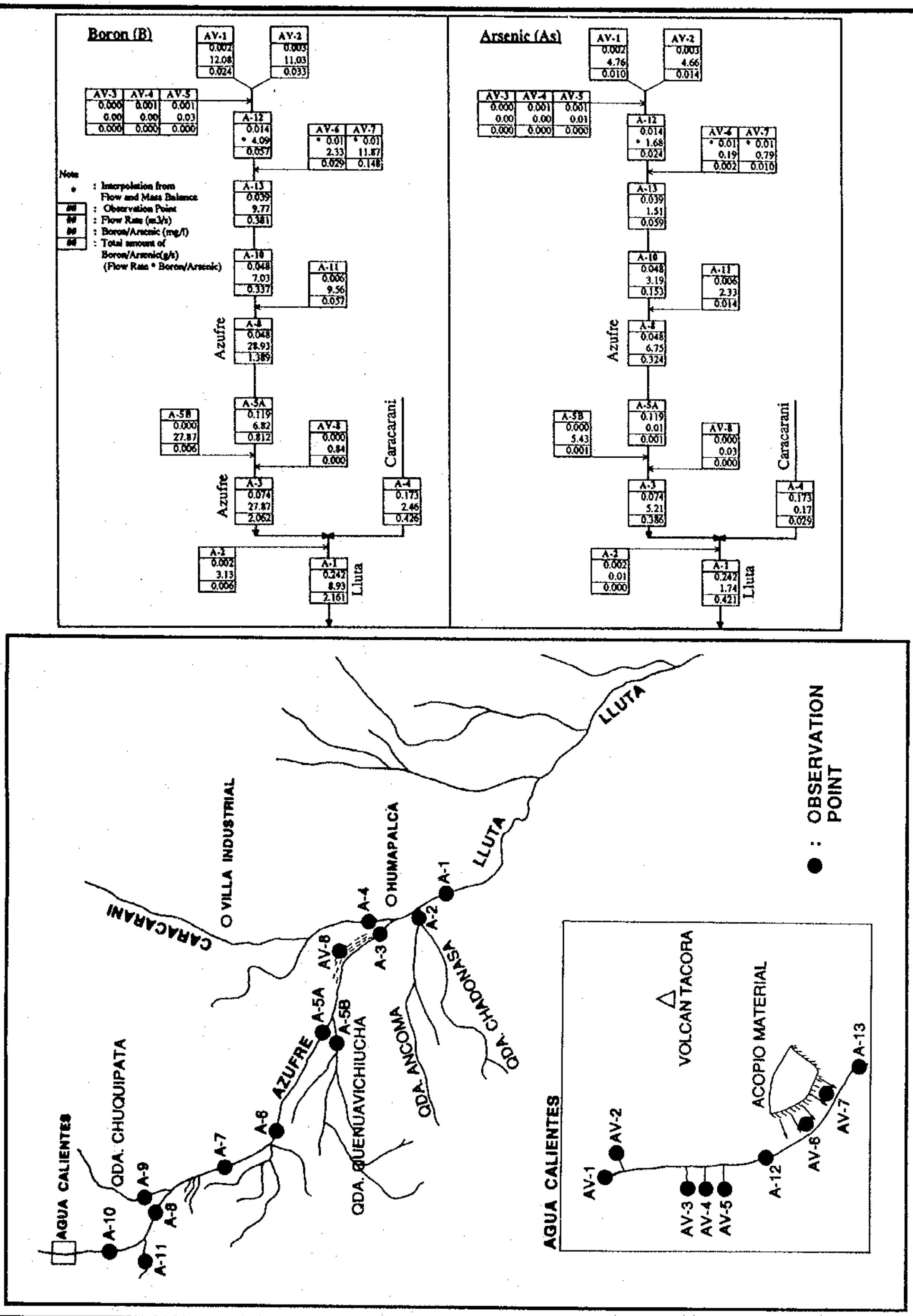
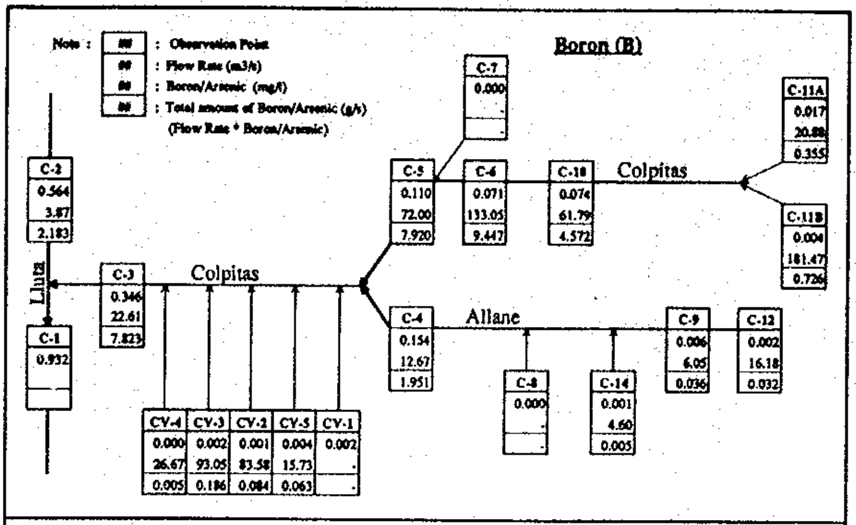
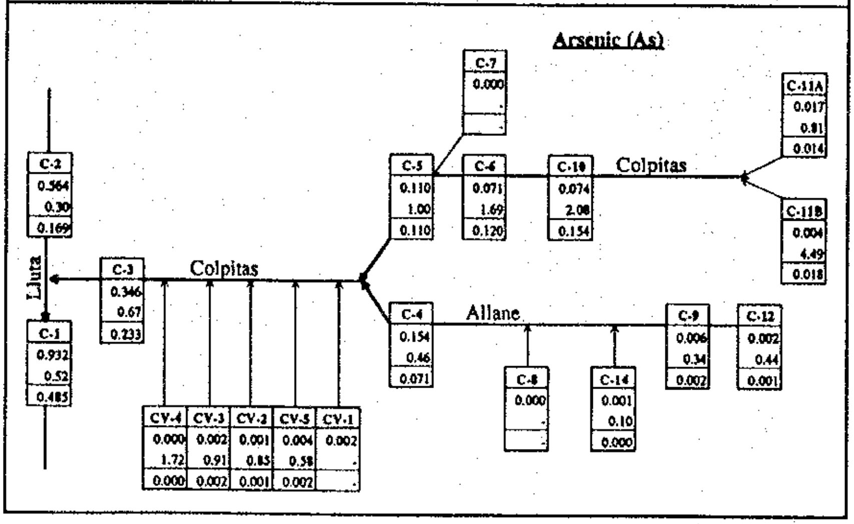


Fig. 2.6 (1) Observed Water Quality in Azufre River

<Calidad de Agua Observad en Rio Azufre>





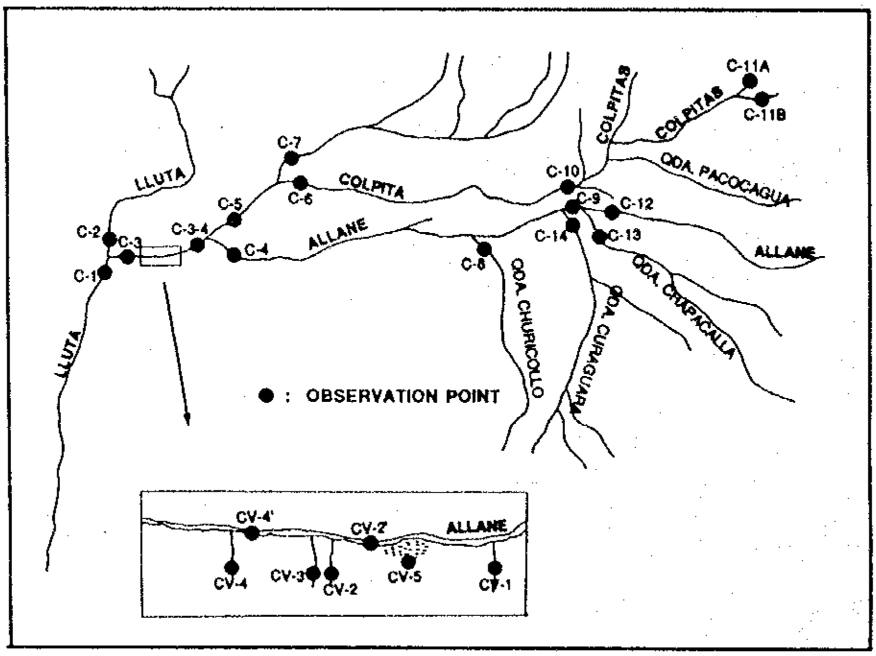


Fig. 2.6 (2) Observed Water Quality in Colpitas River

<Calidad de Agua Observad en Río Colpitas>

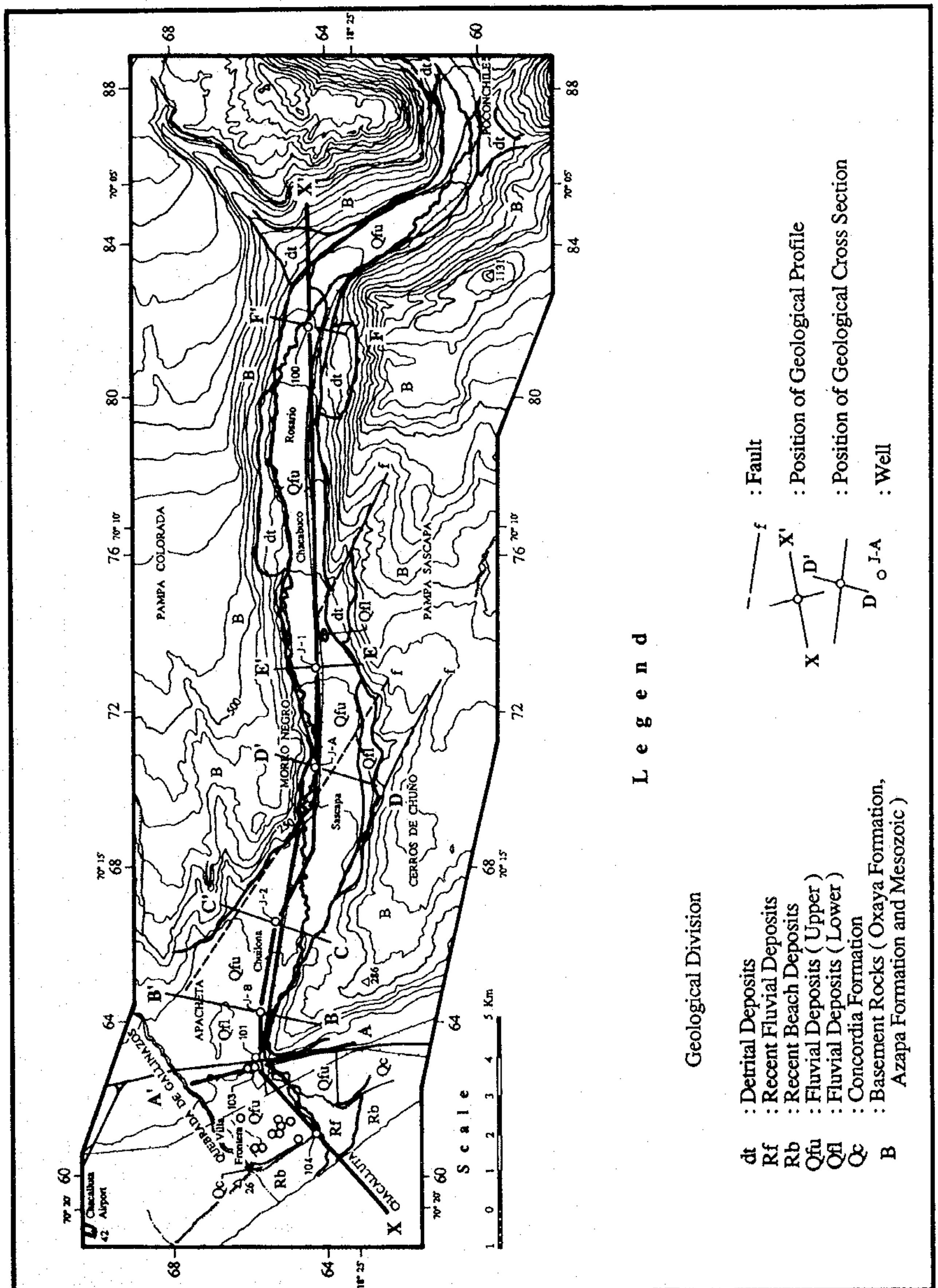


Fig. 2.7 Geological Map (Lower Lluta Valley)

< Mapa Geológico (Curso Bajo del Valle de Lluta)>

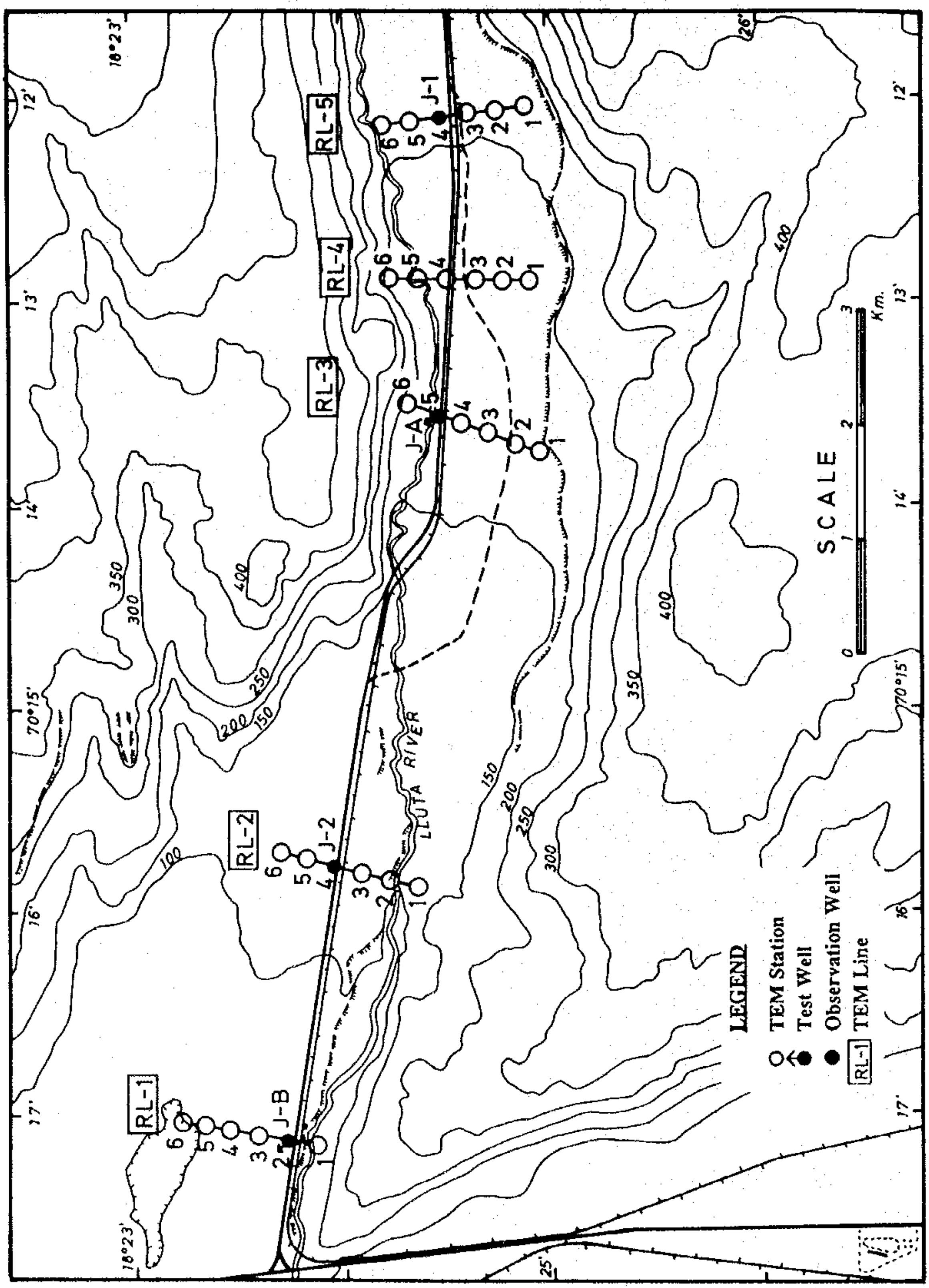


Fig. 2.8 Location of TEM Station and Test/Observation Wells (Lower Lluta Valley)

<Ubicación de las Estaciones TEM y Pozos de Pruebay Observación (Curso Bajo del Valle de Lluta)>

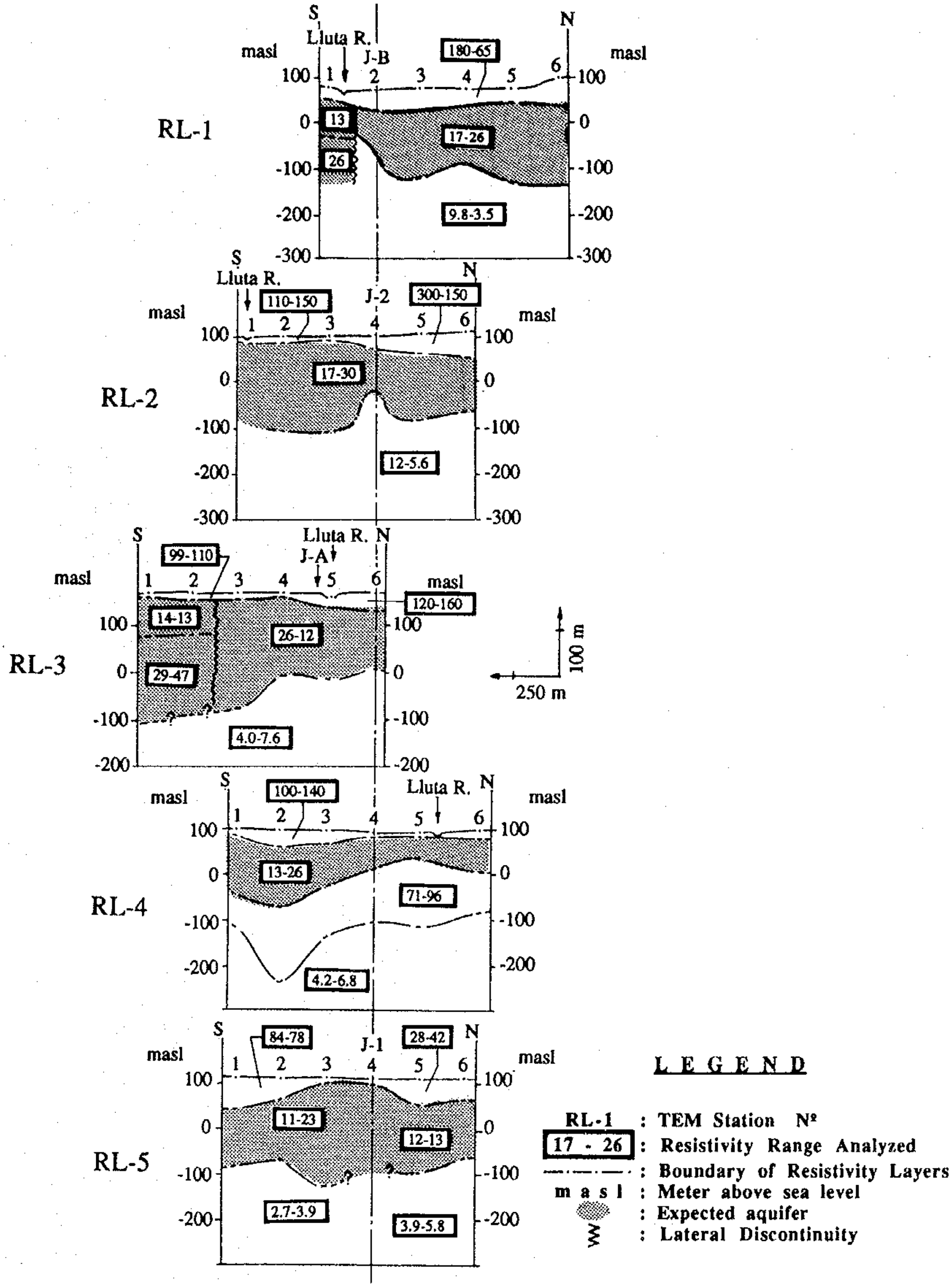


Fig. 2.9 Geoelectric Profiles (Lower Lluta Valley)

<Perfiles Geoeléctricos (Curso Bajo del Valle de Lluta)>

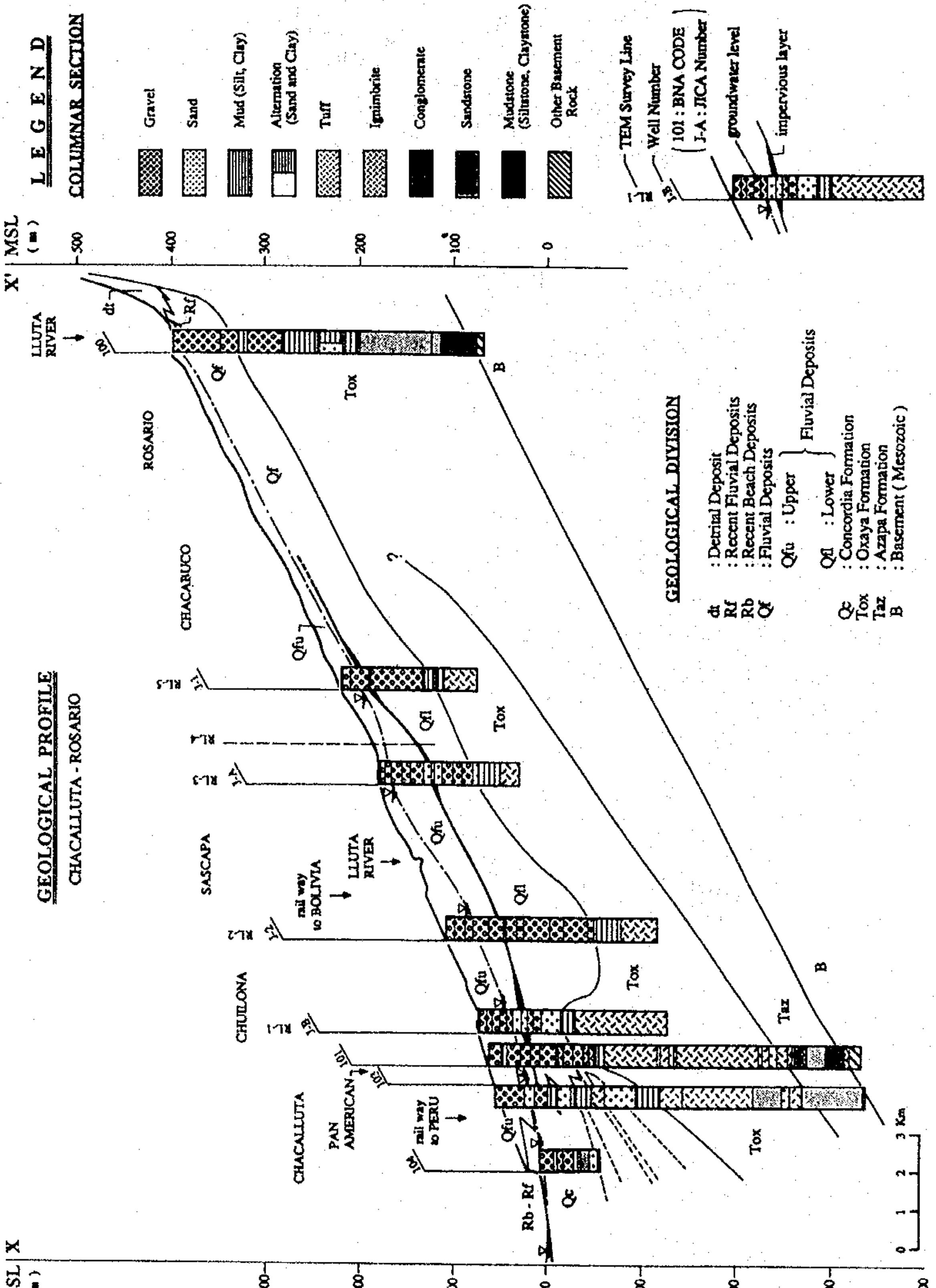


Fig. 2.10 Geological Profile (X-X') (Lower Lluta Valley)

< Perfil Geológico (X-X') (Curso Bajo del Valle de Lluta)>

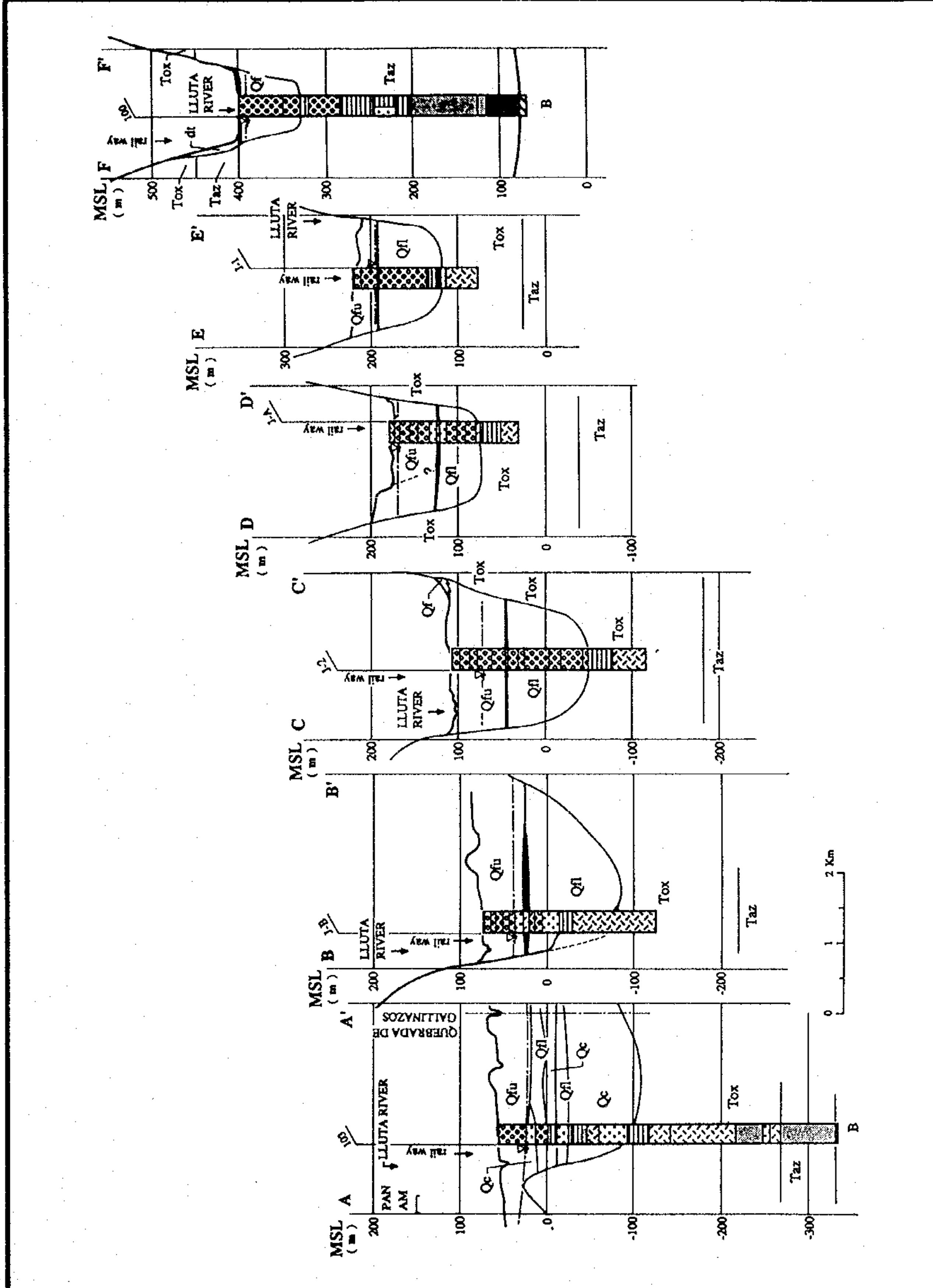


Fig. 2.11 Geological Cross Sections (Lower Lluta Valley)

<Seccion de es Cruce Geológico (Curso Bajo del Valle de Lluta)>

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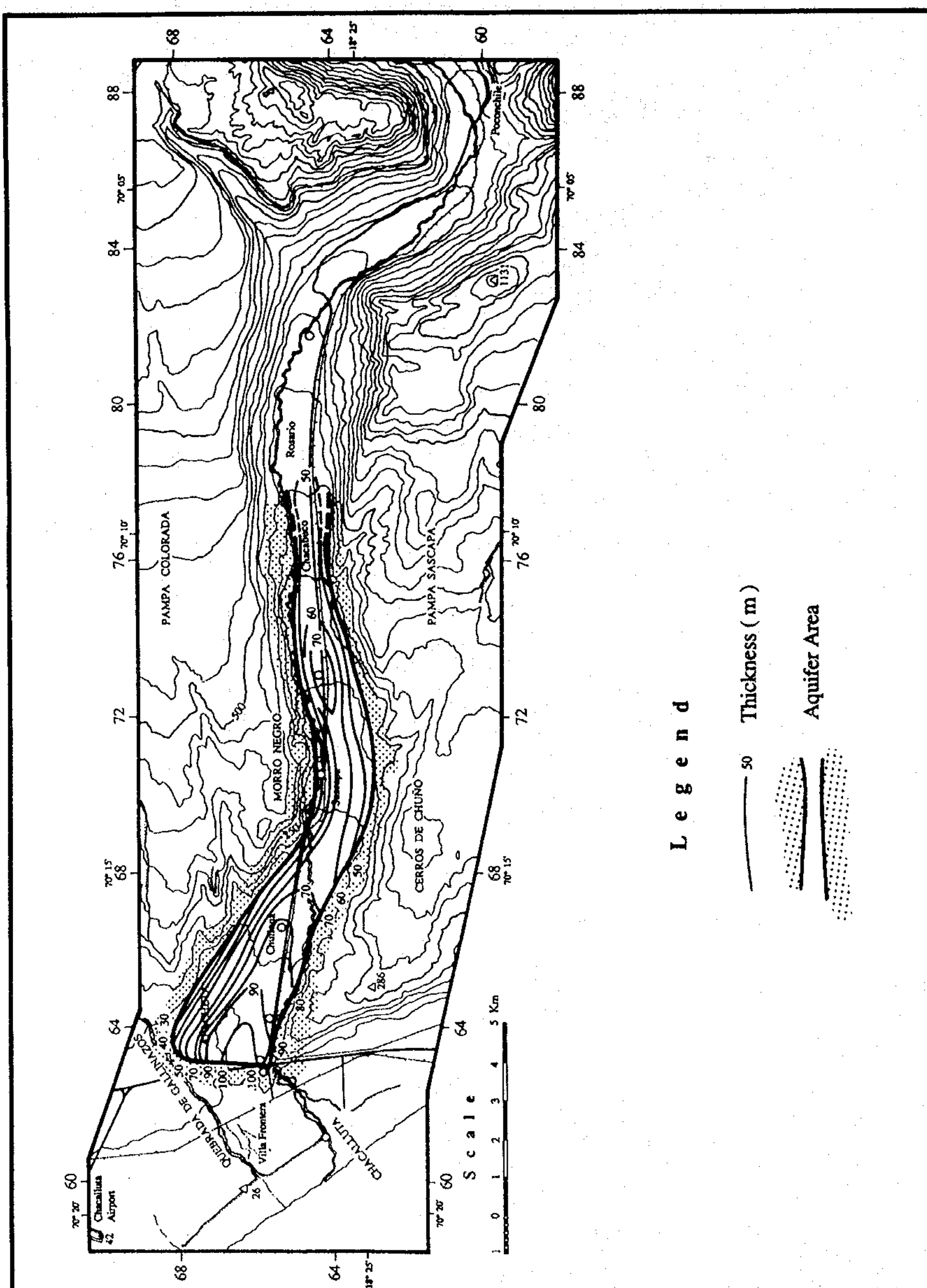

Fig. 2.12 Isopach Map of Deep Aquifer (Lower Lluta Valley)

<Mapa Isopaca de Acuífero Profundo (Curso Bajo del Valle de Lluta)>

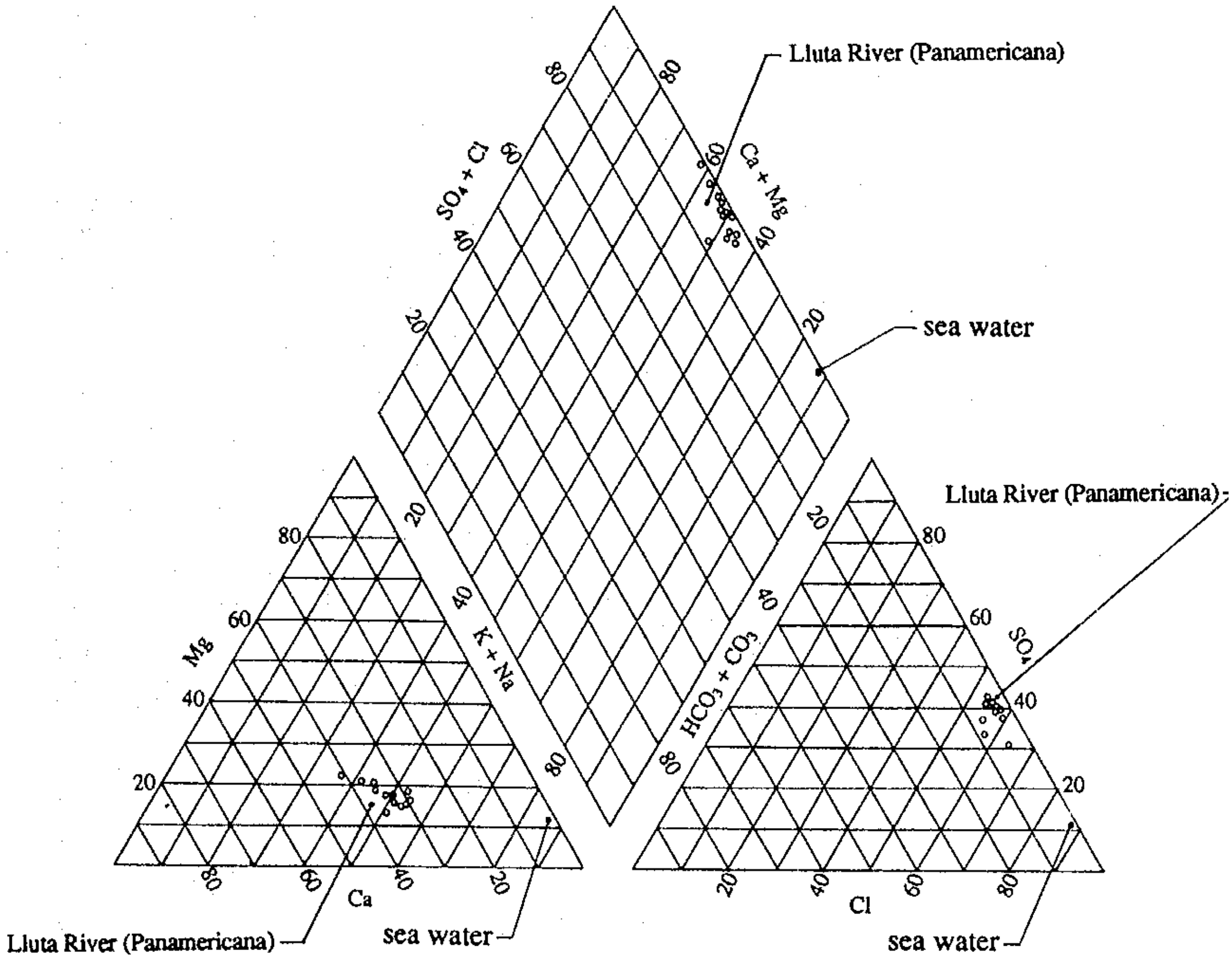

Fig. 2.13 Tri-linear Diagram of Major Ions (Lower Lluta Valley)

< Diagrama Tri-Lineal de Iones Mayores (Curso Bajo del Valle de Lluta)>

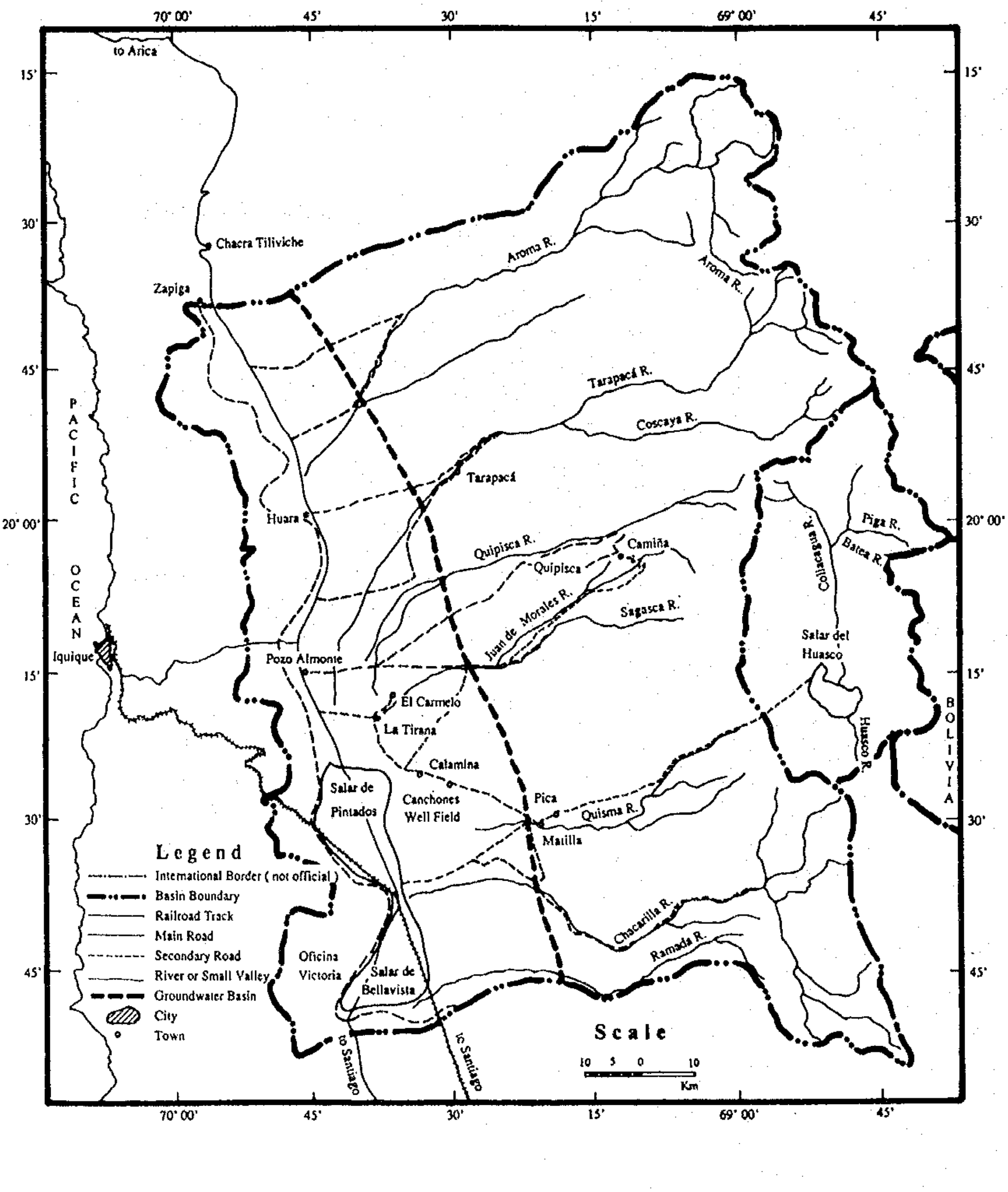

Fig. 2.14 Basin Map of Pampa del Tamarugal and Salar del Huasco

<Plano de Cuencas Pampa del Tamarugal y Salar del Huasco>

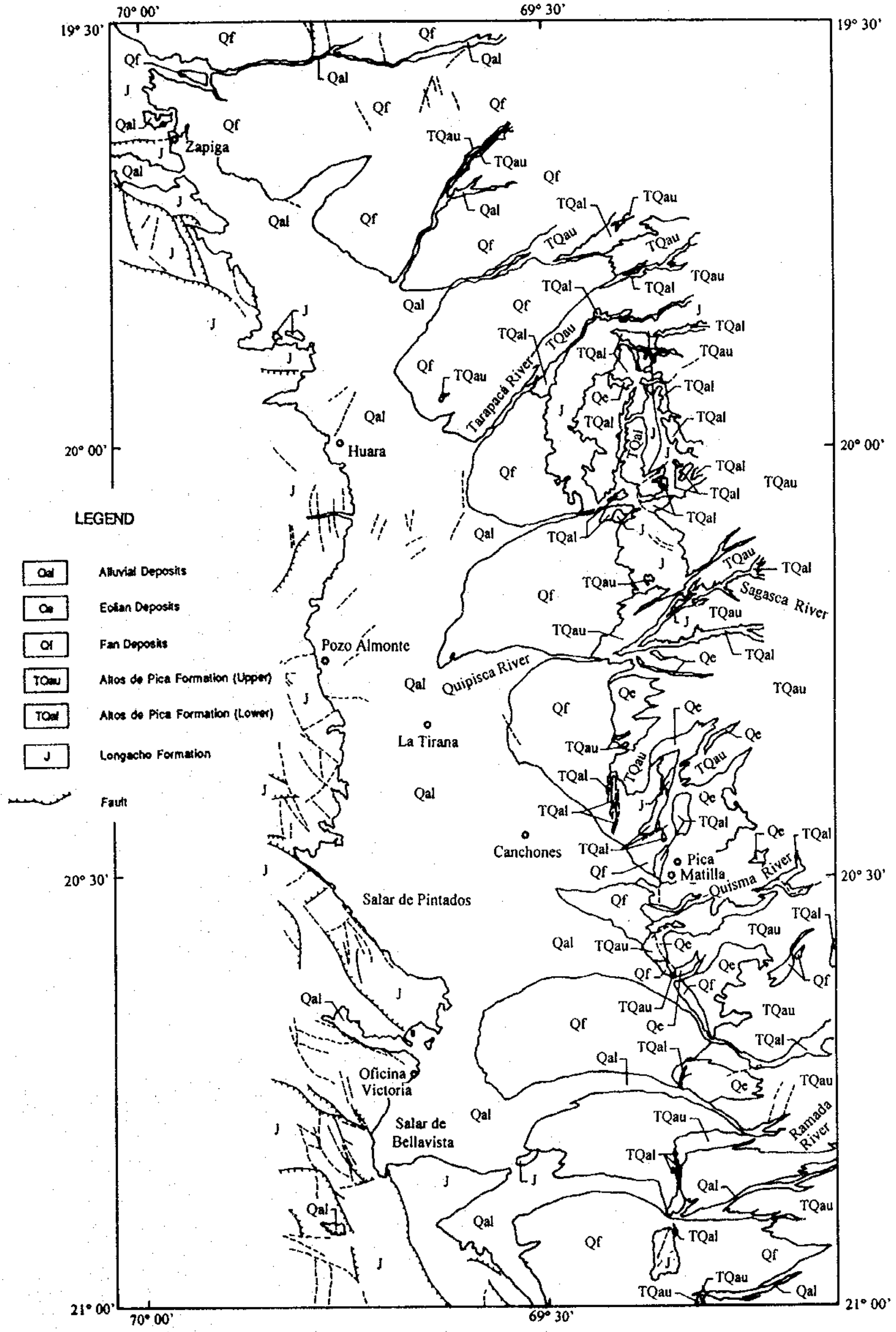

Fig. 2.15 Geological Map (Pampa del Tamarugal)

< Mapa Geológico (Pampa del Tamarugal) >

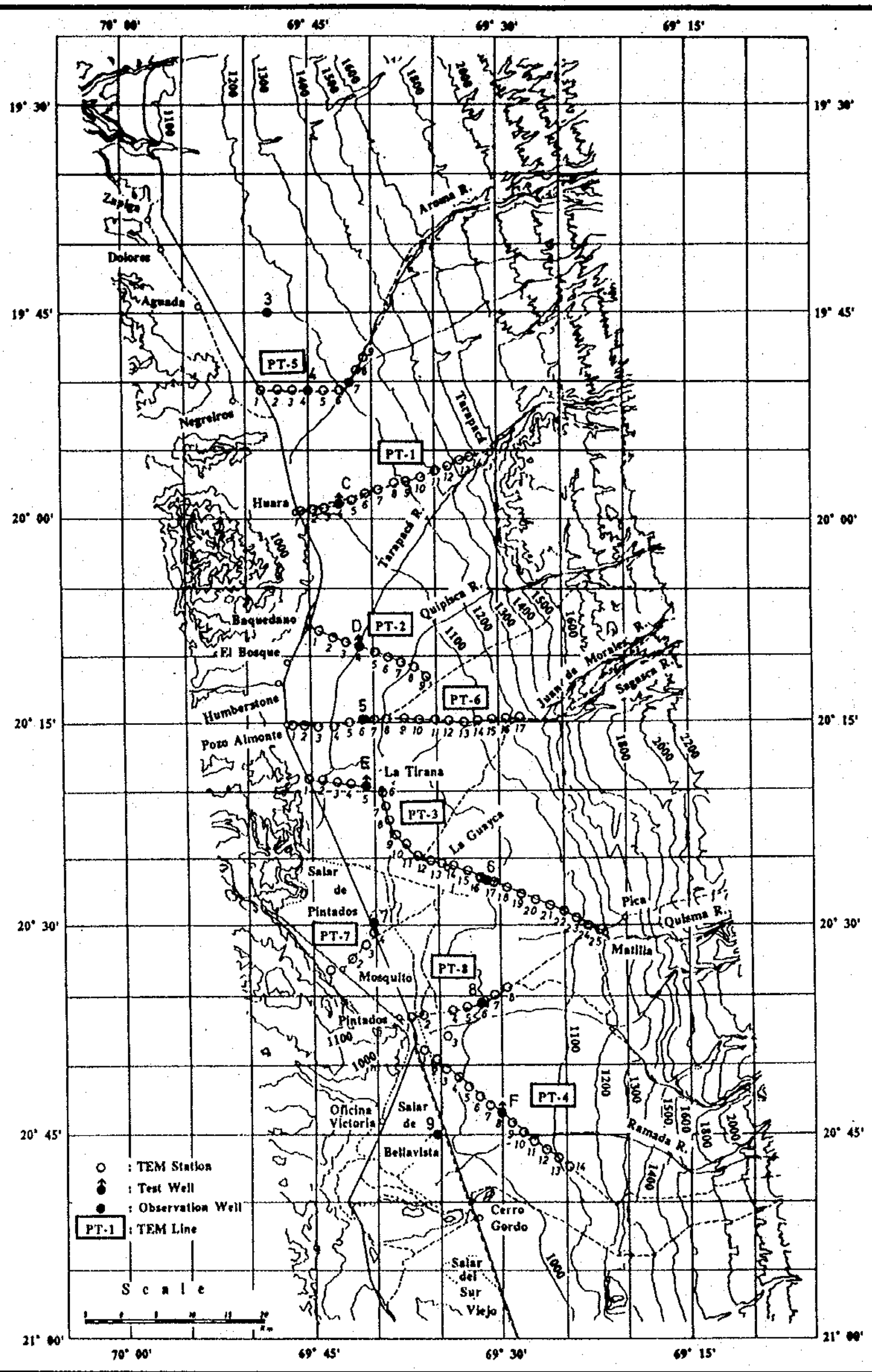

Fig. 2.16 Location of TEM Station and Test/Observation Well (Pampa del Tamarugal)

<Ubicación de las Estaciones TEM y Pozos de Prueba y Observación (Pampa del Tamarugal)>

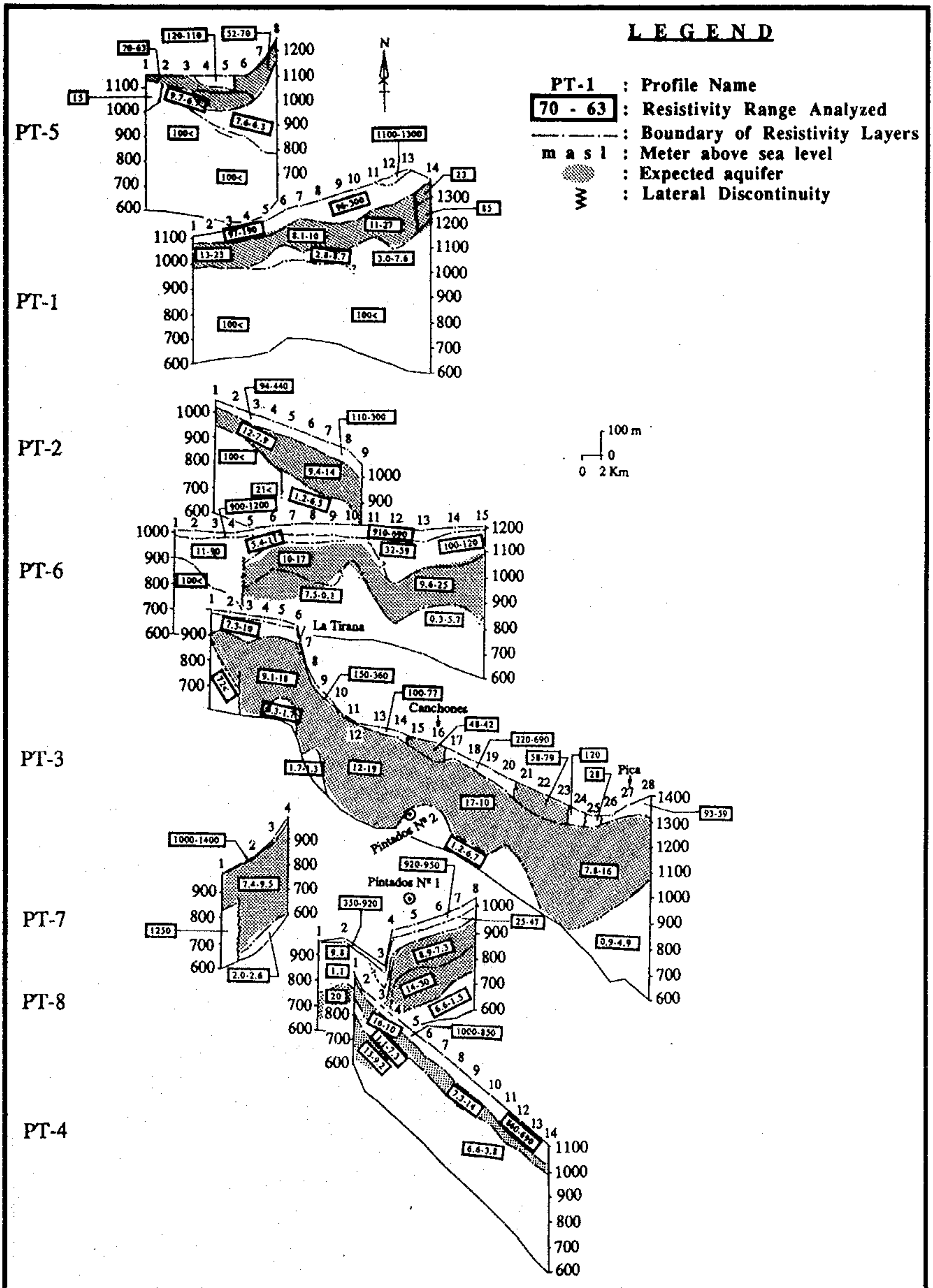

Fig. 2.17 Geoelectric Profile (Pampa del Tamarugal)

<Perfiles Geoeléctricos (Pampa del Tamarugal)>

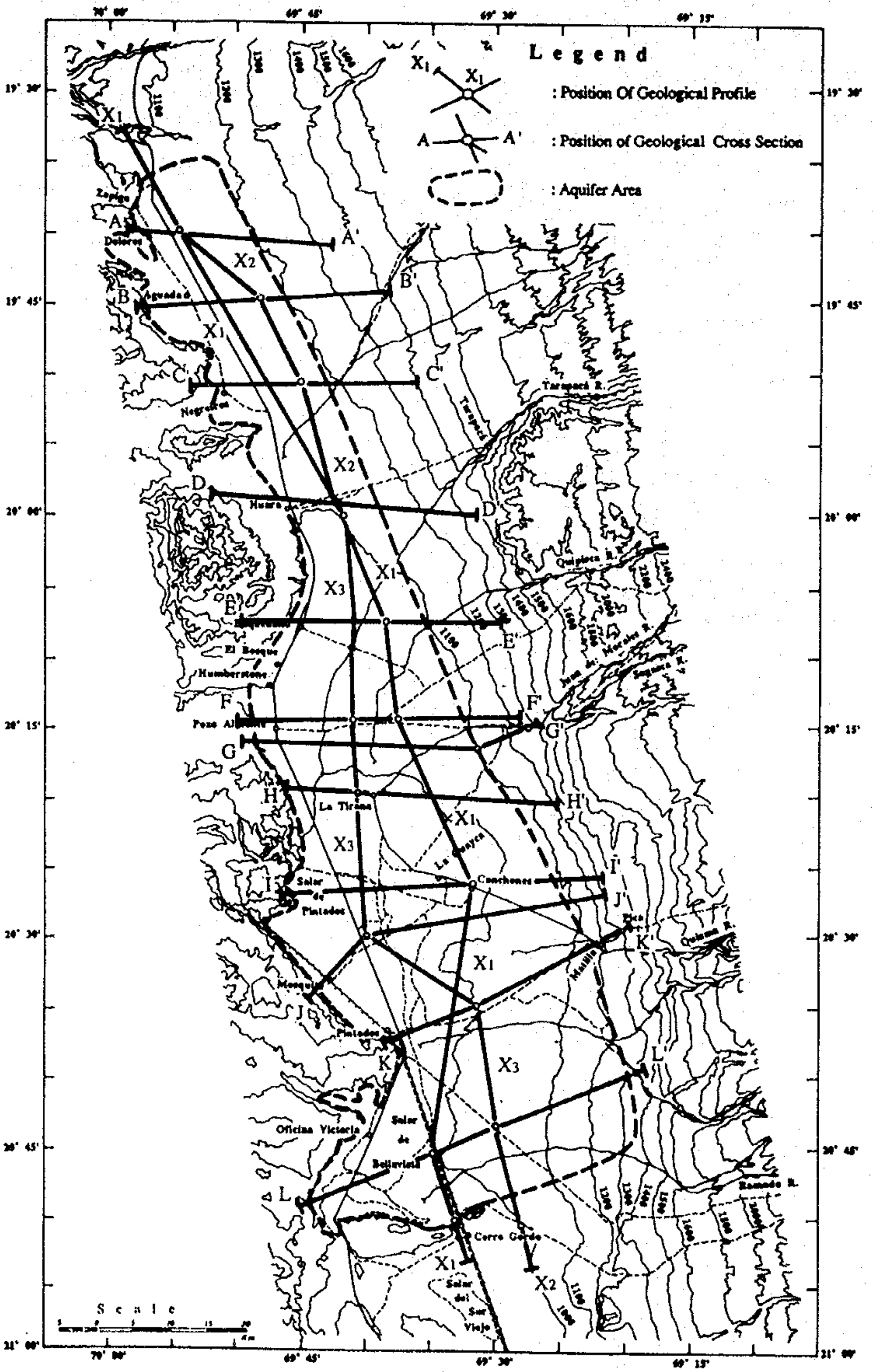

Fig. 2.18 Location of Geological Profile and Cross Section (Pampa del Tamarugal)

< Ubicación Perfil Geológico y Sección Geológica Transversal (Pampa del Tamarugal) >

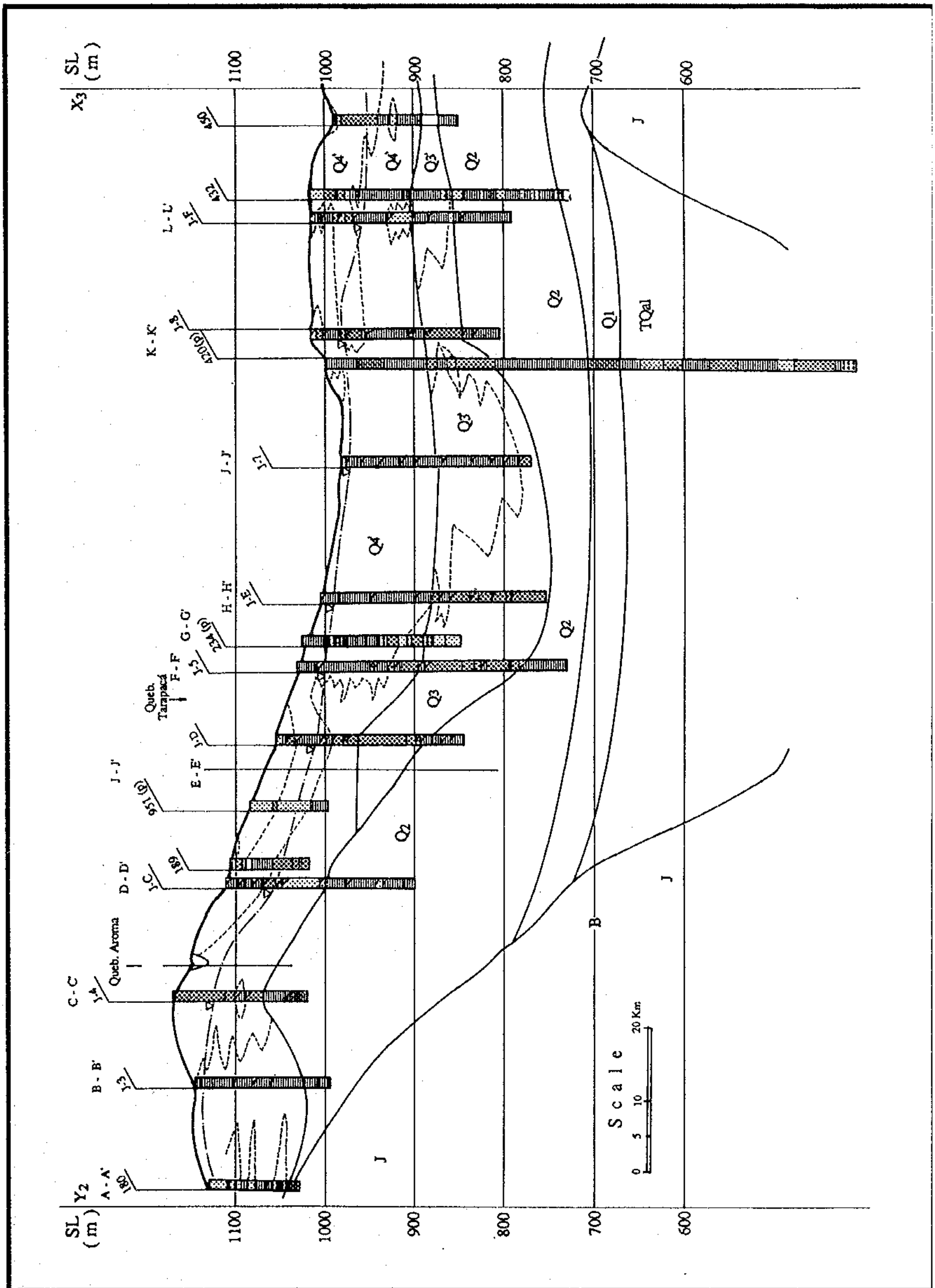

Fig. 2.19 Geological Profile (Pampa del Tamarugal)

< Perfil Geológico (Pampa del Tamarugal)>

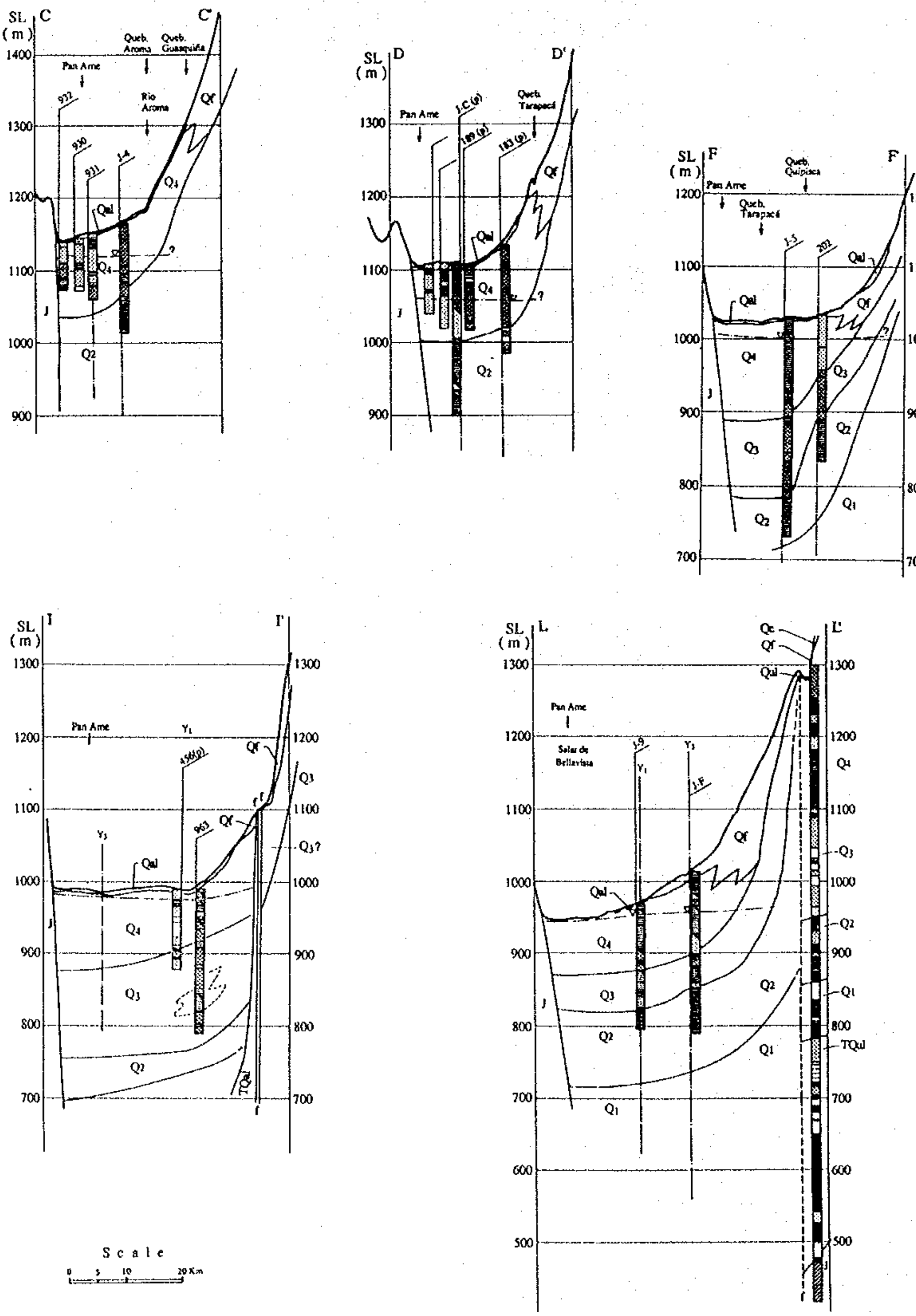

Fig. 2.20 Geological Cross Section (Pampa del Tamarugal)

<Seccion Geologica Transversal(Pampa del Tamarugal)>

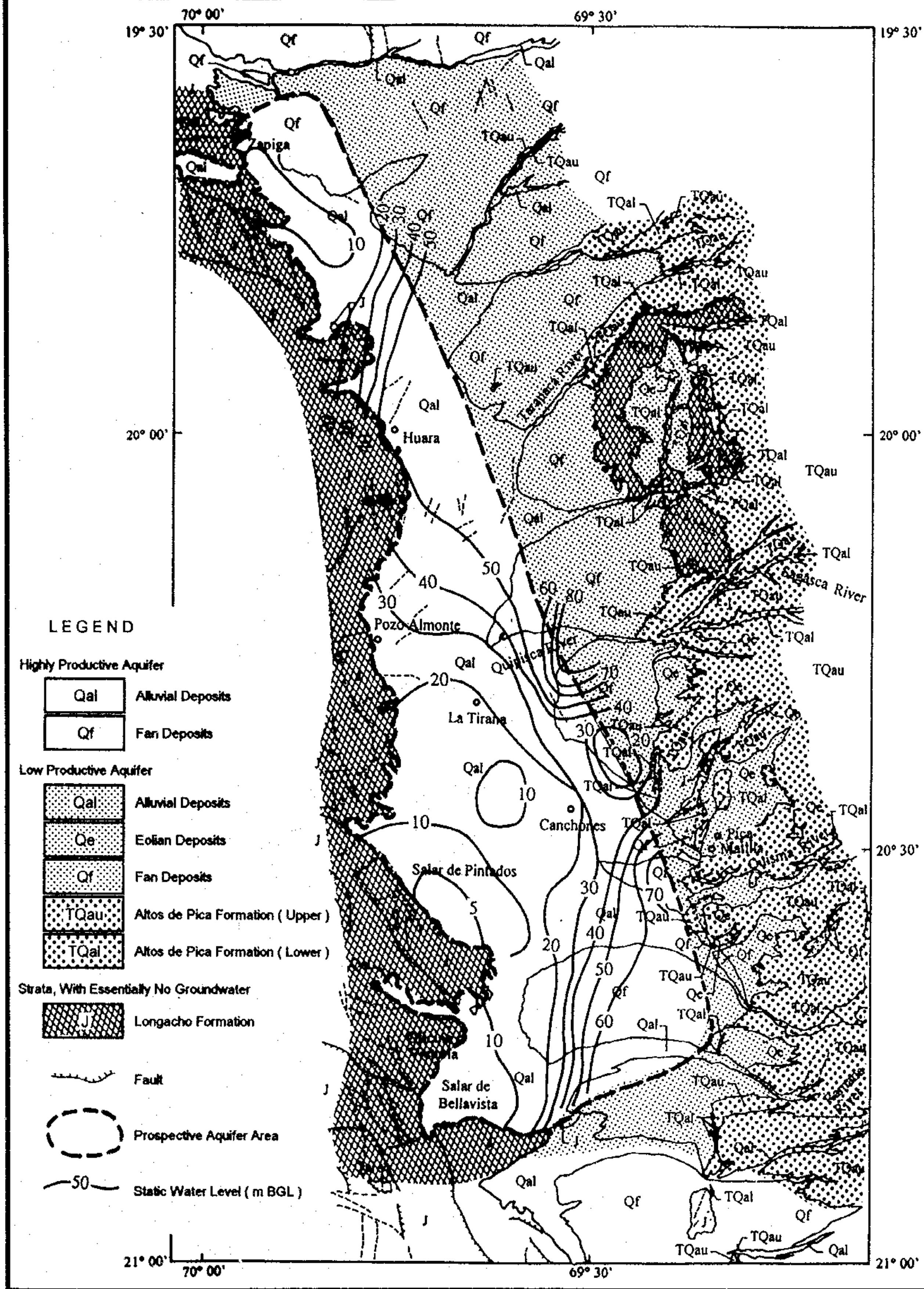

Fig. 2.21 Hydrogeological Map (Pampa del Tamarugal)

< Mapa Hidrogeológico (Pampa del Tamarugal) >

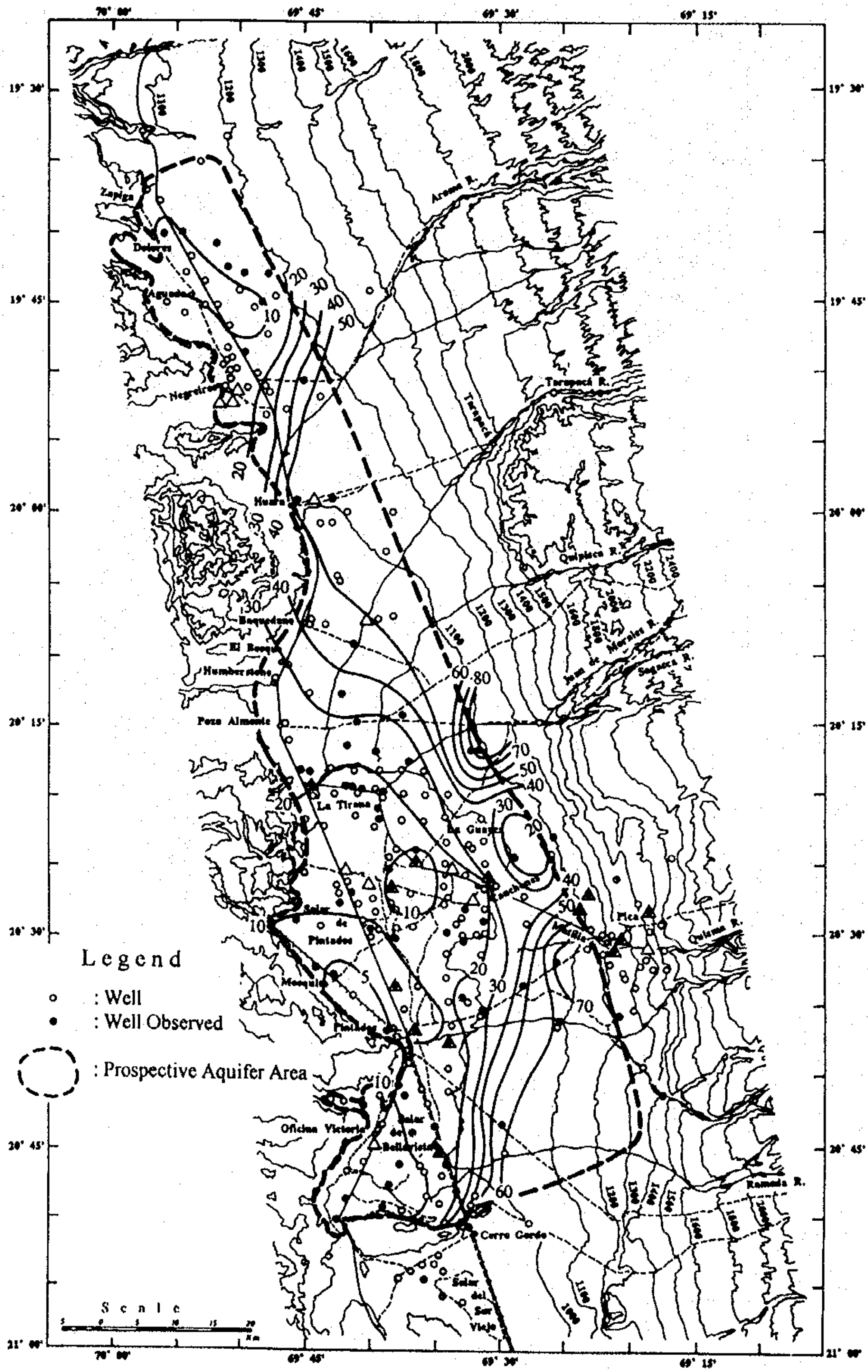

Fig. 2.22 Static Water Level (1993) : unit: m*BGL*

<Nivel Estático (1993) : unidad: mBGL>

Unit. : m BGL

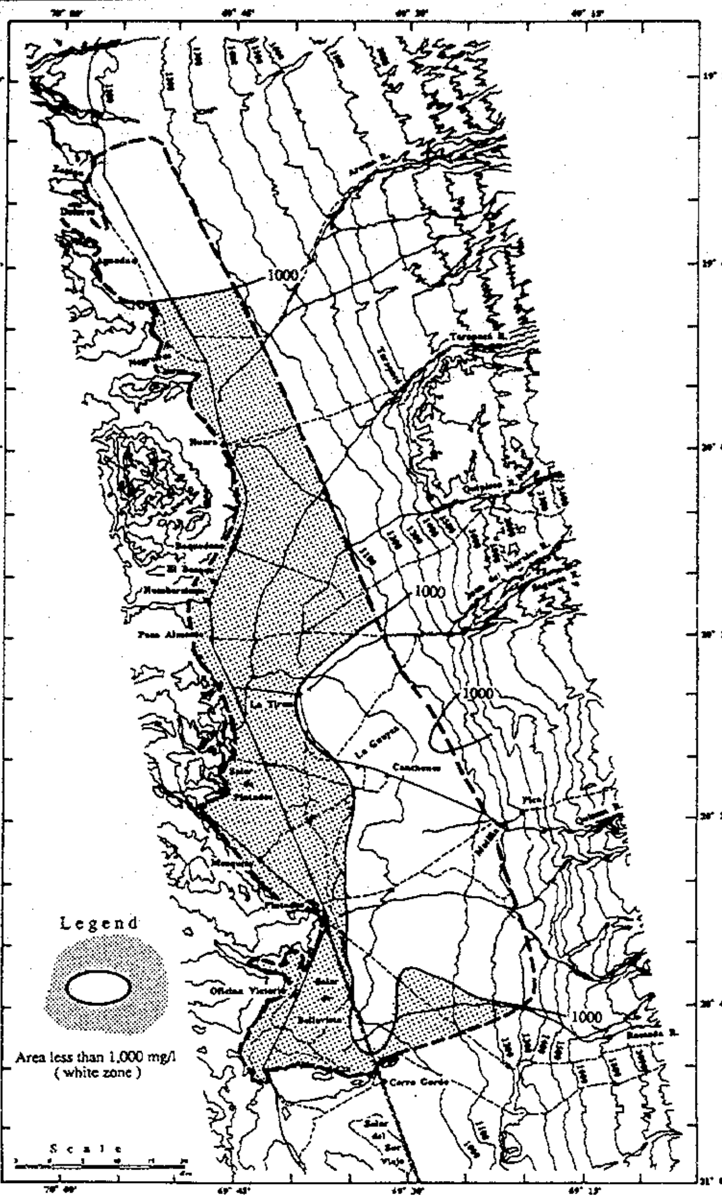

Fig. 2.23 (1) Distribution of TDS (Pampa del Tamarugal)

< Distribución de TDS (Pampa del Tamarugal) >

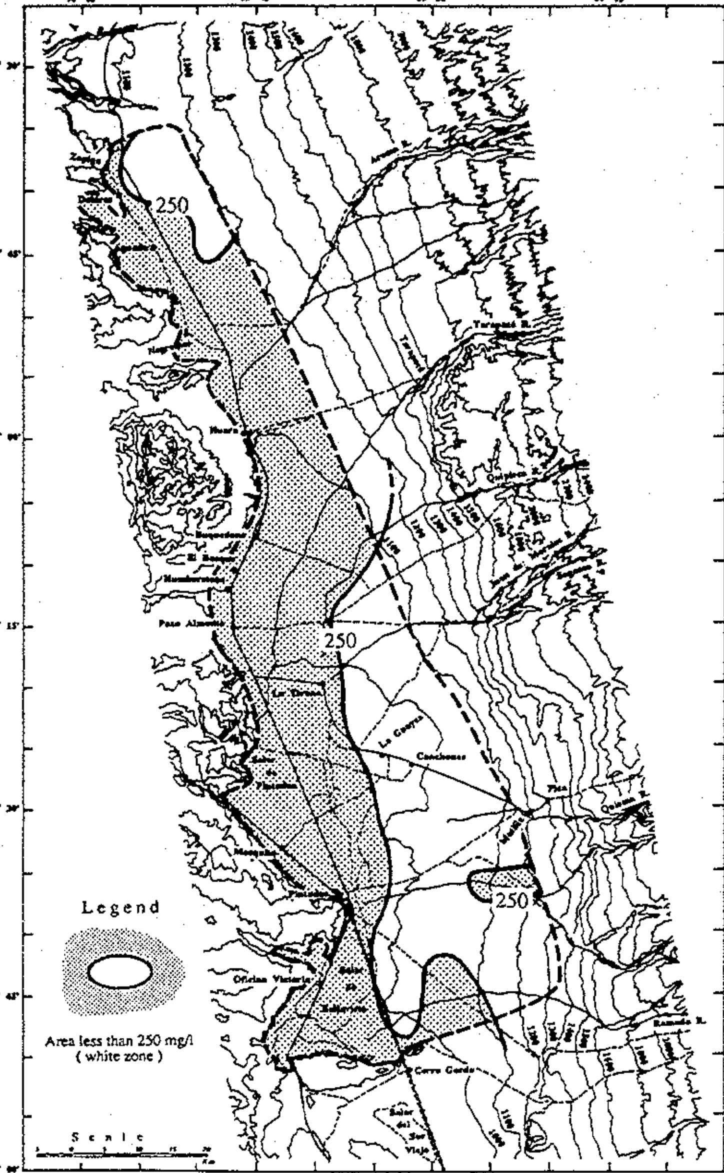

Fig. 2.23 (2) Distribution of Cl (Pampa del Tamarugal)

< Distribución de Cl (Pampa del Tamarugal) >

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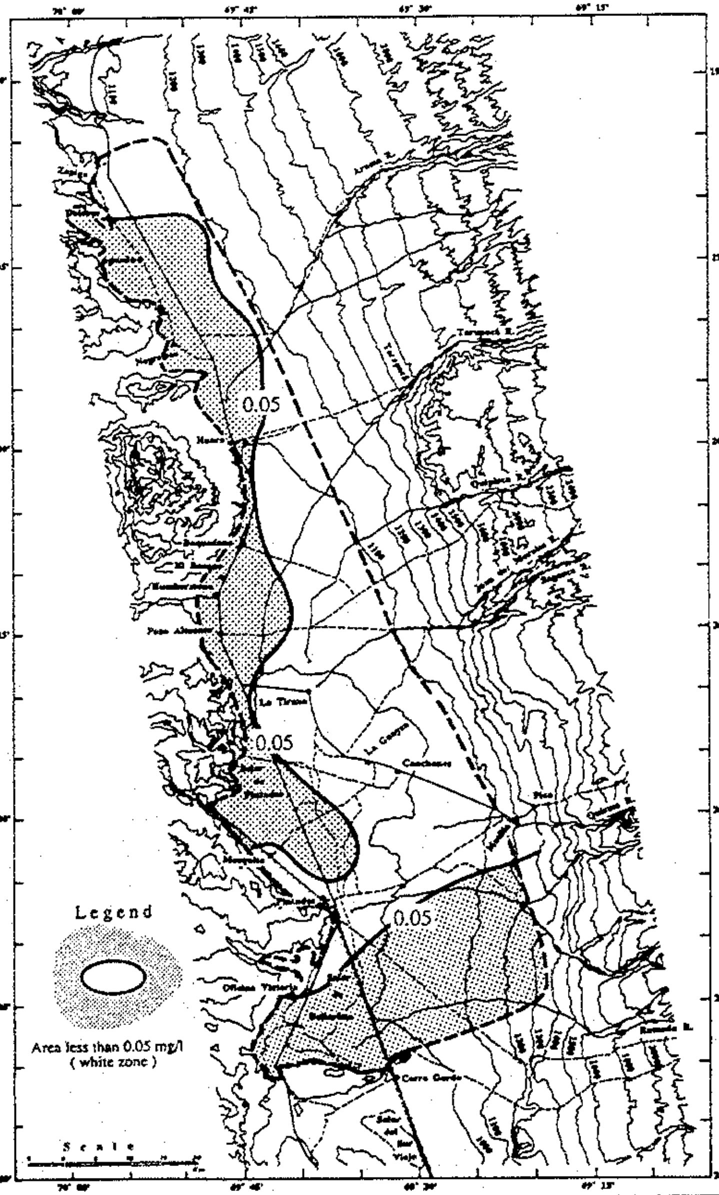

Fig. 2.23 (3) Distribution of As (Pampa del Tamarugal)

< *Distribución de As (Pampa del Tamarugal)* >

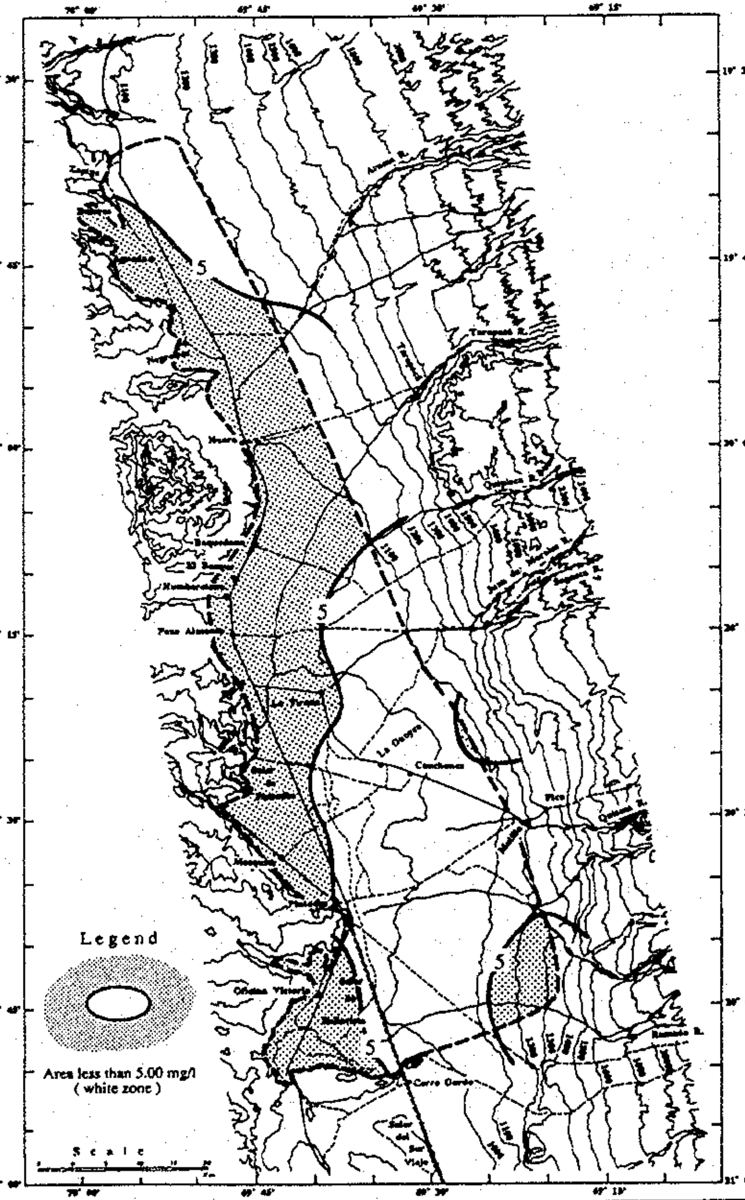

Fig. 2.23 (4) Distribution of B (Pampa del Tamarugal)

< *Distribución de B (Pampa del Tamarugal)* >

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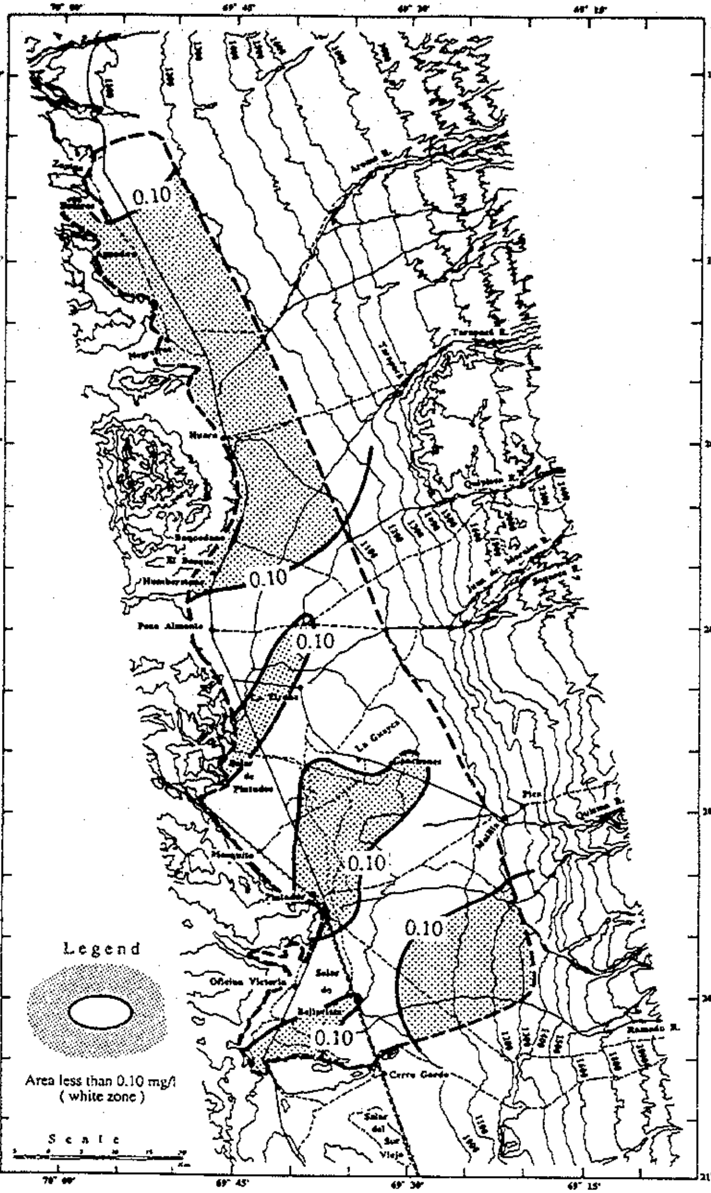

Fig. 2.23 (5) Distribution of Mn (Pampa del Tamarugal)
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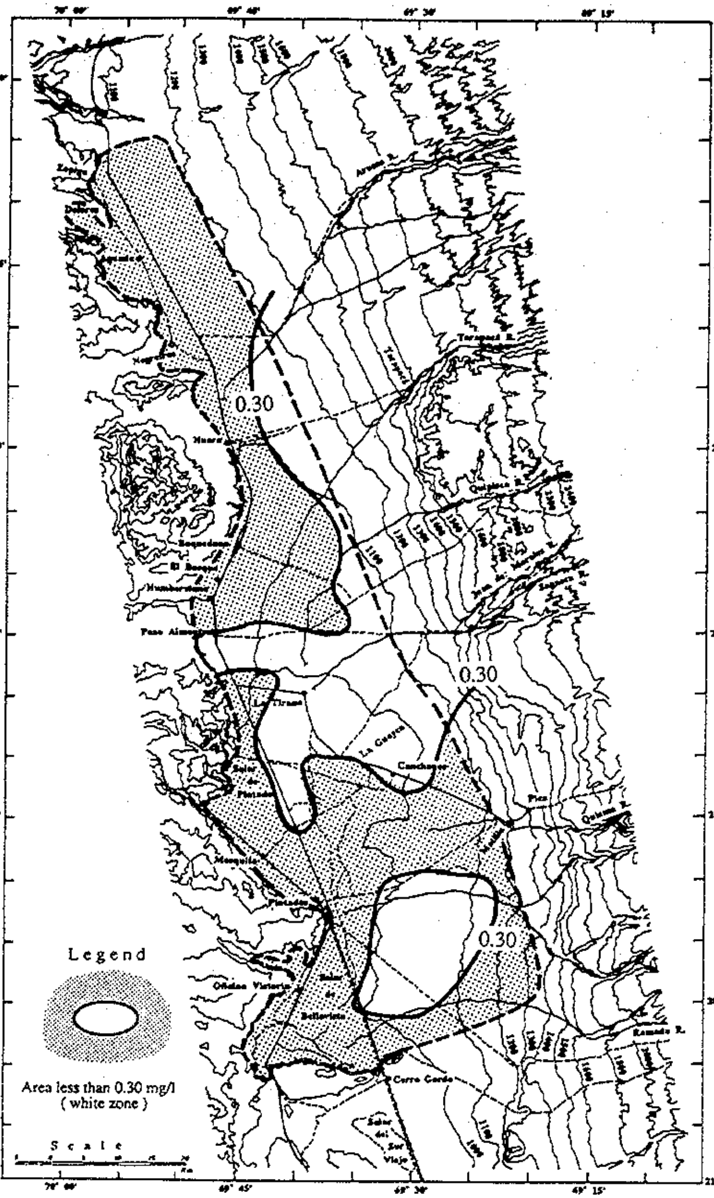

Fig. 2.23 (6) Distribution of Fe (Pampa del Tamarugal)
< Distribución de Fe (Pampa del Tamarugal) >

THE STUDY ON THE DEVELOPMENT OF WATER RESOURCES IN NORTHERN CHILE | JICA

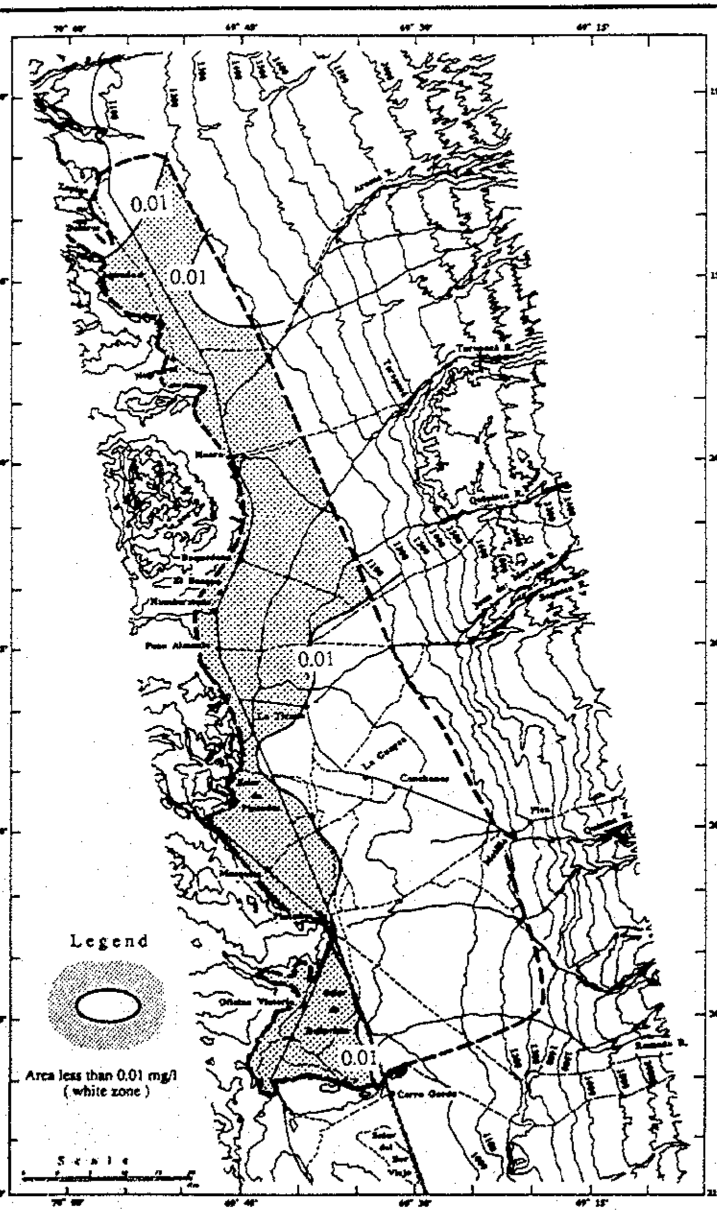

Fig. 2.23 (7) Distribution of Cd (Pampa del Tamarugal)

< Distribución de Cd (Pampa del Tamarugal) >

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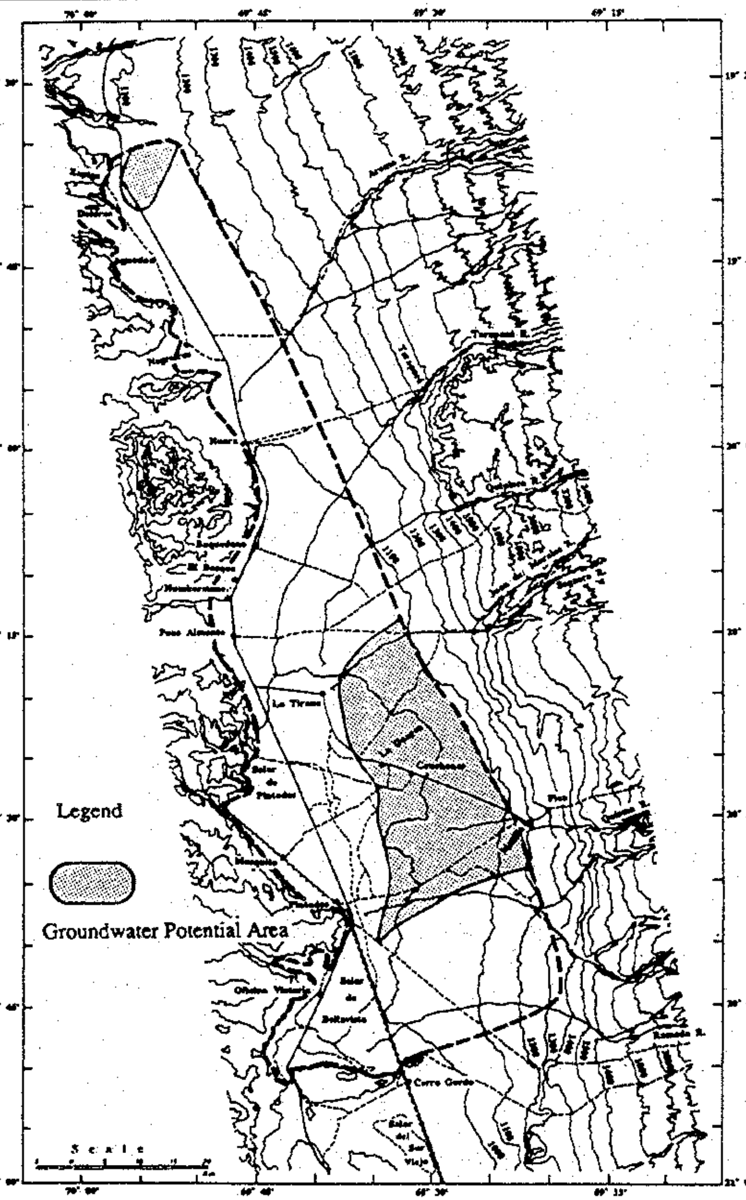

Fig.2.23 (8) Prospective Aquifer Area

<Área de Acuíferos Probables>

THE STUDY ON THE DEVELOPMENT OF WATER RESOURCES IN NORTHERN CHILE | **JICA**

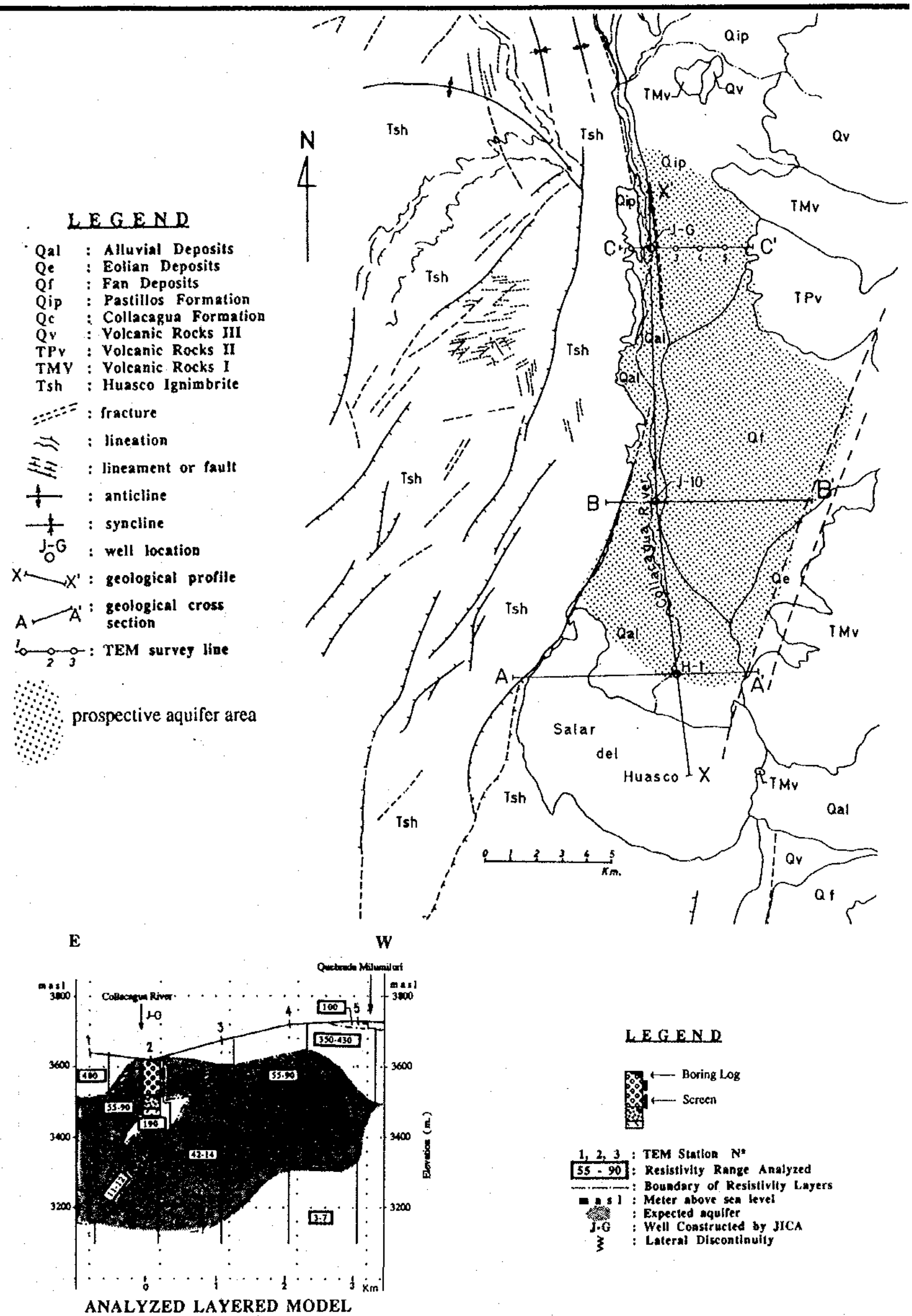

Fig. 2.24 Geological Map and Resistivity Profile of C-C' (Salar del Huasco)

<Mapa Geológico y Perfil de Resistividad del C-C' (Salar del Huasco)>

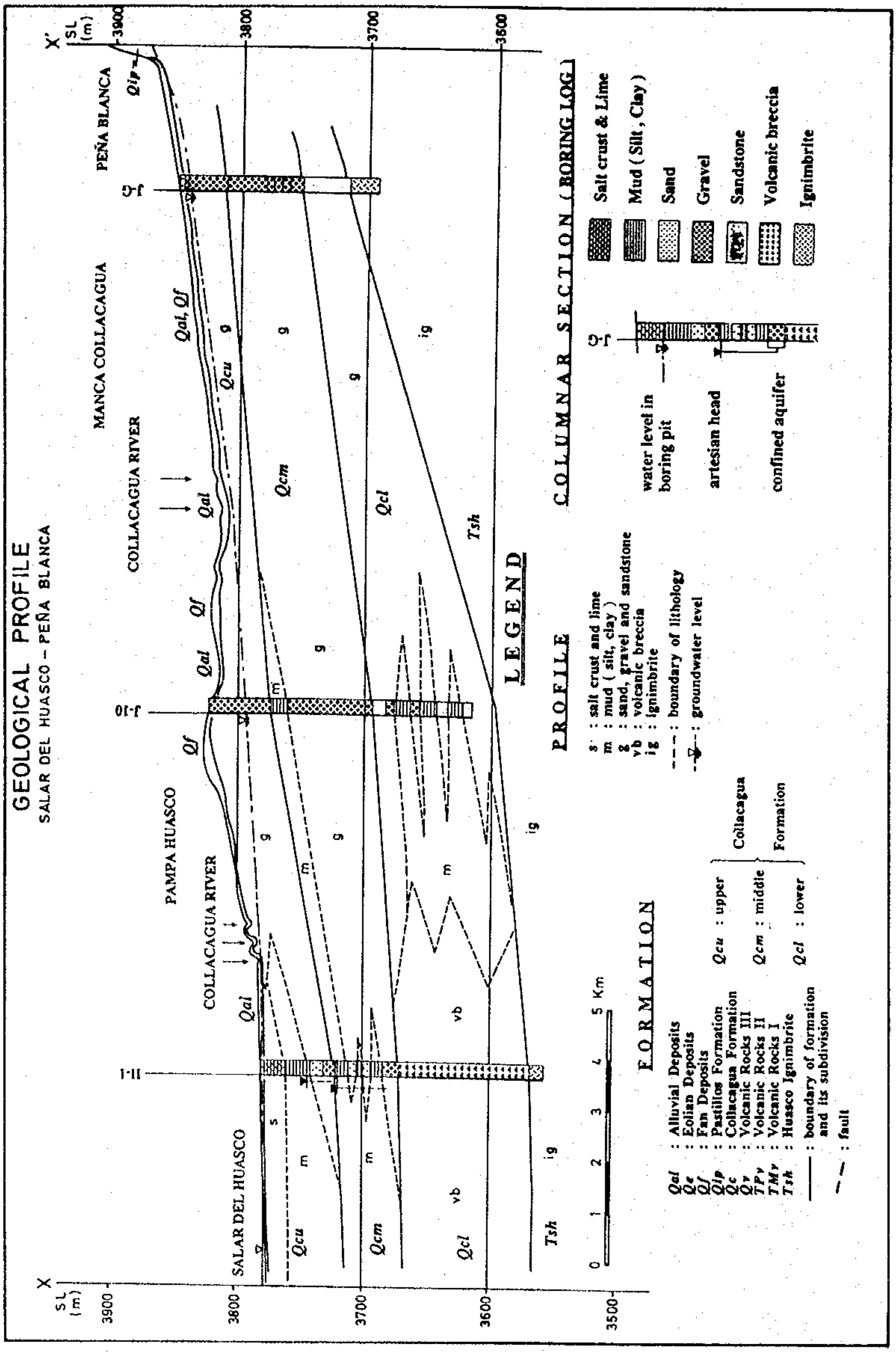

Fig. 2.25 Geological Profile (Salar del Huasco)

<Perfil Geológico (Salar del Huasco)>

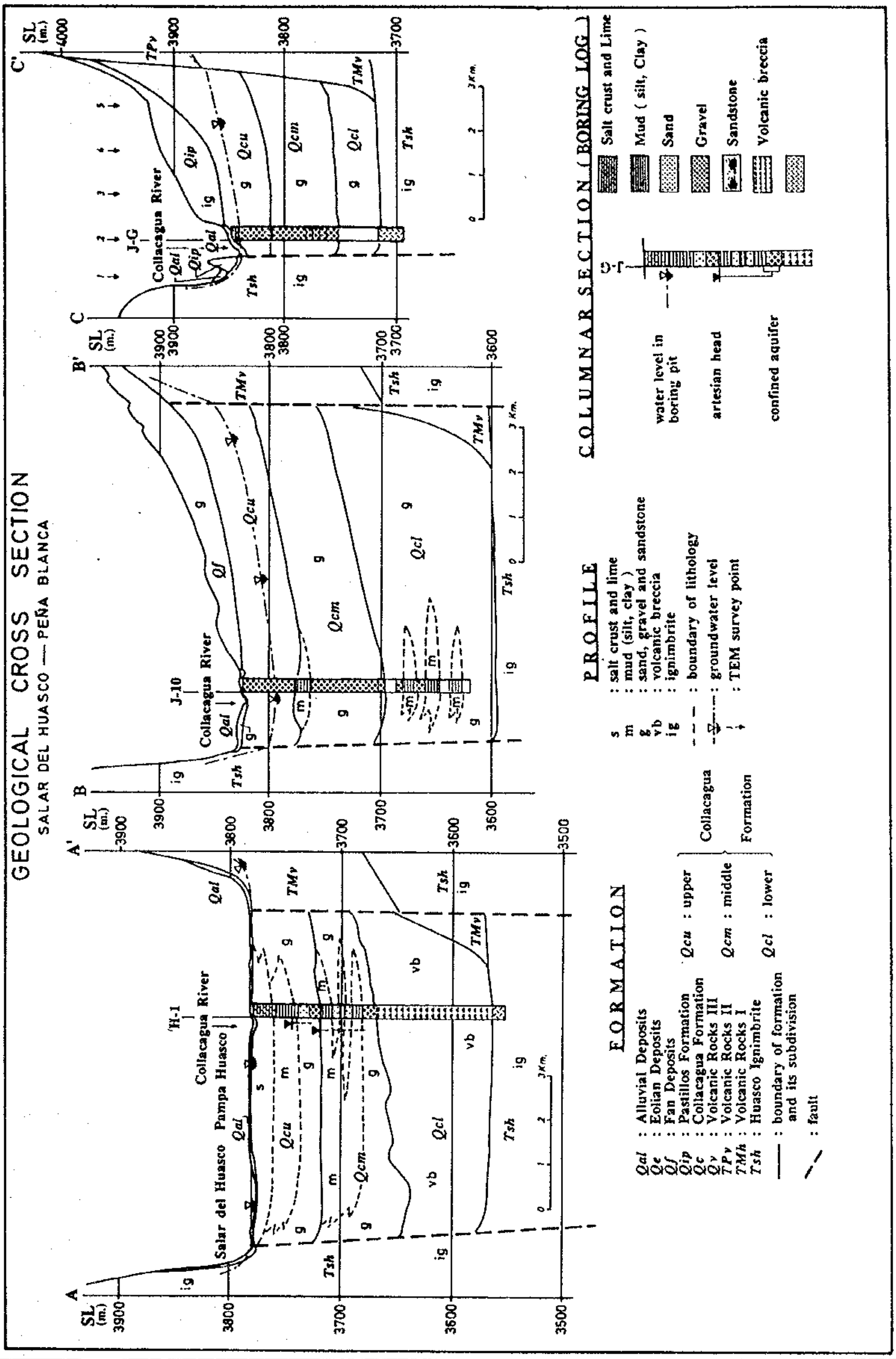

Fig. 2.26 Geological Cross Section (Salar del Huasco)
<Seccion de Cruce Geológico (Salar del Huasco)>

CHAPTER III WATER USE

Chapter III WATER USE

3.1 Municipal Water of Arica

3.1.1 Existing Water Supply Service

1) Water Supply System

The municipal water of Arica city is supplied by ESSAT. The existing municipal water supply system covers about 1,680 ha of the urbanized area of Arica city, serving almost the entire population of the city.

The water supply sources, as of 1992 consisted of 28 wells located in the city area and Azapa Valley. Their total capacity was 503 l/s. Thereafter, however, ESSAT developed additional 17 wells in the city area and Azapa Valley by the end of 1993. As a result, the existing total capacity of the water sources is estimated to be 730 l/s.

A sketch of the existing water supply system is shown in Fig. 3.1.

ESSAT has four (4) legally authorized water rights with a total quantity of 463 l/s for groundwater extraction in the city area and Azapa Valley. Moreover, they rent water rights from farmers and have no customary water rights.

2) Water Production and Consumption

In 1992, ESSAT produced 16,941 x $10^3 m^3$ of municipal water, of which 10,635 x $10^3 m^3$ was consumed for residential, commercial, industrial and other uses. The estimated water loss including water leakage and uninvoiced water use was 6,306 x $10^3 m^3$, corresponding to 37.2% of the production volume.

The 1992 consumption by category and total estimated production are summarized below.

1992			
	Quantity (10^3m^3)	%	Per capita (l/c/d)
Production	16,940.7		277
Consumption	10,635.2	100.0	174
Residential	8,170.8	76.8	134
Commercial	1,087.3	10.2	
Industrial	919.3	8.6	
Other	457.8	4.3	
Losses	6,305.5	(37.2)*	

* Percentage of Production

The total production in 1994 is expected to increase to 23,021 x 10^3m^3/year (=730 /s) by the favor of the Emergency Water Supply Project of ESSAT which was completed at the end of 1993.

3) Water Supply Restriction

The water supply service in the year 1992 - 1993 was limited to 10.5 - 15.0 hours per day due to the shortage of water. This water supply restrictions were relaxed after the completion of the emergency water supply project. The normal water supply hours, as of January, are 14.0 - 24.0 hours per day.

3.1.2 Future Water Demand

1) Projected Population

The census population of Arica city for the period of 1940 - 1992 are available as follows.

Year	Population	Year	Population
1940	14,064	1970	87,795
1952	18,847	1982	139,628
1960	43,344	1992	169,212

For projection of the future population of Arica city, the following three (3) different growth scenarios were studied.

(1) Linear growth (straight line), based on 1982-92 census data
(2) Exponential growth based on 1970-92 census data
(3) Exponential growth based on 1982-92 Region I growth rate.

The scenario (2) gives the highest growth, whereas the scenario (1) shows the lowest one and the scenario (3) presents an intermediate one (See, Fig. 3.2).

The population growth will much depend on the economic developments of the city in the future. Both central and local governments are enforcing various policies for the recovery of the existing depressed economy of the city. Hence, the future population of Arica city is projected based on the scenarios of linear growth until 2000 and exponential Region I growth rate after 2000.

The results are shown below.

Year	Population
1995	178,087
2005	214,524
2015	265,375

2) Future Water Consumption

The future municipal water demand of Arica city is estimated based on the following assumptions.

(1) The existing total per capita water consumption including commercial, industrial and others is estimated to be 220 l/s/d if a 24 hour unrestricted water supply is served.

(2) The future per capita water consumption will increase at the rate of 0.3% per year as the standard of living improves.

(3) The tourism development project being planned for Bajos del Chinchorro area will consume an additional water. This additional water consumption in 1995 is assumed at 10 l/s and it would gradually increase to about 40 l/s in the year 2015.

The projected future water consumption are summarized below.

Year	Population Served	Per Capita Consumption (l/c/d)	Consumption W/O Tourism (l/s)	Allowance for Tourism (l/s)	Total Consumption (l/s)
1995	178,087	221.99	457.6	10	467.6
2005	214,524	228.74	567.9	20	587.9
2015	265,375	235.69	723.9	40	763.9

3) Projected Production

The total loss including leakage and unaccounted-for water is approximately 40% at present time. It is assumed that this percentage will gradually decrease to 30% by the year 2005 by the leakage control program of ESSAT.

Future losses as a percentage of total production and the projected production are estimated as follows.

Year	Total Consumption (l/s)	Losses (%)	Total Production (l/s)
1995	467.6	40	779.3
2005	587.9	30	839.9
2015	763.9	30	1,091.3

3.2 Irrigation and Other Water Uses in Azapa Valley

3.2.1 Existing Irrigated Areas

1) Irrigation System

The cultivation area of Azapa Valley has considerably increased during the recent years from 2,053 ha in 1975 to 2,319 ha in 1984, 2,522 ha in 1989 and 3,213 ha in 1993.

The existing cultivation area of 3,213 ha is divided into 27 irrigation sectors. Of these, 12 sectors, located in the upper reaches (Bocatoma - Cabuza) are irrigated by surface water from the Azapa Canal. Another 10 irrigation sectors, located in the lower reaches (Cabuza - Saucache) are irrigated by surface water of Azapa Canal, supplemented by groundwater. The remaining five (5) irrigation sectors, located in the lower reaches (Cabuza - Saucache) are irrigated by spring water supplemented by groundwater.

(1) Azapa Canal : The Azapa Canal began operations in 1962 when the Lauca Canal to divert the water of Lauca River was completed. The Azapa Canal draws the surface water of San José River at Bocatoma and distributes it to the farmlands of Azapa Valley through the main and secondary canals with a total length of 62.9 km.

(2) Springs : There were originally 17 springs for irrigation use in the lower reaches of Azapa Valley. However, most of them have dried up during the recent years. The number of functioning springs in 1993 is only five (5).

(3) Groundwater Wells : Groundwater for irrigation use is extracted from 122 wells as of 1993 in the lower reaches of the Azapa Valley.

For location of the irrigation sectors, see Fig. 3.3.

2) Crop Areas

The farmland cultivates fruits (olive, tomato, grape fruit, tropical fruit), vegetables (green bean, green vegetable, flower) and pasture (alfalfa). These crops are all irrigated by conventional irrigation or drip irrigation method. The existing cultivation areas by crop type and by irrigation method in 1993 are as follows.

Crop Type	Conventional Irrigation (ha)	Drip Irrigation (ha)	Total
Fruit	1,166	528	1,694
Vegetables	640	753	1,393
Pasture	126	-	126
Total	1,932	1,281	3,213

3) Cropping Pattern and Actual Irrigated Area

The above cultivation areas are not necessarily cropped throughout the year due to the lack of water and marketing limitations. The perennial crops of olive, grape fruit, tropical fruit and alfalfa are cultivated throughout the year. However, the annual crops of tomato, green bean, green vegetable and flower are cropped twice a year for the area of 30% among their total cultivation areas respectively and one time a year for the area of 70%.

Cultivation of the above annual crops concentrates during eight (8) months of March to October and cropping during the other periods of the year is considered negligibly small.

The actual monthly irrigated areas by crop type and by irrigation method are estimated as follows, by assuming that the monthly irrigated areas are uniformly distributed during the eight (8) months.

Crop Type	Conventional Irri. (ha)		Drip Irri. (ha)		Total	
	Mar.-Oct.	Nov.-Feb.	Mar.-Oct.	Nov.-Feb.	Mar.-Oct.	Nov.-Feb.
Fruit	1,143	1,101	367	68	1,510	1,169
Vegetables	416	-	490	-	906	-
Pasture	126	126	-	-	126	126
Total	1,685	1,227	857	68	2,542	1,295

3.2.2 Existing Irrigation Water Use

1) Water Demand

Water demand of the crops are estimated by multiplying their evapotranspiration by irrigation efficiency and irrigation area. In this estimation, the evapotranspiration and irrigation efficiency assumed in the previous study by Araya, Cabrera/Associates Ltda, Ingenieros Consultores, 1989 are applied.

The evapotranspiration of the crops monthly varies according to the change of climate at the crop site. However, the irrigation efficiency is constant throughout the year. The average annual evapotranspiration and irrigation efficiency by crop type and by irrigation method are shown below.

Crop Type	Evapotranspiration (mm/year)	Irrigation Efficiency (%)	
		Conventional	Drip
Fruit	1,236.8	60	95
Vegetables	1,154.7	45	75
Pasture	1,593.1	60	-

For the monthly evapotranspiration by crop type, see Supporting Report C, Table C.2.4.

The existing yearly irrigation water demand of the crops are estimated at 40,012 x $10^3 m^3$/year (=1,269 l/s) with the following break-down.

(unit : 10^3m^3/year)

Crop Type	Conventional Irrigation	Drip Irrigation	Total
Fruit	23,173	3,049	26,222
Vegetables	6,121	4,324	10,445
Pasture	3,345	-	3,345
Total	32,639	7,373	40,012 (=1,269 l/s)

For the monthly irrigation water demand, see Supporting Report C, Table C.2.6.

2) Real Water Consumption

The irrigation water is not all really consumed. A portion is consumed by the evapotranspiration of crops, and another portion infiltrates into underground. The infiltrated water may be re-used after recharging the groundwater.

The irrigation water consumption by the evapotranspiration of crops is considered as the real consumption. The yearly real irrigation water consumption in Azapa Valley is estimated to be 24,810 x 10^3m^3/year (=787 l/s) with the following break-down.

Crop Type	Real Water Consumption (10^3m^3/year)
Fruit	16,802
Vegetables	5,999
Pasture	2,009
Total	24,810 (=787 l/s)

3) Water Rights

The irrigation water is extracted from the river, springs and groundwater based on legally authorized water rights or customary water rights. The existing water rights for irrigation use in Azapa Valley are summarized below.

Type	Number of Water Rights	Water Source	Quantity
Legally Authorized	22	S, G	1,038.05 l/s
Customary	11	R, G	454.77 l/s + 2,437.90 acc.*

S: Spring, G: Groundwater, R: River

* acc. (acción): A kind of water right unit

3.2.3 Existing Other Water Uses

1) Existing Water Use

The groundwater of 1,694 x $10^3 m^3$/year (=53 l/s) is extracted from 45 wells for individual domestic, industrial and miscellaneous uses in Azapa Valley.

A considerable portion of the extracted water is discharged on the lands in Azapa Valley. They will infiltrate into underground, recharging groundwater for reuse. The yearly real water consumption of the other water uses is estimated at 678 x $10^3 m^3$/year (=21 l/s) by assuming that 60% of the extracted water recharges groundwater.

2) Water Rights

Water for the other uses are mostly extracted without rights except for industrial use. The existing water rights are summarized below.

Type	Number of Water Rights	Water Source	Quantity (l/s)
Legally Authorized	5	G	106.1
Customary	4	G	42.0
Total	9		148.1

G: Groundwater

3.3 Irrigation Water of Lluta Valley

3.3.1 Existing Irrigated Area

1) Irrigation System

The total farmland area of the Lower Lluta Valley is estimated at 4,032 ha. This area is located along a 65 km reach between Vilacollo and the river mouth, and is supplied by the river water irrigation system of the Lluta. (See Fig. 2.1).

However, only a portion of the 4,032 ha is cultivated. The cultivated area is normally limited to 2,784.2 ha (69%), and the other 1,248.2 ha (31.0%) is perennially fallow due to lack of irrigation water and the poor drainage capacity of the soil.

The 4,032 ha of farmland along the Lluta River is divided into 6 irrigation sectors and is further divided into 80 irrigation sub-sectors. Each irrigation subsector is supplied river water through its own independent irrigation intake and channel network. Conventional irrigation methods are used for all irrigated areas.

Locations of the above irrigation sectors and sub-sectors, along with the irrigation intakes, are shown in Fig. 3.4.

2) Irrigated Area and Cropping Patterns

Due to river water contamination by Boron (B), the crop types of the Lower Lluta Valley are limited to maize, pasture (alfalfa), and certain kinds of vegetables.

Maize is the predominant crop followed by pasture (alfalfa). The breakdown by crop type is as follows:

Crop	Area (ha)	% of Cultivated Area
Maize	1,698.4	61.0
Alfalfa	683.9	24.6
Vegetable	401.9	14.4
Total	2,784.2	100.0

Maize is cultivated once or twice a year. Double cropping is common for the area downstream of Poconchile. The first crop is cultivated for the period of March to June and second crop is for September to December. However, there is normally only one crop in the upstream area of Poconchile for the period of December to March due to the limitations of climate and marketing. Vegetables and pasture are cultivated throughout the year.

The monthly irrigated areas by crop type are summarized as follows.

	Maize (ha)	Vegetables (ha)	Pasture (ha)	Total (ha)
Jan.-Feb.	371.3	401.9	683.9	1,457.1
Mar.	1,698.4	401.9	683.9	2,784.2
Apr.-Jun.	1,327.1	401.9	683.9	2,412.9
Jul.-Aug.	-	401.9	683.9	1,085.8
Sep.-Nov.	1,327.1	401.9	683.9	2,412.9
Dec.	1,698.4	401.9	683.9	2,784.2

3.3.2 Existing Water Use

1) Water Demand

Water demand of crops are estimated by multiplying their evapotranspiration by irrigation efficiency and irrigation area.

Evapotranspiration and irrigation efficiency of the crops in Lower Lluta Valley were estimated based on the previous studies for Azapa Valley and discussions with SAG, as follows.

Crop	Evapotranspiration (mm/year)	Irrigation Efficiency (%)
Maize	1,385.6	40
Vegetables	1,154.7	50
Pasture	1,593.1	60

For the monthly evapotranspiration by crop type, see Supporting Report C, Section 3.2.1.

The existing yearly irrigation water demand of the crops are estimated to be 64,598 x $10^3 m^3$/year (=2,048 l/s) with the following break-down.

Crop Type	Water Demand ($10^3 m^3$/year)
Maize	36,126
Vegetables	10,313
Pasture	18,159
Total	64,598 (=2,048 l/s)

Out of the above water demand, that in the downstream reaches of Tocontasi/Chapisca is estimated to be 60,708 x 103 m3/year (=1,925 l/s).

For the monthly irrigation water demand, see Supporting Report C, Table C.3.3.

2) Real Water Consumption

All of the required irrigation water is extracted from the Lluta River. However, the irrigated water is not completely consumed by the crops. A significant portion infiltrates into the underground and returns to the river in the downstream reaches. This returned water is available for reuse. The amount actually consumed by the crops (excluding losses due to irrigation efficiencies) is estimated, based on the evapotranspiration.

The yearly real irrigation water consumption in Lower Lluta Valley (Villacollo - river mouth) is estimated to be 29,987 x $10^3 m^3$/year (=951 l/s) with the following break-down by crop type.

Crop Type	Real Water Consumption ($10^3 m^3$/year)
Maize	14,451
Vegetables	4,641
Pasture	10,895
Total	29,987 (=951 l/s)

Out of the above real irrigation water consumption, that in the downstream reaches of Tocontasi/Chapisca station is estimated to be 28,181 x $10^3 m^3$/year (=894 l/s).

3) Water Rights

Most of the irrigation water of the Lower Lluta Valley is extracted based on the legally authorized water rights or customary water rights. The number of water rights and quantity, as of 1994, are summarized below. Almost all the water sources are river.

Type	Number of Water Rights	Water Source	Quantity
Legally Authorized	81	R, G	284.75 l/s+2,729.84 ac
Customary	1	G	10.0 l/s

R: River, G: Groundwater

3.4 Municipal Water of Iquique

3.4.1 Existing Water Supply Service

1) Water Supply System

The municipal water of Iquique city is supplied by ESSAT. The existing municipal water supply system covers approximately 2,162 ha of Iquique city, serving the entire population of the city.

The water source for the city is groundwater from the Pampa del Tamarugal. The groundwater is extracted by 12 wells at or near Canchones located approximately 70 km east of the city. There are also 2 emergency wells and 2 observation wells.

The extracted groundwater is transferred by the transmission mains of 75.3 km in length from Canchones collection tank to the distribution tanks installed on the hills to the east of the city. The transmission mains cross the coastal mountains on the way to Iquique city.

The route of the transmission mains is shown in Fig. 3.5.

Of the 12 operating wells, 8 have legally authorized water rights with a total permitted extraction quantity of 835 l/s.

2) Water Production and Consumption

In 1992, ESSAT produced 17,241 x 10^3m^3 of municipal water, of which 10,822 x 10^3m^3 was consumed for residential, commercial, industrial and other uses. The estimated water loss including water leakage and uninvoiced water use was 6,420 x 10^3m^3, corresponding to 37.2% of the production volume

The water production, consumption by purpose and loss in 1992 are summarized below.

	1992 Quantity (10^3m^3)	%	Per Capita (l/c/d)
Production	17,241.2		313
Consumption	10,821.7	100.0	180
Residential	8,523.8	78.8	142
Commercial	869.5	8.0	
Industrial	1,359.4	12.6	
Other	68.9	0.6	
Losses	6,419.5	(37.2)*	

* Percent of Production

3) Water Supply Restriction

The existing water supply service is available for 24 hours per day. There is no overall limitation on water supply, but some areas have a restricted supply.

3.4.2 Future Water Demand

1) Projected Population

Census data is available since 1940 as follows.

Year	Population	Year	Population
1940	38,094	1970	64,435
1952	39,576	1982	110,534
1960	50,655	1992	152,529

The future population of Iquique city was determined by averaging the projected populations by the following three (3) methods, corresponding to different growth scenarios (See, Fig. 3.6).

(1) Linear growth (straight line) based on 1982-92 census data
(2) Exponential growth based on 1970-92 census data
(3) Exponential growth based on the 1982-92 Region I growth rate.

The results are shown below.

Year	Population
1995	165,236
2005	213,356
2015	272,605

2) Future Water Consumption

The future municipal water demand of Iquique city is estimated based on the following assumptions.

(1) The existing total per capita water consumption including commercial, industrial and others is estimated at 220 l/s/d if a 24 hour unrestricted water supply is served.
(2) The future per capita water consumption will increase at the rate of 0.3% per year as the standard of living improves.

The projected future water consumptions are summarized below.

Year	Population Served	Per Capita Consumption (l/c/d)	Total Consumption (l/s)
1995	165,236	221.9	424.5
2005	213,356	228.74	564.8
2015	272,605	235.69	743.6

3) Projected Production

The total loss including leakage and unaccounted-for water is approximately 40% at present time. It is assumed that this percentage will gradually decrease to 30% by the year 2005 by the leakage control program of ESSAT.

Future losses as a percentage of total production and the projected production are estimated as follows.

Year	Total Consumption (l/s)	Losses (%)	Total Production (l/s)
1995	424.5	40	707.5
2005	564.8	30	806.9
2015	743.6	30	1,062.3

3.5 Water Use in Pampa del Tamarugal

3.5.1 Domestic Water Use

1) Town Water Use

(1) Existing Water Supply Service

Water of the following seven (7) towns in three (3) districts (comunas) is supplied by ESSAT.

Comuna		Town
Huara	;	Huara, Pisagua
Pica	;	Pica, Matilla
Pozo Almonte	;	Pozo Almonte, Huayca, Tirana

Location of the towns is shown in Fig. 3.7.

Water of Pica, Matilla, Huayca, Tirana and Pozo Almonte is supplied from the springs and groundwater at Chintagua near Pica. Huara is provided from the well owned by Chilean Army at Dupliza. Pisagua is provided from the well at Dolores. See Fig. 3.5 and Fig. 3.7.

(2) Existing Water Consumption and Production

The total water consumption of the towns in 1992 was estimated at 962,509 m^3/yr based on the information of ESSAT. This water consumption includes a considerable amount of agricultural usage.

Further, the corresponding production volume in 1992 was estimated also based on the information obtained from ESSAT.

The total water consumption, loss and production of the towns in 1992 are summarized below.

Total Consumption		Loss		Total Production	
(m^3/yr)	(l/s)	(m^3/yr)	(l/s)	(m^3/yr)	(l/s)
962,509	30.5	710,799	22.6	1,673,308	53.1

The water loss is equivalent to 42.5% of the production.

ESSAT has two (2) existing water rights of spring at Chintaguay with a total amount of 99 l/s. In addition, they have one (1) water right of groundwater for 22.5 l/s in Dolores.

(3) Future Water Demand and Production

The future water demand and production of the towns are estimated based on the following assumptions.

i) The served population will increase at an annual growth rate of 2.46% that is equivalent to the average annual growth rate during the recent 10 years (1982 - 1992).

ii) The existing per capita consumption is assumed at 200 l/c/d and it will gradually increase at a rate of 0.5% per year.

iii) The agricultural usage of ESSAT water will grow at a rate of 0.5% per year.

iv) Percentage of water loss will decrease from more than 40% at present time to 30% by the year 2005.

The results are summarized below.

Year	Population Served	Total Consumption (l/s)	Total Production (l/s)
1995	7,070	32.1	53.6
2005	9,011	38.6	55.1
2015	11,485	47.0	67.1

2) Other Water Use

The existing rural population in the year 1992 is estimated to be 5,170. The future rural population in the year 2015 is estimated to be 7,657, equivalent to 40% of the total population.

The rural domestic water demand in 1992 and 2015 are estimated to be 4.2 l/s and 7.1 l/s respectively by assuming that the existing per capita water demand is 70 l/c/d and that it increases at an annual rate of 0.5%.

According to the interview survey, the Chilean military is pumping up groundwater of approximately 60 l/s at Dupliza for their own use at present time. It is assumed that it will not change in future.

3) Real Water Consumption

The existing and future domestic water production in Pampa del Tamarugal are summarized as follows.

(Unit: l/s)

	Town	Rural	Military	Total
Existing (1992)	53.1	4.2	60.0	117.3
Future (2015)	67.1	7.1	60.0	134.2

It is estimated that the portion of domestic water production returned to the Pampa del Tamarugal basin will be on the order of 60%. The real water consumption will then be on the order of 40% of the water production, equivalent to an average of about 47 l/sec in 1992 and 54 l/s in 2015.

3.5.2 Irrigation Water Use

1) Irrigation of River Valley

(1) Existing Irrigated Area

In addition to the Pica and Matilla area, irrigation farming is practiced within the Pampa del Tamarugal Basin in the valleys of the Aroma, Tarapacá, Quipisca and Mamiña rivers.

In these river valleys, an area of 275 ha is irrigated by river and spring water. The major crops are maize and pasture (alfalfa).

For location of the irrigated areas, see Fig. 3.7.

(2) Existing Water Demand and Water Rights

The existing water demand was estimated by multiplying evapotranspiration of crop by irrigation efficiency and irrigation area. The following values were used for this estimating purpose.

Crop	Area (ha)	Evapotranspiration (mm/yr)	Irrigation Efficiency (%)
Maize	137.5	1,385	40
Pasture	137.5	1,593	50

The total irrigation water demand in the river valleys are estimated to be 9,141.7 x $10^3 m^3$/year (= 290 l/s).

The total annual crop evaporation is considered as the total real irrigation water consumption in the river valleys. This is estimated at 4,094,800 m^3/yr or 130 l/s.

There are 14 legally authorized water rights with a total quantity of 198.66 l/s for river, spring and groundwater, and further, two (2) customary water rights of spring water with a total quantity of 10.88 l/s.

(3) Future Water Demand

The farmers in the river valleys are expected to migrate to the CAPPTA Project Area (See, Fig. 3.7) in future. Therefore, the irrigation water demand in the river valleys will gradually decrease to zero in future.

2) Irrigation of Pica and Matilla Area

(1) Existing Irrigated Area and Crops

Approximately 305 ha of farmland in the Pica and Matilla area are irrigated by spring and groundwater. The major crops are fruits and vegetables. Drip irrigation is performed to a considerable extent. For location of the irrigation area, see Fig. 3.7.

The existing irrigated area by crop and irrigation type are as follows.

Crop / Irrigation Type	Area (ha)
Fruits	
Flooding	155
Microspray	130
Vegetables	
Drip	20
Total	305

(2) Existing Water Demand and Water Rights

The existing water demand was estimated by multiplying evapotranspiration of crop by irrigation efficiency and irrigation area.

The annual crop evapotranspiration and irrigation efficiency are assumed as follows.

		Evapotranspiration	Irrigation Efficiency		
Fruits	:	1,236.7 mm/yr.	Fruits by Flooding	:	60%
Vegetables	:	1,154.7 mm/yr	Fruits by Microspray	:	80%
			Vegetables by Drip	:	90%

The estimated total irrigation water demand in the Pica and Matilla area are 5,342.8 x $10^3 m^3$/yr (=169.4 l/s).

The total annual crop evapotranspiration is calculated at 3,755.5 x $10^3 m^3$/year (=119 l/s). This is considered as the total real irrigation water consumption in Pica and Matilla area.

The existing water rights for irrigation use in Pica and Matilla area are summarized below.

Water Right	Nos. of Water Right	Water Source	Quantity (l/s)
Legally Authorized	12	S, G	182.9*
Customary	2	G	2.3
Total	14		185.2

* : Includes 4.2 l/s between Matilla and Tirana

S: Spring, G: Groundwater

(3) Future Water Demand

There is no specific long range plan with regard to overall crop development in Pica and Matilla area. Future irrigation in the area will depend on the availability of additional water, marketing of crops and development cost.

In addition to the existing water rights, 179.7 l/s of water rights have been applied for in Pica and Matilla area. Another 205 l/s have been applied for in the area between Matilla and Tirana. However, these water rights have not been applied for based on concrete development program. Some of them are considered speculative.

Therefore, in this report, it is assumed that the irrigated area and water demand in Pica and Matilla area including the area between Matilla and Tirana will double by the year 2015. The results are summarized below.

	Irrigated Area (ha)	Total Production (l/s)	Total Real Consumption (l/s)
Existing (1992)	305	169.4	119
Future (2015)	610	338.8	238

3) CAPPTA Project Irrigation Water

CAPPTA (Corporación Agrícola Proyecto Pampa del Tamarugal) is a private corporation formed for the purpose of promoting productive settlements of people based on agriculture and handicraft. The project contemplates the relocation of families, predominantly Aymara, from the Altiplano to an area generally to the northeast of Huara. The corporation has been granted rights to the use of 33,550 hectares, and plans to relocate about 430 families to this area.

For location of CAPPTA Project area, See Fig. 3.7.

The future irrigation water demand has been preliminarily estimated by the CAPPTA Project based on an area of 5.0 ha per family. The water demand in the year 2015 is assumed as follows.

Annual Average water demand = 0.6 l/s/ha x 5.0 ha x 430 families
= 1,290 l/s

Real water consumption is estimated at approximately 839 l/s (=2,150 ha x 0.39 l/s/ha) by applying the same unit real water consumption as that of Pica and Matilla area.

However, development scale of CAPPTA Project depends on the availability of irrigation water in both quantity and quality. The above estimation may be optimistic, considering that the water quality of the area contains a high content of boron.

According to the water quality analysis conducted during this study, available water resources for CAPPTA Project may be limited to the groundwater in the northern fringe areas of the CAPPTA Project.

In this report, therefore, the agricultural development areas of CAPPTA Project is assumed to be 20% of the above preliminary studies. Then, the average water demand and real water consumption are estimated as follows.

Average Water Demand : 430 ha x 0.6 l/s/ha = 258 l/s
Real water Consumption : 430 ha x 0.39 l/s/ha = 168 l/s

4) Total Irrigation Water Use in Pampa del Tamarugal

The existing and future total water demand and real water consumption in Pampa del Tamarugal are summarized below.

	Water Demand (l/s)				Real Water Consump. (l/s)			
	River Valley	Pica & Matilla	CAPPTA	Total	River Valley	Pica & Matilla	CAPPTA	Total
Existing(1992)	290	169.4	-	459.4	130	119	-	249
Future (2015)	-	338.8	258	596.8	-	238	168	406

3.5.3 Mining Water Use

1) Existing Mines

There are four (4) major companies with mining operations within the Pampa del Tamarugal Basin. These companies and their mining operations are as follows.

Company	Mine Name
Minera Mapocho	Mapocho
Minera La Cascada	La Cascada
Cosayach S.A.	Cala Cala
Minera Lucic	Boraton

The latter mines (Boraton and Cala Cala) were not in production as of November, 1993.

In addition, A.C.F. Minera is operating at Minera Iris to the south of the Pampa del Tamarugal basin, using groundwater sources within the basin, near the southern boundary.

For location of these mining operations, see Fig. 3.7.

2) Existing Water Demand and Water Rights

The existing water demand for mining operations in Pampa del Tamarugal Basin were estimated from the field interviews of companies. The results are summarized below.

Pampa Area	:	35.0 l/s including 5.0 l/s diversion to outside
Upstream Valley	:	34.2 l/s
Total	:	69.2 l/s

The existing water rights for mining use are summarized below.

Type	Nos. of Water Right	Water Source	Quantity (l/s)
Legally authorized	16	G	187.0
Customary	2	S, R	37.0
Total	18		224.0

G: Groundwater, S: Spring, R: River

3) Future Water Demand

In addition to the existing water rights, 67 water rights with a total quantity of 4,170.7 l/s have been applied for in the Pampa del Tamarugal basin.

However, only 24 among the above 67 water rights have been applied after water extraction test was completed. The other 43 water rights have been applied without water extraction test and so, they are considered as speculative.

Therefore in this report, the requested water quantity of 1,262.3 l/s of the above 24 applications are assumed as the additional future water demand for mining use on peak basis. The annual average water demand is estimated at 883.6 l/s by assuming the average water demand as 70% of the peak one. This additional future water demand is distributed for Pampa and upstream valley areas as shown below.

	Nos. of Applications	Requested Water (l/s) (Peak)	(Average)
Pampa	23	1,252.3	876.6
Upstream Valley	1	10.0	7.0
	24	1,262.3	883.6

4) Real Water Consumption

A significant portion of the water extracted for mining operations is returned into underground to recharge groundwater. In this report, it is assumed that real water consumption is 60% and groundwater recharge is 40%.

The existing and future real water consumption in the years 1992 and 2015 are estimated as follows.

(Unit: l/s)

	Existing (1992)	Future (2015)
Pampa	23.0	549.0
Upstream Valley	20.5	24.7
Total	43.5	573.7

3.5.4 Total Water Use

The total existing water demand of Pampa del Tamarugal in 1992 is estimated to be 1,192 l/s of which the real water consumption is assumed to be 887l/s. The total future water demand will increase to 2,746 l/s in 2015 of which the real water consumption is considered as 2,096 l/s.

Their break-down by water use sector are shown in Table 3.1.

Table 3.1 Total Existing and Future Water Demand and Real Consumption (Pampa del Tamarugal)
<Demanda Total de Agua Existente y Futura y Consumo Real (Pampa del Tamarugal)>

	Existing (1992)		Future (2015)	
	Demand (l/s)	Real Consump. (l/s)	Demand (l/s)	Real Consump. (l/s)
Iquique Municipal Water	547	547	1,062	1,062
Domestic Water in Pampa	117	47	134	54
Irrigation Water				
River Valley Area	290	130	-	-
Pica/Matilla	169	119	339	238
CAPPTA Project	-	-	258	168
Sub-total	459	249	597	406
Mining Water				
River Valley Area	34	21	41	25
Pampa Area	35	23	912	549
Sub-total	69	44	953	574
Total	1,192	887	2,746	2,096

Note : The above water demand and real water consumption are on annual average basis.

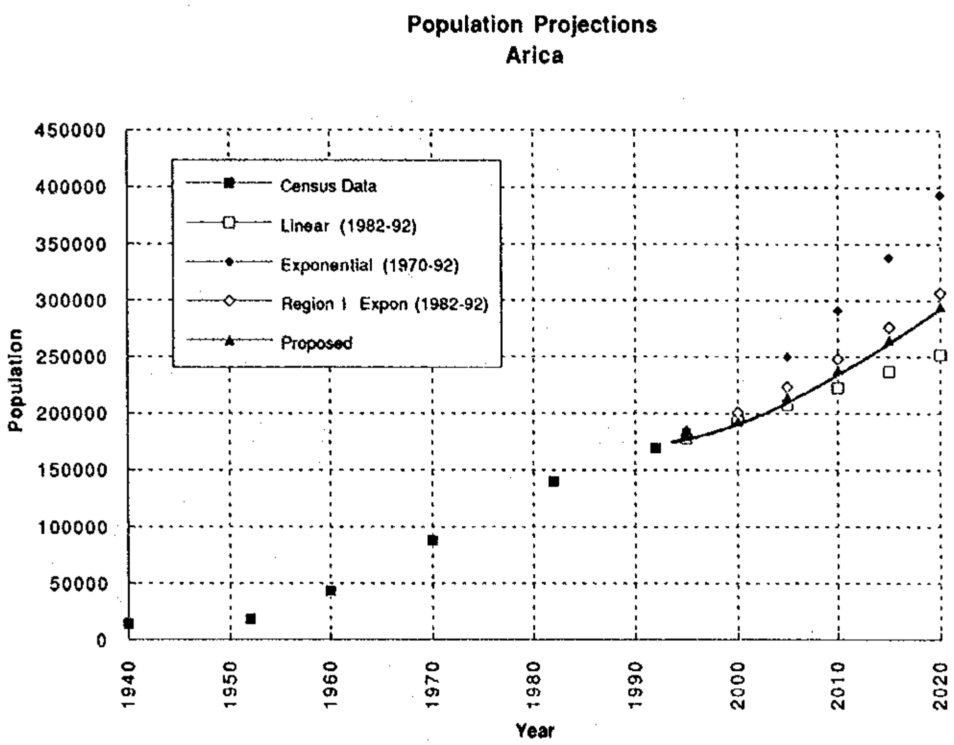

Fig. 3.2 Population Projections - Arica

< Proyección de la Población - Arica >

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JICA

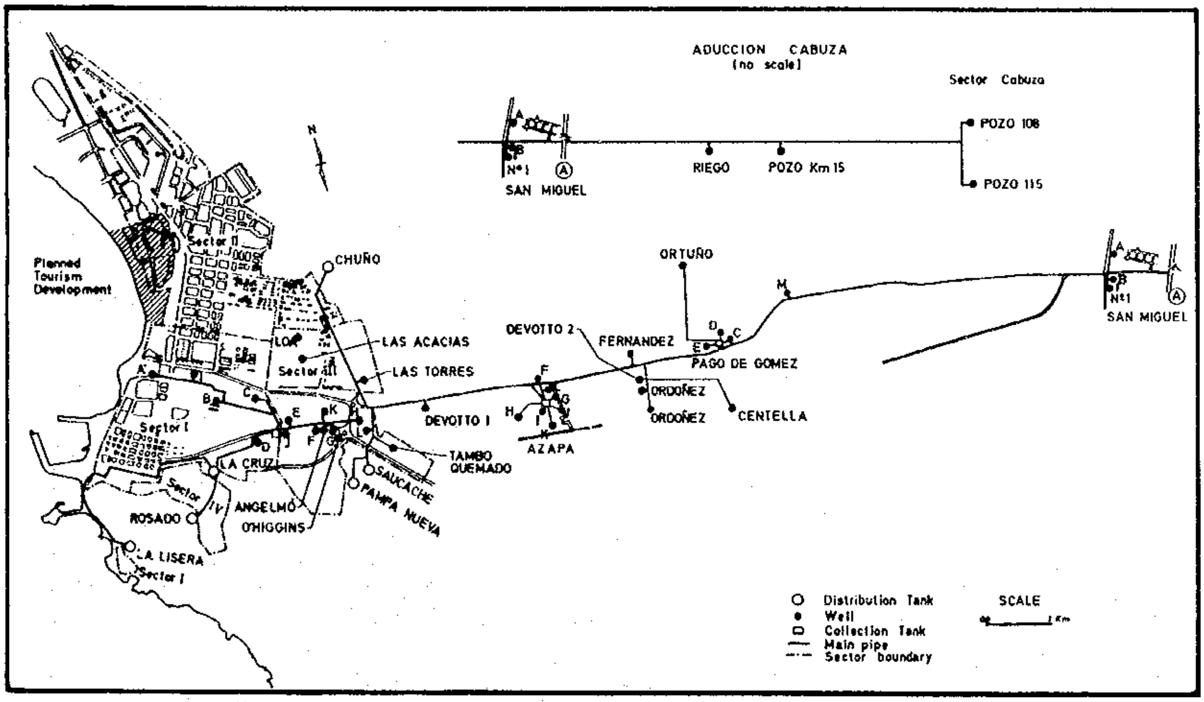

Fig. 3.1 Existing Municipal Water Supply System of Arica City

<Sistema de Abastecimiento de Agua Potable Existente de Arica>

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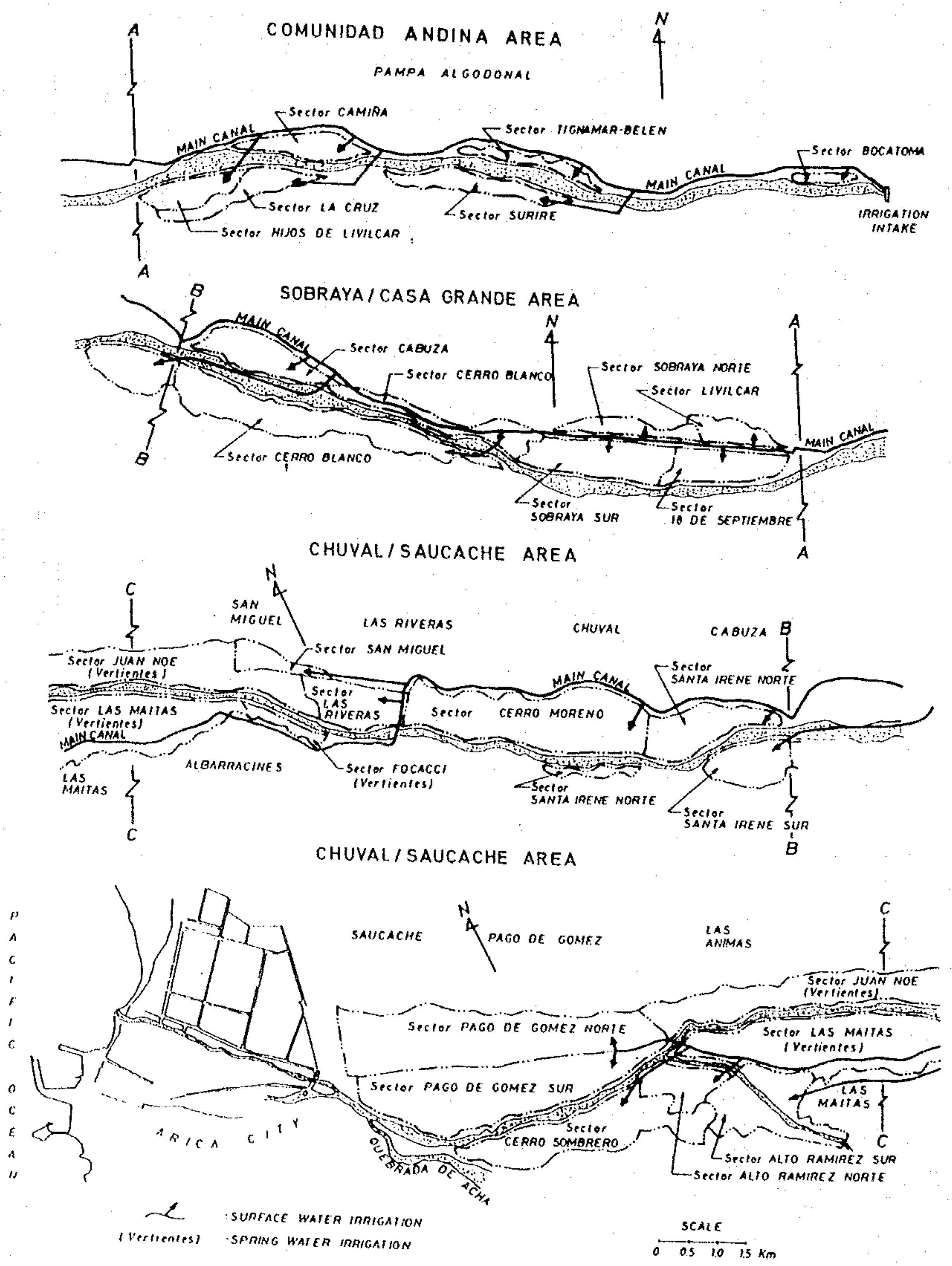

Fig. 3.3 Location of Irrigation Sectors and Sub-sectors - Azapa Valley

<Ubicación de Sectores y Sub-sectores de Riego -Valle de Azapa

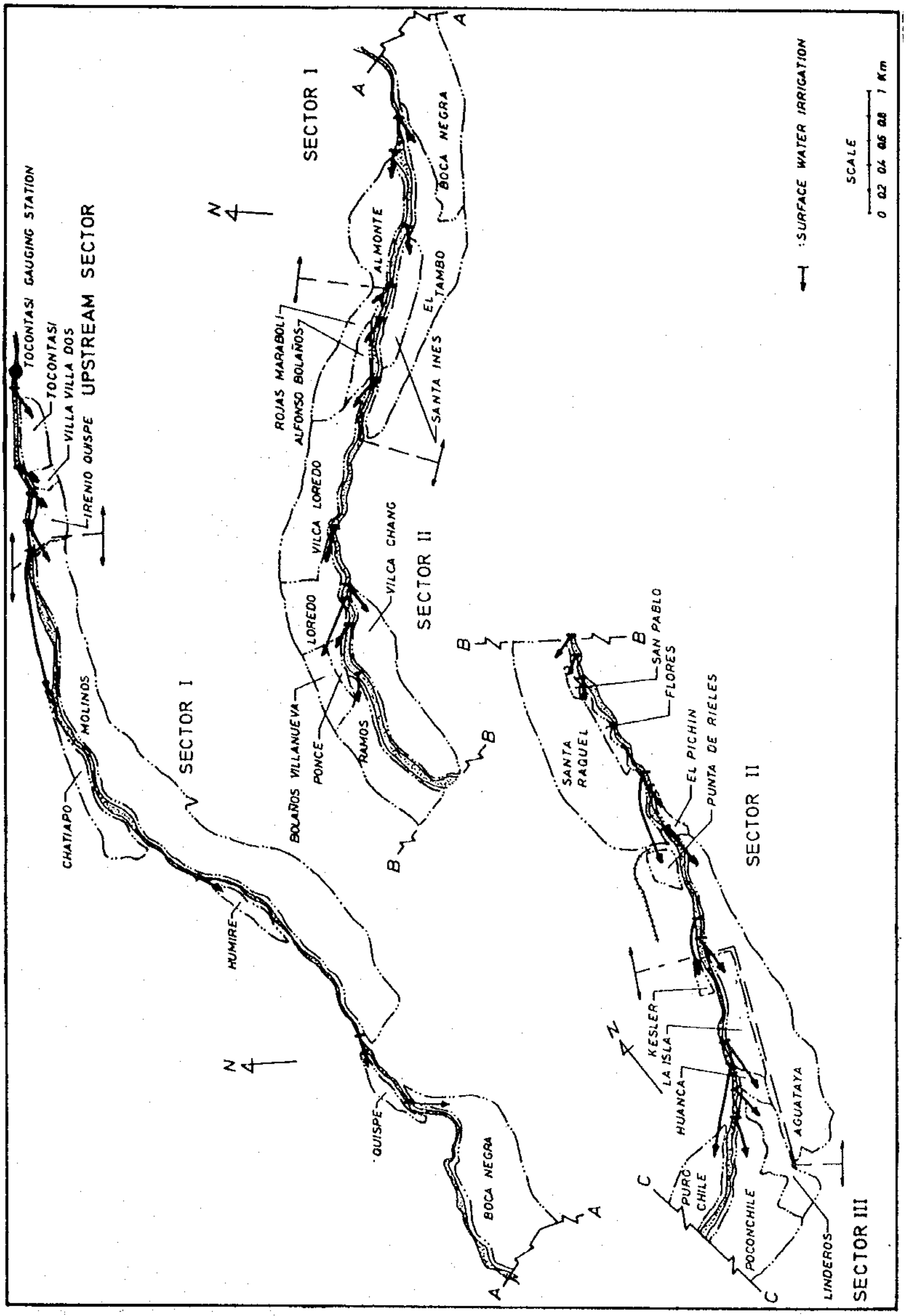

Fig. 3.4 (1) Location of Irrigation Sectors and Sub-sectors - Lluta Valley
<Ubicación de Sectores y Sub-sectores de Riego - Valle de Lluta>

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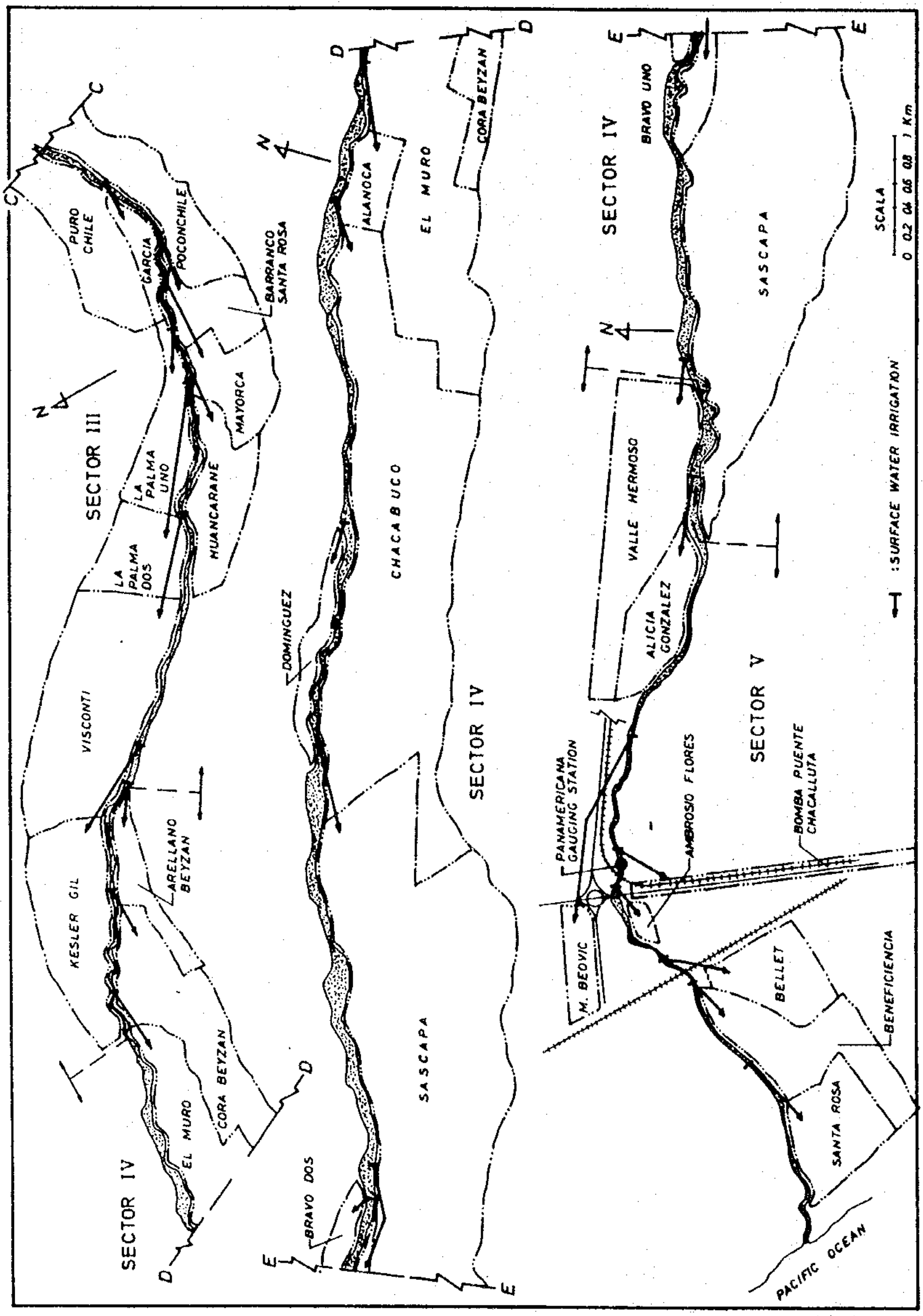

Fig. 3.4 (2) Location of Irrigation Sectors and Sub-sectors - Lluta Valley

<Ubicación de Sectores y Sub-sectores de Riego - Valle de Lluta>

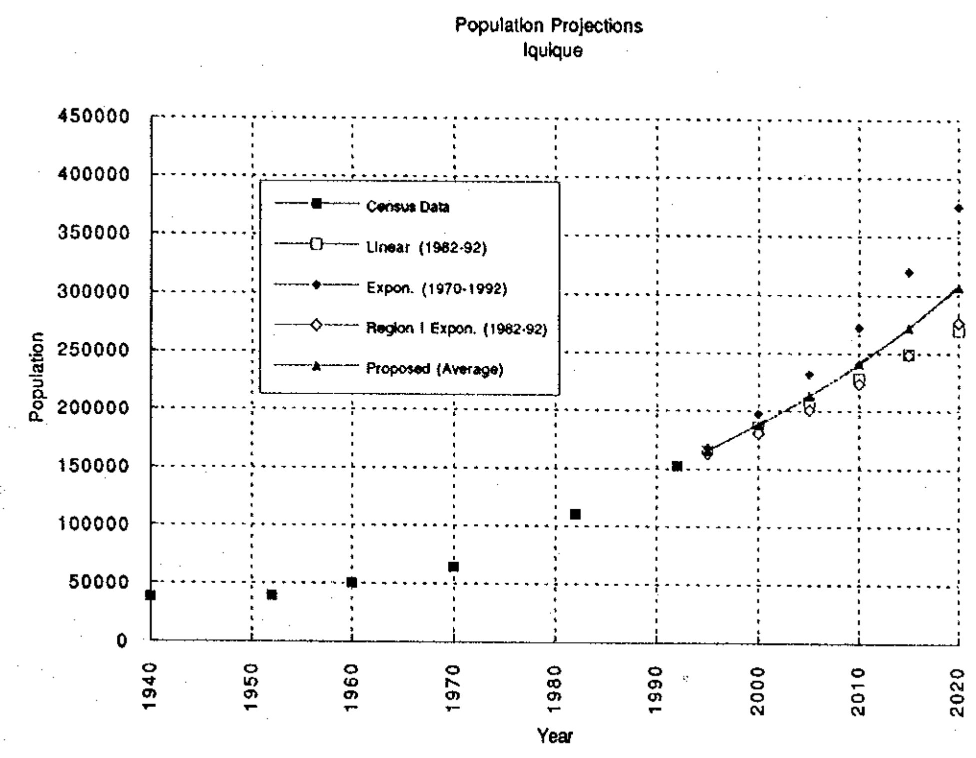

Fig. 3.6 Population Projections - Iquique
< Proyección de la Población - Iquique >

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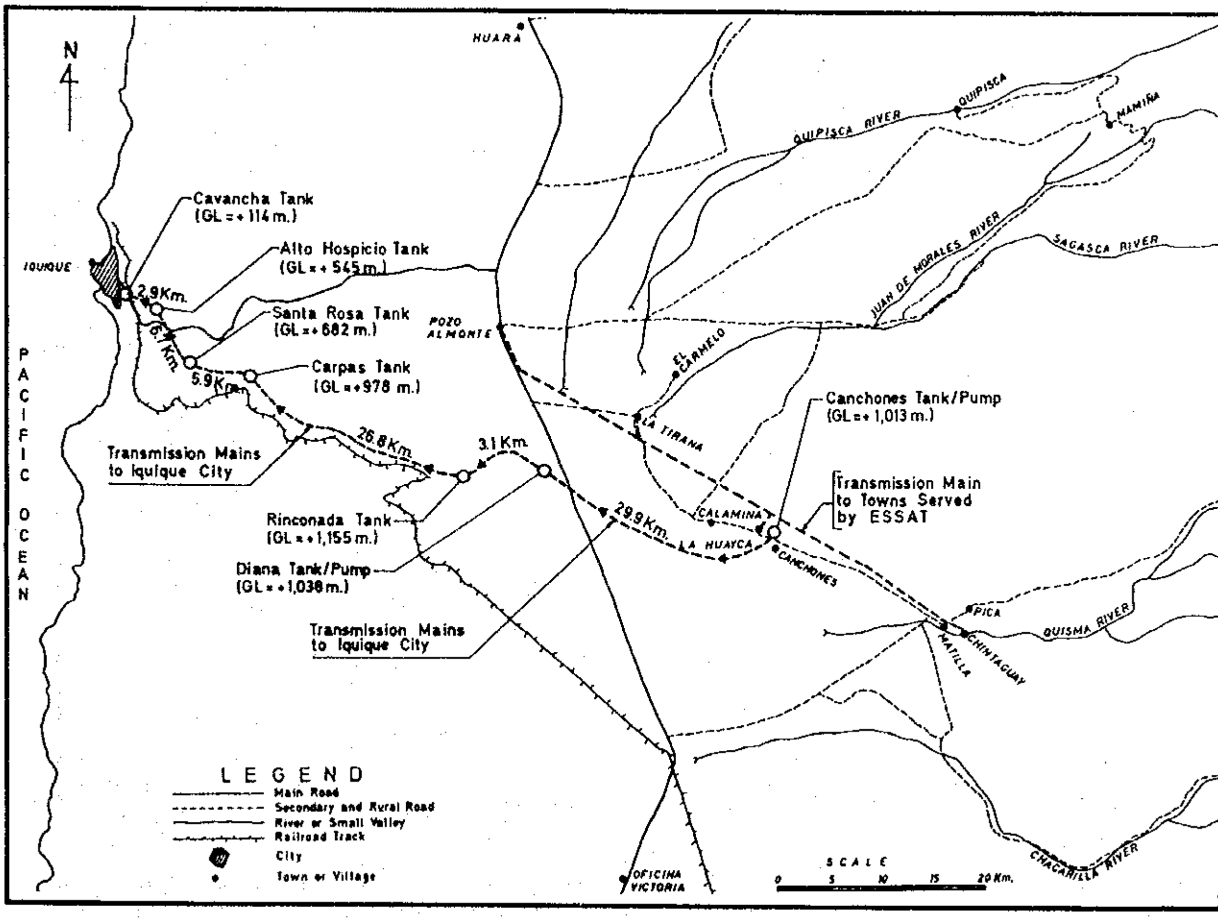

Fig. 3.5 Water Conveyance Systems of Iquique City and Province
< Sistemas de Conducción de Agua de la Ciudad y Provincia de Iquique >

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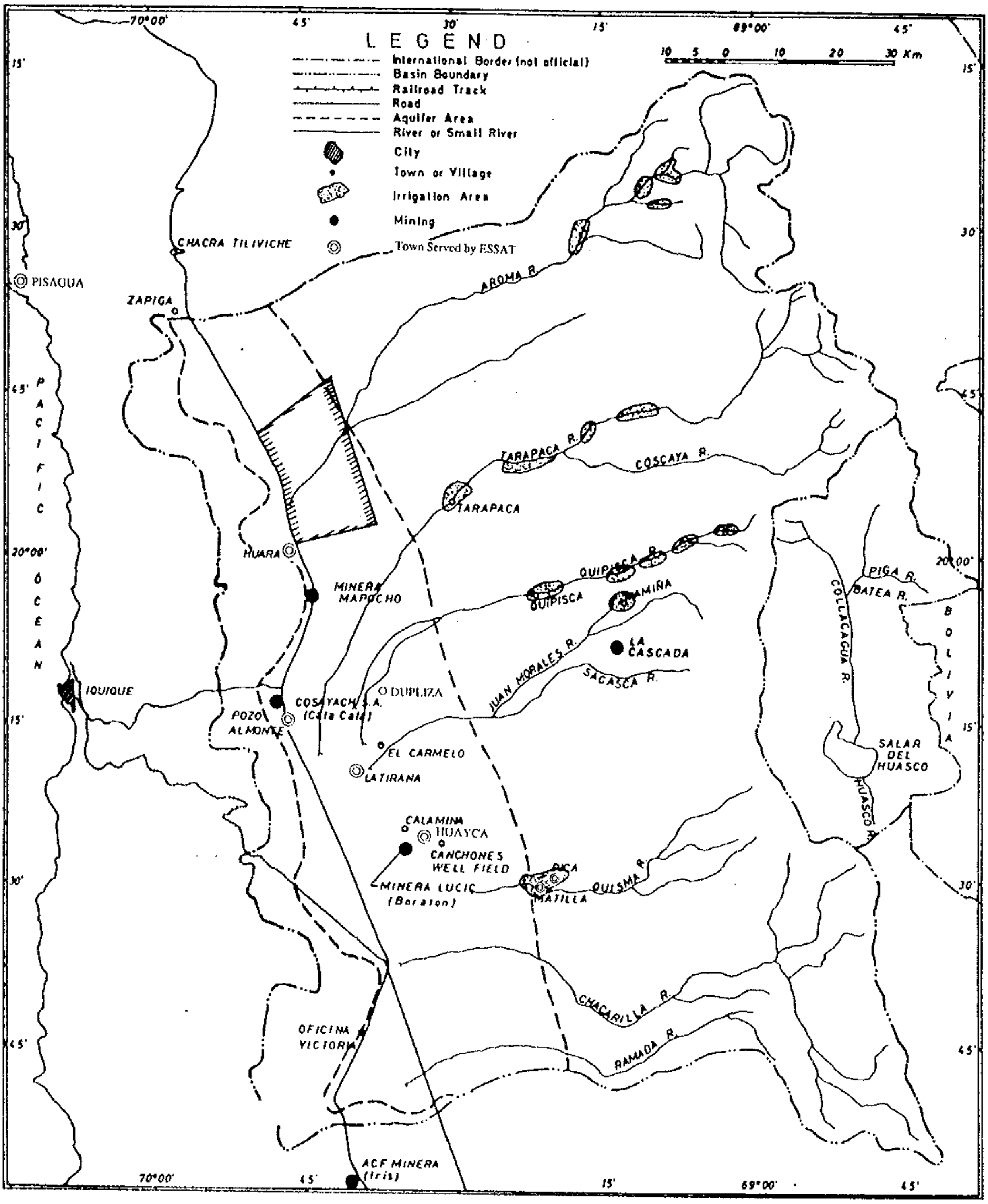


CAPPTA Project Area

Fig. 3.7 Location of Water Served Towns and, Irrigation and Mining Area in Pampa del Tamarugal
<Ubicación de Areas de Riego y Mineras en la Pampa del Tamarugal>

CHAPTER IV ENVIRONMENTAL ASPECTS

Chapter IV ENVIRONMENTAL ASPECTS

4.1 General

This project aims to supply municipal water to Arica and Iquique cities by exploiting groundwater in the surrounding areas of the cities.

The potential groundwater aquifers are located in the Azapa Valley, Lower Lluta Valley, Pampa del Tamarugal and Salar del Huasco. However, groundwater development of these aquifers may draw down the existing water level, causing adverse effects on the natural and social environments in the neighbouring areas.

The following environmental factors were identified, by the initial field reconnaissance, as the major ones which might be affected by the groundwater development.

a) Existing water uses in Azapa Valley
b) Existing water uses in Lower Lluta Valley
c) Existing water uses in Pampa del Tamarugal
d) Plants, especially Tamarugo forest in Pampa del Tamarugal
e) Ecological and social environments in Salar del Huasco

The other environmental factors are considered minor.

Existing water uses in Azapa Valley, Lower Lluta Valley and Pampa del Tamarugal are studied in Chapter II and Chapter III. Hence, the remaining two (2) major environmental factors are discussed in this Chapter.

4.2 Tamarugo Forest in Pampa del Tamarugal

4.2.1 Tamarugo Forest

1) Tamarugo Forest Area

Natural Tamarugo forest had covered a wide area of Pampa del Tamarugal in old days. However, they almost disappeared during the last century since they were cut to provide fuel of saltpeter mining.

Thereafter, planting of Tamarugo trees started with fodder and fuel production purposes in the 1930's. The existing total planted Tamarugo forest is 20,704 ha. On the other hand, a natural Tamarugo forest has grown in a wide area since before 1930. It was estimated to be 3,241 ha in 1981 by the Institute of Forest.

The existing Tamarugo area by species are summarized below.

Species	Area (ha)
Planted Tamarugo	20,704
Tamarugo	18,334
Algarrobo	1,950
Mixed Plantation	420
Natural Tamarugo	3,241
Total	23,945

All of the above planted Tamarugo forest exist in the National Reserved Area of Zapiga and Salar de Pintados/Salar de Bellavista. On the other hand, the natural forests are mainly located in the Pampa Yuri National Reserved Area and its surrounding lands.

For location of the planted Tamarugo forest, see Fig. 4.1.

2) National Reserved Area

The total existing National Reserved Area is 100,650 ha, distributing over three (3) districts of Zapiga, Salar de Pintados/Salar de Bellavista and Pampa Yuri as follows:

Area	Area (ha)
Zapiga	: 17,750
Salar de Pintados/Bellavista	: 77,675
Pampa Yuri	: 5,225
Total	: 100,650

For location of the National Reserved Area, see Fig. 4.1.

3) Beneficial Effects

The Tamarugo forests produce the following beneficial effects.

(1) Cattle Breeding : local people of 57 families make their living by raising 18,000 sheep as of 1993.

(2) Wood Production : materials of charcoal and handicraft.

(3) Recreational Use: Approximately 7,000 people visited the forest for recreation in 1993.

(4) Opportunities for Research :The forest offers a valuable experimental field for improvement of the deserts.

4.2.2 Characteristics and Features of Tamarugo Tree

1) The tree comes into bloom in November, fruits fall down in February to March and leaves wither in winter.

2) The tree usually grows up to 8 - 18 m in height.

3) Tamarugo of Pampa del Tamarugal usually grows in the areas where groundwater depth is 5 - 12 m.

4) According to the previous studies,

   (1) Tamarugo tree absorbs water through both roots and leaves. In the day time, roots absorb groundwater and leaves evaporate water. At night, leaves absorb water from atmosphere along with groundwater absorption by roots and the absorbed water is stored in roots. This mean that water consumption of Tamarugo tree is smaller than other plants.

   (2) The tree forms a mat of roots in a depth of less than 1.0 m from where tap roots grow downward to extract groundwater.

5) According to the information from CONAF, well drilling stroke the tap roots of Tamarugo trees in 1987 and 1993. The depth of the tap roots were estimated at 25 - 30 m in the cases of both years.

4.2.3 Transpiratory Water Consumption

1) Existing Transpiratory Water Consumption

Evapotranspiration of Tamarugo tree increases as the tree grows. Evapotranspiration of the Tamarugo trees in Pampa del Tamarugal corresponding to tree age was estimated by Grill, Vidaly and Grain in 1986, as shown in Fig. 4.2. In this estimation, planting density of the Tamarugo trees was assumed as 50 trees/ha..

Evapotranspiration of the Tamarugo tree reaches the maximum value of about 280 mm/year (= 0.089 l/s/ha) when the tree becomes 50 years old. Even this maximum value is very little compared with the average evapotranspiration of agricultural plants.

On the other hand, the age distribution of the Tamarugo trees in Pampa del Tamarugal was estimated by the Institute of Forest for the areas of Salar de Pintados and Salar de Bellavista in 1981.

The age distribution of the Tamarugo trees in the whole Pampa del Tamarugal area as of 1993 are estimated by modifying the above age distribution in 1981. The results are shown below.

Year	Age	Area (ha)	Year	Age	Area (ha)
1993	1	5	1970	24	1,435
1987	7	25	1969	25	3,415
1985	9	300	1968	26	1,809
1984	10	300	1967	27	1,505
1983	11	125	1966	28	899
1981	13	234	1960	34	12
1973	21	617	1947	47	108
1972	22	3,677	1934	60	3,255
1971	23	2,984	Before 1931	>63	3,241

The existing total transpiratory water consumption of the Tamarugo trees in the whole Pampa del Tamarugal in 1993 is estimated to be 1,019 l/s by using the above table and Fig. 4.2.

2) Future Transpiratory Water Consumption

The future transpiratory water consumption of the Tamarugo trees in the whole Pampa del Tamarugal is estimated based on the following assumptions:

(1) 350 ha of trees will be additionally planted in 1994.

(2) During the period of 1995-2015, an additional 50 ha will be planted every year. After 2015, the Tamarugo area will not be extended.

(3) Life of Tamarugo tree is 75 years.

(4) Tamarugo tree will be replanted soon after its life expires.

The Tamarugo tree areas in the future are estimated as follows.

Year	Tamarugo Area (ha)
1993	23,945
2005	24,846
2015	25,346
2025	25,346

The average annual transpiratory water consumptions in the future are estimated as follows.

Existing (1993)	:	1,019 l/s ≒ 1,000 l/s
Future (2015)	:	1,523 l/s ≒ 1,500 l/s
Future 50 years (1993-2042)	:	1,566 l/s ≒ 1,600 l/s
Future 100 years (1993-2092)	:	1,413 l/s ≒ 1,400 l/s

4.3 Environments of Salar del Huasco

The existing environmental conditions of Salar del Huasco were surveyed during the period of November and December, 1993, and January, 1994. The major environmental factors are described below.

4.3.1 Topography and Water Quality

1) Topography

Salar del Huasco is located at an altitude of approximately 3,800 m. It covers a total area of 29 km^2 of which the water surface area was 2 km^2 and the remaining 27 km^2 was wet land in December, 1993.

The water surface area consists of three (3) zones: Laguna Huasco, Huasco Lipez and Laguna Cerro Huasco (see Fig. 4.3). The water depth was 16 cm at the deepest point, averaging 4 cm.

2) Water Quality

(1) Spring Water

Two (2) springs are located at the north-western fringe areas of Salar del Huasco. They supply clean fresh water to Laguna Huasco. For the location of the springs (H_0, H_3), see Fig. 4.3.

The water quality is within the standards of drinking water except Turbidity. Dominant ions are Na and HCO_3. The water is classified as Sodium Bicarbonated Water.

(2) Laguna Huasco Water

Water quality of Laguna Huasco was analyzed for two (2) locations (H_2, H_4).

Water is much contaminated in all the observed elements. The major contaminated elements are as follows.

Elements	H_2 Point	H_4 Point
TDS (mg/l)	34,290 - 66,683	96,312 -203,420
Cl (mg/l)	10,774 - 16,323	23,079 -69,768
B (mg/l)	110 -145	203 - 513
As (mg/l)	12 - 18	36 - 66

Water at H_2 is less contaminated than that at H_4 due to the dilution effects of spring water.

Dominant ions of the Laguna water are Na, Cl, and SO_4. The water is classified as Chloride Sulphated Sodium Water or Sulphated Chlorided Sodium Water.

4.3.2 Ecology

1) Fishes, Amphibious and Mollusks

Two (2) fish species, three (3) amphibious species and three (3) mollusks species are identified in the fresh water. Fishes and mollusks are not scarce species.

2) Plankton

Plankton is one of the major foods of flamingos. Fitoplankton of 24 species and zooplankton of 7 species are identified in the Salar.

The composition of the fitoplankton in Salar del Huasco is characterized by dominance of two (2) species of Bacillariophyceae: *Suriella* sp. 1 and *Navicula* sp. 1. The composition of the zooplankton is represented mainly by two (2) species of Artropoda: Copepoda Calanoidea and Copepoda Ciclopoidea.