THE REPUBLIC OF CHILE

THE STUDY
ON
THE DEVELOPMENT OF WATER RESOURCES
IN
NORTHERN CHILE

PROGRESS REPORT

MAIN REPORT

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JAPAN INTERNATIONAL COOPERATION AGENCY

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MAIN REPORT

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Chapter I INTRODUCTION

This Progress Report covers the results of all the studies of Phase II conducted during the period of September, 1993 to March, 1994. The Report also includes the results of Phase I study for convenience.

The Report is composed of ;

(1) Main Report
(2) Supporting Report
    A. Surface Water
    B. Geology and Groundwater
    C. Water Use
    D. Municipal Water Supply Development
    E. Environment

Progress of the Study is summarized as follows.

(1) Surface water study has almost been completed except finalization of report.
(2) Study on geology and groundwater has made a significant progress. However, some major works including evaluation of development potential, groundwater simulation and planning of groundwater development are left to the next stage.
(3) Water use study has almost been completed except finalization of future water demand and report.
(4) Study for water supply and demand balance is all left to the next stage.
(5) Study of municipal water supply development is in the initial stage at present time.
(6) Environment study has almost completed the initial assessment of the existing environmental conditions except finalization of report.
(7) Study on economy and finance is in the initial stage at present time.

Chapter II. WATER RESOURCES POTENTIAL

2.1 Lluta River Basin

2.1.1 Basin System

The Lluta River covers a drainage basin of 3,378 km^2. The water originates from the Andes Mountains with an elevation of 4,000 - 6,000 m. The water is collected by the upstream tributaries and transferred by the main river to the downstream fluvial plains, finally discharged to the sea at the northern edge of Arica city.

The major upstream tributaries to collect the water are Azufre, Caracarani, Cascavillane, Teleschuno, Guancarane, Chuquiananta, Colpitas, Allane, Putre, Aroma and Socoroma.

For the river system of the Lluta River Basin, see Fig. 2.1.1.

The detailed networks of the rivers and valleys (quebrada) were established based on the Landsat images and aerophotographs. See, Supporting Report B, Fig. B-I, 1.1.2.

2.1.2 Surface Flow Rate

1) Surface Flow Rate of Main River and Tributaries

The flow rate of Lluta River at Tocontasi/ Chapisca has been observed by DGA since 1946. The average, 80% drought and 90% drought flow rates by season are summarized below.

(Unit: l/s)

	Jan. - Mar.	Apr. - Jun.	Jul. - Sep.	Oct. - Dec.	Average
Average	3,950	1,790	1,742	1,382	2,216
80% Drought	1,752	1,455	1,454	1,116	1,444
90% Drought	1,357	1,261	1,370	1,050	1,260

For the monthly flow rate, see Supporting Report A, Table A.2.5.

The water sources of the Lluta River are limited to the following upstream tributaries (see, Fig. 2.1.1).

(1) Caracarani
(2) Azufre
(3) Eastern Slope Tributaries (Cascavillane, Teleschuno, Guancarane and Chuquiananta).
(4) Colpitas (Colpitas and Allane)
(5) Putre & Others (Putre, Aroma and Socoroma)

A simultaneous flow rate observation for the upstream tributaries along with Chapisca of Lluta Main River was conducted by this study in June, 1993. The results are shown below.

River	Flow Rate	%
Caracarani	394	33
Azufre	76	6
Eastern Slope Tributaries	334	29
Colpitas	231	19
Putre & Others	360	31
Loss	-211	-15
Lluta (at Chapisca)	1,184	100

Note: Loss includes the irrigation water consumption in Putre, Socoroma and Lluta Valley upstream of Chapisca.

2) Surplus Surface Flow Rate

There are approximately 2,500 ha of irrigated farmland in the downstream reaches of Tocontasi / Chapisca. They consume a large portion of the surface water for crop irrigation. The remaining water is discharged to the sea as surplus water.

The observation station of flow rate located in the lowermost reaches of the River is Panamericana. The station is located 2 km upstream from the river mouth. The observed surface flow rate at this station gives an approximation to the surplus surface water of the Lluta River Basin.

The average, 80% drought and 90% drought flow rates by season at Panamericana are as follows.

	Jan. - Mar.	Apr. - Jun.	Jul. - Sep.	Oct. - Dec.	Average
Average	3,744	906	643	248	1,385
80% Drought	520	390	409	76	349
90% Drought	340	274	348	63	256

For the monthly flow rate, See Supporting Report A, Table A,2.5.

2.1.3 Surface Water Quality

1) Salient Features of Surface Water Quality

A full scale analysis of the water quality of Lluta River has been carried out by DGA since 1967. The water quality of Lluta Valley is much contaminated by the water of the upstream tributaries of Azufre and Colpitas. The major water quality parameters exceeding the permissible limits of drinking water are As, B, Fe, Cl and SO_4. The concentration of As, B, Fe, Cl and SO_4 at the major locations of Lluta River Basin are shown in Table 2.1.1.

A simultaneous water quality analysis of the upstream tributaries along with Lluta River (Chapisca) was conducted in this study to identify the contamination sources. The observed As, B and Fe of the tributaries (the most critical parameters of the Lluta Valley) are summarized in Table 2.1.2.

The salient features of the water quality of the Lluta River Basin are as follows.

(1) The major sources of As are Azufre and Upper Colpitas rivers which share 86.4% of the total As of the Basin.

(2) The major source of Fe is Azufre river with a share of 75.0% of the total Fe of the Basin.

(3) Azufre and Upper Colpitas rivers are the large sources of B. However, a considerable portion originates from the other sources than the tributaries observed in June, 1993.

(4) In Lluta Valley, As and Fe gradually decrease toward downstream from Tocontasi to Panamericana by natural purification effects. On the other hand, B, Cl and SO_4 increase toward downstream.

2) Contamination Sources of Surface Water

A detailed water quality observation was carried out in November, 1993 by this study to identify the major water contamination sources of Azufre and Colpitas rivers.

The observed water quality of As and B at each point in Azufre and Colpitas rivers are shown in Fig. 2.1.2 (1) and Fig. 2.1.2 (2) respectively.

The results are summarized below.

(1) In Azufre River, the major contamination sources of As and B are both located in the upstream basin of A-8 point. Share of the pollution load at A-8 point to the total load of Azufre River is 84% for As and 67% for B.

(2) In Colpitas River, the major portion of As and B both originate from the upper basin of C-10 point. Share of the pollution load at C-10 point to the total load of Colpitas River is 66% for As and 58% for B.

(3) The pollution load of A-8 point at Azufre River and C-10 point at Colpitas River share a significant percentage of the total pollution load of Lluta River.

The loads of As and B at both points are compared with those at Chapisca of Lluta Main River as follows.

	(1) A-8 Point	(2) C-10 point	(3) Chapisca	Share (%) ((1)+(2)) / (3)
Flow Rate (m^3/s)	0.048	0.074	1.184	10
As Content (mg/l)	6.75	2.08	0.27	
As Load (g/s)	0.324	0.154	0.320	149
B Content (mg/l)	28.93	61.79	12.22	
B Load (g/s)	1.389	4.572	14.47	41

Note: (3): Water quality observed in June, 1993.

2.1.4 Hydrogeology of Lluta Valley

Geology of Lluta Valley

Geology of the Lluta River Basin is generally classified into Basement Rocks and Quaternary Formations.

Basement Rocks are composed of Azapa Formation, Oxaya Formation, El Diablo Formation and their slid blocks in this order upwards. Fissures and joints are well developed in the upper layer, however, less developed in the lower layer. Therefore, it is considered impermeable.

Quaternary Formations consist of the following four (4) units.

(1) Fluvial Deposits

Fluvial Deposits mainly cover the middle and upper reaches of the Lower Lluta Valley. Total thickness of the formation is estimated to be approximately 200 m.

The deposits are divided into three (3) units of upper, middle and lower. The upper and lower units are mainly composed of gravel beds with a diameter of 5 to 30 cm. On the other hand, the middle unit consists of impermeable tuff beds.

Matrix of the deposits are mainly filled in with silt and very fine sand originated from volcanic ashes. This decreases the permeability of the deposits.

(2) Concordia Formation

Concordia Formation of marine deposits is distributed over Villa Frontera and Concordia areas in the lower reaches of the Lower Lluta Valley. Total thickness of the formation reaches approximately 200 m.

The formation is divided into three (3) units of upper, middle and lower. The upper and lower units are mainly composed of unconsolidated sand. The middle unit mainly consists of volcanic ashes.

Judging from the lithofacies, the upper and lower units are considered permeable, however the middle unit is regarded impermeable.

(3) Detrial Deposits

Detrial Deposits consist of talus sediments, slope sediments and fan sediments. The talus and slope sediments are composed of clastics of different size. The fan sediments are mainly composed of silt and sand.

This deposits are distributed on the foots of the mountains.

(4) Pumice Tuff

Pumice tuff, consisting of pumice and volcanic ash, is distributed in Gallinazos and Apacheta in the lower reaches of the Lower Lluta Valley. Permeability is considered small.

(5) Recent Beach Deposits

Recent Beach Deposits are distributed along the sea coast forming a beach. The deposits consist of sand and gravels. Fine materials are less in the matrix. Thus, the permeability is high.

(6) Recent Fluvial Deposits

Recent Fluvial Deposits, consisting of sand, gravel and silt, are distributed along the channel of Lluta River. The deposits are less permeable because the matrix is filled in with a large quantity of fine materials.

Geological map of the Lower Lluta Valley is shown in Fig. 2.1.3.

2.1.5 Supplementary Geological Survey

The following geological surveys were executed by the JICA Study Team, to supplement the existing geological data. The surveys location is shown in Fig. 2.1.4.

a) Electromagnetic Survey		30 survey points (5 lines)
b) Boring Test		
(a)	Drilling	
	Test well drilling	2 wells
	Observation well drilling	2 wells
(b)	Pumping Test	4 wells
c) Water Quality Analysis		4 wells (JICA wells)
d) C-14 analysis		1 well

1) Electromagnetic (TEM) Survey

(1) Survey Area

The survey area is located along the route 11 in the Lluta valley (Fig. 2.1.4). Five (5) TEM lines were set perpendicular to the main axis of the Lluta River. A total of 30 stations were set at an interval of 250m each as shown below

Quantity of TEM Survey

Profile	Stations	Station Interval
RL-1	6	250 m
RL-2	6	250 m
RL-3	6	250 m
RL-4	6	250 m
RL-5	6	250 m
Total	30	

(2) Survey Results

Geoelectrical profiles are made by the apparent resistivity curve of each station. The geoelectrical profiles along Line RL-1 to RL-5 are shown in Fig. 2.1.5. According to the data from DGA, conductivity of well water in this area shows a high values of 2600 (3.8 ohm-m) to 5200 (1.9 ohm-m) micro mho/cm.

The resistivity structure in this area consists of 3 to 4 layers, with a stratiform structure, in general. Resistivity of the layers are relatively low, less than 200 ohm-m. The geophysical characteristics of each layer are summarized as follows.

a) The first layer (5 m to 70 m thick) shows a resistivity range of 28 to 300 ohm-m. The resistivity of the layers other than profile RL-5, are relatively high (99 - 300 ohm-m). These layers are considered dry. On the other hand, RL-5 shows a relatively low resistivity (28 - 84 ohm-m). This is probably due to the wet land conditions by irrigation water.

b) The second layer (50 m to 250 m thick) shows a resistivity range of 11 to 30 ohm-m. This layer is distributed in the whole area. It is considered as expected aquifer. Because the resistivity value of prospective aquifer is usually in the order of ten (10) times of that of the well water in the area

c) The third layer (70 to 190 m thick) shows a resistivity range of 29 to 96 ohm-m. The layer exists only in station 1 and 2 of RL-3, and in the all stations of RL-4. The layer of RL-3 is considered as expected aquifer because of its low resistivity. On the other hand, the layer of RL-4 is considered dry or impermeable, judging from its high resistivity.

d) The forth layer shows a resistivity value of less than 9.8 ohm-m. The layer is distributed in the whole area. The layer is presumed to have grandwater potential to same degree. However, its extremely low resistivity would indicate that the layer is much contamination by salt.

Lateral discontinuities of resistivity exist between station No.1 and No.2 of profile RL-1 and between stations No. 2 and No.3 of RL-3. These discontinuities may be coincident with geological boundaries, such as faults or fracture zones.

2) Boring Test

(1) Location and Depth of Well

Two (2) Test Wells (J-A, J-B) and two (2) Observation Wells (J-1, J-2) are placed along on the line of the TEM survey (see Fig. 2.1.4). Location, drilling depth and casing size of each well are summarized as follows.

Well No.	Location	Latitude	Longitude	Elevation (m.msl)	Casing (inch)	Depth (m.bgl)
J-A	Lluta	18° 23' 08.95"	70° 13' 58.16"	178.028	8-5/8"	150.0
J-B	Panameracana	18° 24' 03.85"	70° 17' 19.04"	73.907	8-5/8"	200.4
J-1	Chacabuco	18° 25' 42.54"	70° 13' 03.31"	219.515	5-1/2"	145.0
J-2	Lluta	18° 23' 40.05"	70° 16' 06.17"	141.332	5-1/2"	225.0

(2) Method of Boring Test

The boreholes were drilled by rotary drilling method with direct mud circulation system for both of Test and Observation Wells. ASTM casing pipes and Johnson type screen pipes with more than 20% opening ratio, were installed after borehole drilling. In order to identify the promising position of the screen pipe, a well logging including spontaneous potential, gamma ray, resistivity and temperature was carried out.

Gamma ray logging measures a natural radiation coming from materials encountered in the borehole. Spontaneous potential logging measures electrical potentials (voltage) spontaneously occurring at the contact surface between muddy layer and permeable deposit. Records of gamma ray and spontaneous potential are used as a qualitative guide for stratigraphic correlation and permeability of lithology. Resistivity logging gives the characteristics and thickness of various strata at the well site. It further gives groundwater quality by measuring the apparent resistivity of the materials in the surroundings of the borehole. Groundwater flow into the borehole can be found out by temperature logging.

Position of the screen pipes were carefully determined by the above loggings together with lithological observation of cutting sample.

(3) Results of Boring Test

The results of boring tests are summarized in Table 2.1.3. Detailed information including lithological column, casing design and well loggings are shown in Fig. B-II, 2.3.15 to 2.3.18 of the supporting report. The results of the boring tests are concluded as follows ;

i) Geological Conditions

The lithology of deep aquifer is mainly composed of sand, gravel and clayey to sandy gravel of Quaternary Fluvial Deposit. Except J-2, it is clearly confirmed that the deep aquifer is overlain by impermeable layer consisting of tuff and clay. This impermeable layer is the boundary of shallow and deep aquifers. A similar layer is also observed at J-2 in the depth from 61 to 64m. However, it is clayey gravel of which matrix is filled in with much clay. Thus, the deep aquifer of J-2 is also overlain by an impermeable layer like the other wells. The thickness of these impermeable layer is thin, 2m to 7m.

ii) Geophysical Conditions

Apparent resistivity value is similar in all the wells. The value is in the range of 15 to 32 ohm-m. This range is in well agreement with the results of TEM measurement (11 - 30 ohm-m). Therefore, the deep aquifer confirmed by boring test regarded as identical with the second layer classified by TEM survey.

(4) Method Pumping Test

Three (3) different kind of pumping tests; step drawdown test, constant discharge test and recovery test were conducted for both of Test and Observation wells, after completion of drilling work and air lifting development.

Each test was carried out by the following standard methods.

Step drawdown test : At least 7 round steps (discharge increased and decreased) and duration of each step is 120 minutes.

Constant discharge test : 24 hours measurement is conducted as soon as the water level in the well has recovered its static water level after completion of the step drawdown test.

Recovery test : The test starts immediately after completion of the constant discharge test and continues until water level in the well recovers its static water level.

(5) Analysis of Pumping Test

i) Aquifer Constants

Major aquifer constants necessary for aquifer evaluation are transmissibility, storage coefficient and permeability. These aquifer constants were estimated by using the results of the constant discharge and recovery tests. For the above estimation, Theis and Jacob methods were applied.

ii) Well Efficiency and Area of Influence

In order to estimate critical discharge and safe yield, well efficiency and area of influence is calculated by the data of step drawdown test.

Critical discharge is determined by an incline of the Q (Discharge Rate) - Sw (drawdown) chart. Maximum pumping rate which dose not cause a large drawdown is defined as critical discharge. On the other hand, safe yield is estimated by the ratio of well efficiency and area of influence calculated by the following equations ;

Well Efficiency (%) $E_w = BQ/BQ+CQ^2$

Where B = aquifer loss

C = well loss

Q = discharge rate (l/s)

Area of Influence (m) $R = (4Ttu / S)^{1/2}$

Where T = transmissibility (m^3/day/m)
t = pumping time
$u = r^2 \times S / 4 \times T \times t$
S = storage coefficient

In this report, the following criteria are determined for well efficiency and area of influence.

Well Efficiency	: more than 85%
Area of Influence	: Radius of influenced area with 1m drawdown is less than 250m for 18 hours pumping operation.

The pumping rate satisfying the above two (2) criteria is defined as Safe Yield.

(6) Result of Pumping Test

The results of pumping test are summarized in Table 2.1.4. The table includes pumping data, aquifer constants and well capacity represented by critical yield and safe yield. Results of the pumping test are concluded as follows ;

i) Pumping Data

The static water level of the four (4) wells is in the range of 9.82m and 35.02m. Specific yield is calculated by pumping rate and drawdown. J-1 has the highest value of 1.44 l/s/m among four (4) wells. The lowest specific yield of 0.24 l/s/m is obtained at J-A. The average specific yield of the four (4) wells is calculated as 0.76 l/s/m.

ii) Aquifer Constants

The average of the transmissibility of four (4) wells is calculated as 212.73 m^3/day/m. The highest value of 368.06 m^3/day/m is found at J-1 which has the highest specific yield. J-1 is considered to have high groundwater potential. On the other hand, lowest transmissibility is estimated at J-A (22.72 m^3/day/m). The well has also lowest specific yield (0.24 l/s/m). The well is considered to have low groundwater potential.

Permeability value of the four (4) wells a similar. The highest value is 1.93 x 10^{-3} cm/sec at J-2, and the lowest one is 6.25 x 10^{-4} cm/sec at J-A. The average of permeability is calculated as 3.64 x 10^{-3} cm/sec. This value is lower than permeability usually expected in this lithology mainly consisting sand, gravel and clayey to sandy gravel.

The storage coefficient of the four (4) wells is in the range of 4.72 x 10^{-4} and 6.62 x 10^{-6}.

iii) Well Capacity

Well capacity is evaluated by the amounts of critical discharge and safe yield. The average critical discharge of Test Wells and Observation Wells are estimated as 17.80 l/s and 4.13 l/s respectively. On the other hand, the average safe yield of Test Wells and Observation Wells are 10.25 l/s and 2.25 l/s respectively. Safe yield is approximately the half of critical discharge for both type of well.

2.1.6 Aquifer

1) Configuration of Aquifer

(1) General

Location and size of the aquifers in the Lower.Lluta Valley were estimated based on the JICA boring tests along with previous boring data.

The major portion of the aquifer is situated in the Fluvial Deposits distributing in the Valley between Panamericana and Rosario. The distance between Panamericana and Rosario is approximately 18 km. The remaining small portion of aquifer is contained in the Concordia Formation distributing in the downstream areas of Panamericana. The distance between Panamericana and sea coast is approximately 2 km.

Fluvial Deposits are divided into two (2) units of upper and lower by a thin tuff layer in the area between Panamericana and Chacabuco. However, the tuff layer disappears at Chacabuco, integrating both upper and lower units in the upstream area of Chacabuco. Concordia Formation is also divided into two (2) units of upper and lower by the thin tuff layer

The geological profile and cross sections of the aquifer are shown in Fig. 2.1.6 and Fig. 2.1.7.

(2) Shallow Aquifer

The shallow aquifer contained in the upper units of Fluvial Deposits and Concordia Formation does not have a large depth. The depth is in the range of 10 m and 30 m. However, its width is large, ranging from 800 - 1,000 m at Chacabuco to 3 - 4 km at Chacalluta.

(3) Deep Aquifer

The deep aquifer contained in the lower units of Fluvial Deposits and Concordia Formation extends over the whole Lower Lluta Valley between Rosario and sea coast. The thickness and width of the aquifer both gradually increase toward downstream.

Thickness, width, top level below ground surface and base level above mean seal level of the aquifer are summarized below.

Location	Thickness (m)	Width (m)	Top Level (m. BGL)	Base Level (m. MSL)
Rosario	70	1,000	10	330
Chacabuco	70	800 to 1,000	15	110
Sascapa	50	1,500	30	90
Chuilona	100	2,800 to 3,000	30	-25
Villa Frontera	100	3,000	20 to 25	-80 to -90

Area and thickness distributions of the deep aquifer for the major part (between Panamericana and Rosario) are shown in Fig. 2.1.8.

2) Hydrogeological Characteristics of Aquifer

(1) Shallow Aquifer

This shallow aquifer is of unconfined type.

No data are available concerning the hydrogeological characteristics of the shallow aquifer. However, the hydrogeological characteristics of the shallow aquifer is considered similar to those of the deep aquifer because of the similarity in the lithofacies of both aquifers.

The permeability coefficient of the aquifer is roughly estimated to be in the order of 10^{-3} cm/sec (about 1 m/day), judging from the JICA pumping tests for the deep aquifer.

(2) Deep Aquifer

This deep aquifer is of confined type.

The deep aquifer is considered to be recharged by the surface water of Lluta River from the upstream reaches of Chacabuco. Because the deep aquifer is covered by an impermeable tuff layer in the downstream reaches of Chacabuco. In the downstream reaches of Chacabuco, the surface water recharges only the shallow aquifer.

The above presumptions are supported by the following facts.

i) Groundwater gradient of the deep aquifer is steeper than gradient of the river bed for the downstream reaches of Chacabuco.

ii) NO_3 content of the shallow aquifer is very high compared to those of the deep aquifer and surface water as shown below

Type	Average (NO_3) (mg/l)
Shallow Aquifer	9.56
Deep Aquifer	0.78 (average of JICA wells)
Surface Water	0.21 (Tocontasi / Chapisca)

This would mean that the shallow aquifer is recharged by the surface water contaminated by fertilizer and that NO_3 is accumulated in the aquifer.

The Hydrogeological constants of the deep aquifer are estimated based on the pumping tests of JICA along with the previous data as follows.

Well No.	Specific Yield (l/sec/m)	Transmissibility (m^3/day/m)	Storage Coeff.	Permeability (cm/sec)
J-1	1.44	368	6.62×10^{-6}	7.01×10^{-3}
J-A	0.24	23	8.54×10^{-4}	6.25×10^{-4}
J-2	0.73	150	6.60×10^{-6}	1.93×10^{-3}
J-B	0.62	310	4.72×10^{-3}	4.98×10^{-3}
100-2	0.36			
101-0	2.60			
102-9	0.99			
103-7	2.70			
104-5	4.26			
average	1.72	213	3.35×10^{-4}	3.63×10^{-3}

For location of the wells , see Fig. 2.1.3.

Permeability coefficients are in the order of 10^{-3} cm/sec which is equivalent to the values in normal aquifers. However, this value is smaller than that is usually expected in an aquifer of gravels. This is due to that the matrix is filled in with fine materials.

Specific yield changes in place to place, ranging from 0.24 l/s/m to 4.26 l/s/m. This means that productivity of the deep aquifer is different in places.

i) Average specific yield of the JICA wells located between Panamericana and Chacabuco is 0.76 l/s/m, showing a medium production.
ii) Specific yield of Rosario area is small.
iii) specific yield of Villa Frontera area (downstream of Panamericana) is 2.64 l/s/m on an average. It shows a high productivity.

3) Estimated Groundwater Storage

The major aquifer of the Lower Lluta Valley extends from Rosario to the sea coast. However, a large groundwater development can not be expected for the aquifer of Concordia Formation distributed in the downstream of Panamericana due to the effects of sea water intrusion.

Therefore, the aquifer located in the area between Panamericana and Rosario is considered as the prospective one.

The total groundwater storage is estimated to be 160 million m^3 with the following break-down by zone.

Zone No.	Section	Storage (10^3m^3)
1	A-A' to B-B'	21.8
2	B-B' to C-C'	35.4
3	C-C' to D-D'	35.6
4	D-D' to E-E'	20.6
5	E-E' to F-F'	47.0
Total		160.4

For location of the sections, see Fig. 2.1.3.

In the above estimation, effective porosity of the aquifer was assumed as 30%.

2.1.7 Groundwater Level and Quality

1) Existing Groundwater Extraction

The existing groundwater extraction in the Lower Lluta Valley is small. Groundwater is extracted from only ten (10) wells and two (2) springs for irrigation, potable and industrial uses. They are summarized as follows.

Area	Shallow Aquifer	Deep Aquifer
Chuilona / Villa Frontera	8 wells	2 wells
Poconchile	-	1 spring
Bocanegra	-	1 spring

2) Groundwater Level

The groundwater level of the shallow aquifer in the Villa Frontera area is in the range of 5 m to 27 m, averaging 20 m below ground surface.

The groundwater level of the deep aquifer distributing from Panamericana to Rosario ranges from 6 m to 74 m with an average of 30 m.

3) Groundwater Quality

(1) Major Water Contamination Elements

Groundwater quality of both shallow and deep aquifers were analyzed by this study in July 93, October 93 and February 94.

The water quality exceeds the permissible limit of drinking water for some water quality elements. Such elements are TDS, Na, SO_4, Cl, Cd, B and Fe.

As of the groundwater is within the allowable limit although the surface water of the Lluta River is much contaminated by As.

Content of the above major elements are summarized below, compared with those of the surface water.

	Groundwater		Surface Water	Permissible
Element	Shallow	Deep	Tocontasi/Chapisca	Limit
TDS	3,522	3,452		1,000
Na	503	529	198.9	200
SO_4	919	852	310	400
Cl	1,110	949	323	250
Cd	0.003	0.010		0.005
B	18.94	21.87	10.69	
Fe	0.51	1.53	3.817	0.30
As	0.033	0.029	0.305	0.050

(2) Major Ion Composition

Such major ions as Mg, Ca, K, Na, SO_4, Cl, HCO_3 and CO_3 in the water quality of the eight (8) shallow wells and five (5) deep wells are plotted in a tri-linear diagram as shown in Fig. 2.1.9.

Water quality of all the wells fall in the same zone of the tri-linear diagram as well as surface water quality of Lluta River. This means that water of all the wells are recharged by the surface of Lluta River.

Table 2.1.1 Surface Water Quality of Lluta Valley
<Calidad de Agua Superficial Valle de Lluta>

River	Location	As	B	Fe	Cl	SO4	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	1.00	0.30	250	400	6.0-8.5

Table 2.1.2 Surface Water Quality of Upstream Tributaries (Observed in June, 1993)
<Calidad de Agua Tributarios de 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		1.00		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 2.1.3 Result of Boring test of Lluta River Area

< Resultado de Prueba de Sondaje en el Area del Rio Lluta>

Well No.	Bore hole Depth (m)	Casing Pipe		Screen Pipe		Geological Conditions of Aquifer			Geophysical Data	
		Size (inches)	Total Length (m)	Position (m)	Total Length (m)	Lithology	Formation	Period	Well Logging Resistivity (ohm-m)	TEM 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	15-30	12-26
J-B	200.4	8-5/8"	126.00	60.05 to 90.10	72.12	clayey gravel, sand	Fluvial Deposit	Quaternary	15-30	17-26
				102.10 to 144.17		fissured ignimbrite	Oxaya Formation	Tertiary	15-30	17-26
J-1	145	5-1/2"	85.00	31.00 to 91.00	60.00	gravel, sandy gravel	Fluvial Deposit	Quaternary	22-32	11-23
J-2	225	5-1/2"	136.00	64.02 to 154.01	89.99	silty to sandy gravel	Fluvial Deposit	Quaternary	20-30	17-30

Table 2.1.4 Result of Pumping Test of Lluta River Area

< Resultado de Prueba de Bombeo en el Area del Rio Lluta >

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)	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

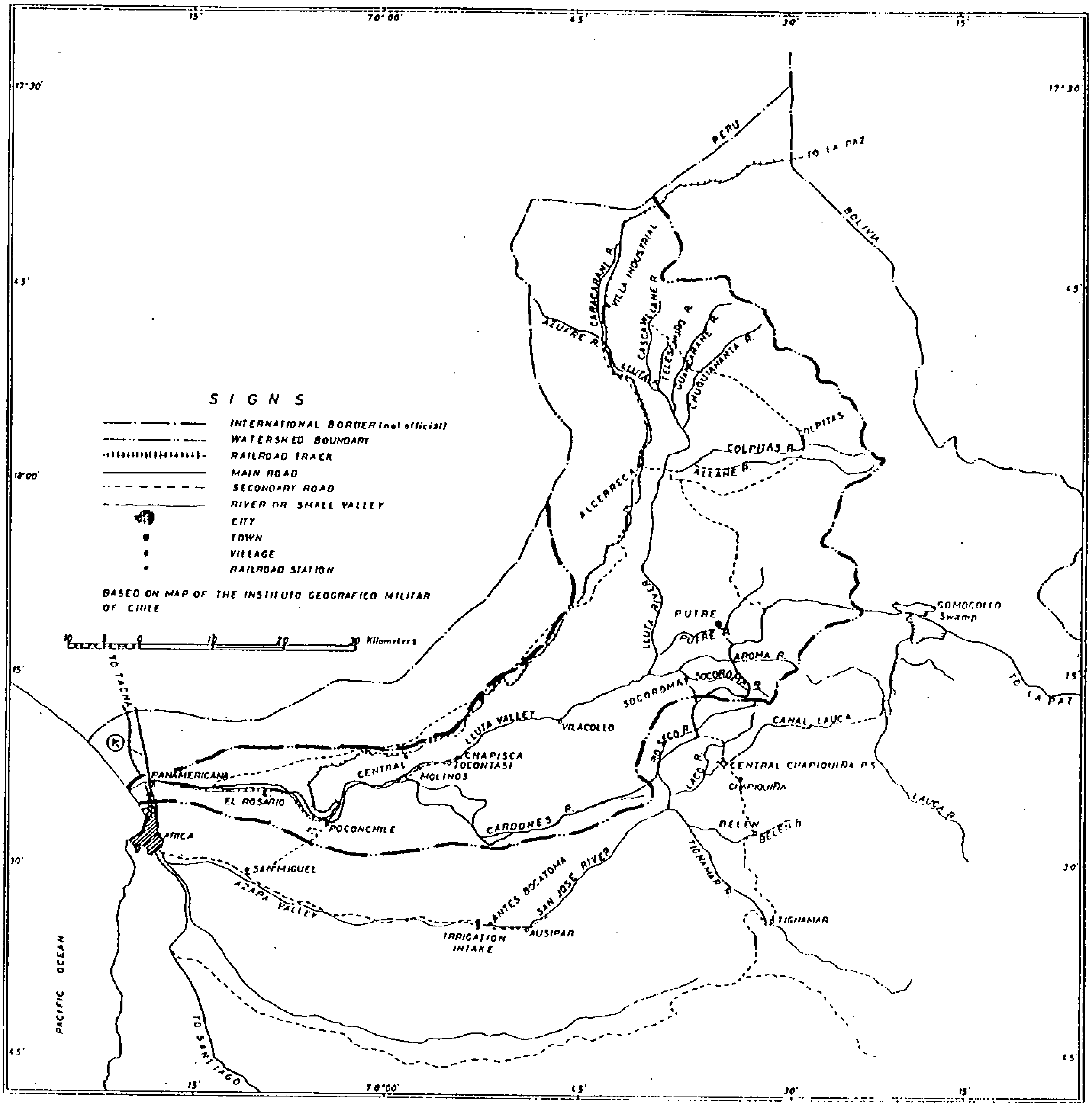


Fig. 2.1.1 River System of Lluta River Basin

<Systema Fluvial de la Cuenca del Río Lluta>

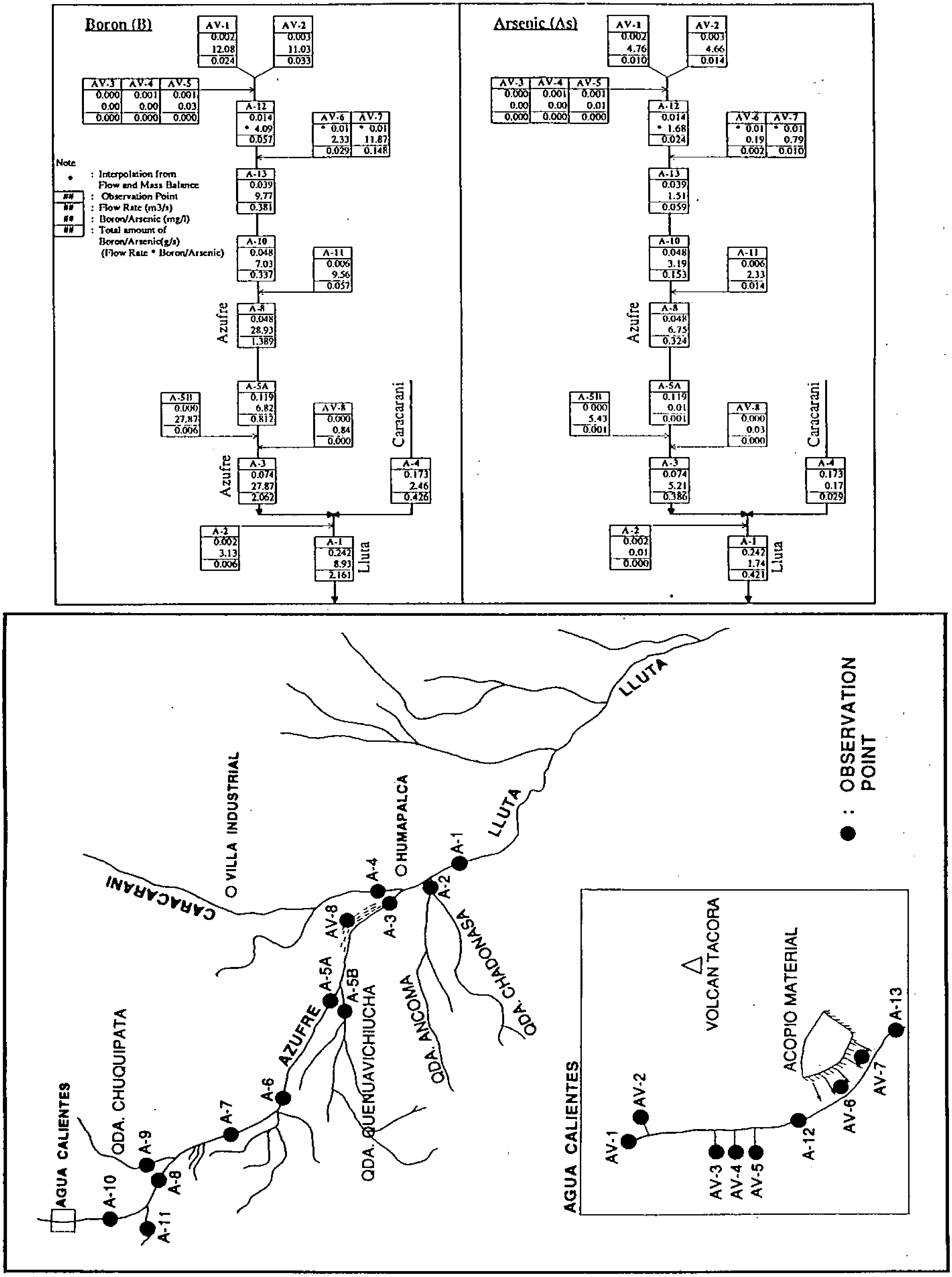


Fig. 2.1.2 (1) Observed Water Quality in Azufre River

<Calidad de Agua Observad en Rio Azufre>

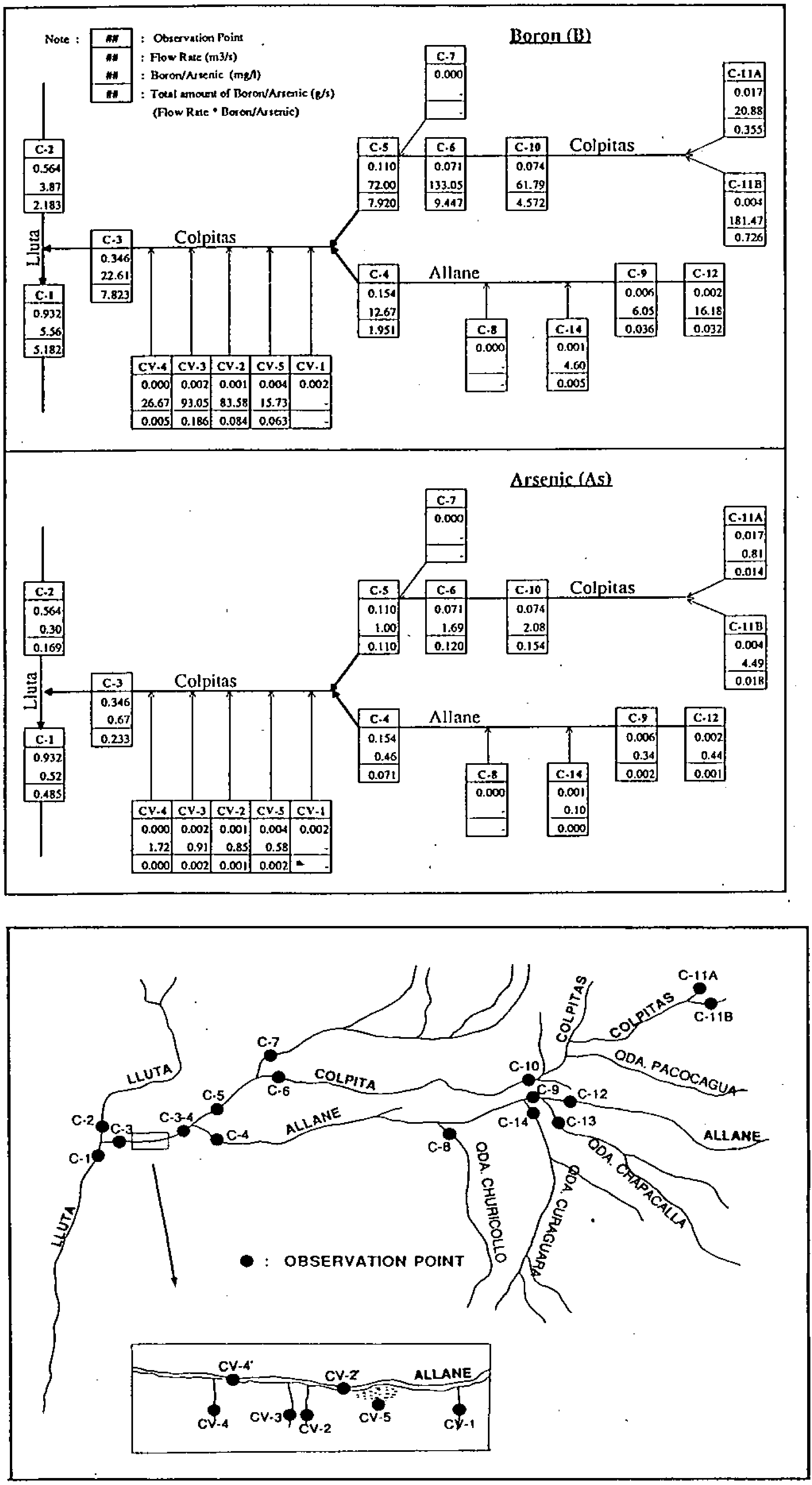
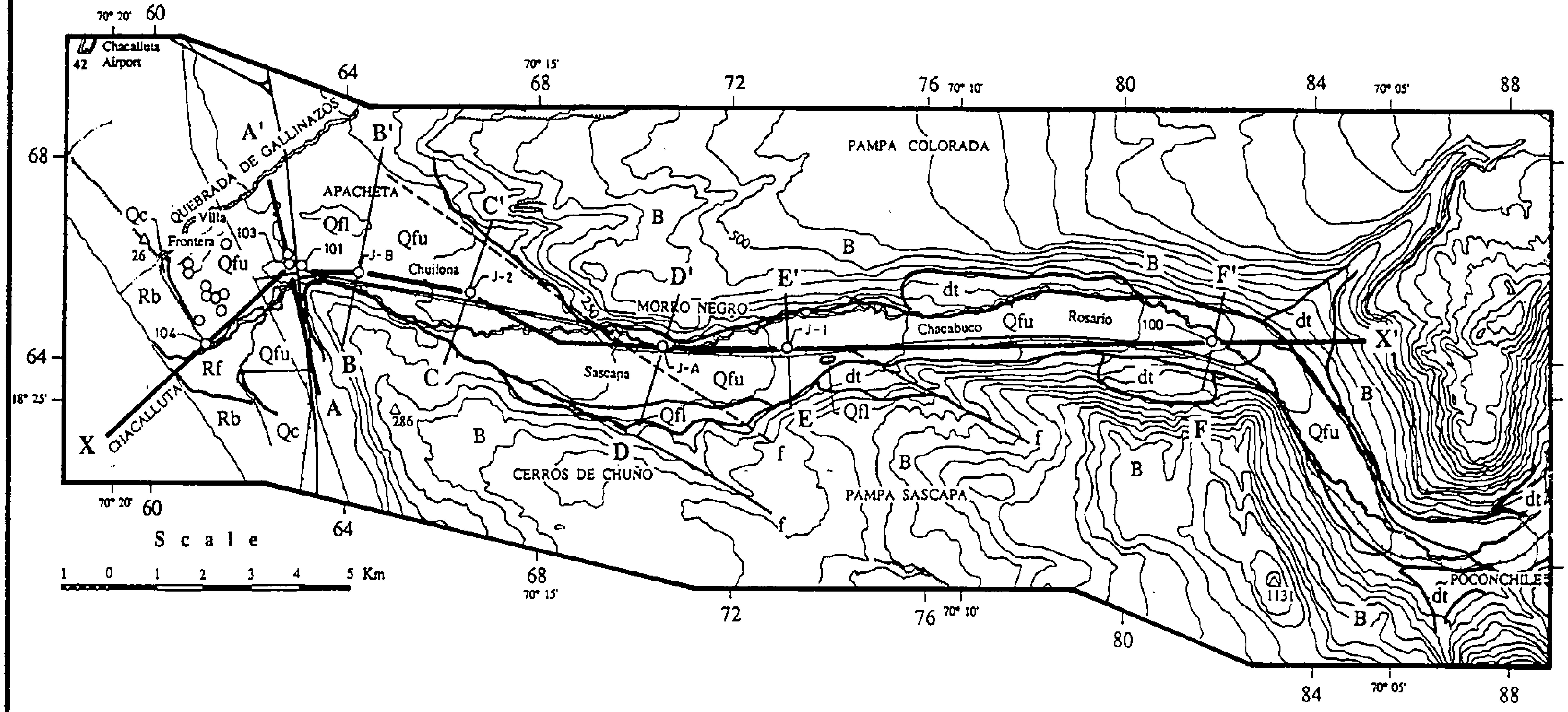


Fig. 2.1.2 (2) Observed Water Quality in Colpitas River

<Calidad de Agua colpitas en Rio Azufre>



L e g e n d

Geological Division

dt : Detrital Deposits
Rf : Recent Fluvial Deposits
Rb : Recent Beach Deposits
Qfu : Fluvial Deposits (Upper)
Qfl : Fluvial Deposits (Lower)
Qc : Concordia Formation
B : Basement Rocks (Oxaya Formation, Azapa Formation and Mesozoic)

f : Fault
X X' : Position of Geological Profile
D D' : Position of Geological Cross Section
J-A : Well

Fig. 2.1.3 Geological Map (Lluta Valley)
< Mapa Geológico (Valle de Lluta) >

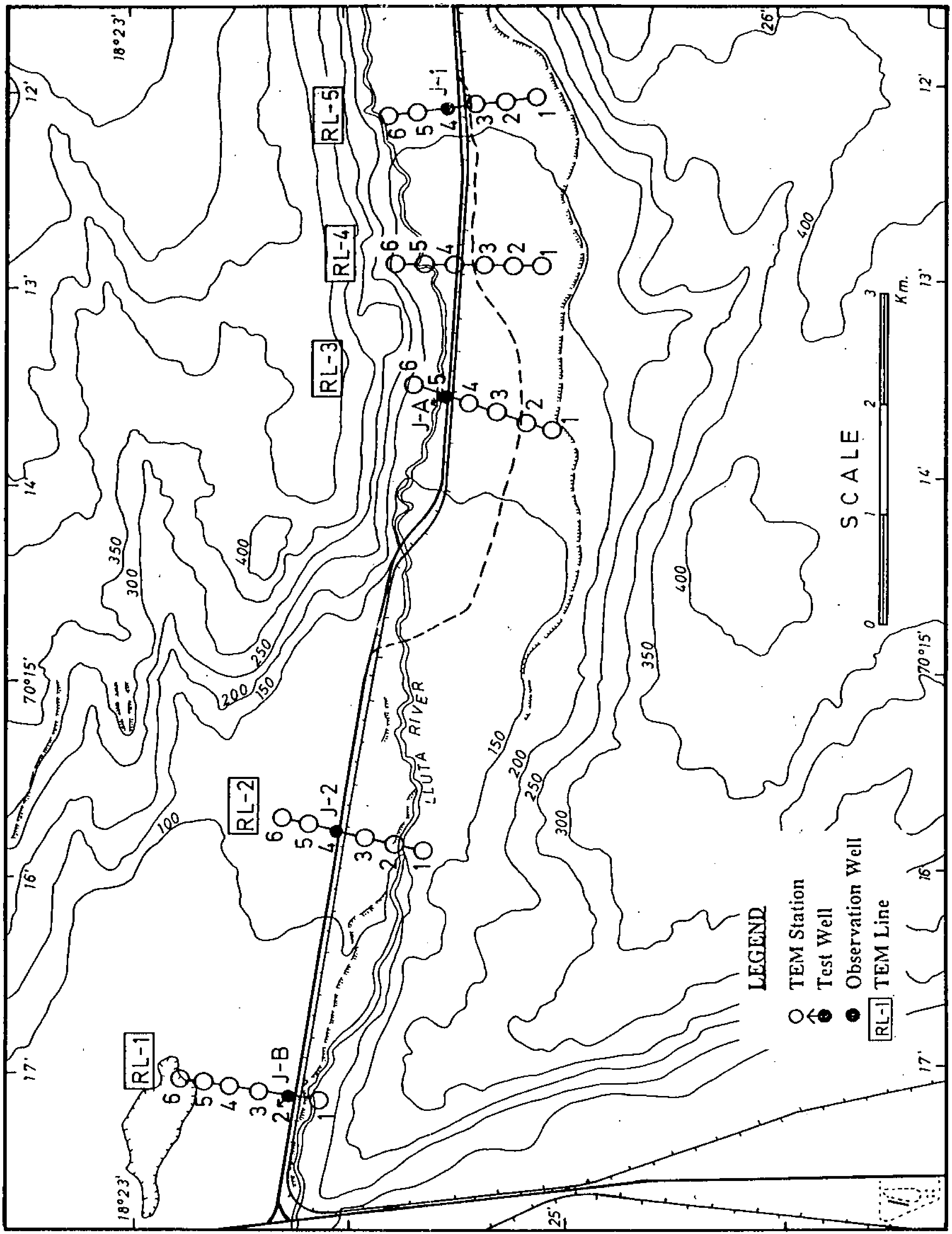


Fig. 2.1.4 Location of TEM Station and Test/Observation Well in Lluta River Area

< Ubicación de las Estaciones TEM y pozos de Prueba y Observación en el Area del Río Lluta >

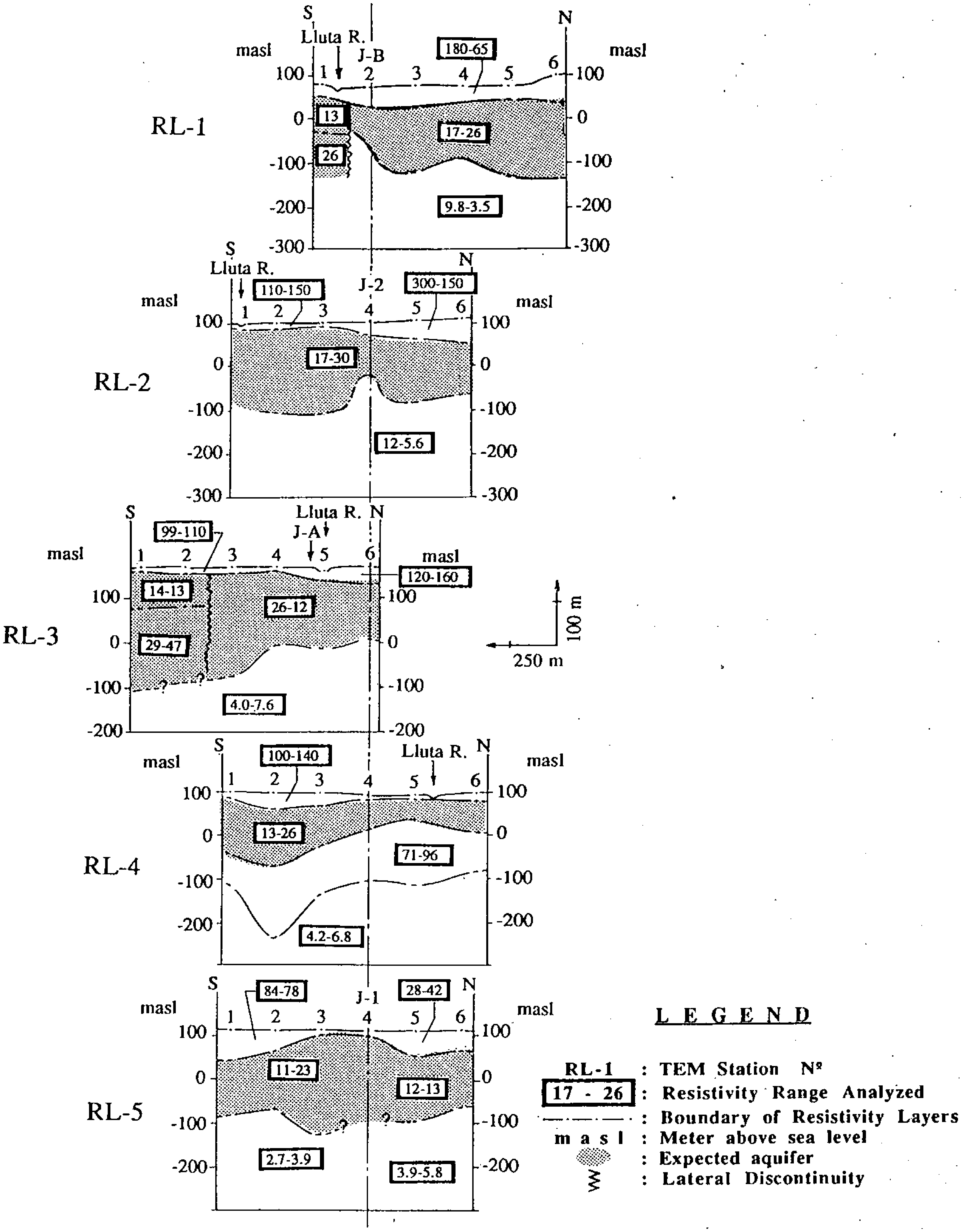
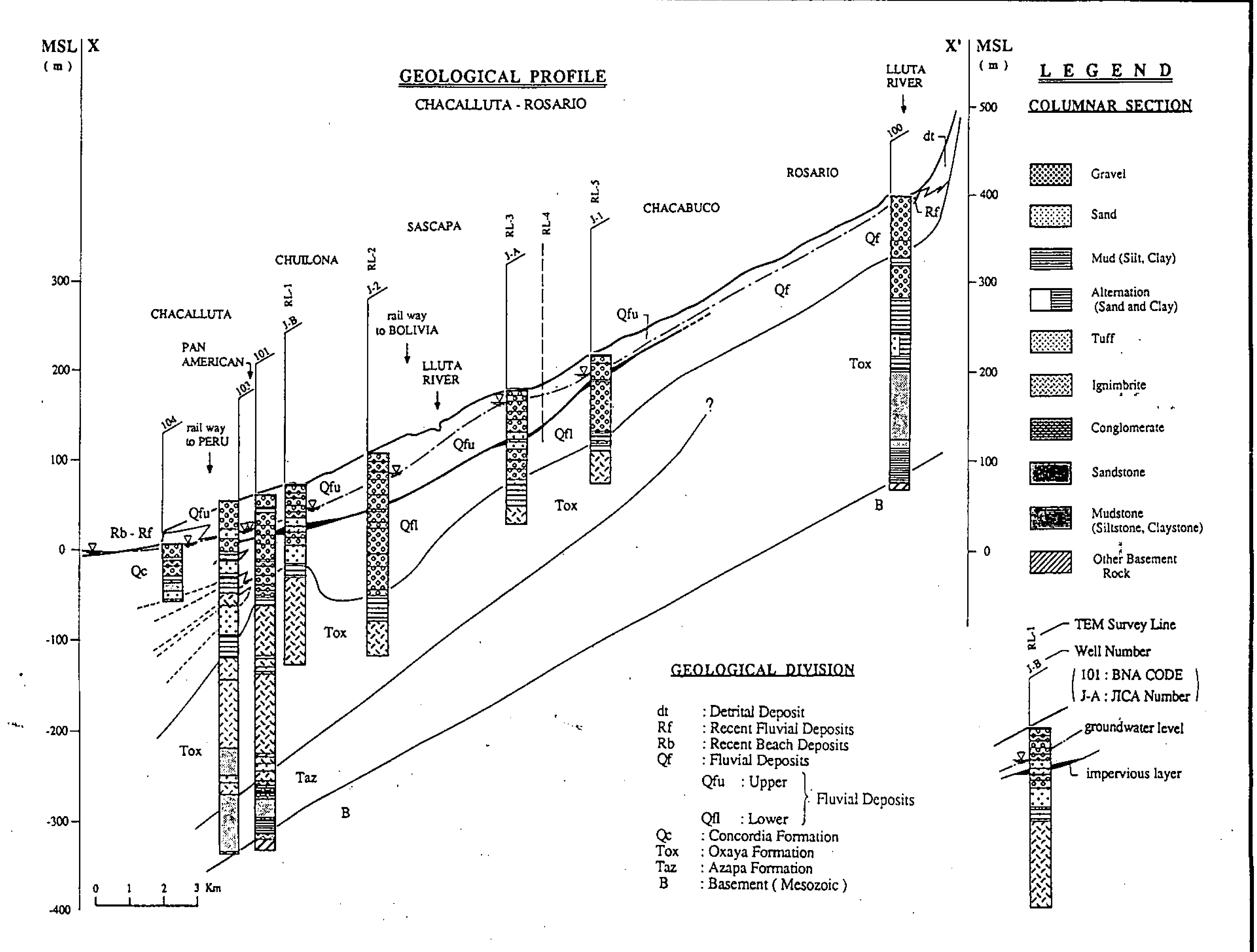


Fig. 2.1.5 Geoelectric Profiles Constructed from all TEM Soundings in Lluta River Area

< Perfiles Geoeléctricos Construidos de todos los sondeos TEM en el Area del Río Lluta >

Fig. 2.1.6 Geological Profile (X - X')

< Perfil Geológico (X - X') >



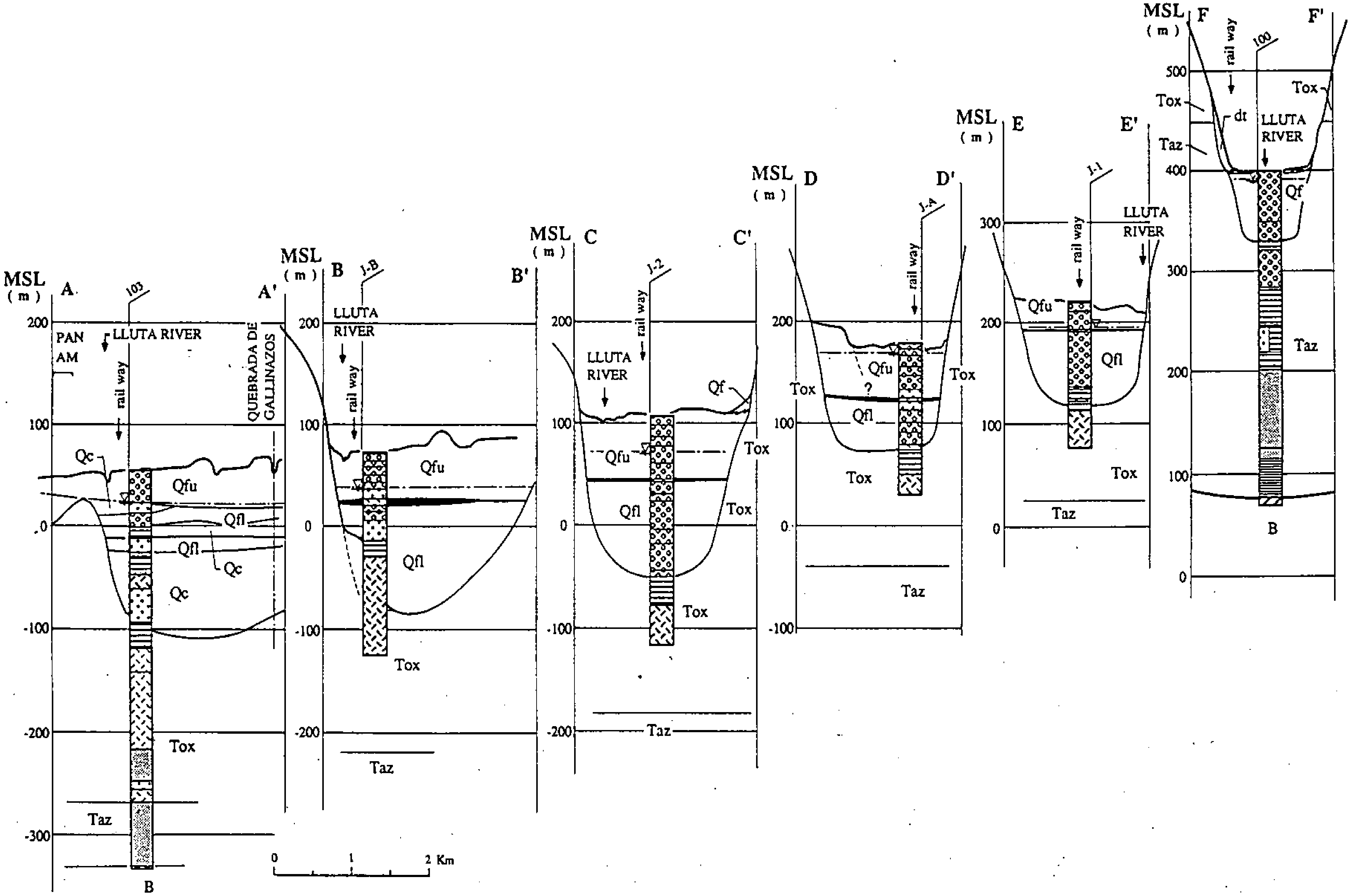


Fig. 2.1.7 Geological Cross Sections

< Secciones de Cruce Geológico >

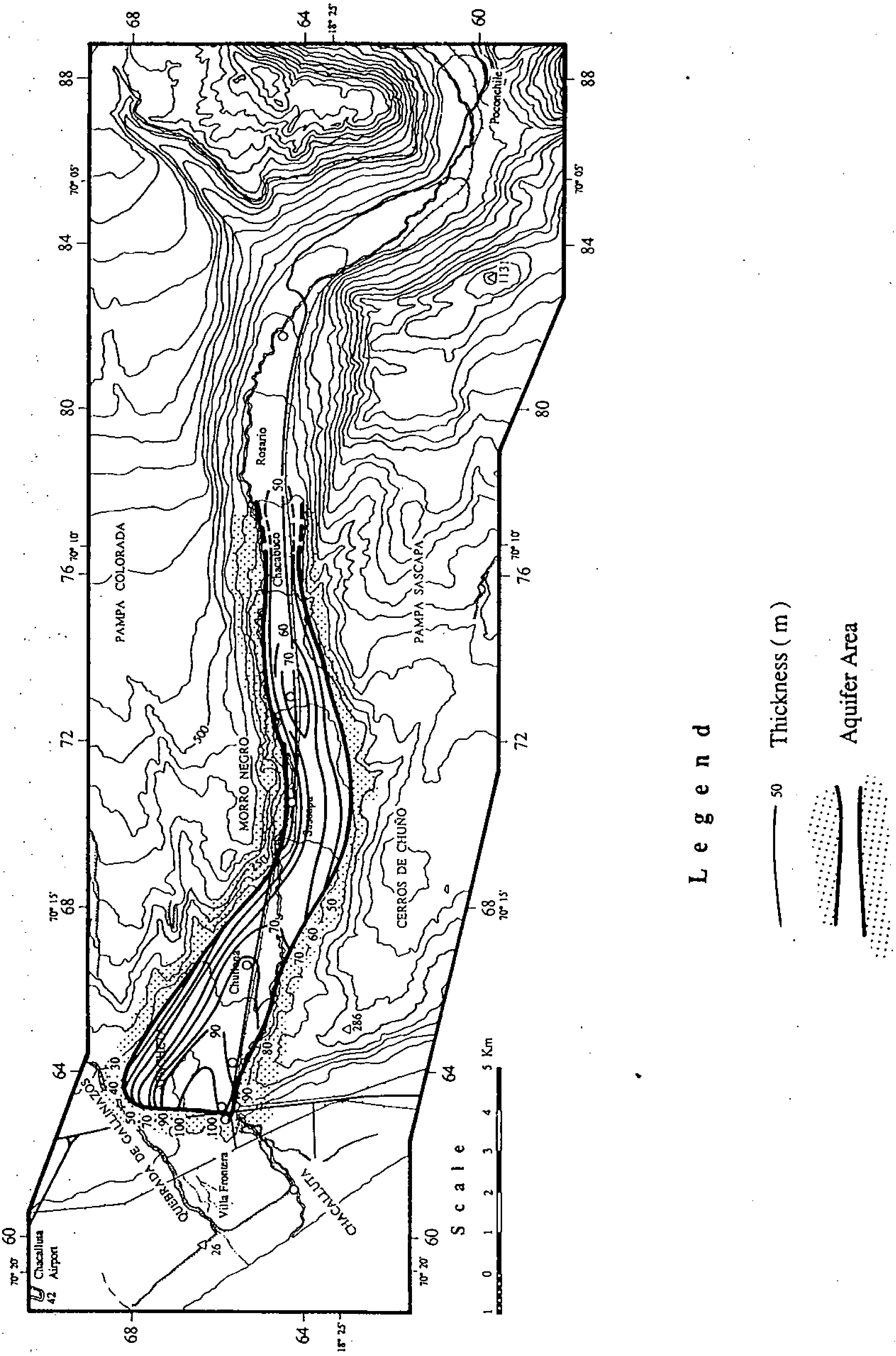


Fig. 2.1.8 Isopach Map of Deep Aquifer

< Mapa Isopaca de Acuifero Profundo >

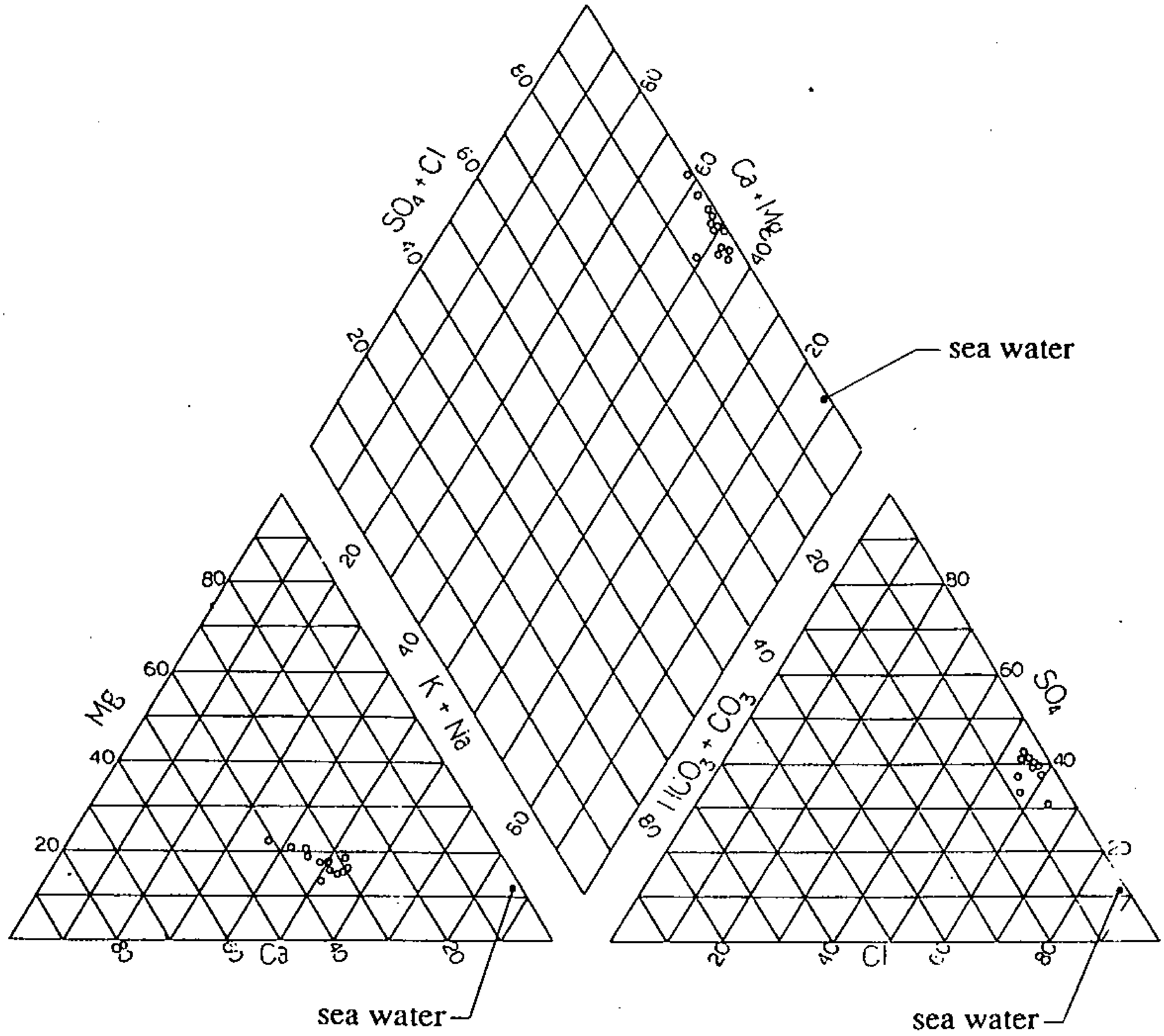


Fig. 2.1.9 Tri-linear Diagram of Major Ions (Lower Lluta Valley)

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

2.2 Pampa del Tamarugal Basin

2.2.1 Basin System

The Pampa del Tamarugal Basin consists of the Andes Mountains, Pampa del Tamarugal and Coastal Ranges. It covers a hydrologically closed area of 18,005 km^2, bounded by Andes Mountains to the east, Coastal Ranges to the west, watershed of Qda. Aroma to the north and Cerro Gordo hills to the south.

The rivers originating from the Andes Mountains recharge the groundwater of Pampa del Tamarugal. No water flows out across the border. The major rivers recharging the groundwater are Qda. Aroma, Qda. Tarapacá, Qda. Quipisca, Qda. Sagasca (Juan Morales), Qda. Quisma, Qda. Chacarilla and Qda. Ramada.

The lowest location of the Basin is Salar de Bellavista. The whole recharged groundwater flow down toward Salar de Bellavista.

For the basin system, see Fig. 2.2.1. For the detailed river networks, see Fig. 2.2.2.

2.2.2 Surface Water

1) Surface Flow Rate

The surface flow rate of Pampa del Tamarugal is observed only in Tarapacá River. No flow data is available for the other rivers.

Average surface flow rate at Mina San Juan of Tarapacá River by season are as follows.

	Jan. - Mar.	Apr. - Jun.	Jul. - Sep.	Oct. - Dec.	Average
Flow Rate (l/s)	394	295	321	200	303

For the monthly flow rate, see Supporting Report A, Table A, 3.3.

The average yearly surface flow rate of the above-mentioned seven (7) major rivers is estimated from the average yearly rainfall of each river basin multiplied by run-off coefficient

Run-off coefficient of river basin generally increases according to the increase of rainfall depth. The relationship between average yearly rainfall and run-off coefficient in this Study Area are estimated based on the observed average flow rate at several stations in the Study Area as shown below.

$$R = 1{,}192.39 f + 38.96$$

where,

R : Average yearly rainfall depth of river basin.

f : Run-off coefficient.

For details, see Supporting Report A, Chapter V.

The above relationship is applied for estimation of the river flow rates in Pampa del Tamarugal Basin.

The results are summarized below.

	Drainage Basin (Km^2)	AverageYearly Rainfall (mm)	Runoff Coeficient	Yearly Average Flow Rate (l/s)
Aroma	1,746	102	0.053	297
Tarapacá	1,716	104	0.054	307
Quipisca	846	82	0.036	78
Sagasca	971	71	0.027	58
Quisma	298	70	0.026	17
Chacarilla	1,221	89	0.042	145
Ramada	244	49	0.009	3
Total	7,042			905

This total run-off of the seven (7) rivers of 905 l/s is considered as the amount of groundwater recharge in Pampa del Tamarugal.

2) Surface Water Quality

The surface water quality of Pampa del Tamarugal has been observed only for Tarapacá River Basin by DGA. Hence, an additional water quality observation was conducted by this study in October, 1993 for Aroma, Tarapacá, Quipisca and Sagasca rivers.

The surface water quality of Pampa del Tamarugal is characterized as follows.

(1) Aroma River is much polluted by As, B and Cl.
(2) Tarapacá River is comparatively clean except B.
(3) Quipisca River is contaminated by Mn and Al.
(4) Sagasca River is much contaminated by mining activities. It contains a high concentration of As, Cd, F, P_b, SO_4, Zn, Al, Cu, Fe and Mn.

The water contamination of the above rivers are summarized as follows:

(Unit = mg/l)

	Aroma	Tarapacá	Quipisca	Sagasca	Permissible Limit
As	1.764			0.176	0.05
Cd				0.050	0.005
F				5.10	1.50
P_b				2.00	0.05
Cl	1,472				250
SO_4				4,035	400
Zn				16.00	5.00
Al			2.5	190.0	0.20
Cu				35.80	1.00
Fe				956.0	0.30
Mn			0.48	727.0	0.10
B	22.87	6.60			

2.2.3 Hydrogeology of Pampa del Tamarugal

Geology of Pampa del Tamarugal is classified into the following three (3) units from the hydrogeological point of view.

(1) Recent Sediments
(2) Altos de Pica Formation
(3) Basement Rocks

Pampa del Tamarugal is a closed basin called as "Intermediate Depression". It is filled in with Recent Sediments and Altos de Pica Formation.

Recent Sediments consisting of alluvial deposits, eolian deposits and fan deposits cover the top surface of the basin. On the other hand, Altos de Pica Formation consisting of gravel, sand and mud fills up the major portion of the basin.

Basement Rocks are mainly composed of impermeable Longacho Formation (Mesozoic Formation).

Geological map of Pampa del Tamarugal is shown in Fig. 2.2.3.

Principal aquifers exist in Altos de Pica Formation. Altos de Pica Formation is distributed over the whole Pampa del Tamarugal. The thickness of the Formation is less than 100 m in the northern fringe of the basin. However, it increases toward south, reaching 700 m at Salar de Pintados located in the southern part of the basin.

In Pica area, Altos de Pica Formation is thickly deposited in the eastern side of the rise of Basement Rocks. Groundwater flowing into Altos de Pica Formation is dammed up and appears as spring. Similar hydrogeological conditions are identified in the areas along the eastern edge of the basin (Intermediate Depression). For details, see Supporting Report B-III, 1.2.3.

2.2.4 Geological Survey

The following geological surveys were executed by the JICA Study Team to supplement the existing geological data. The survey location is shown in Fig. 2.2.4.

a) Electromagnetic Survey	100 survey points (8 lines)
b) Boring Survey	
(a) Drilling	
Test well drilling	4 wells
Observation well drilling	7 wells
(b) Pumping Test	11 wells
c) Water Quality Analysis	11 wells (JICA wells)
d) C-14 analysis	5 wells

1) Electromagnetic (TEM)Survey

(1) Survey Area

Transient Electro Magnetic (TEM) survey is conducted at Pampa del Tamarugal area as shown in Fig. 2.2.4. Eight (8) TEM lines were set perpendicular to main axis of Precordillera range. A total of 100 stations were set at interval of 2000m each as shown below.

Quantity of TEM Survey

	Profile	Stations	Station Interval
	PT-1	14	2000 m
	PT-2	9	2000 m
	PT-3	28	2000 m
	PT-4	14	2000 m
	PT-5	8	2000 m
	PT-6	15	2000 m
	PT-7	4	2000 m
	PT-8	8	2000 m
Total		100	

(2) Survey Results

The geoelectrical profiles along line PT-1 to PT-8 are shown in Fig. 2.2.5. According to well logging (long normal) data of three (3) existing wells (Pintados No. 1, No. 2 and Dolores No. 1), the resistivity value of aquifer with no contamination is in the range of 10 to 40 ohm-m.

The resistivity structure of the surveyed area is classified as 3 to 4 layers with stratiform structure. The geophysical characteristics of each layer are summarized as follows

a) The first layer (10 m to 120 m thick) shows a resistivity range of 28 to 1400 ohm-m. The layer is distributed in the whole area. In same area, such as at station No. 1 to 3 and 6 to 8 of PT-5, and station No.13 to 16, 21 to 23, and 25 to 28 of PT-3, the layer shows a relatively low resistivity (28 to 100 ohm-m). This is probably due to the wet land conditions by irrigation water. The resistivity of the layers at station 11 to 13 of PT-1 and all stations of PT-7 are extremely high (more than 1000 ohm-m). This is probably due to the hard and dry land conditions. In general, the eastern part of the area, the layer shows higher resistivity than the western part. This resistivity range is between 200 and 1200 ohm-m. It is considered that the surface of eastern part of the area is rather dry than the western part. The thickness of the layer is gradually increased to southeastwards.

The depth to the boundary of between the first and second layer is almost coincident with the water levels of wells in the area.

b) The second layer (between 20 and 400 m thick) shows a resistivity range of approximately 10 to 50 ohm-m. The layer is distributed in mostly all the stations of profiles. According to the resistivity logging data of the existing well of Pintados No. 1 (located at near station No. 5 on profile PT-8), this layer is considered as expected aquifer. The thickness of the layer is gradually increased from 100m (PT-1) to 400m (PT-7). However, it is rapidly decreased from 200m (PT-8) to less than 100m (PT-4). At the west of PT-4, the layer is divided into two parts by the third layer.

c) The third layer (more than 50 m thick) shows a resistivity value approximately lower than 10 ohm-m. The layer is distributed in the whole area. The layer is presumed to have groundwater potential to same degree. However, its low resistivity would indicate that the layer is contaminated by salt. The depth to the layer is gradually increased southwards.

d) The forth layer shows a resistivity value approximately higher than 100 ohm-m. The layer is distributed in the northern and western part of the area. According to the existing data such as well logging of Dolores No.1 and gravity map of the area, the layer is considered as the geological basement composed of high density rocks. Thus, the layer is classified as impermeable basement.

Lateral discontinuities of resistivity exist between station No. 4 and No. 5 of PT-2, between station No. 4 and No.5 of PT-6, between station No. 2 and No. 3 of PT-3, and between station No. 1 and No. 2 of PT-7. These discontinuities may be coincident with geological boundaries such as faults of fracture zones.

2) Boring Test

(1) Location and Depth of Wells

Four (4) Test Wells (J-C, J-D, J-E and J-F) and seven (7) Observation Wells (J-3, J-4, J-5, J-6, J-7, J-8 and J-9) are placed along on the line of the TEM survey (see, Fig. 2.2.4). Location, drilling depth and casing size of each well are summarized as follows.

Well No.	Location	Latitude	Longitude	Elevation (m.msl)	Casing (inch)	Depth (m.bgl)
J-C	Huara	19° 59' 05.7"	69° 42' 09.8"	1,110.875	8-5/8"	209
J-D	Baquedana	20° 09' 54.2"	69° 41' 10.4"	1,056.686	8-5/8"	210
J-E	La Tirana	20° 19' 53.2"	69° 41' 18.6"	1,006.028	8-5/8"	250
J-F	Ramada	20° 43' 53.2"	69° 30' 17.3"	1,016.158	8-5/8"	200
J-3	Aguada	19° 45' 09.1"	69° 49' 15.3"	1,143.898	5-1/2"	150
J-4	Negreiros	19° 51' 37.2"	69° 44' 51.8"	1,168.043	5-1/2"	150
J-5	Pozo Almonte	20° 15' 10.7"	69° 41' 26.1"	1,030.800	5-1/2"	300
J-6	Canchones	20° 26' 40.9"	69° 31' 15.7"	991.897	5-1/2"	200
J-7	Conaf	20° 30' 44.4"	69° 39' 56.9"	981.635	5-1/2"	210
J-8	Pintados	20° 35' 37.7"	69° 31' 08.2"	1,016.119	5-1/2"	210
J-9	Oficina Victoria	20° 45' 12.6"	69° 35' 26.3"	969.796	5-1/2"	172

(2) Method of Boring Test

For the details of methodology, see section 2.1.5 of Chapter II.

(3) Results of Boring Test

The results of boring tests are summarized in Table 2.2.1. Detailed information including lithological column, casing design and well loggings are shown in Fig. B-III, 2.3.13 to 2.3.23 of the supporting report. The results of the boring tests are concluded as follows ;

i) Geological Conditions

As shown in Table 2.2.1, the lithology of aquifer of the area is mainly composed of clayey gravel, gravely clay and sandy clay of Quaternary Altos de Pica Formation. Depth of the aquifer is in a range of 43m to 282m, in general. The proportion of content for each lithology is summarized as following table.

Lithology	conglo -merate	gravel	sandy gravel	clayey gravel	sand	clayey sand	gravely clay	sandy clay	gypsum clay
Screen Length (m)	6.02	59.87	50.03	387.55	6.00	36.02	194.28	179.45	6.00
Proportion (%)	0.65%	6.47%	5.41%	41.89%	0.65%	3.89%	21.00%	19.40%	0.65%

According to the above table, the proportion of two (2) major lithology of clayey gravel and gravely clay is indicated more than 60% of total thickness of the aquifer. Sandy clay shows second highest proportion of 19.4%. Proportion of other minor lithology is less than 7% for each.

Following table shows the proportion of each lithology according to geological unit.

Unit	Lithology	Screen Length (m)	Proportion
Q4	clayey gravel	159.20	43.99%
	sandy clay	65.86	18.20%
	gravely clay	56.96	15.74%
	gravel	29.84	8.25%
	sandy gravel	26.03	7.19%
	clayey sand	24.01	6.63%
	Total Thickness (m)	361.90	100.00%
Q3	clayey gravel	180.25	50.13%
	gravely clay	101.27	28.17%
	gravel	30.03	8.35%
	sandy gravel	24.00	6.68%
	clayey sand	12.01	3.34%
	sandy clay	11.97	3.33%
	Total Thickness (m)	359.53	100.00%
Q2	sandy clay	101.62	49.86%
	clayey gravel	48.10	23.60%
	gravely clay	36.07	17.70%
	conglomerate	6.02	2.95%
	sand	6.00	2.94%
	gypsum clay	6.00	2.94%
	Total Thickness (m)	203.81	100.00%

The lithology which has largest proportion at unit Q4 and Q3 is clayey gravel. It is 43.99% at Q4 and 50.13% at Q3. On the other hand, sandy clay has largest proportion of 49.86% at Q3. From this lithological viewpoint, it is considered that the unit Q4 and Q3 which is upper layer of Altos de Pica Formation is rather permeable than lower layer of Q2.

ii) Geophysical Conditions

A apparent resistivity value is similar in all the wells. The value in the range of approximately 10 to 30 ohm-m, in general. This range is in well agreement with the result of TEM (approximately 10 - 50 ohm-m). Therefore, the aquifer in the area confirmed by boring test regarded as identical with the second layer classified by TEM survey.

(4) Method of Pumping Test

For the details of methodology, see section 2.1.5 of Chapter II.

(5) Analysis of Pumping Test

For the details of method for analysis, see section 2.1.5 of Chapter II.

(6) Result of Pumping Test

The result of pumping test are summarized in Table 2.2.2. The table include pumping data, aquifer constants and well capacity represented by critical discharge and safe yield. Result of the pumping test are concluded as follows ;

i) Pumping Data

The static water level of eleven (11) wells is in the range of 7.94m and 57m. The highest specific yield of 8.33 l/s/m is obtained at J-5. It is extremely high capacity. On the other hand, J-C has the lowest value of 0.09 l/s/m. The average specific yield of eleven (11) wells is calculated as 2.76 l/s/m.

ii) Aquifer Constants

The average of the transmissibility of eleven (11) wells is calculated as 404.35 m^3/d/m. High value of the transmissibility is found at J-D (1506.17 m^3/d/m) as highest, J-5 (769.61 m^3/d/m) and J-E (633.33 m^3/d/m) . These wells has also high value of the specific yield. The location of these wells are converged on almost central of the study area (between Baquedano and La Tirana). Therefore, this area considered to have high grandwater potential. On the other hand, the wells which has lower value of transmissibility (less than 150 m^3/d/m) are distributed in the northern and southern part of the area (J-C, J-F, J-3, and J-6).The lowest transmissibility is estimated at J-C (8.29 m^3/d/m). The well has also lowest specific yield.

Permeability value of the eleven (11) wells a similar. The highest value is 1.18×10^{-2} cm/sec at J-D, and the lowest one is 1.23×10^{-4} cm/sec at J-4. The average of permeability is calculated as 5.13×10^{-3} cm/sec. This value is in well agreement with the permeability usually expected in this lithology mainly consisting clayey gravel, gravely clay and sandy clay.

The storage coefficient of the eleven (11) wells is in the range of 1.56×10^{-2} to 4.99×10^{-7}.

iii) Well Capacity

At the most of wells, critical discharge is confirmed as larger amount than maximum pump capacity. The highest rate of more than 27 l/s is obtained at J-E among Test Wells. The safe yield of the well is 20 l/s. Among Observation Wells, highest rate of more than 5 l/s is found at J-3, J-5, J-7 and J-9. According to the rate of safe yield both of Test and Observation Well, high pumping rate as a critical discharge is expected except J-C, J-F and J-4.

2.2.5 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. 2.2.7 and Fig.2.2.8 respectively. For their location, see Fig. 2.2.6.

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. 2.2.9.

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 90 m at the northern fringe to 700 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 storage coefficient 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)	Storage Coefficient	Permeability (cm/sec)
Dolores	J-3	0.73	113.81	2.66×10^{-3}	2.20×10^{-3}
Negreiros	J-4	2.22	271.08	1.56×10^{-2}	5.22×10^{-3}
Huara	J-C	0.09	8.29	7.71×10^{-2}	1.23×10^{-4}
	J-D	3.47	1506.17	3.28×10^{-6}	1.81×10^{-2}
Pozo Almonte	J-5	8.33	769.61	9.40×10^{-6}	8.23×10^{-3}
	J-E	6.77	644.33	4.27×10^{-3}	7.31×10^{-3}
Canchones	J-6	0.26	21.63	3.29×10^{-3}	3.20×10^{-4}
	J-7	2.72	383.83	5.35×10^{-5}	5.30×10^{-3}
Pintados	J-8	2.18	376.27	1.07×10^{-3}	5.18×10^{-3}
Bellavista	J-9	1.92	266.06	2.06×10^{-3}	3.54×10^{-3}
	J-F	1.65	86.81	4.99×10^{-7}	9.57×10^{-4}
Average		2.76	404.35	9.65×10^{-3}	5.13×10^{-3}

The results of the previous pumping tests are summarized in Table 2.2.3.

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 progress 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. 2.2.6.

2.2.6 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	600.24*
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 observation, water of 160 wells were observed by this study in 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. 2.2.9.

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 1982 to 1993 was not more than 2.0 m, equivalent to 0.2 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 sorrounding areas.

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

(3) Water Quality

There is no difference between shallow well and deep well in 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. 2.2.10 (1) to Fig. 2.2.10 (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.

Table 2.2.1 (1) Result of Boring test of Pampa del Tamarugal Area

< Resultado de Prueba de Sondaje en el area de la Pampa del Tamarugal >

Sheet No.1

Well No.	Bore hole Depth (m)	Casing Pipe		Screen Pipe		Geological Conditions of Aquifer			Geophysical Data	
		Size (inches)	Total Length (m)	Position (m)	Total Length (m)	Lithology	Altos de Pica Formation	Period	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		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 2.2.1 (2) Result of Boring test of Pampa del Tamarugal Area

< Resultado de Prueba de Sondaje en el area de la Pampa del Tamarugal >

Sheet No.2

Well No.	Bore hole Depth (m)	Casing Pipe		Screen Pipe		Geological Conditions of Aquifer			Geophysical Data	
		Size (inches)	Total Length (m)	Position (m)	Total Length (m)	Lithology	Formation	Period	Well Logging Resistivity (ohm-m)	TEM Resistivity (ohm-m)
J-5	300	5-1/2"	193.35	103.12-109.13	108.29	clayey gravel	Q4	Quaternary	10 - 20	10 -17
				121.19-145.28		clayey gravel	Q4		10 - 30	10 - 17
				168.46-174.48		clayey gravel	Q3		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
J-6	200	5-1/2"	126.63	49.54-73.57	78.10	sandy gravel	Q4	Quaternary	25 - 40	10 - 19
				91.66-103.69		sandy gravel	Q3		30 - 35	10 - 19
				115.75-127.72		sandy gravel	Q3		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
J-7	210	5-1/2"	126.75	55.79-61.76	83.79	sandy clay	Q4	Quaternary	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
				144.87-156.85		gravely clay	Q3		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
J-8	210	5-1/2"	129.35	53.12-65.13	84.04	clayey gravel	Q4	Quaternary	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
				123.64-129.63		gravely clay	Q4		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
J-9	172	5-1/2"	87.92	58.59-115.64	86.98	clayey gravel	Q4	Quaternary	5 - 20	-
				121.67-133.63		gravely clay	Q4		10 - 20	-
				144.87-156.84		sandy clay	Q3		10 - 30	-
				162.87-168.87		gypsum clay	Q2		15 - 45	-

Table 2.2.2 Result of Pumping Test of Pampa del Tamarugal Area

< Resultado de Prueba de Bombeo en el Area de la 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)	Storage Coefficient	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	7.71E-02	1.23E-04	2.50	0.80
J-D	46.05	22.5	52.53	6.48	3.47	1506.17	3.28E-06	1.81E-02	25.00<	10.00
J-E	13.73	27.00	17.72	3.99	6.77	644.33	4.27E-03	7.31E-03	27.00<	20.00
J-F	57.00	20.00	69.15	12.15	1.65	86.81	4.99E-07	9.57E-04	8.33	1.80
J-3	9.17	5.00	16.05	6.88	0.73	113.81	2.66E-03	2.20E-03	5.00<	3.75
J-4	46.22	4.40	48.20	1.98	2.22	271.08	1.56E-02	5.22E-03	4.00	0.30
J-5	29.08	5.00	29.68	0.60	8.33	769.61	9.40E-06	8.23E-03	5.00<	2.00
J-6	14.04	4.04	29.70	15.66	0.26	21.63	3.29E-03	3.20E-04	4.04<	5.00
J-7	7.94	5.00	9.78	1.84	2.72	383.83	5.35E-05	5.30E-03	5.00<	10.00
J-8	37.99	3.34	39.52	1.53	2.18	376.27	1.07E-03	5.18E-03	3.34<	29.00
J-9	13.97	5.00	16.57	2.60	1.92	266.06	2.06E-03	3.54E-03	5.00<	3.50

Table 2.2.3 Previous Pumping Tests

<Prueba de Bombeo Pozos Existentes>

BNA NO.	Discharge Rate (l/s)	Specific Yield (l/sec/m)	Transmissibility (m3/d/m)	Permeability (cm/sec)	Storativity	Remarks
(Zapiga-Dolores-Negreiros Area)						
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	9.99E-10	J
930	8.0	0.60	110	4.55E-03	2.84E-04	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	0.0142	
(Huara Area)						
190-6			1440			C
946	2.2	4.1	39	1.56E-04	5.26E-07	J
949		4.0	935	3.37E-02	6.00E-04	C
951	18.0	2.9	284	2.35E-02		J
Average		3.7	675	0.0191	0.0003	
(Pica-Matilla Area)						
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	2.81E-01	J
390-9	1.0	0.04	312	1.39E-02	4307	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	2.15E+03	

BNA NO.	Discharge Rate (l/s)	Specific Yield (l/sec/m)	Transmissibility (m3/d/m)	Permeability (cm/sec)	Storativity	Remarks
(Pozo Almonte-Canchones-Pintados Area)						
129-9	36.0	5.14				J
130-2		1.66	47		4.29E-02	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	4.14E-01	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	2.62E-03	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	5.00E-04	C
Average		3.26	1102	0.044	0.115	
(Oficina Victoria-Bellavista Area)						
432-b	25.0	1.51				J
445-k	26.0		420	1.39E-02	3.30E-01	J
985		3:04	220		3.00E-03	C
986		0.32	81		5.00E-02	C
987		0.32	157		1.00E-01	C
Average		1.30	219.5	0.014	0.121	
(TOTAL PAMPA AREA: except Pica-Matilla Area)						
Average		2.27	547	0.024	0.081	

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

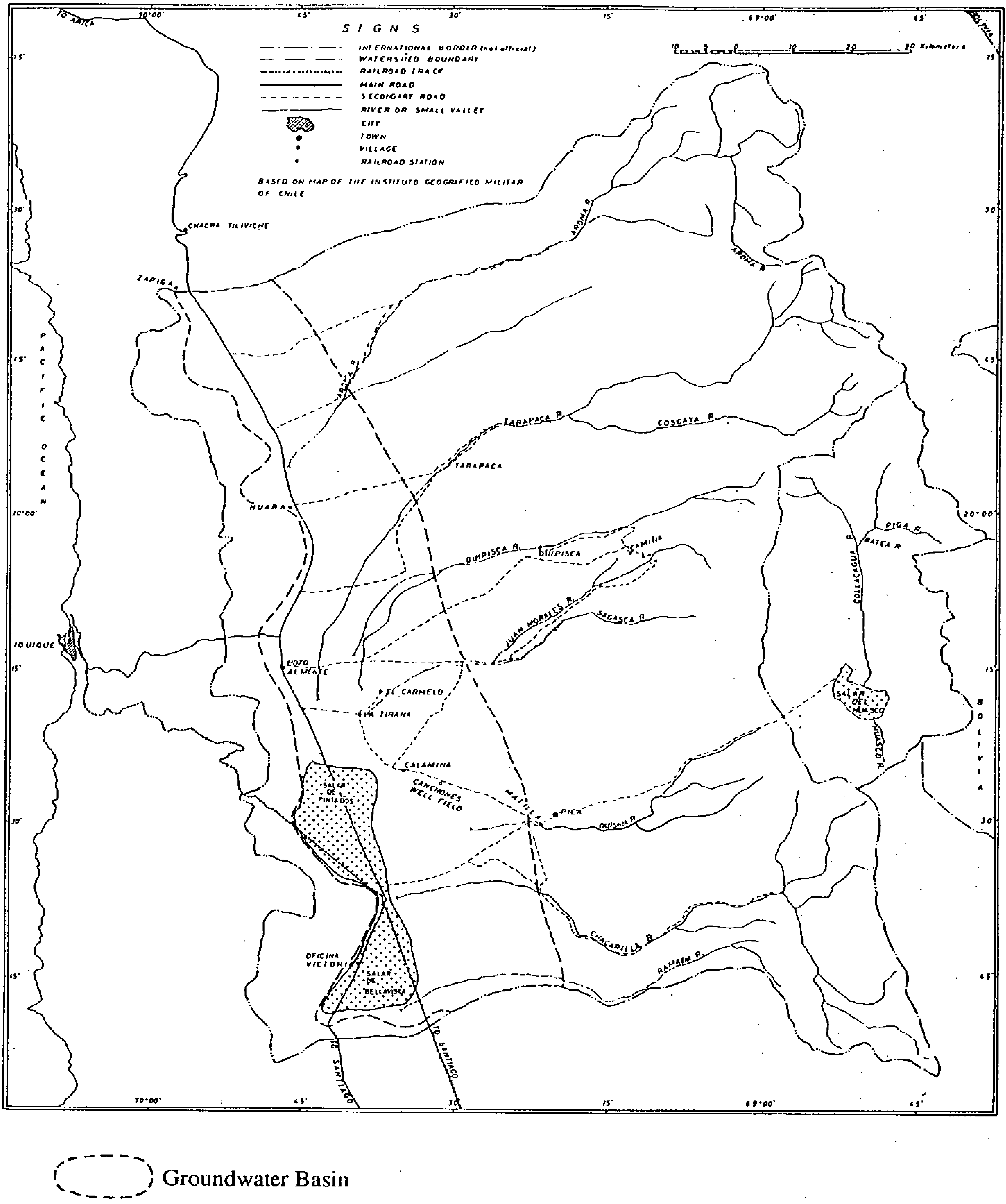


Fig. 2.2.1 Basin Map of Pampa del Tamarugal and Salar de Huasco

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

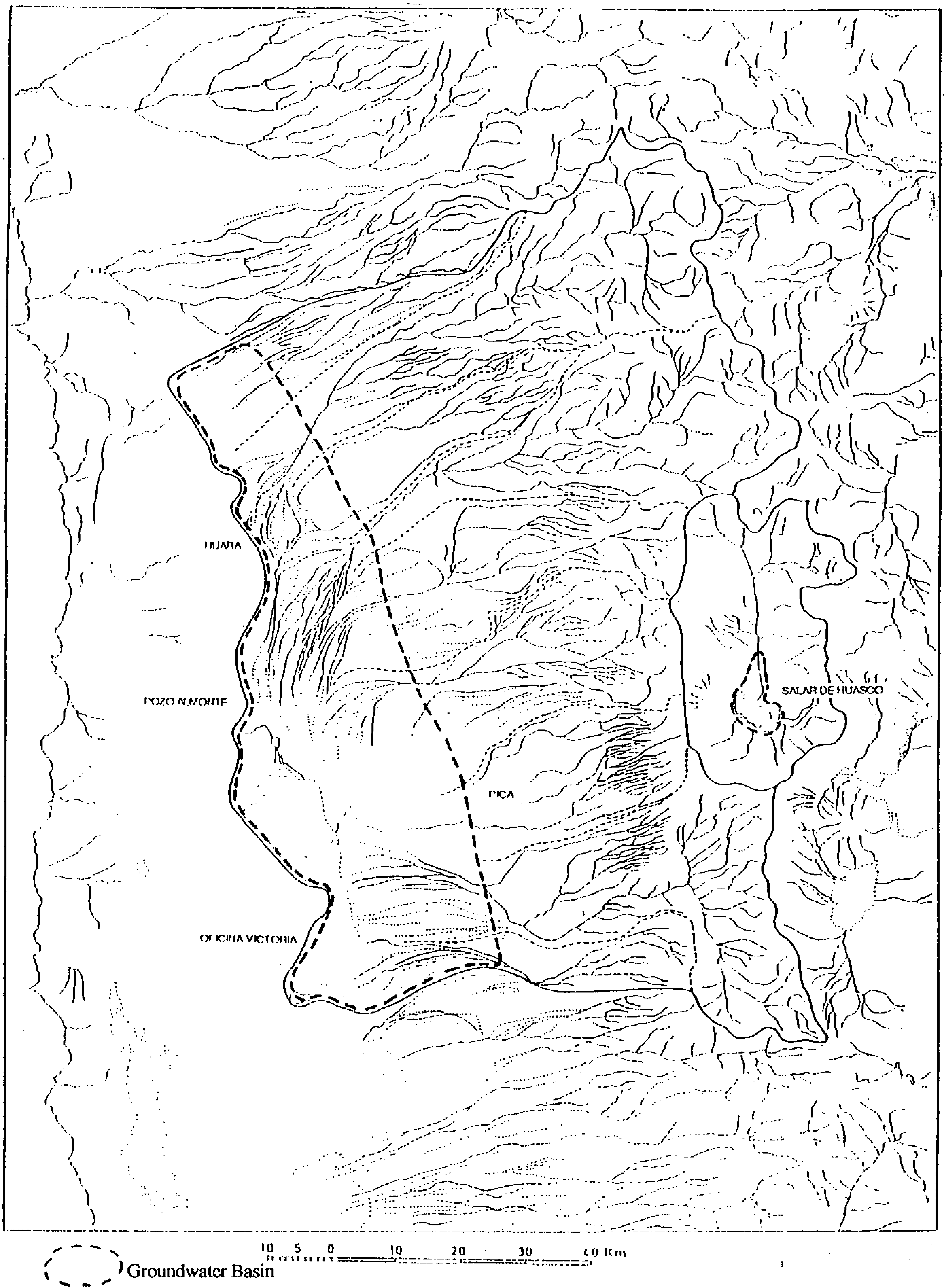


Fig. 2.2.2 River Networks of Pampa del Tamarugal and Salar de Huasco

<Red de Drenaje Pampa del Tamarugal y Salar de Huasco>

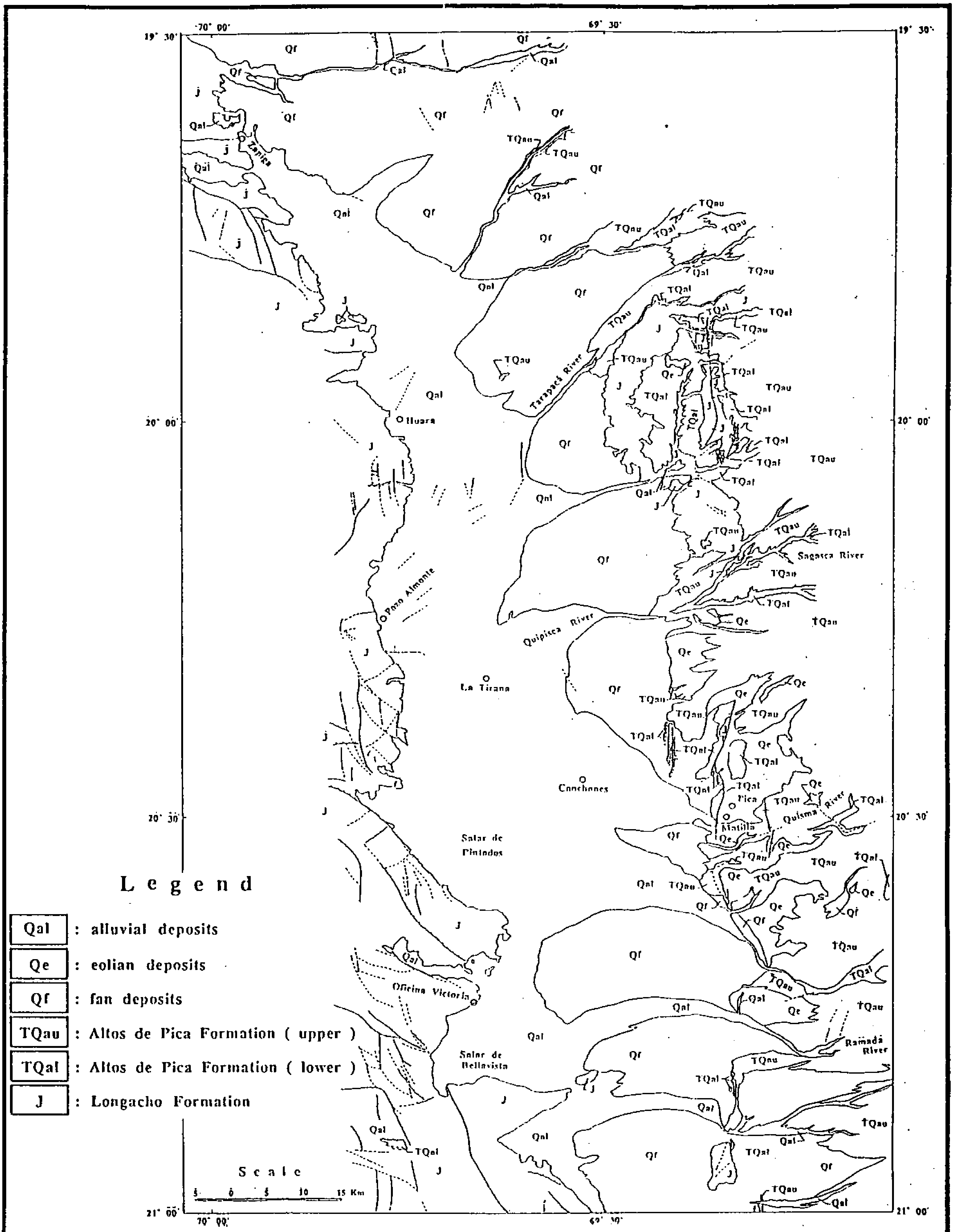


Fig. 2.2.3 Geological Map (Pampa del Tamarugal)

< Mapa Geologico (Pampa del Tamarugal)>

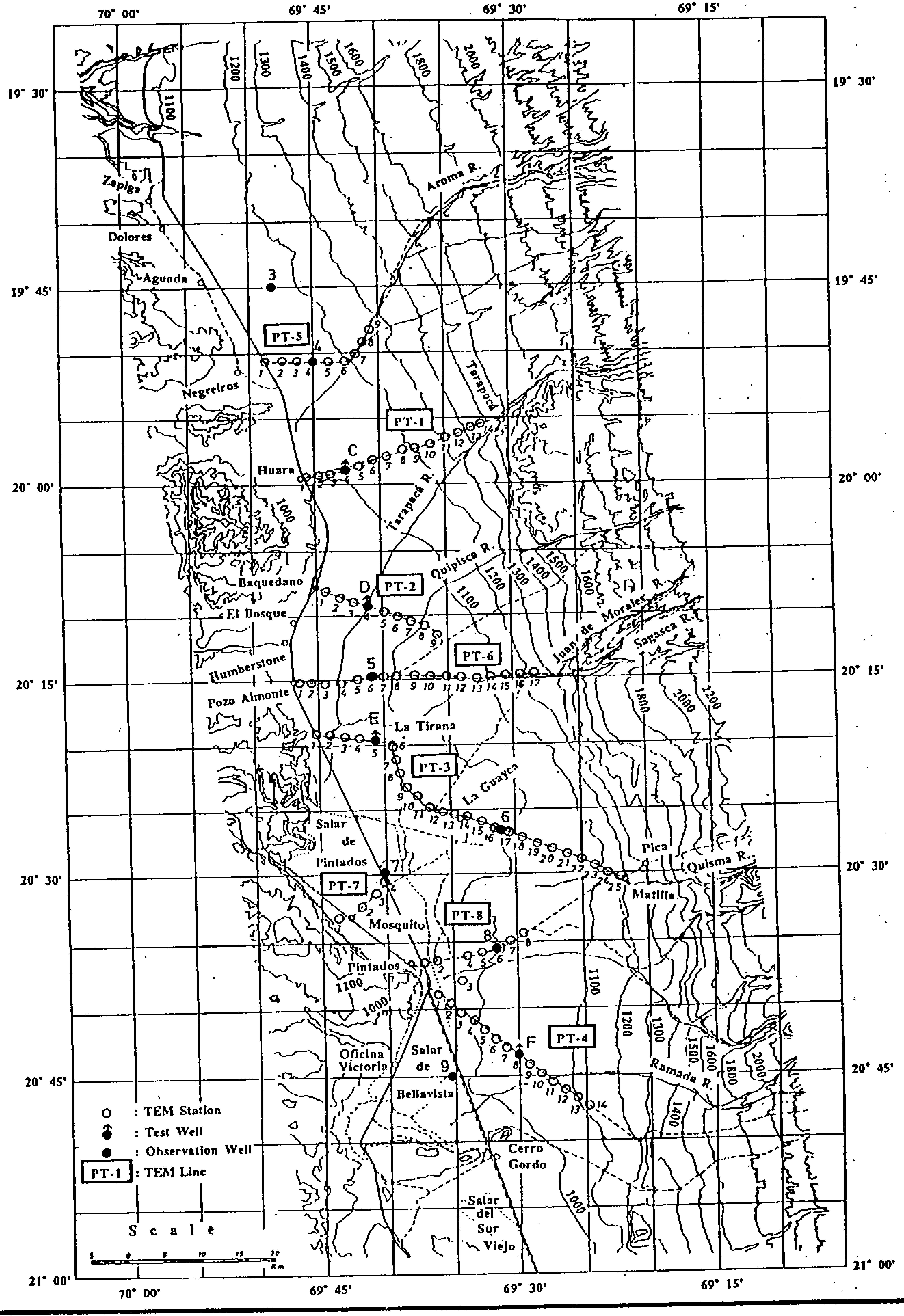


Fig. 2.2.4 Location of TEM Station and Test/Observation Well in Pampa del Tamarugal Area

< Ubicación de las Estaciones TEM y pozos de Prueba y Observación en el Area de la Pampa del Tamarugal >

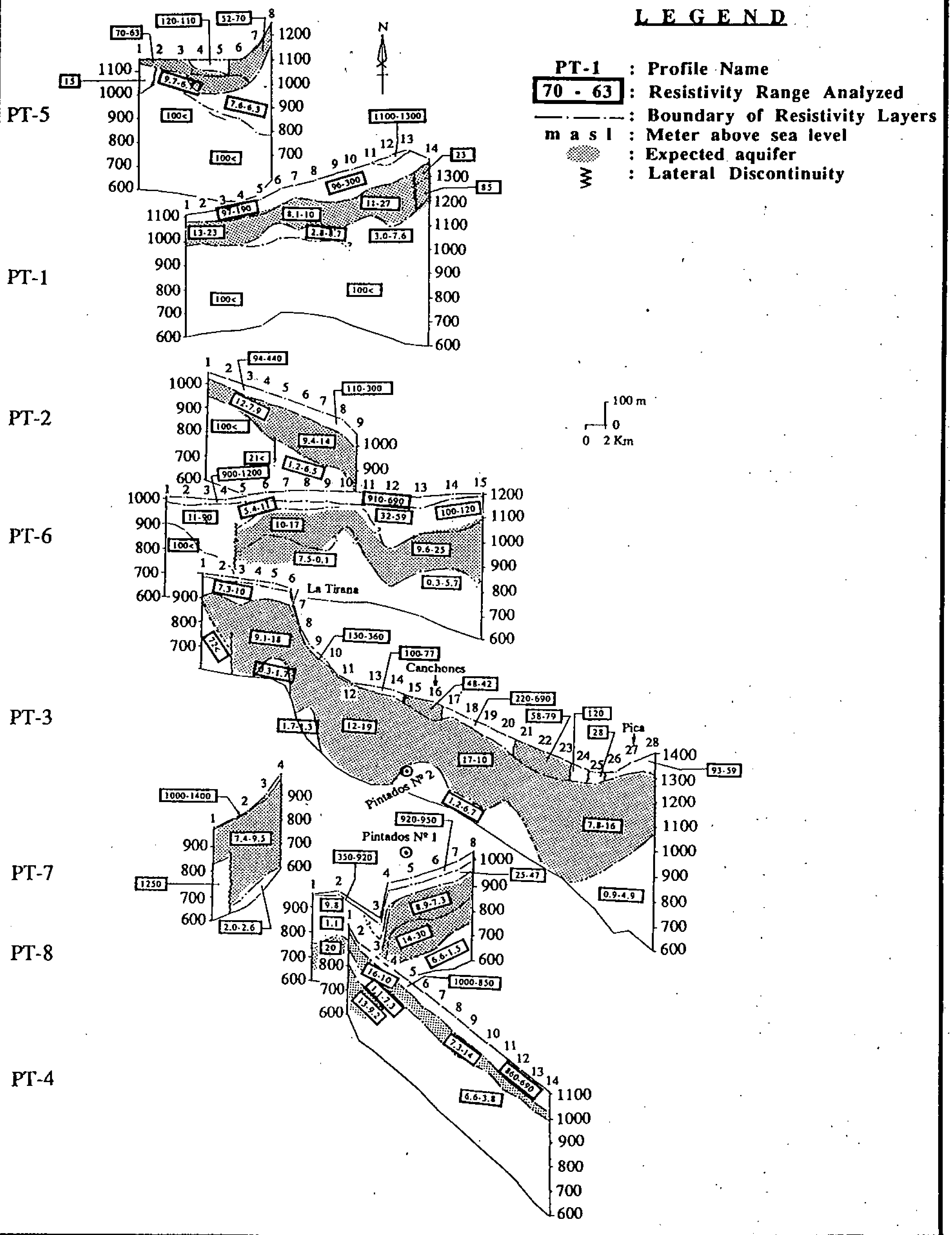


Fig. 2.2.5 Geoelectric Profiles Contructed from all TEM Soundings in Pampa del Tamarugal Area

< Perfiles Geoeléctricos Construídos de todos los Sondeos TEM del Area de la Pampa del Tamarugal >

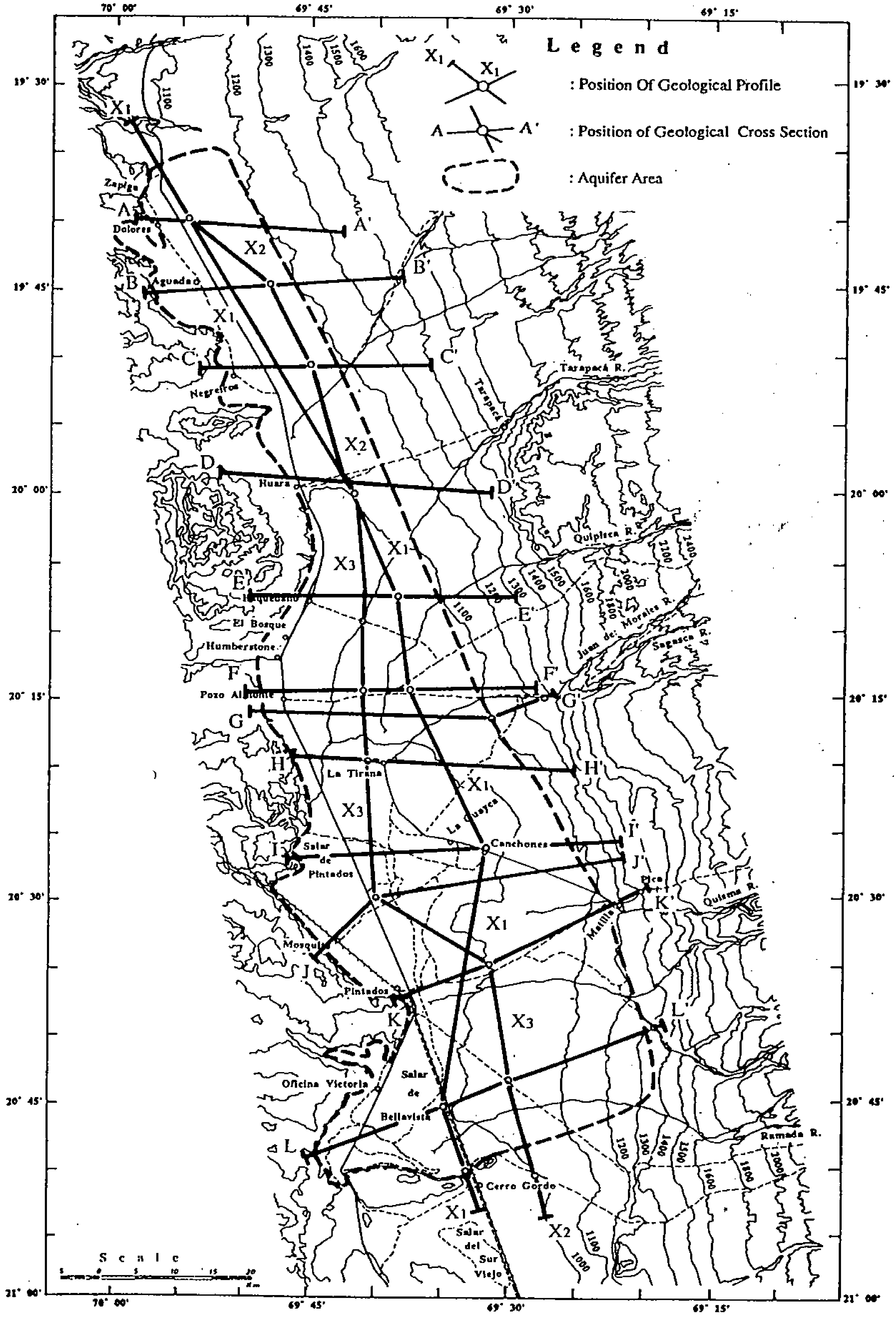


Fig. 2.2.6 Location of Geological Profile and Cross Section (Pampa del Tamarugal)

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

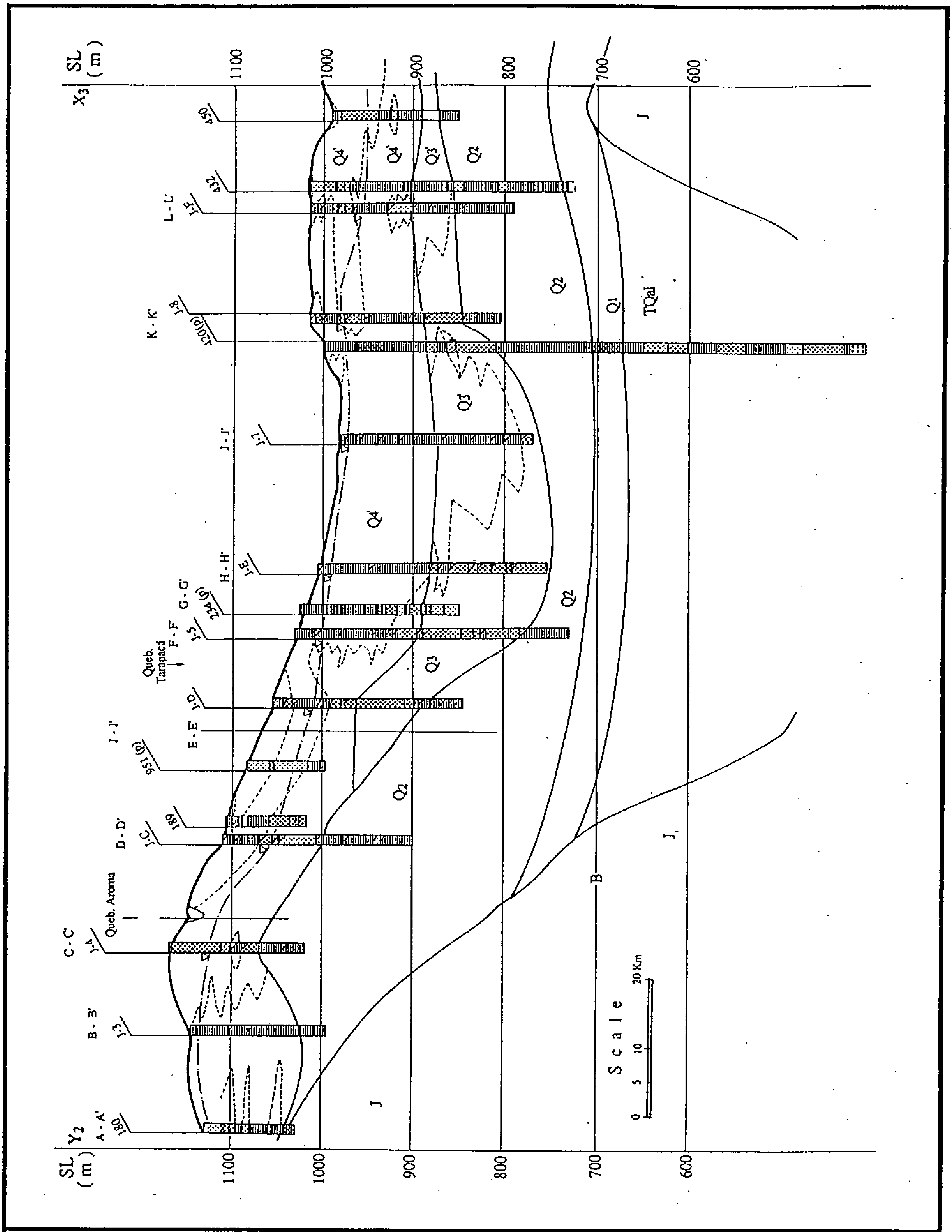


Fig. 2.2.7 Geological Profile (Pampa del Tamarugal)

< Perfil Geológico (Pampa del Tamarugal)>

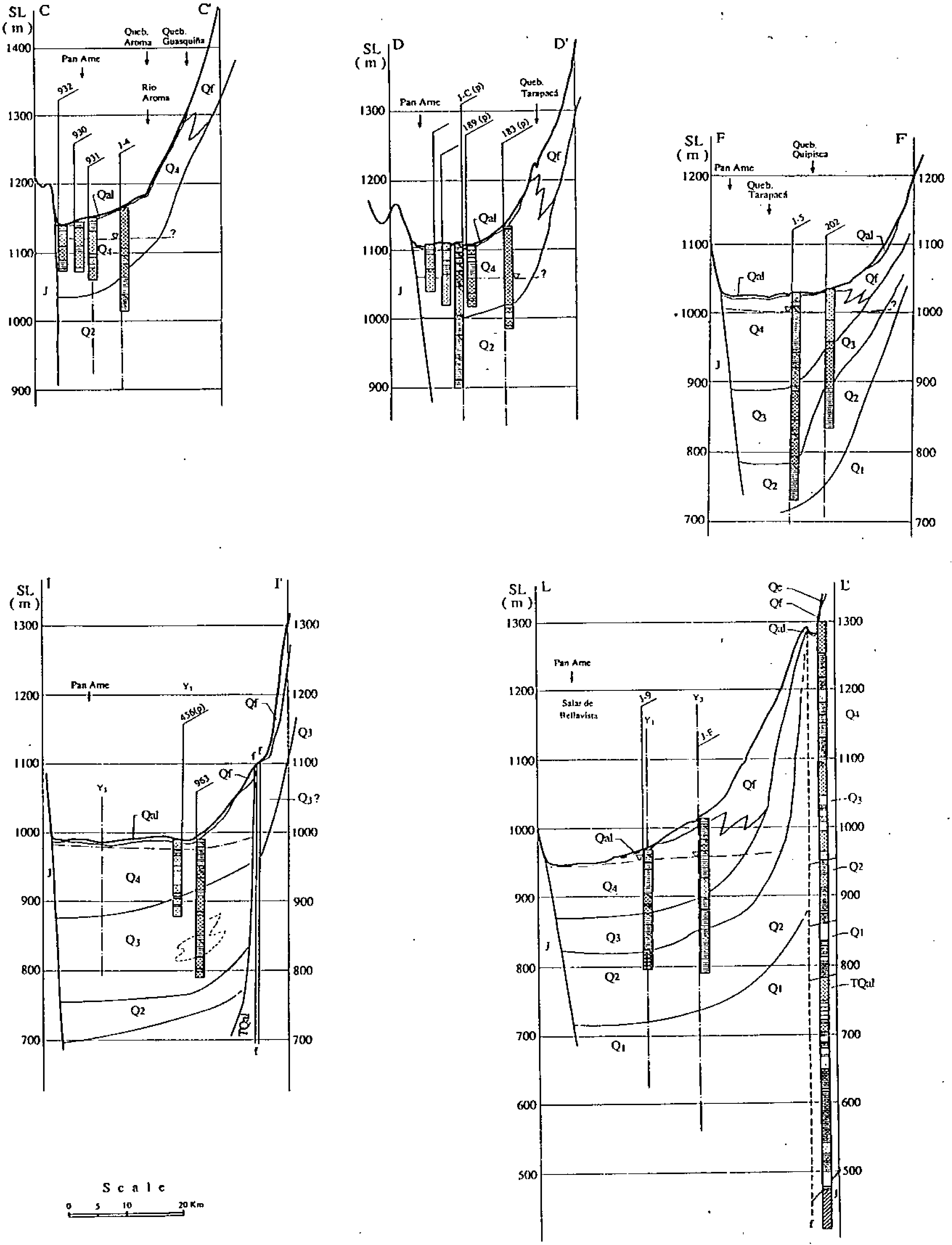


Fig. 2.2.8 Geological Cross Section (Pampa del Tamarugal)

<Seccion Geologica Transversal(Pampa del Tamarugal)>

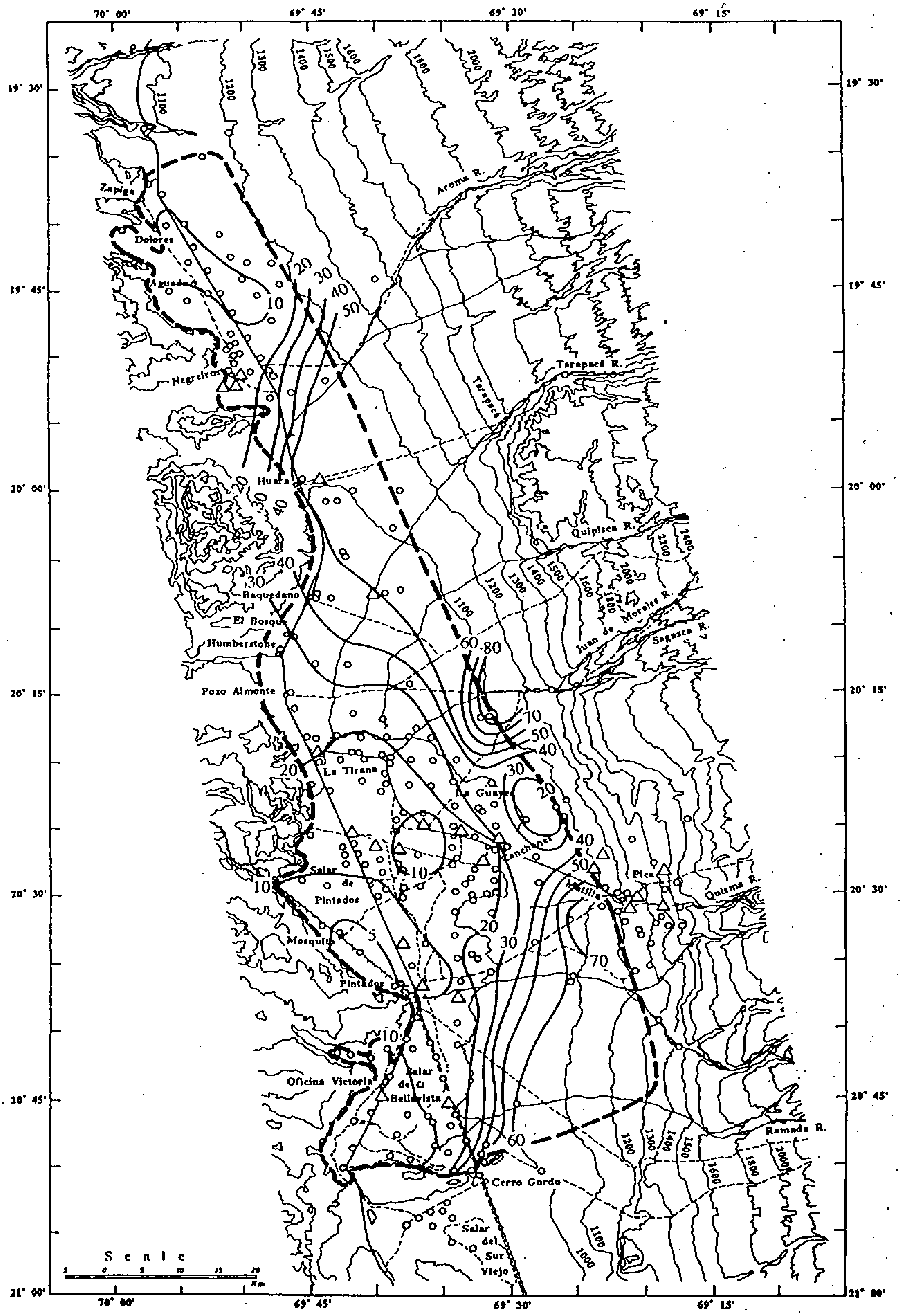


Fig. 2.2.9 Static Water Level (1993)

<Nivel Estático (1993)>

Unit : m BGL

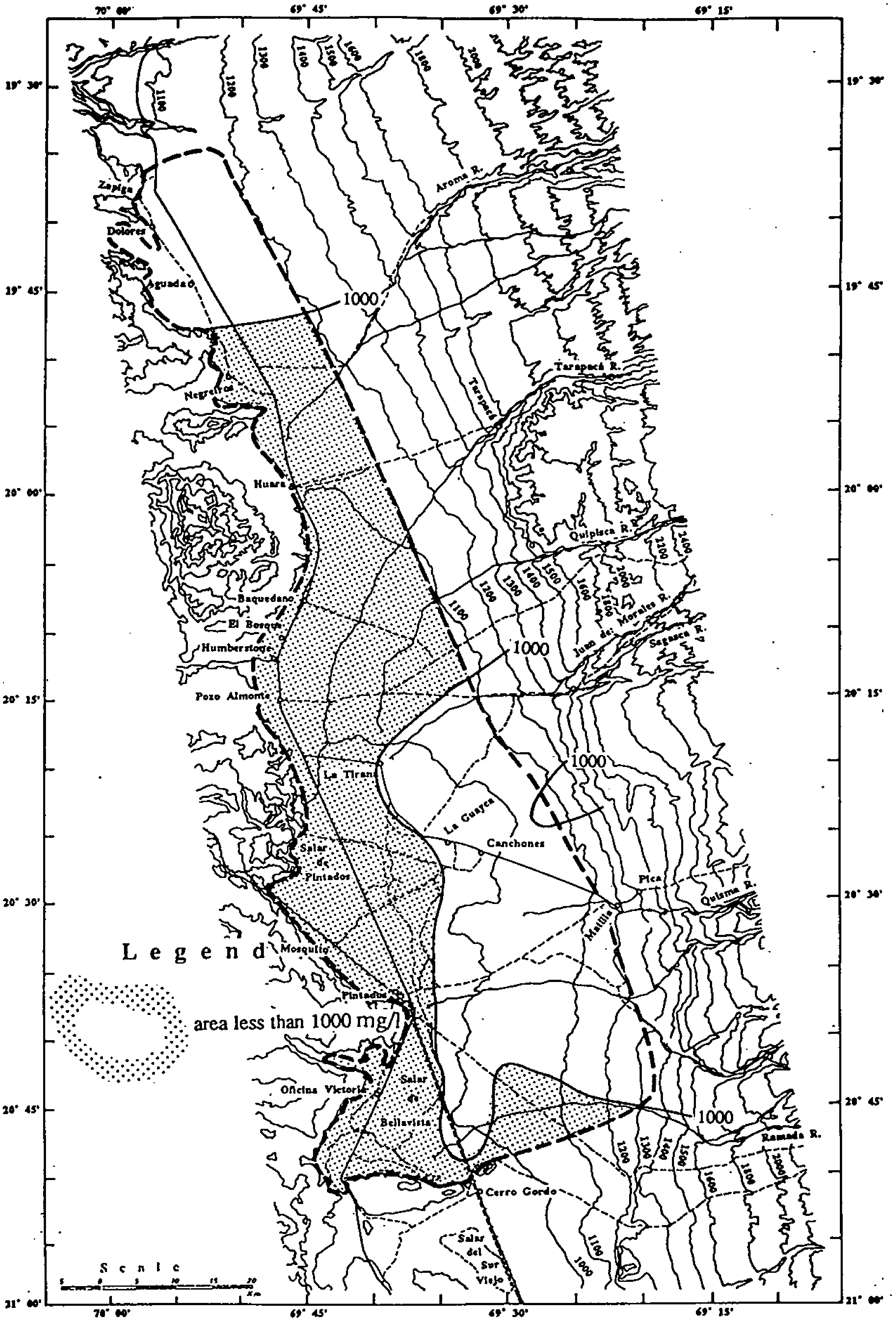


Fig. 2.2.10 (1) Distribution of TDS (Pampa del Tamarugal)

<Distribución de TDS (Pampa del Tamarugal)>

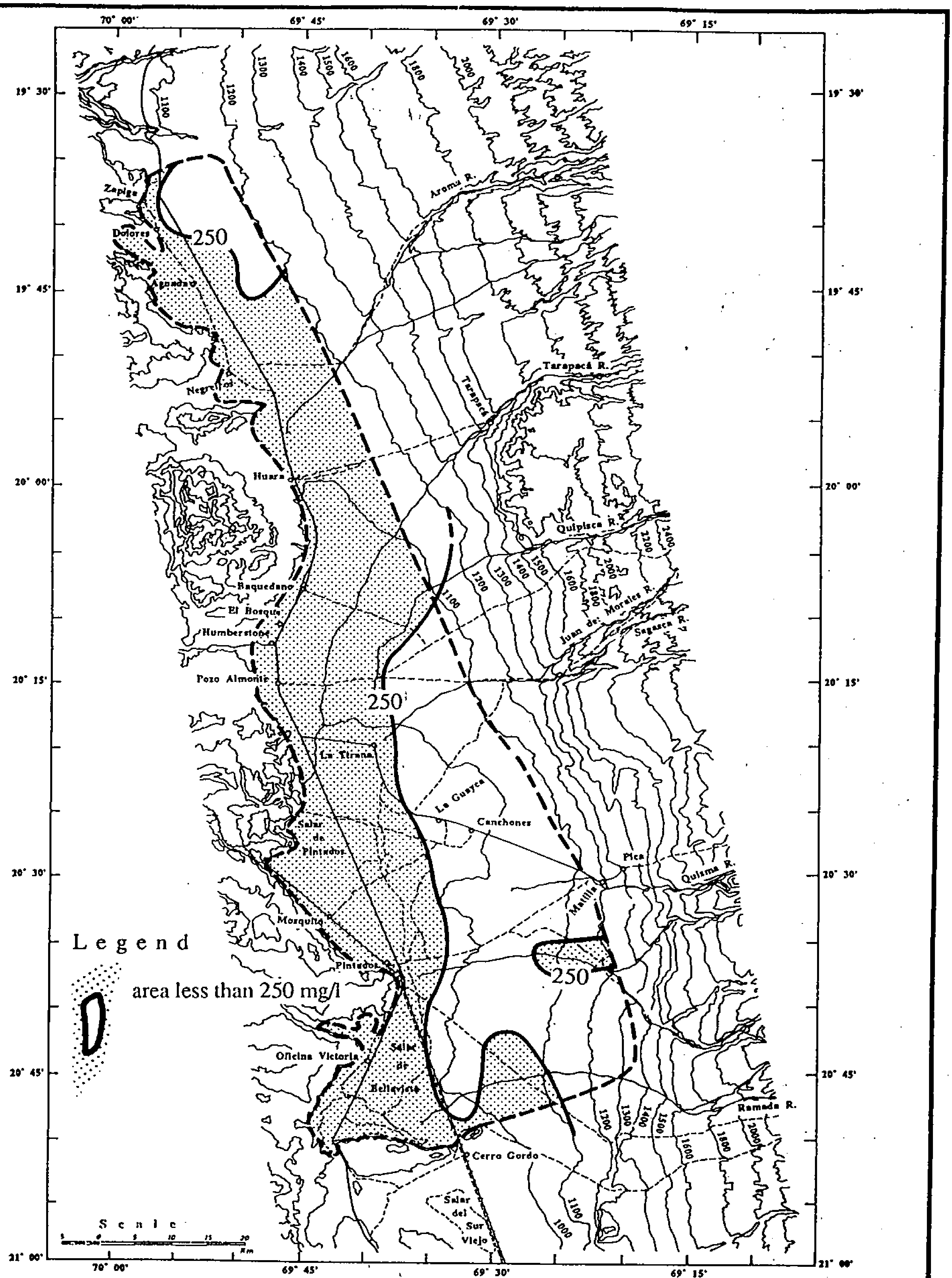


Fig. 2.2.10 (2) Distribution of Cl (Pampa del Tamarugal)

< Distribución de Cl (Pampa del Tamarugal) >

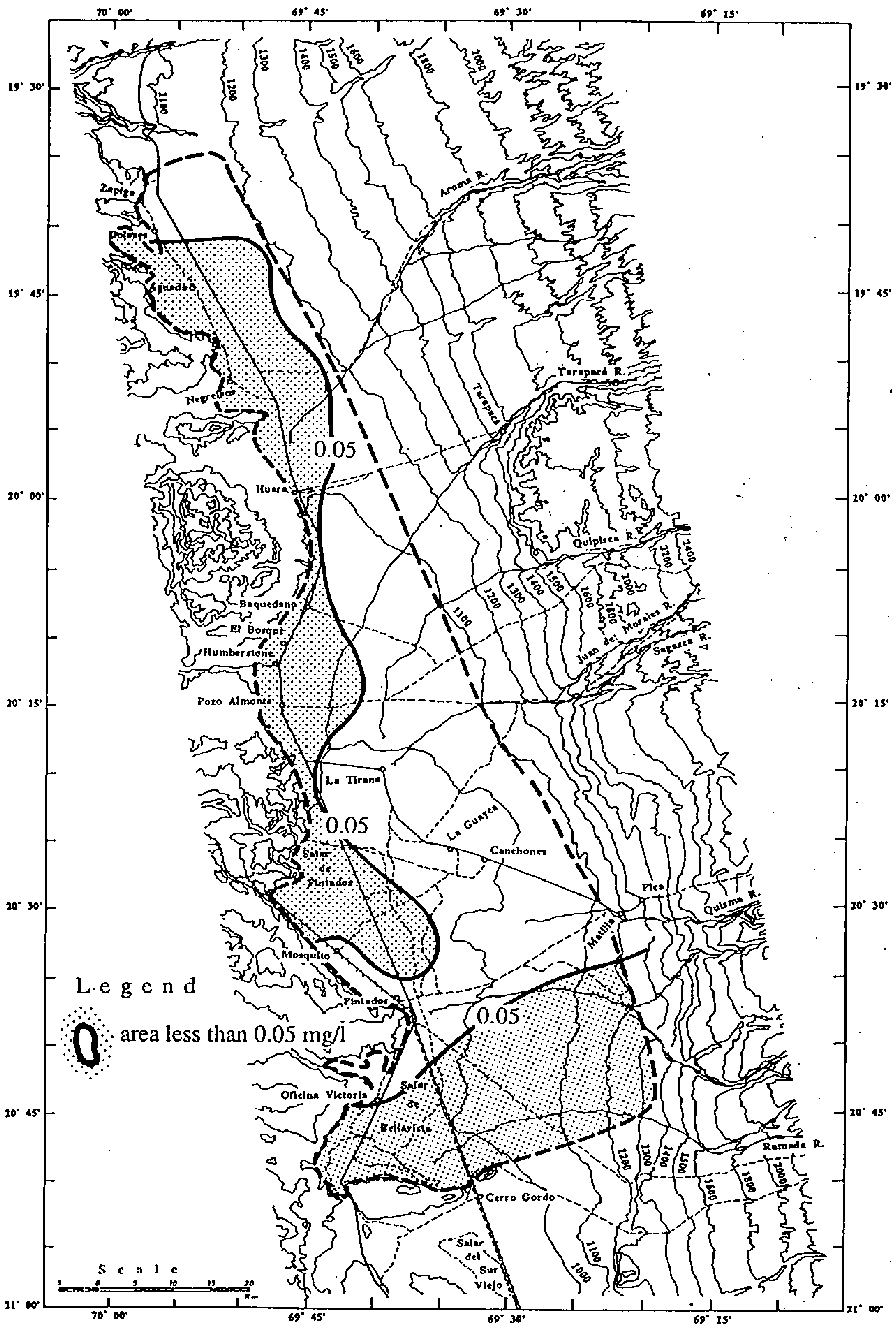


Fig. 2.2.10 (3) Distribution of As (Pampa del Tamarugal)

< Distribución de As (Pampa del Tamarugal) >

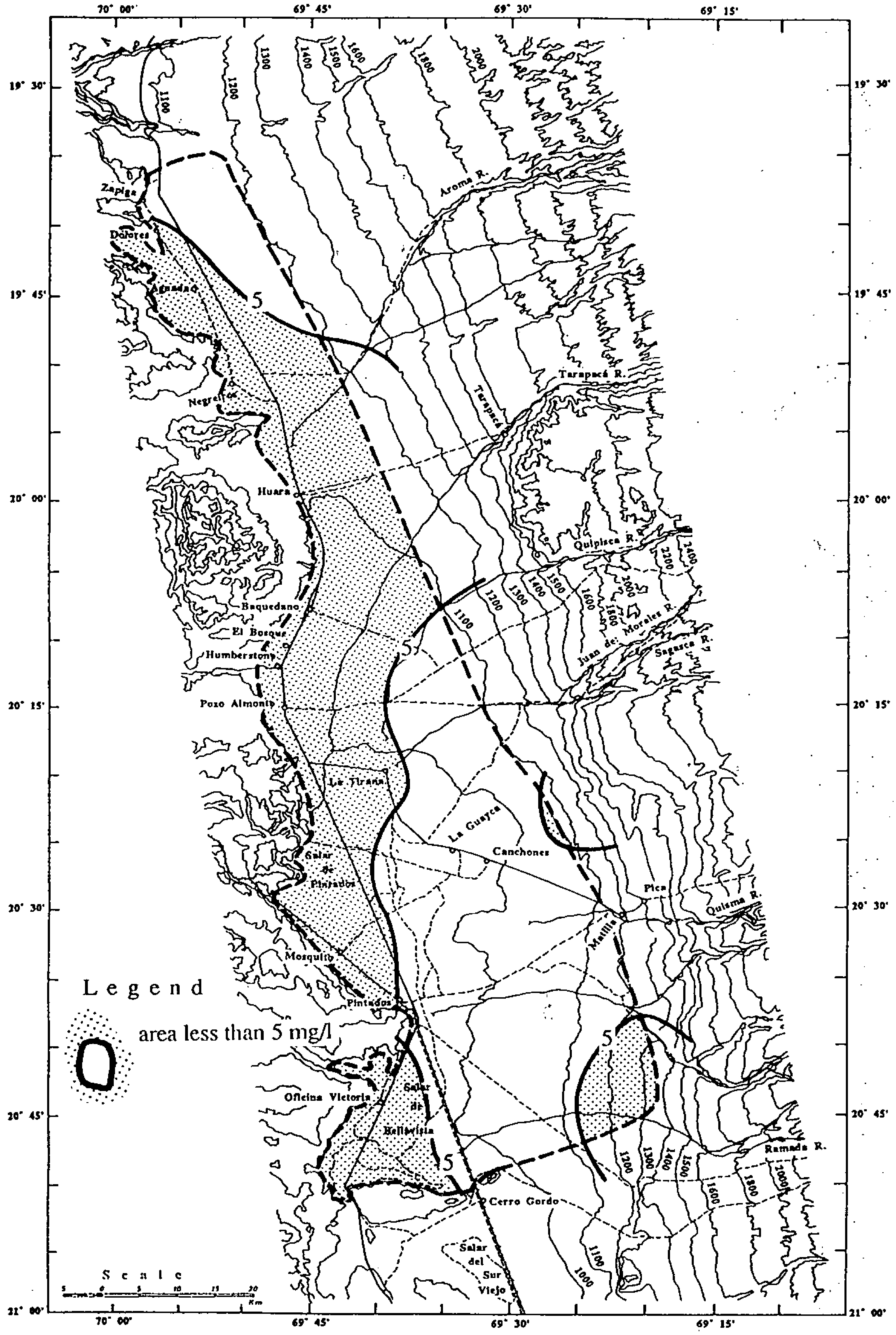


Fig. 2.2.10 (4) Distribution of B (Pampa del Tamarugal)

< Distribución de B (Pampa del Tamarugal) >

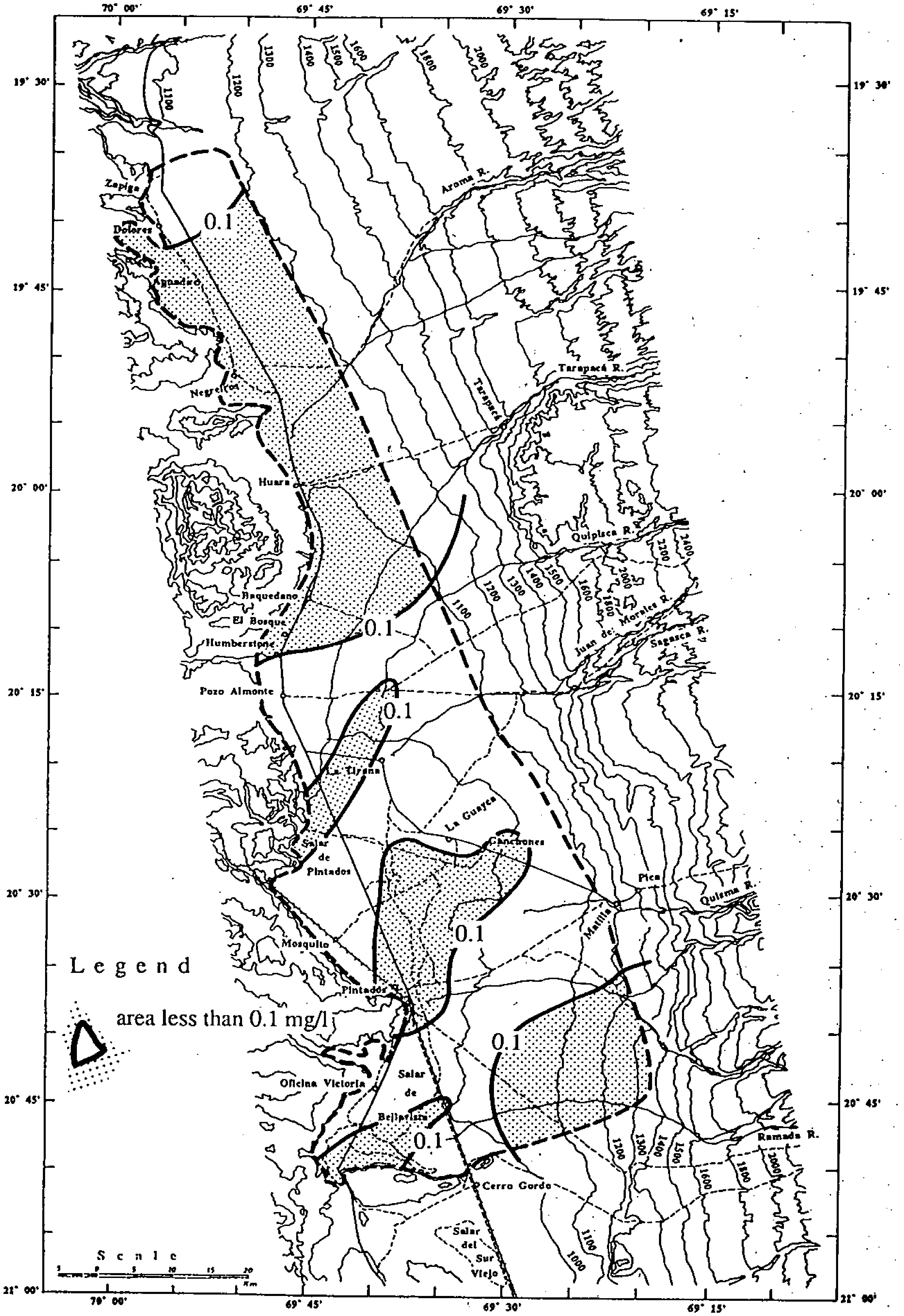


Fig. 2.2.10 (5) Distribution of Mn (Pampa del Tamarugal)

< Distribución de Mn (Pampa del Tamarugal) >

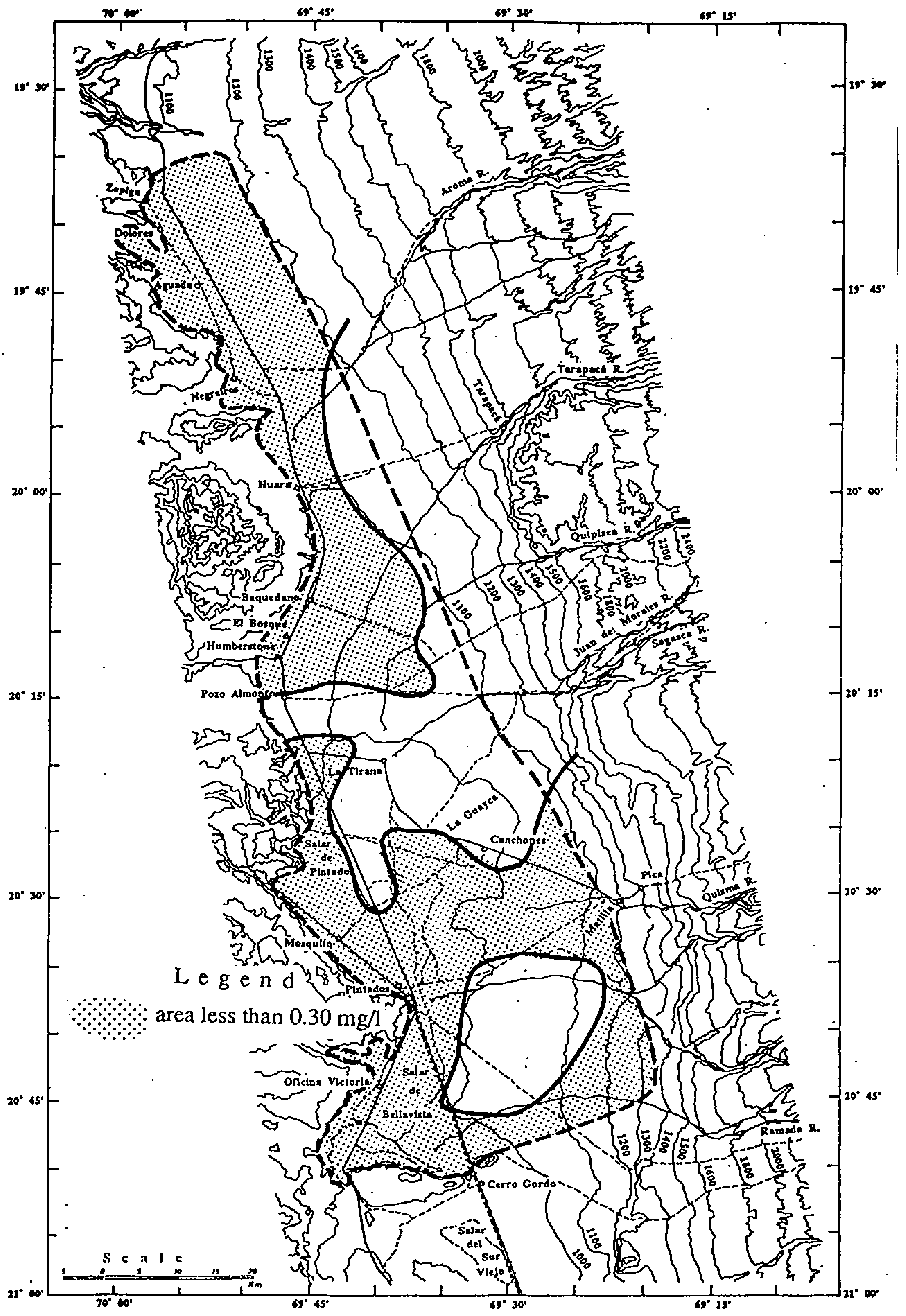


Fig. 2.2.10 (6) Distribution of Fe (Pampa del Tamarugal)

<Distribución de Fe (Pampa del Tamarugal)>

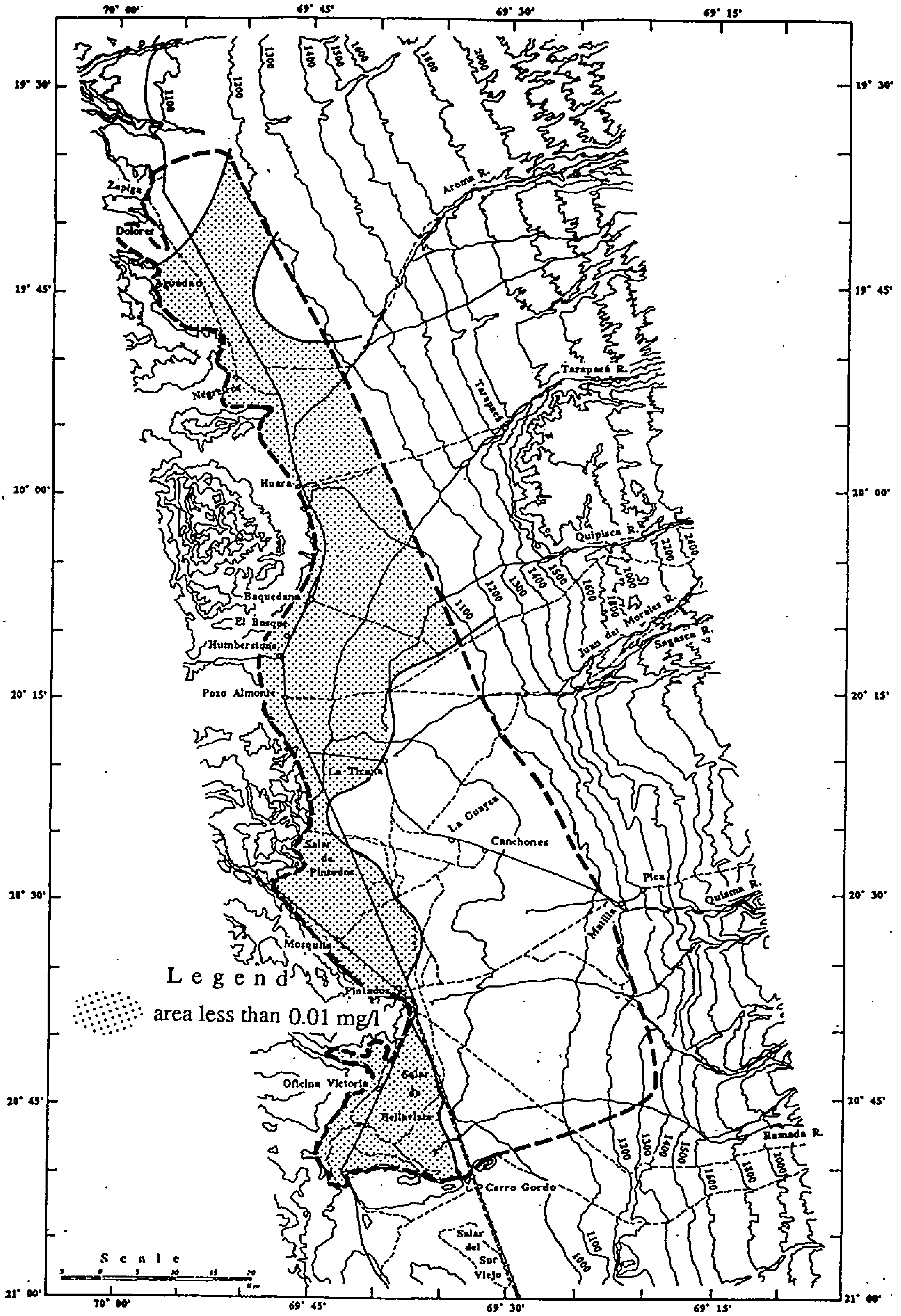


Fig. 2.2.10 (7) Distribution of Cd (Pampa del Tamarugal)

<Distribución de Cd (Pampa del Tamarugal)>

2.3 Salar del Huasco

2.3.1 Basin System

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. 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 between 3,800 m and 4,200 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.

For location of the Basin, see Fig. 2.2.1.

2.3.2 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 0.100 based on the formula established in Section 2.2.2.

Then, average yearly run-off of the Basin is estimated to be 26,961 x 10^{3}m^3/year (= 855 l/s). This is considered as the amount of groundwater recharge.

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

2.3.3 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 aluvial 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 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. 2.3.1.

2.3.4 Geological Survey

The following geological surveys were executed by the JICA Study Team, to supplement the existing geological data. The surveys location is shown in Fig. 2.3.1.

a) Electromagnetic Survey	5 survey points (1 lines)
b) Boring Survey	
(a) Drilling	
Test well drilling	1 well
Observation well drilling	1 well
(b) Pumping Test	2 wells
c) Water Quality Analysis	2 wells (JICA wells)
d) C-14 analysis	1 well (JICA well)

1) Electromagnetic (TEM) Survey

(1) Survey Area

Transient Electro Magnetic (TEM) survey is conducted at north of Salar del Huasco (Fig. 2.3.1). One (1) TEM line was set perpendicular to the main axis of Collacagua River. A total of 5 stations were set at interval of 1000m each as shown below.

Quantity of TEM Work

	Profile	Stations	Station Interval
	SH-1	5	1000 m
Total		5	

(2) Survey Results.

Geoelectrical profile along Line SH-1 is shown in Fig. 2.3.2. The resistivity structure along the profile is classified as 6 layers. The geophysical characteristics of each layer are summarized as follows.

a) The first layer shows a resistivity value of higher than 350 ohm-m. This resistivity represents a relatively dry layer composed sand and gravel. On the other hand, at only station No. 5, the resistivity of the layer is relatively low (100 ohm-m) due to wet land condition of river side.

b) The second layer shows a resistivity range of 55 to 90 ohm-m. The layer is distributed in the all stations except No.5. It is considered as expected aquifer.

c) The third layer shows a resistivity value of 190 ohm-m. This layer exists only at station No. 2. Due to high value of the resistivity, the layer is considered as impermeable bed.

d) The forth layer shows a resistivity range of 11 to 12 ohm-m. The layer is expected as aquifer. However, its rather lower resistivity than second layer would be indicate that the layer is contaminated. The layer is distributed in station No.1 and No.2.

e) The fifth layer shows a resistivity range of 14 to 42 ohm-m. The layer is distributed in the all stations. However, the depth to the boundary of sixth layer is not clear. The layer is also considered as aquifer with less contamination by the same reason of forth layer.

f) The sixth layer shows a resistivity range of 3 to 7 ohm-m. This layer is considered as aquifer with much concentration of dissolved solids. Because resistivity value is extremely low.

2) Boring Test

(1) Location and Depth of Each Well

One (1) Test Wells of J-G and one (1) Observation Wells of J-10 are placed on the line of the TEM survey (see, Fig. 2.3.1). Location, drilling depth and casing size of each well are summarized as follows.

Well No.	Location	Latitude	Longitude	Elevation (m.msl)	Casing (inch)	Depth (m.bgl)
J-G	Salar del Huasco	20° 06' 29.5"	68° 49' 00.4'	3,850	8-5/8"	157
J-10	Salar del Huasco	20° 11' 38.0"	68° 49' 52.9'	3,825	5-1/2"	207

(2) Method of Boring Test

For the details of methodology, see section 2.1.5 of Chapter II.

(3) Results of Boring Test

The results of boring tests are summarized in Table 2.3.1. Detailed information including lithological column, casing design and well loggings are shown in Fig. B-IV, 2.2.4 to 2.2.5 of the supporting report. The results of the boring tests are concluded as follows ;

i) Geological Conditions

The lithology of aquifer of the area is mainly composed of clayey gravel, sandy gravel and gravel of Quaternary Collacagua Formation. Except lower layer (Qcl) of J-10, most of aquifer is thick clayey gravel layer. It is confirmed that more than 85% of the total thickness of aquifer is clayey gravel, in the two(2) wells. Tertiary Huasco Ignimbrite is confirmed at the depth of 135m of J-G.

ii) Geophysical Conditions

A resistivity range is similar in both wells except upper layer of J-10. The value is in the range of 25 to 90 ohm-m, in general. This range is in well agreement with the result of TEM (55 - 90 ohm-m). Thus, the aquifer confirmed by boring test regarded as identical with the second layer classified by TEM survey.

(4) Method of Pumping Test

For the details of methodology, see section 2.1.5 of Chapter II.

(5) Analysis of Pumping Test

For the details of method for analysis, see section 2.1.5 of Chapter II.

(6) Result of Pumping Test

The result of pumping test are summarized in Table 2.3.2. The table indicates pumping data, aquifer constants and well capacity represented by critical yield and safe yield. Result of the pumping test are concluded as follows ;

i) Pumping Data

Shallow static water of 5.86m is observed at J-G. On the other hand, it is deep at J-G (26.56m). However, the value of specific yield is a similar in both well. It is 0.74 l/s of J-G and 1.23 l/s at J-10.

ii) Aquifer Constants

A similar value of the aquifer constants in all item is obtained at both wells. A range of 156 to 191 $m^3/d/m$ of transmissibility would indicate that the aquifer has middle groundwater potential. Considering the proportion of the each lithology, it is presumed that a range of 2.4×10^{-3} to 2.7×10^{-3} cm/s represents the permeability of clayey gravel.

iii) Well Capacity

Critical discharge is estimated as more than 25 l/s at J-G and more than 5 l/s at J-10. It is confirmed that the amount of critical discharge is larger than maximum pumping rate capacity. Safe yield is estimated as 6.7 l/s at Test Well and 1.75 l/s at Observation Well.

2.3.5 Aquifer

1) Configuration of Aquier

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 distance 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. 2.3.1.

The geological profile and cross sections of the aquifers are shwon in Fig. 2.3.3 and Fig.2.3.4.

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, storage coefficient 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
Storage Coefficient : 3.86 x 10^{-5}, Permeability : 2.60 x 10^{-3} cm/sec

The above specific yield and transmissibility show a normal value. However, the permeability is 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.

2.3.6 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. 2.3.1 for the location of JICA wells and Supporting Report B, Fig. B-IV, 1.1.1 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 2.3.1 Result of Boring test of Salar del Huasco Area
< Resultado de Prueba de Sondaje en el Area del Salar del Huasco>

Well No.	Bore hole Depth (m)	Casing Pipe		Screen Pipe		Geological Conditions of Aquifer			Geophysical Data	
		Size (inches)	Total Length (m)	Position (m)	Total Length (m)	Lithology	Formation	Period	Well Logging Resistivity (ohm-m)	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 2.3.2 Result of Pumping Test of Salar del Huasco Area
< Resultado de Prueba de Bombeo en el Area del Salar del Huasco >

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)	Storage Coefficient	Permeability (cm/sec)	Critical Discharge (l/s)	Safe Yield (l/s)
J-G	5.86	25.00	39.76	33.90	0.74	156.39	6.60E-05	2.74E-03	25.00<	6.70
J-10	26.56	5.00	30.64	4.08	1.23	191.38	1.12E-05	2.46E-03	5.00<	1.75

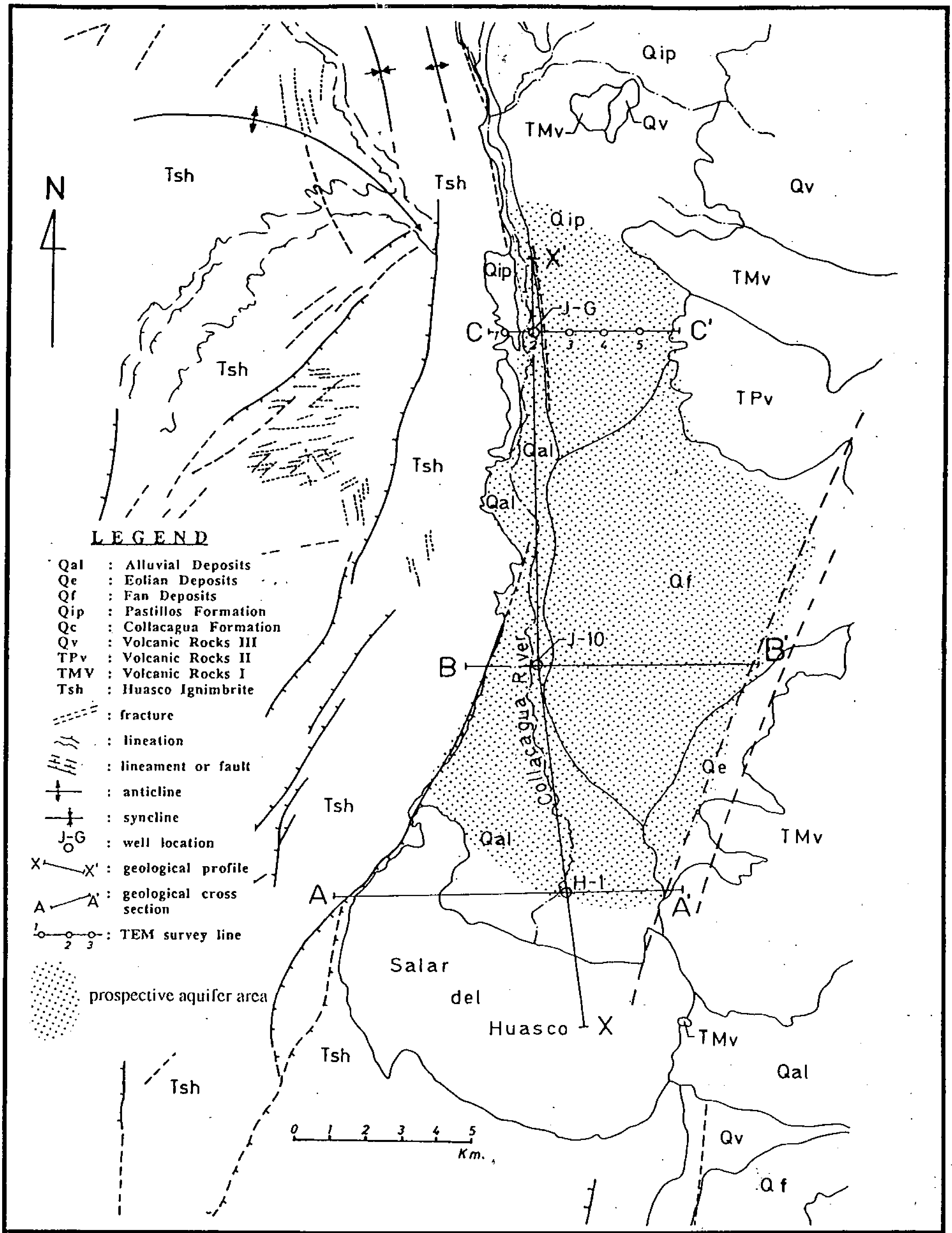


Fig. 2.3.1 Geological Map (Salar del Huasco)

< Mapa Geológico (Salar del Huasco) >

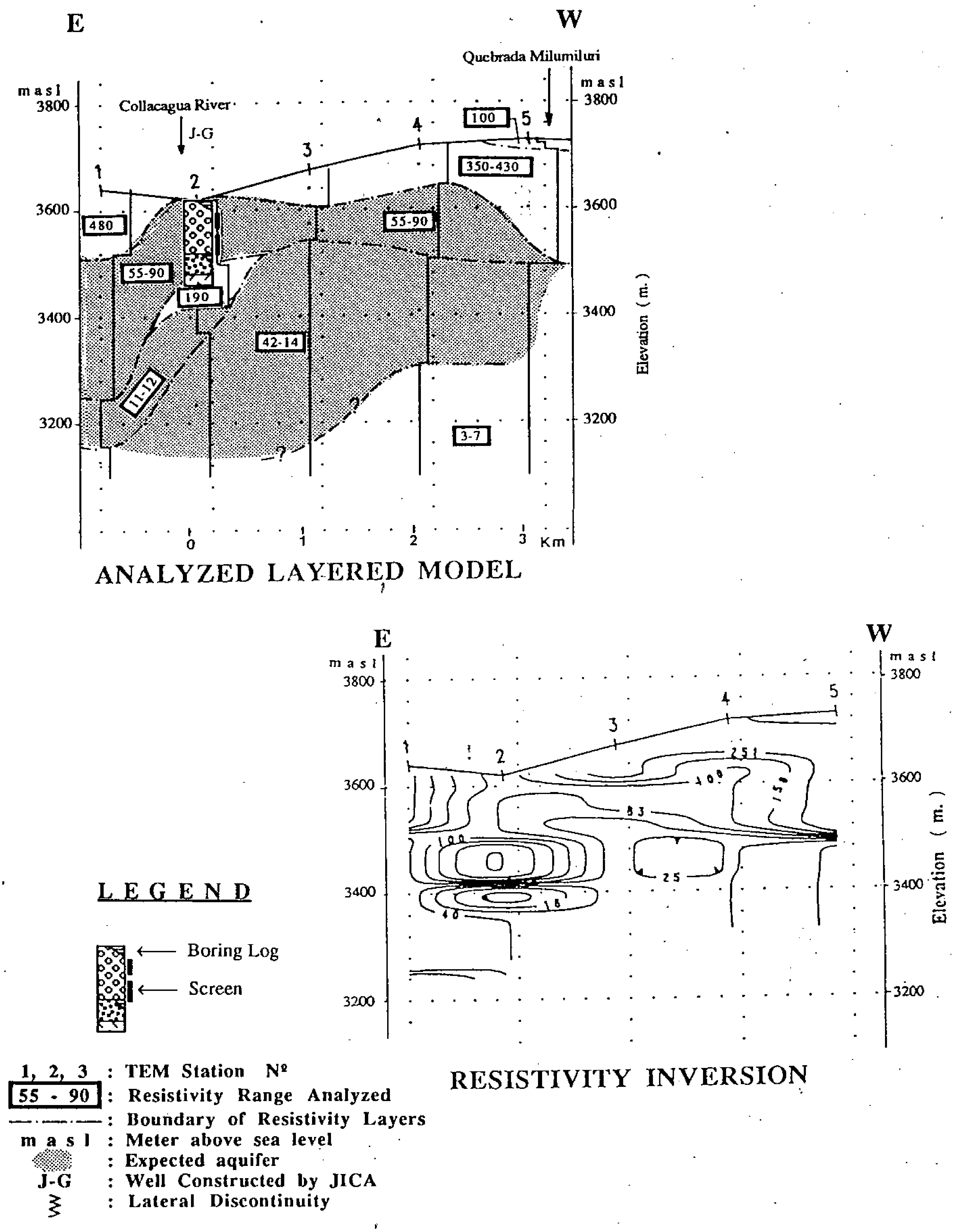


Fig. 2.3.2 Resistivity Profile of SH-1 in Salar del Huasco Area

<Perfil de Resistividad del SH-1 en el Area del Salar del Huasco>

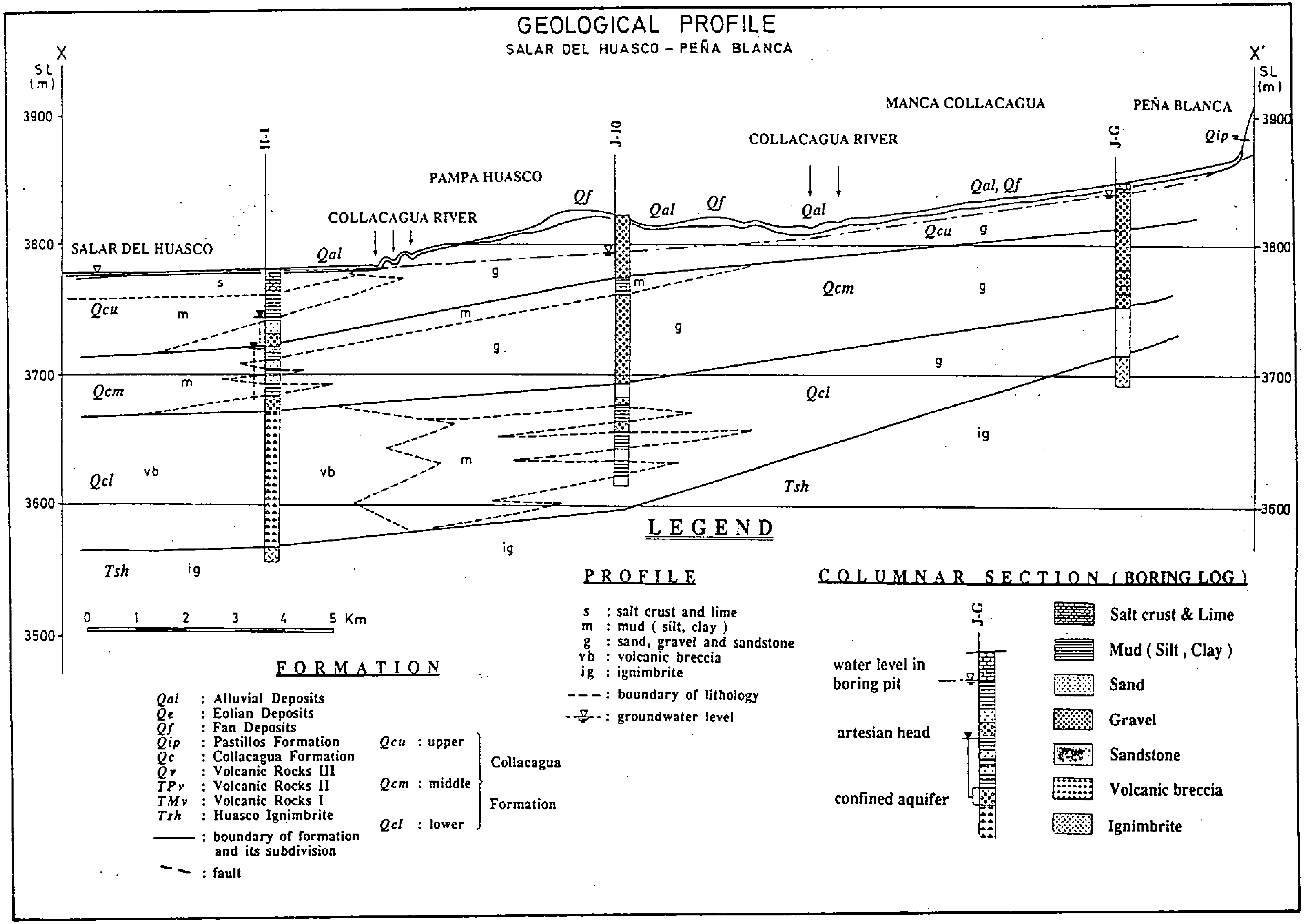
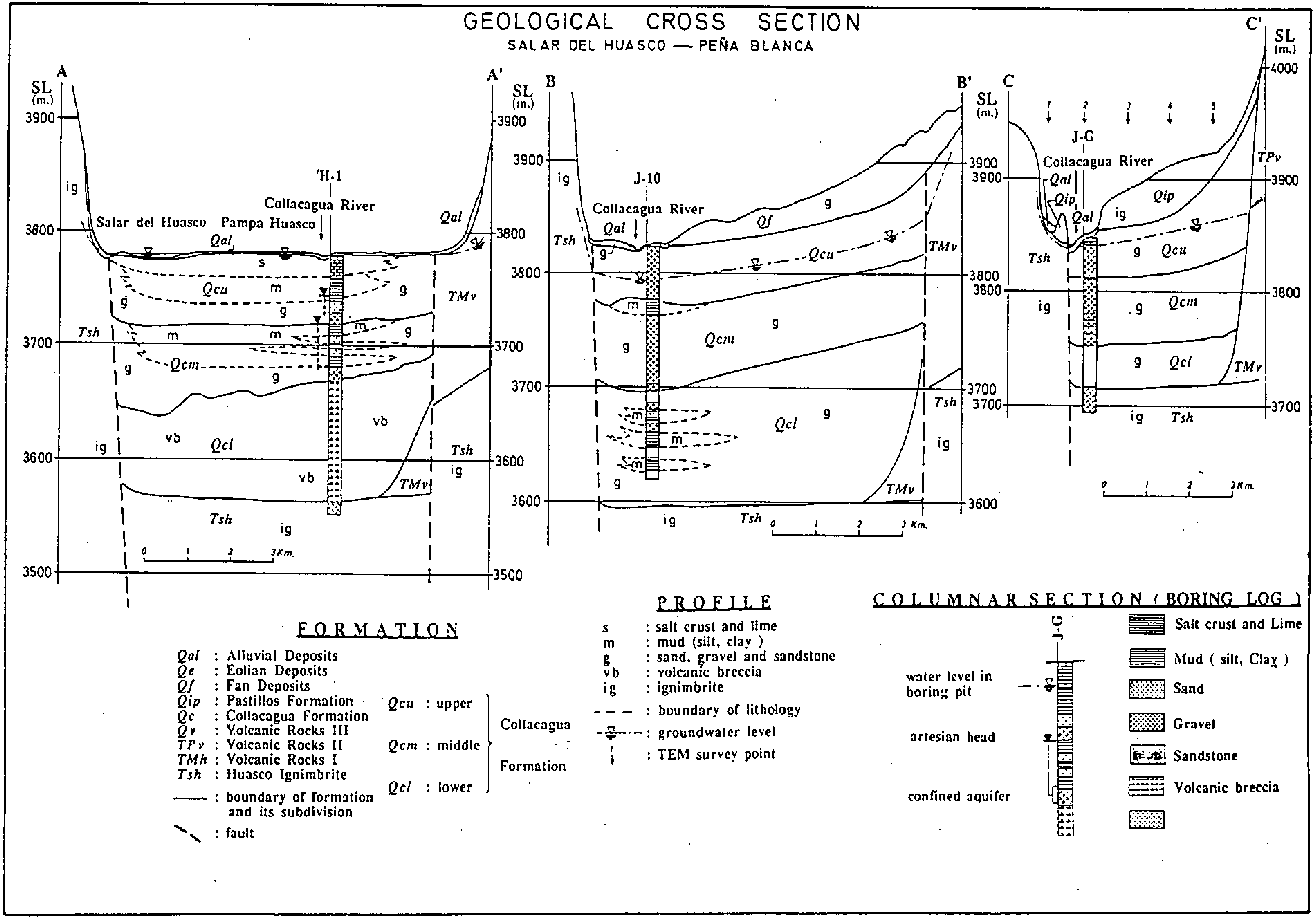


Fig. 2.3.3 Geological Profile

< Perfil Geológico >

Fig. 2.3.4 Geological Cross Section

< Sección de Cruce Geológico >



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 drilled additional 11 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 755 l/s.

A sketch of the existing water supply system is shown in Fig. 3.1.1.

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 6,681 x $10^3 m^3$, corresponding to 39.4% 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	6,681.0	(39.4)*	

* Percentage of Production

The total production in 1994 is expected to increase to 24,440 x 10^3m^3/year (=775 l/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

The future population of Arica city was determined by averaging the projected populations by the following three (3) methods, corresponding to different growth scenarios (See, Fig. 3.1.2).

(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 regional growth rate.

The results are shown below.

Year	Population
1995	181,221
2005	227,029
2015	283,841

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	181,221	221.99	465.6	10	475.6
2005	227,029	228.74	601.0	20	621.0
2015	283,841	235.69	774.3	40	814.3

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	475.6	35	731.7
2005	621.0	30	887.2
2015	814.3	30	1,163.3

4) Alternative Projection of Future Water Demand

As an alternative, the future population of Arica city is projected by using the low growth scenario, that is, linear growth (straight line) based on 1982-92 census data.

The projected future water consumption and production are summarized as follows by adopting the same per capita consumption, allowance for tourism and water losses as those of the above projection.

Year	Population Served	Total Consumption (l/s)	Total Production (l/s)
1995	178,086	467.6	719.4
2005	207,666	569.8	814.0
2015	237,246	687.2	981.7

3.2 Irrigation Water of Lluta Valley

3.2.1 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. 2.1.1).

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 sub-sector 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. 3.2.1

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. However, there is normally only one crop in the upstream area of Poconchile due to the limitations of climate and marketing. Vegetables and pasture are cultivated throughout the year.

For details, see Supporting Report C, 3.1.2.

3.2.2 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

Then, yearly water demand of crops are estimated as follows.

Crop	Irrigated Area (ha)	Unit Water Demand (l/s / ha)	Total Water Demand 10^3m^3/yr (l/s)
Maize	1,698.4	0.675	36,126.4 (1,145.6)
Vegetables	683.9	0.478	10,312.8 (327.0)
Pasture	401.9	1.433	18,158.7 (575.8)
Total	2,784.2	0.736	64,597.9 (2,048.4)

2) Real Water Consumption

The yearly irrigation water demand in the Lower Lluta Valley, estimated above at 64,597.9 x $10^3 m^3$, is equivalent to 2048.4 l/s and an overall average of 0.736 l/sec/ha. However, this total amount is not completely consumed by the crops. A significant portion infiltrates into the groundwater. The infiltrated water is available for reuse. The amount actually consumed by the crops (without considering losses due to irrigation efficiencies) is estimated, based on the evapotranspiration.

The total real water consumption in Lower Lluta Valley (Vilacollo - river mouth) are summarized below.

Crop	Irrigated Area (ha)	Unit Real Water Consumption (l/s ha)	Total Real Water Consumption $10^3 m^3/yr$	(l/s)
Maize	1,698.4	0.270	14,450.6	(458)
Vegetable	683.9	0.215	4,640.7	(147)
Pasture	401.9	0.860	10,895.2	(346)
Total	2,784.2	0.342	29,986.5	(951)

The real water consumption by river reaches are summarized below.

River Reaches	Irrigated Area (ha)	Real Water Consumption $10^3 m^3/yr$	(l/s)
Upstreams of Tocontasi	186.3	1,803.7	57
Tocontasi-Panamericana	2,530.4	27,403.1	869
Downstream of Panamericana	67.5	779.7	25
Total	2,784.2	29,986.5	951

3) Water Rights

Most of the irrigation water of the Lower Lluta Valley is extracted based on the lagally authorized water rights or customary water rights. The number of water rights and quantity , as of 1992, are summarized below. Almost all the water sources are river water.

Type	Number of Water Right	Quantity
Legally Authorized	3	284.75 l/s
Customary	79	10.0 l/s + 2,729.84 ACC

3.3 Municipal Water of Iquique

3.3.1 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 72.1 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. 3.3.1.

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 ($10^3 m^3$)	%	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 are no overall limitations on water supply, but some areas have a restricted supply.

3.3.2 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. 3.3.2).

(1) Linear growth (straight line) based on 1982-92 census data
(2) Exponential growth based on 1982-92 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	35	653.1
2005	564.8	30	806.9
2015	743.6	30	1,062.3

3.4 Water Use in Pampa del Tamarugal

3.4.1 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
Pozo Almonte;	Pozo Almonte, Matilla, Huayca, Tirana

Location of the towns is shown in Fig. 3.4.1

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. 3.3.1 and Fig. 3.4.1.

(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 does 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.

3.4.2 Irrigation Water Use

1) Irrigation of River Valley

(1) Existing Irrigated Area

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

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

For location of the irrigated areas, see Fig. 3.4.1

(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 (= 0.472 l/s/ha).

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 inmigrate to the CAPPTA Project Area (See, 3.4.2,3) 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. 3.4.1.

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 10^3m^3/yr (=169.4 l/s).

The total annual crop evapotranspiration is calculated at 3,755.5 x 10^3m^3/year or 119 l/s (= 0.390 l/s/ha). 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	Source	Quantity (l/s)
Legally Authorized	12	Spring, Groundwater	182.9*
Customary	2	Groundwater	2.3
Total	14		185.2

* : Includes 4.2 l/s between Matilla and Tirana

(3) Future Water Demand

There is no specific long range plan with regard to overall crop development in the 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 the 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 the 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 (Corporation 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. 3.4.1.

The future irrigation water demand has been preliminary 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 in this report.

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 840 l/sec 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. Therefore, the above estimation should be considered as the expected maximum case.

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	1,290	1,628.8		238	840	1,078

3.4.3 Mining Water Use

1) Existing Mines

There are four 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. 3.4.1.

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	Source	Quantity (l/s)
Legally authorized	16	Groundwater	187.0
Customary	2	Spring, River	37.0
Total	18		224.0

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 (Peak)	Water (l/s) (Average)
Pampa	22	972.3	680.6
Upstream Valley	2	290.0	203.0
	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 40% and groundwater recharge is 60%.

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	17.0	289.2
Upstream Valley	13.7	94.9
Total	30.7	384.1

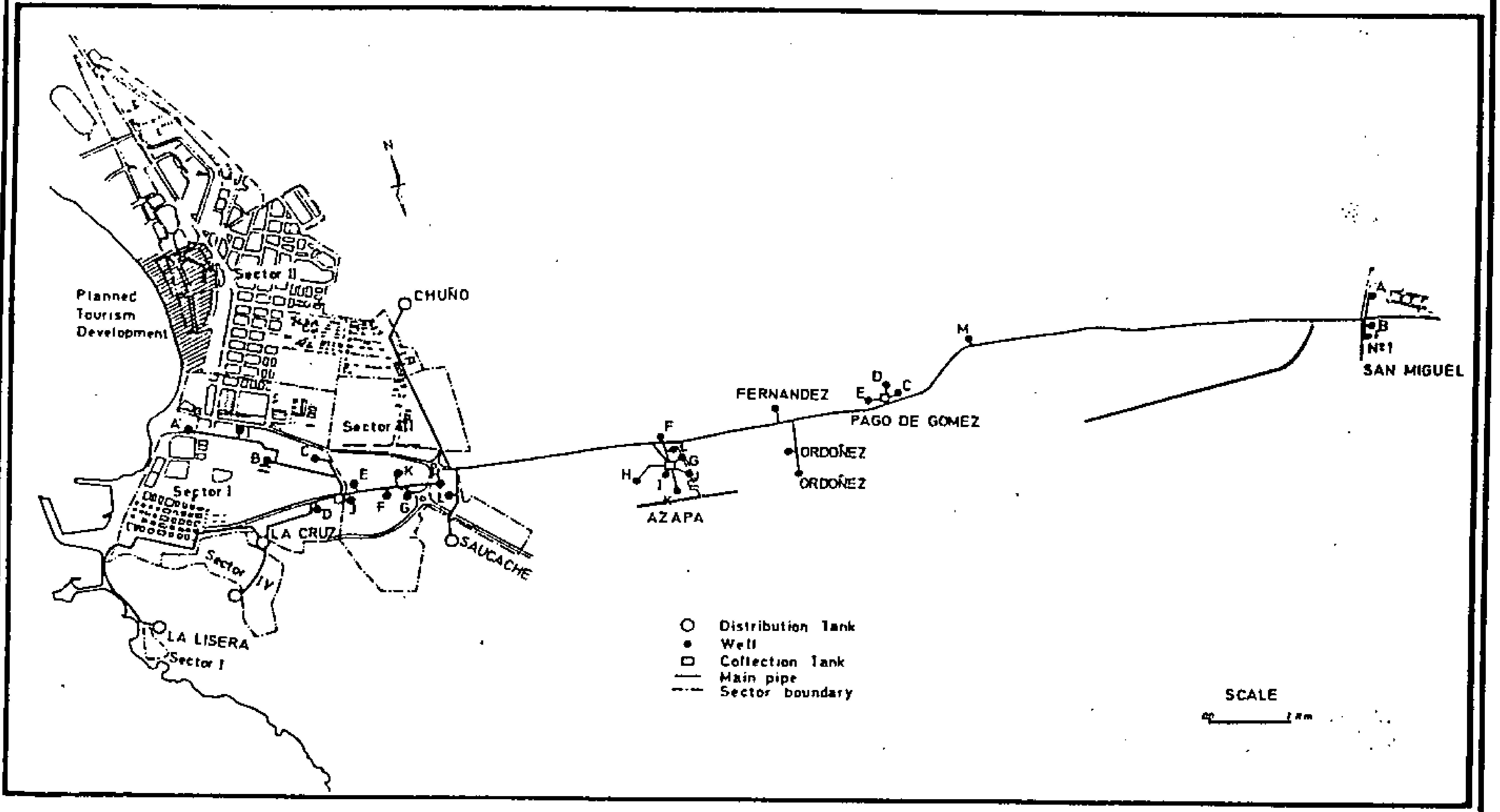


Fig. 3.1.1 Existing Municipal Water Supply System of Arica City
<Sistema de Abastecimiento de Agua Potable Existente de Arica>

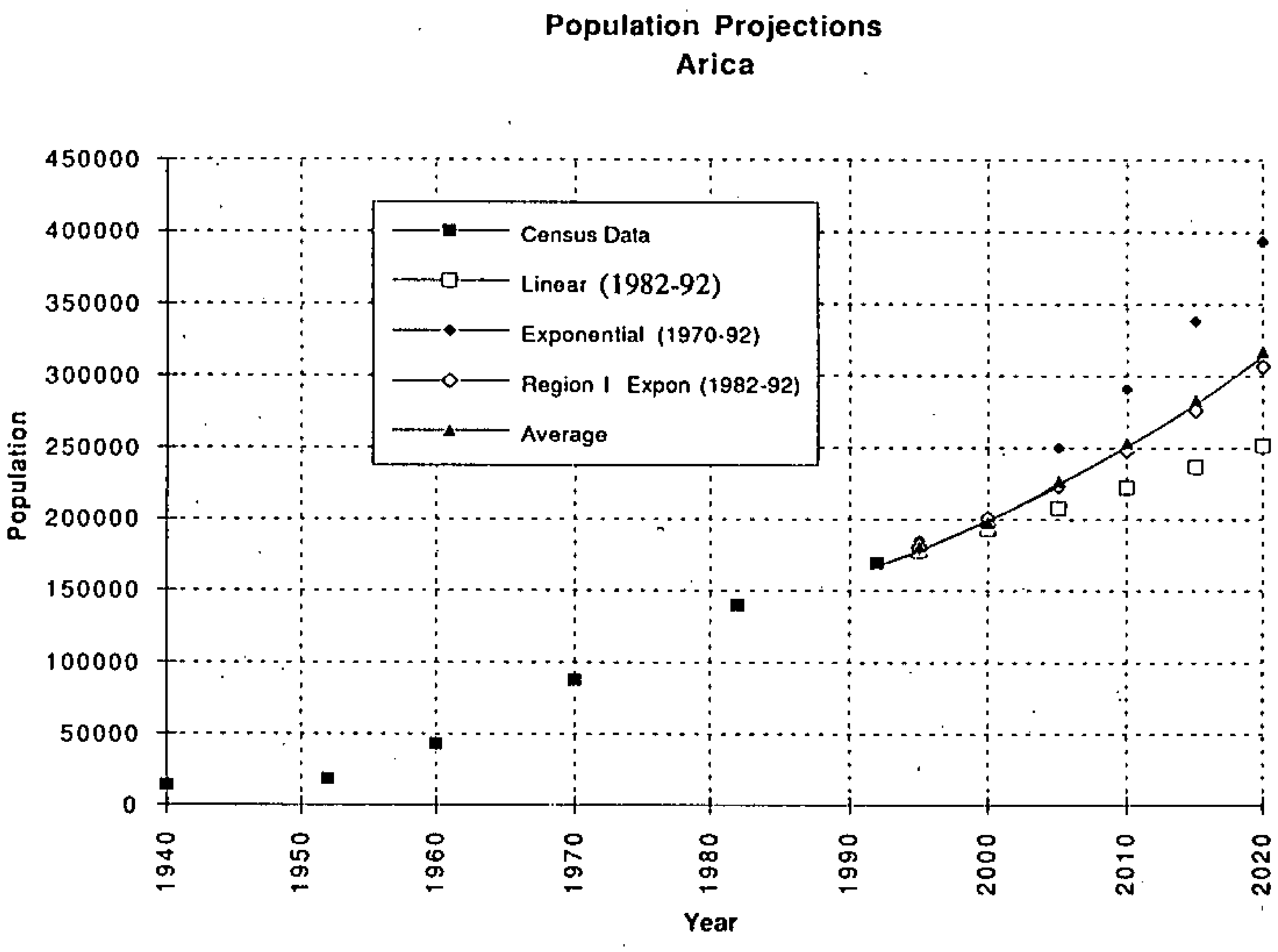


Fig. 3.1.2 Population Projections - Arica
< Proyección de la Población - Arica >

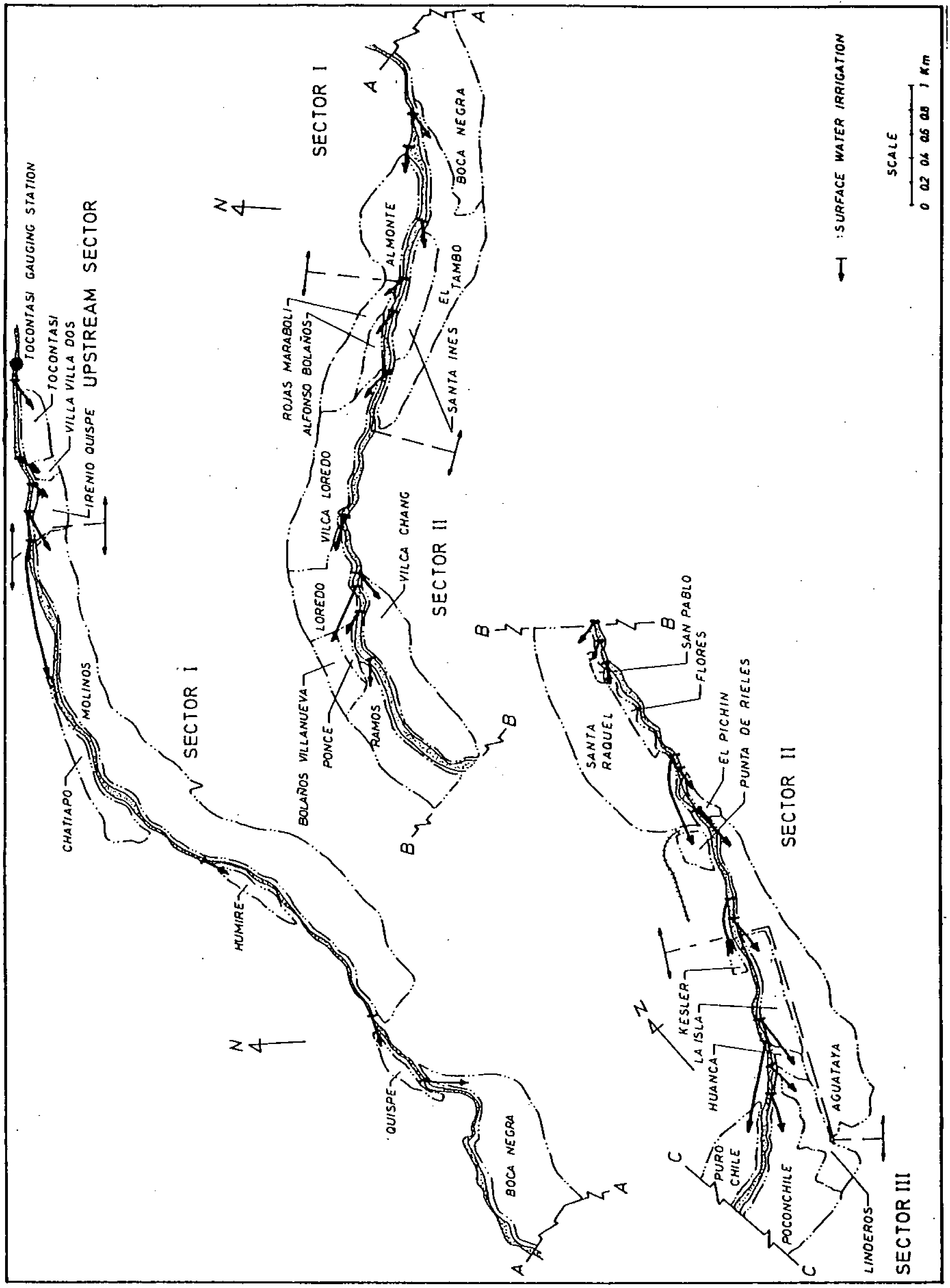


Fig. 3.2.1 (1) Location of Irrigation Sectors and Sub-sectors - Lluta Valley

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

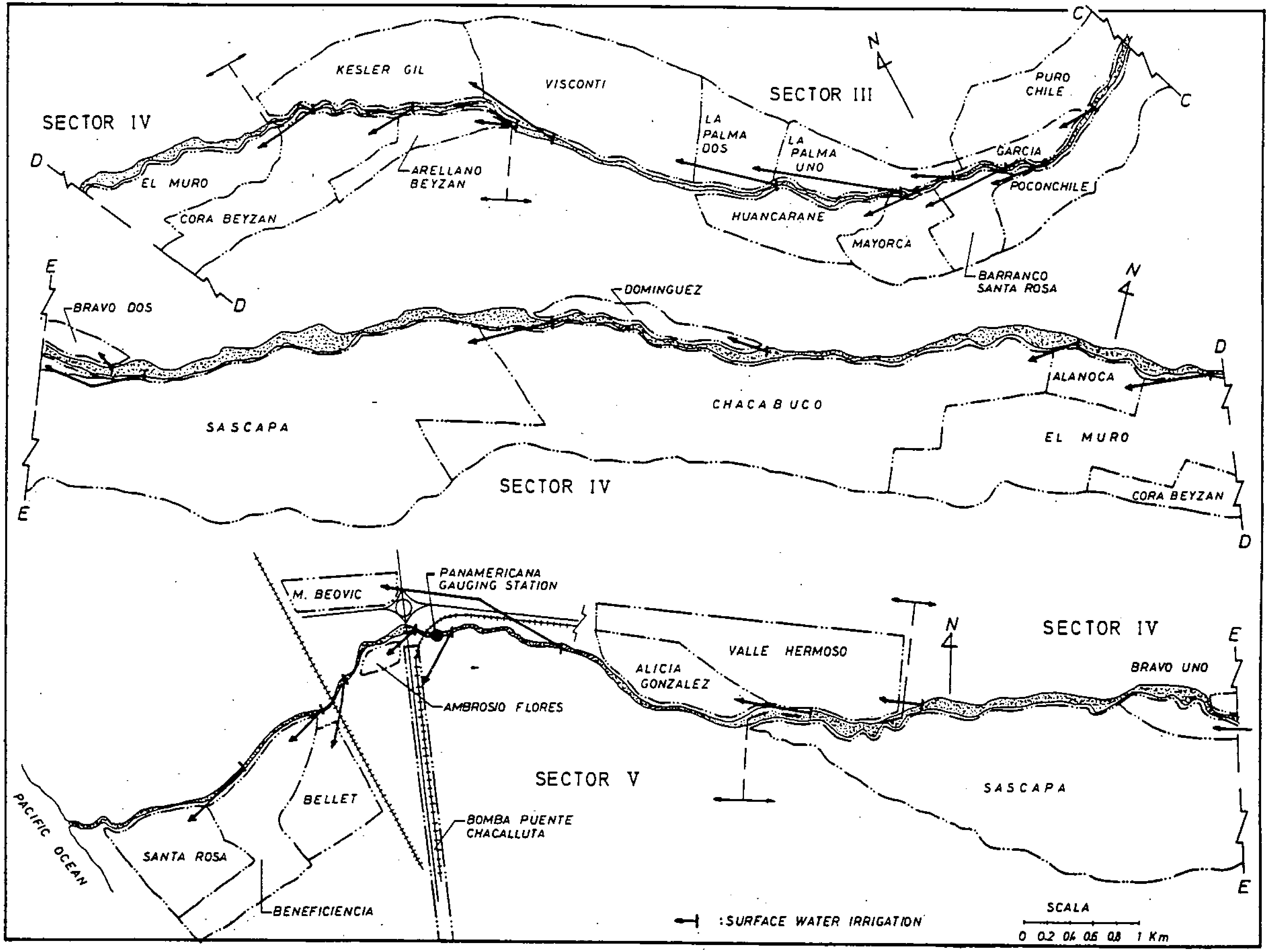


Fig. 3.2.1 (2) Location of Irrigation Sectors and Sub-sectors

< Ubicación de Sectores y Sub-sectores de Riego >

Fig. C.4.1 Water Conveyance Systems of Iquique City and Province

<Sistemas de Conducción de Agua de la Ciudad y Provincia de Iquique>

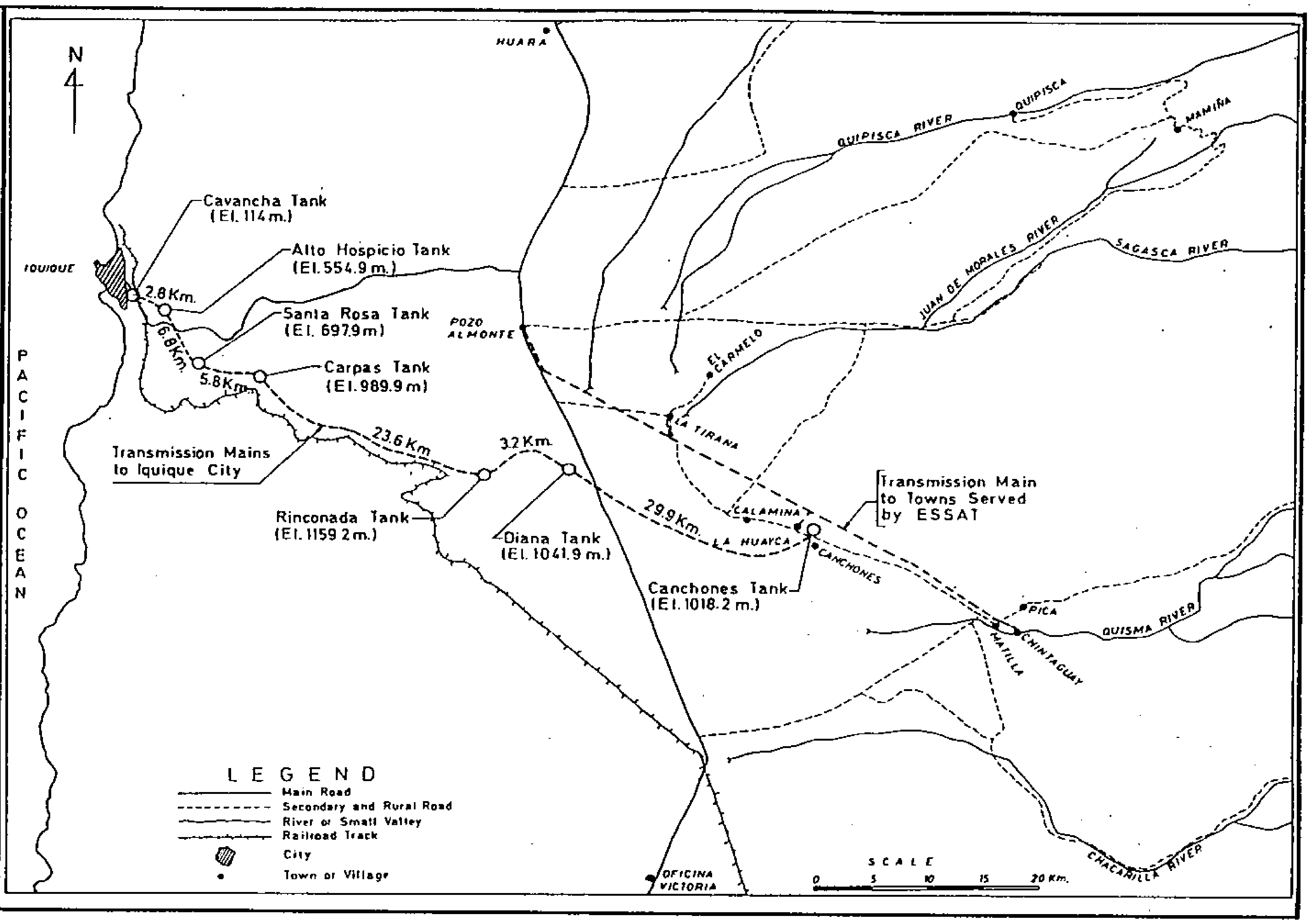
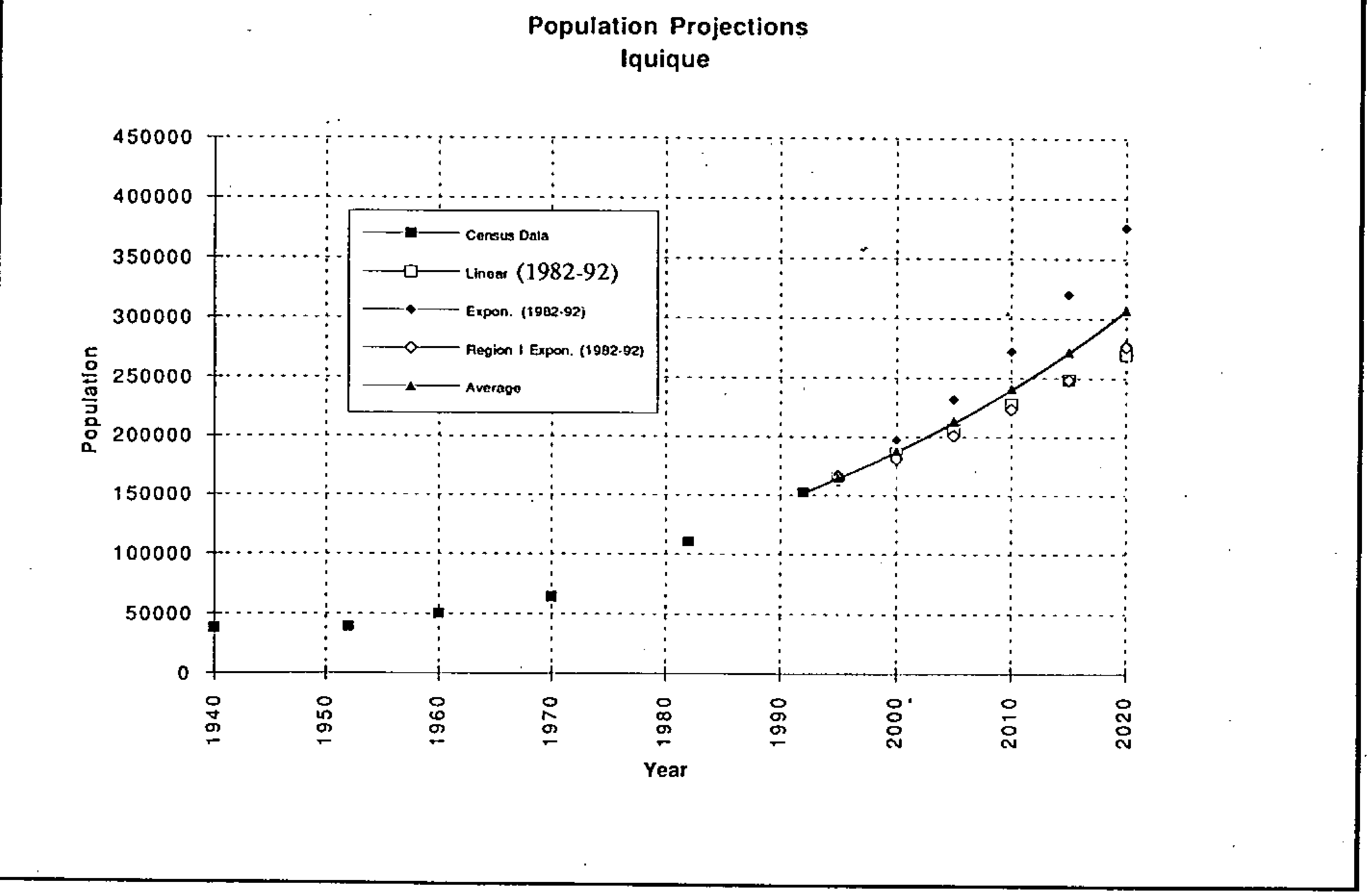


Fig. 3.3.2 Population Projections - Iquique

< Proyección de la Población - Iquique >



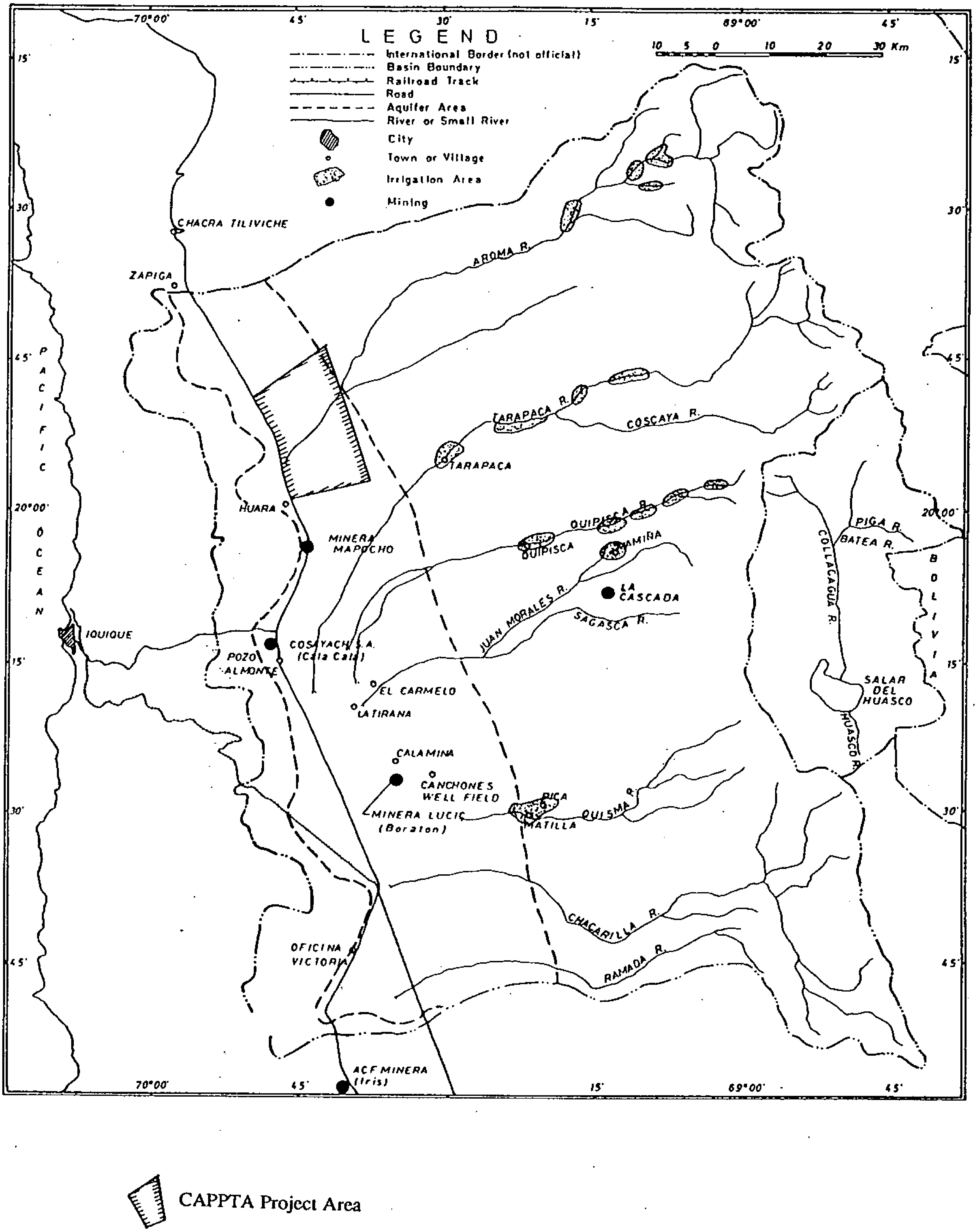


Fig. 3.4.1 Location of Irrigation and Mining Areas in the Pampa del Tamarugal

<Ubicación de Areas de Riego y Mineras en la Pampa del Tamarugal>

Chapter IV MUNICIPAL WATER SUPPLY DEVELOPMENT

4.1 Water Supply Development for Arica

4.1.1 Existing Water Supply System

1) Outline of System

The existing municipal water supply system for Arica city is operated and maintained by ESSAT.

The water source is groundwater of San Jose River Basin. The groundwater is extracted from the deep wells located in Azapa Valley and city area by means of submergible pumps installed in each well.

Water taken from the wells is first transmitted through an intake pipeline to a collection tank located nearly at the central place in the well-field. At the collection tank, the water is sterilized by hypo-chloride which is injected to the inlet pipeline or to the outlet pipeline of the tank. Then, the chlorinated water is transmitted to distribution tanks located on hilly areas in the east of the city. From the distribution tanks, water is supplied by gravity through distribution networks to consumers in the city.

The existing water supply system covers about 1,680 ha divided into four (4) service sectors of the urbanized area of the city.

For the existing water supply system and service areas, see Chapter 3, Fig. 3.1.1.

2) Production and Consumption

In 1992, ESSAT produced 16,941 x $10^3 m^3$ (=537 l/s) 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 was 6,681 x 10^3, corresponding to 39.4% of the production volume.

The above production was obtained from 28 deep wells located in Azapa Valley and city area. During the year 1993, additional wells were developed and commissioned by ESSAT, increasing the total production amount to 775 l/s.

3) Water Supply Facilities

(1) Deep Well and Intake Pump

The existing deep wells of ESSAT water supply system count 45 in number as of February 1994. Depth of the wells ranges approximately from 50 m to 110 m, their casing pipe diameter 250 - 340 mm and their yield approximately 15 - 25 l/s. All the wells are equipped with submergible pump.

The groundwater extracted from the deep wells is lifted up by the submergible pumps to a collection tank in principle, through pressured intake pipelines.

Power for the pumps is supplied by the electricity enterprise.

(2) Collection Tank

There are three (3) collections tanks;

i) Pago de Gomez Station located in Azapa Valley
ii) Azapa Station located in Azapa Valley
iii) Estudio Station located in the city area.

They are made of steel or reinforced concrete and situated on the semi-ground level.

The collected water is transmitted to distribution tanks through transmission pipelines. Water of Pago de Gomez and Azapa stations is transmitted by gravity to Chuño distribution tank and Saucache distribution tank, and further to Pampa Nueva distribution tank. Water of Estudio Station is lifted by pumps to La Cruz distribution tank.

Some of La Cruz tank water is pumped up to Rosado tank. Furthermore, some water of La Cruz tank is transferred toward La Lisera area by gravity and is pumped up to La Lisera tank.

3) Distribution Tank

There are (6) distribution tanks as of February 1994. All the tanks are made of steel or reinforced concrete and located on semi-ground level in the eastern or southern hills of the city.

Salient Features of the tanks are as follows.

i) Chuño Tank (V=5,000 m^3, HWL= 84.5 m; to Service Sector II)
ii) Saucache Tank (V=2,500 m^3, HWL=104.6 m; to Sector III)
iii) Pampa Nueva Tank (V=1,000 m^3, HWL= 129.1 m; to higher land of Sector III)
iv) La Cruz Tank (V=2,500x2 = 5,000 m^3, HWL= 81.5m; to Sector I)
v) Rosado Tank (V=800 m^3, HWL= 109.5m; to Sector IV)
vi) La Lisera Tank (V=200 m^3, HWL= xxx; to south-coastal area of Sector I)

The water being stored in the distribution tanks is supplied, by gravity in principle, through distribution networks to service sectors in Arica city.

Outline of the existing water supply system and facilities are shown in Fig. 4.1.1.

4) Existing Water Supply Problems

(1) Supply Capacity

The water supply service was limited to 10.5-15.0 hours per day for all the service sectors until the end of 1993 due to shortage of water. This water restriction was relaxed by the emergency water supply project which was completed at the end of 1993. However, water supply service in two (2) service sectors (II and III) are still limited to 14-15 hours per day.

(2) Water Source

Groundwater of San Jose River Basin has been developed to excess for irrigation of Azapa Valley and municipal water of Arica city. No further development in the Basin can be expected. Hence, water for the future demand should be obtained from Lluta Valley and other sources than San Jose River Basin.

(3) Water Quality

Water quality of the groundwater in the Azapa Valley and city area is getting worse due to the excessive development. Especially TDS in the wells of city area is increasing.

(4) Water Loss

The existing water loss is as high as approximately 40% of the total production.

4.1.2 Water Supply Development Policy

1) Development Capacity

In this report, the water supply by groundwater development of Lower Lluta Valley is proposed to meet the future water demand of Arica city.

However, the groundwater potential of Lower Lluta Valley is limited in quantity as well as quality. Then, the other water sources shall also be exploited to meet the long-term future water demand of Arica. Lauca River Basin is considered as only one (1) possible other water sources.

On the other hand, groundwater of Azapa Valley including city area will run short in near future if the existing groundwater extraction continues. Then, some of the existing water use in Azapa Valley shall be substituted by water sources of Lauca River Basin.

Therefore, the development capacity of water supply to Arica shall be determined, taking into consideration the following subjects.

(1) Maximum groundwater development potential
(2) Sustainable groundwater use in Azapa Valley
(3) Water production to be expected for Lauca River Basin

- The water supply development capacity is being studied -

2) Water Treatment System

The groundwater quality of Lower Lluta Valley is much contaminated by TDS, Cd, B and Fe as follows.

Water Quality Element	Groundwater Quality (mg/l)	Standard of Drinking Water (mg/l)
TDS	3,452	1,000
Cd	0.010	0.005
B	21.87	
Fe	1.53	0.30

Some special water treatment method will be proposed to cope with the above problems. Reverse Osmosis (RO) is considered the most feasible treatment method.

RO will treat / remove:

(1) TDS to a required treatment level
(2) almost all of Cd
(3) 90% of B

However, Fe will be treated by a sand filter attached before the RO plant.

- Details are being studied -

4.2 Water Supply Development for Iquique

4.2.1 Existing Water Supply System

1) Outline of the System

The Existing municipal water supply system is operated and maintained by ESSAT.

The water source is groundwater of Pampa del Tamarugal. The groundwater is extracted from the deep wells in the Canchones well field, located approximately 70 Km east of Iquique city, by means of submergible pumps installed in each well.

Water taken from the wells is first transmitted through an intake pipe to a collection tank located nearly at the central place of the Canchones well field.

Then, water is pumped at Canchones pump station (ground level; GL. 1,013 m above sea level) to Rinconada tank (GL. 1,155 m). On the way to Rinconada tank, water is once boosted at Diana tank (GL. 1,038 m). From Rinconada tank, water is conveyed by gravity to Cavancha distribution tank (GL. 114 m) located on the eastern hills of the city.

Between Rinconada and Cavancha, there are three (3) tank stations with pressure break and water storage purposes. They are Carpas tank (GL. 978 m), Santa Rosa tank (GL. 682 m) and Alto Hospicio tank (GL. 555m).

In Cavancha distribution tank, water is sterilized by hypo-chloride. The chlorinated water is distributed by gravity to the consumers.

For the above existing water supply system, see Chapter 3, Fig. 3.3.1.

2) Production and Consumption

In 1992, ESSAT produced 17,241 x 10^3 m^3 (=547 l/s) of municipal water of which 10,822 x 10^3 m^3 was consumed for residential, commercial, industrial and other uses. The estimated water loss was 6,420 x 10^3 m^3, corresponding to 37.2 % of the production volume.

3) Water Supply Facilities

(1) Deep Well and Intake Pump

There are 12 production well and two (2) emergency wells. Depth of the wells is approximately 120 m and their yields are 62-83 l/s each. All the wells are equipped with submergible pumps with each discharge capacity of 60 - 100 l/s and each total head of 60 - 100 m.

The extracted groundwater is lifted up by submergible pumps to the collection tank by means of pressurized intake pipelines.

(2) Collection Tank

There are two (2) collection tanks made of steel in Canchones station. Their salient features are as follows.

Groundwater level	: GL. 1,013 m
Capacity	: 1,000 m^3 x 2 = 2,000 m^3
High Water Level	:HWL. 1,018.15 m

(3) Transmission and Booster Pumps

The transmission pipelines cross over the coastal mountains with an altitude of 1,155 m at Rinconada. Transmission and booster pumps are installed to cope whit the ground level difference of 142 m between Canchones and Rinconada.

Six (6) transmission pumps are installed at Canchones station to lift up water to Diana tank located between Canchones and Rinconada. Total required electric power is 2,000 kw.

Four (4) booster pumps are installed at Diana tank to further boost to Rinconada. Total required electric power is 1,500 kw.

(4) Transmission Tank

There are five (5) transmission tanks between Canchones collection tank and Cavancha distribution tank. They are Diana, Rinconada, Carpas, Santa Rosa and Alto Hospicio. Their major functions are to break high pressure as well as to store water.

Their are made of either steel or reinforced concrete and installed on semi-ground level. Their total storage capacity is 37,700 m^3.

(5) Distribution Tank

There are three (3) distribution tanks on the east hills of the city. They are Cavancha, Norte and Las Dunas. Cavancha distribution tank has a capacity of 27,000 m^3 or 90% of the total capacity of 30,000 m^3 of the three (3) distribution tanks.

Water for Norte tank is branched from Cavancha tank and that for Las Dunas is branched from the transmission pipelines.

Water is distributed to the consumers from the above tanks by gravity.

(6) Transmission Pipeline

Length of the transmission pipelines between Canchones and Cavancha is 752 km. Two (2) pipelines, old and new ones, are installed in parallel for the major part of the route.

The old pipeline (ø 600 mm, steel) was installed in 1960. The new pipeline (ø 800 mm, ductile iron) was constructed during 1981-82.

The capacity of the pipeline is about 700 l/s with the break-down of 220 l/s for old pipeline and 480 l/s for new one.

Electric power required for operation of the facilities is all supplied by the electric company.

Outline of the existing water supply system/facilities are shown in Fig. 4.2.1. Longitudinal profile of the existing transmission pipelines are shown in Fig. 4.2.2.

4) Existing Water Supply Problems

(1) Water Quality

The groundwater in Canchones contains higher concentration of Mn and As than the standards of drinking water. The standards of Mn and As are 0.1 mg/l and 0.05 mg/l respectively.

The water quality of Mn in Canchones collection tank is about 0.5 mg/l on an average. However, this content of Mn decreases to 0.5 mg/l at Cavancha distribution tank. This is because Mn is oxidized by natural aeration in the tanks existing on the way and the manganese oxide is deposited on the bottom of the tanks or adhered to the inner surface of the pipes.

Further, the groundwater in Canchones contains 0.03-0.08 mg/l of As. However, this content decreases to 0.03-0.04 mg/l at Cavancha. This may be due to that As is caught by manganese oxide.

The above natural purification effects are not reliable. Hence, an artificial treatment of Mn and As is considered necessary.

(2) Water Source

Groundwater in Canchones area has been fully developed. Development of new water sources is necessary to meet the future water demand of Iquique.

(3) Power Cost

A large electric power is necessary for operation of the pumps. The total required power is 3,500 kw. The electric charge is more than 50 % of the total operation and maintenance cost.

(4) Water Loss

The existing water loss is as high as approximately 40 % of the total production volume.

4.2.2 Water Supply Development Policy

1) Development Capacity

The future production demands of Iquique on daily average basis are estimated to be 807 l/s for the year 2005 and 1,062 l/s for the year 2015. Those on daily maximum basis are calculated to be 1,049 l/s for 2005 and 1,381 l/s for 2015 by assuming the ratio of peak demand and average demand as 1.30.

On the other hand, the existing capacity is estimated to be 690 l/s. Then, the additional production capacity of 359 l/s and 691 l/s shall be developed by the years of 2005 and 2015 respectively.

2) Water Treatment System

Development of water treatment system entirely depends on water quality of the water sources to be developed.

- Necessity of water treatment plant is being studied. -

4.3 Institutional and Financial Aspects

4.3.1 Existing Organization of ESSAT

ESSAT is a stock company, 99 % of which shares are owned by CORFO. ESSAT serves municipal water supply and sewerage for the cities/towns of Region I including Arica, Iquique, Pozo Almonte, Pica, Matilla, La Tirana, La Huayca, Huara and Pisagua.

It has the following four (4) departments and two (2) branch offices under the top management.

(1) General Management
(2) Engineering
(3) Administration and Finance
(4) Planning
(5) Arica Branch
(6) Iquique Branch

The personnel of the organization totals 289, being classified as follows.

Top Management	10
Technical Staff	53
Other Staff	226
Total	289

4.3.2 Existing Tariff

1) Number of Client

Number of the clients received the water supply services of Arica and Iquique in the recent years are shown below, along with their coverage.

	Arica		Iquique	
	Nos. of Client	Coverage(%)	Nos. of Client	Coverage(%)
1991	34,770	99	30,175	98
1992	37,423	99	33,332	98
1993	38,821	99	35,126	98

2) Tariff Structure

Water tariffs are set by the Government, aiming to cover the costs of water supply services. The Government sets the target tariff which must be attained in a period of five (5) years.

The existing water tariffs of Arica and Iquique, as of February 1994, are as follows.

(1) Monthly Fixed Charge

Monthly fixed charge varies according to service pipe diameter.

Pipe Diameter (mm)	Arica ($)	Iquique ($)
13	231	209
15	334	337
19	667	675
25	1,335	1,350
32	2,002	2,025
38	3,003	3,037
50	5,005	5,062
75	11,678	11,812
100	20,019	20,249
125	30,028	30,373
150	45,042	45,560
200	80,075	80,995

(2) Monthly Variable Charge

Monthly variable charge includes charge during off season (April-November), charge during peak season (December- March) and overconsumption charge. These charges depend on the consumed water volume measured in m^3.

Overconsumption charge is applied for peak season to the consumption over the average consumption during off season. This charge is applied to the consumption over 30 m^3.

The monthly variable charges of Arica and Iquique are shown below.

Category	Arica ($/m3)		Iquique ($/m3)	
	Normal	Rebated	Normal	Rebated
Off Season	140.02	108.68	233.44	130.90
Peak Season	140.02	108.68	230.82	130.20
Overconsumption	363.74	363.74	564.20	564.20

3) Tariff Collection Efficiency

Invoicing is done on monthly basis for all clients. During the recent four (4) years (1990-1993), 96 % of the total invoiced tariff was actually collected on an average.

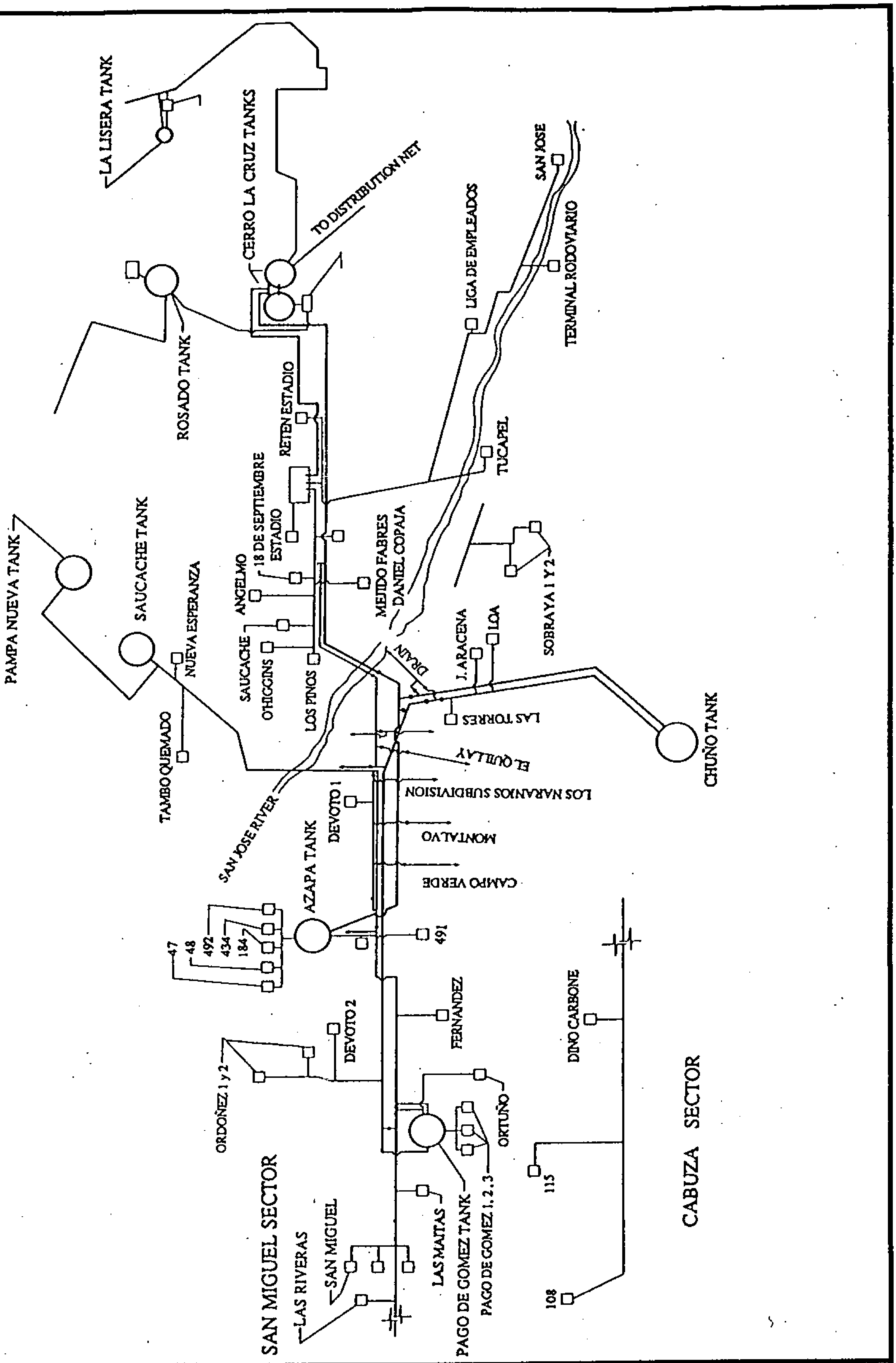


Fig. 4.1.1 Outline of the Water Supply System/Facilities for Arica

< Bosquejo del Sistema de Abastecimiento de Agua para Arica >

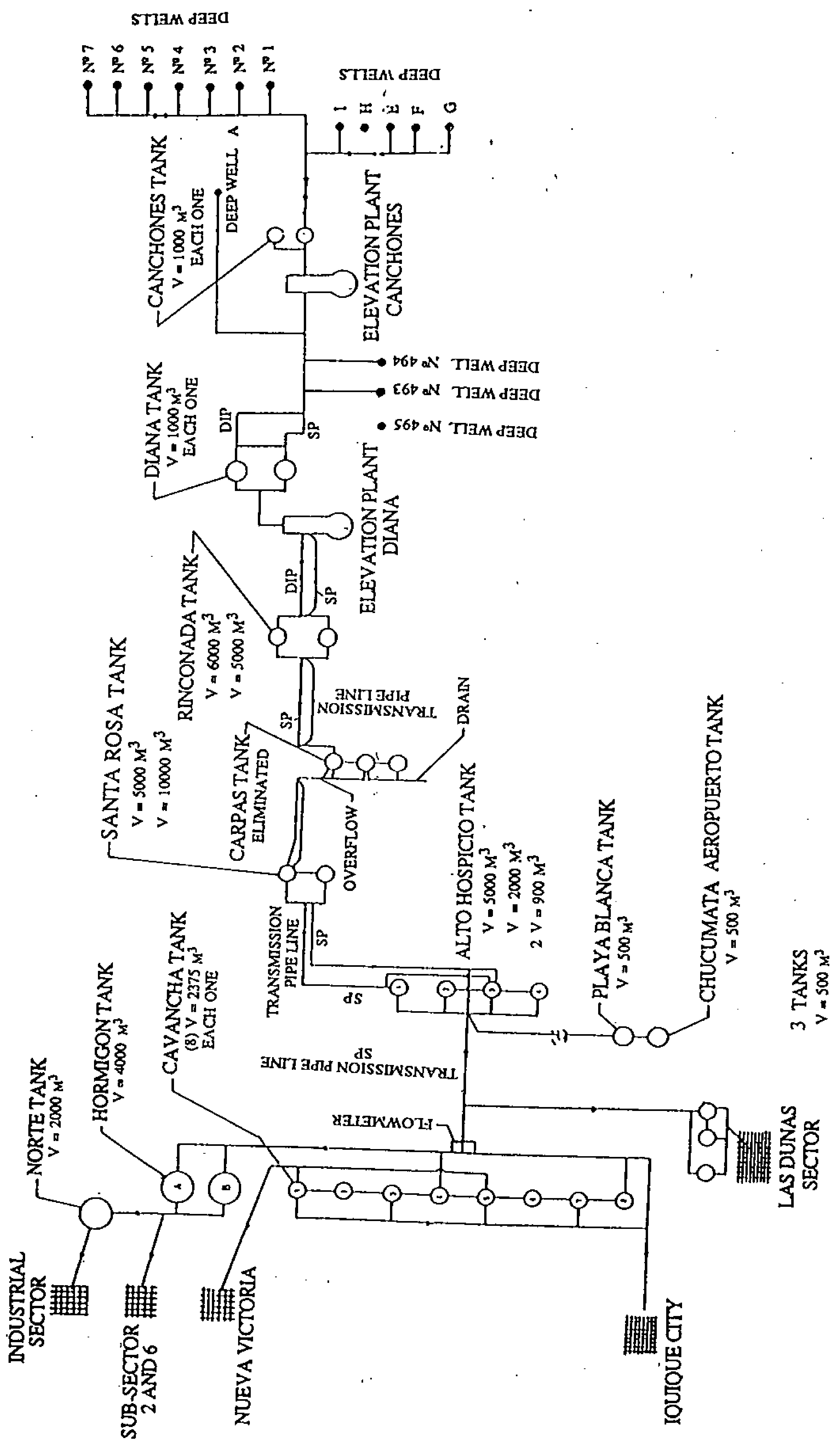


Fig. 4.2.1 Outline of the Water Supply System/Facilities for Iquique

< Bosquejo del Sistema de Abastecimiento de Agua para Iquique >

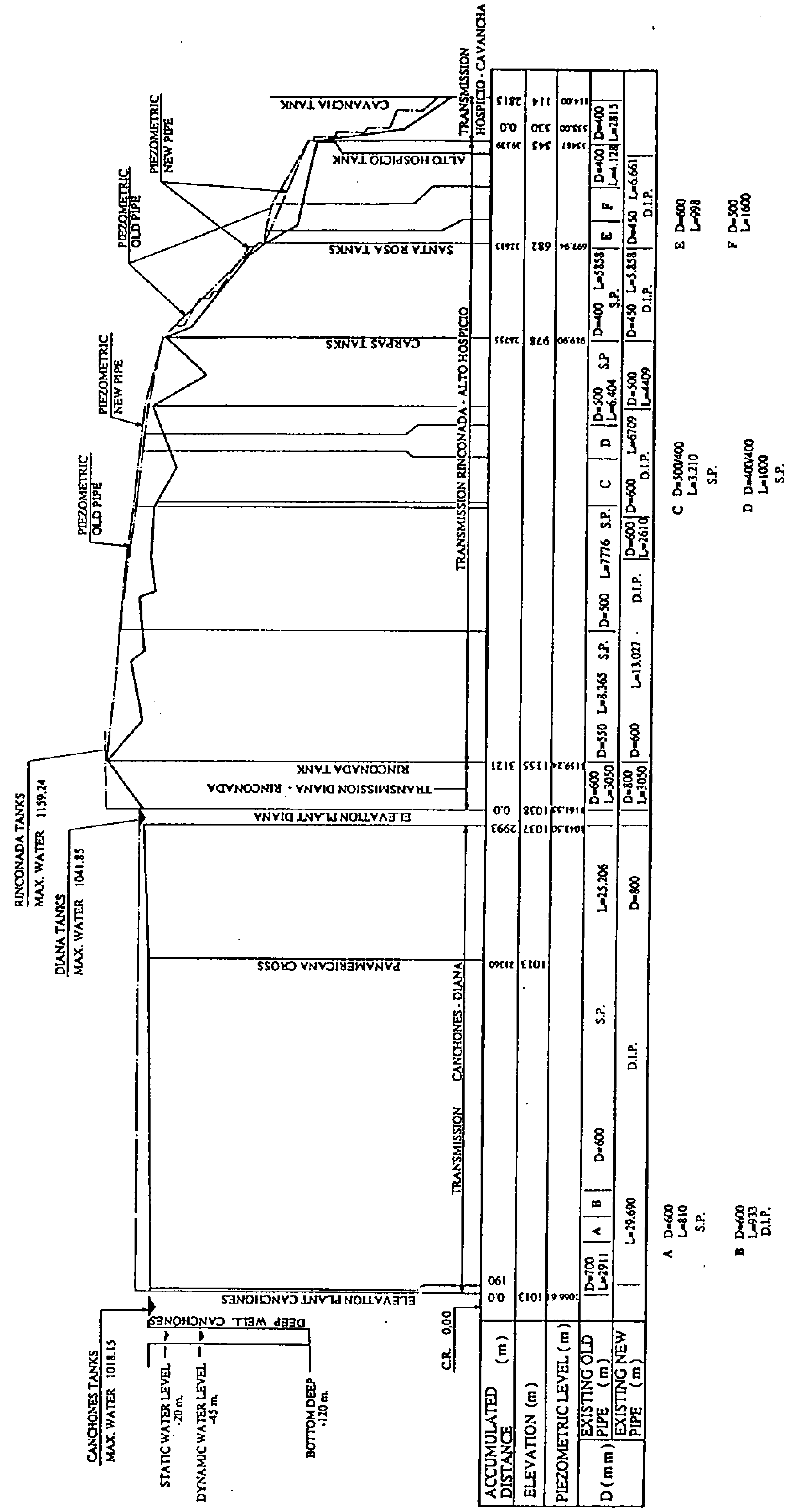


Fig. 4.2.2 Longitudinal Profile of Transmission Pipelines (Canchones - Cavancha - Iquique)

< Perfil Longitudinal de las Cañerías de Transmisión (Canchones - Cavancha - Iquique) >

Chapter V ENVIRONMENTAL STUDIES

5.1 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 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) Plants, specially Tamarugo forest in Pampa del Tamarugal
b) Existing groundwater uses in Pampa del Tamarugal
c) Ecological and social environments in Salar del Huasco

The other environmental factors are considered minor.

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

5.2 Tamarugo Forest in Pampa del Tamarugal

5.2.1 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

Source: CONAF

The above planted Tamarugo forest all 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. 5.2.1.

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	Ara (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. 5.2.1.

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.

5.2.2 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.

5.2.3 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 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 1,000 l/s by using the above table and Fig. 5.2.2.

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.

(3) Life of Tamarugo tree is 75 years.

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

The results are summarized as follows:

Year	Tamarugo Area (ha)	Water Consumption (l/s)
1993	23,945	1,000
2005	24,846	1,700
2015	25,346	1,500
2025	25,346	1,700

5.3 Environments of Salar del Huasco

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

5.3.1 Topography and Water Quality

1) Topography

Salar del Huasco is located at an altitude between 3,800 m and 4,000 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. 5.3.1). 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. 5.3.1.

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.

5.3.2 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.

A higher concentration of fitoplankton / zooplankton and a greater diversity of species are identified in Laguna Huasco. A lesser diversity of species is confirmed in Laguna Cerro Huasco, different from other lagoons in biological components.

3) Plants

Four (4) species of aquatic plants are identified in the fresh water area.

4) Birds

Birds of 40 species are identified in or around Salar del Huasco. Among them, the following seven (7) species of birds are designated by CONAF as endangered species or vulnerable species to be preserved.

(1) Endangered Species: Lesser Rhea

(2) Vulnerable Species: Punta Tiramou, Chilean Flamingo, Andean Flamingo, Puna Flamingo, Andean Goose, Giant Coot

5.3.3 Flamingo

1) Species and Population

Three (3) species of flamingos are identified in Salar del Huasco. The maximum population by species counted during the period of November 1993 to January 1994 as follows.

Species	Population
Chilean Flamingo	544
Andean Flamingo	1,267
Puna Flamingo	1,533
Total	3,344

These are designated by CONAF as vulnerable species and further authorized by CITES (Convension on International Trade in Endangered Species of Wild Fauna and Flora) as endangered ones.

2) Population Share in Northern Chile

The population of flamingos in Northern Chile were surveyed in 1985 to 1987 by Corporation National Forest of U.S.A. The maximum counted population by species during the survey period are shown below, compared with the population of Salar del Huasco.

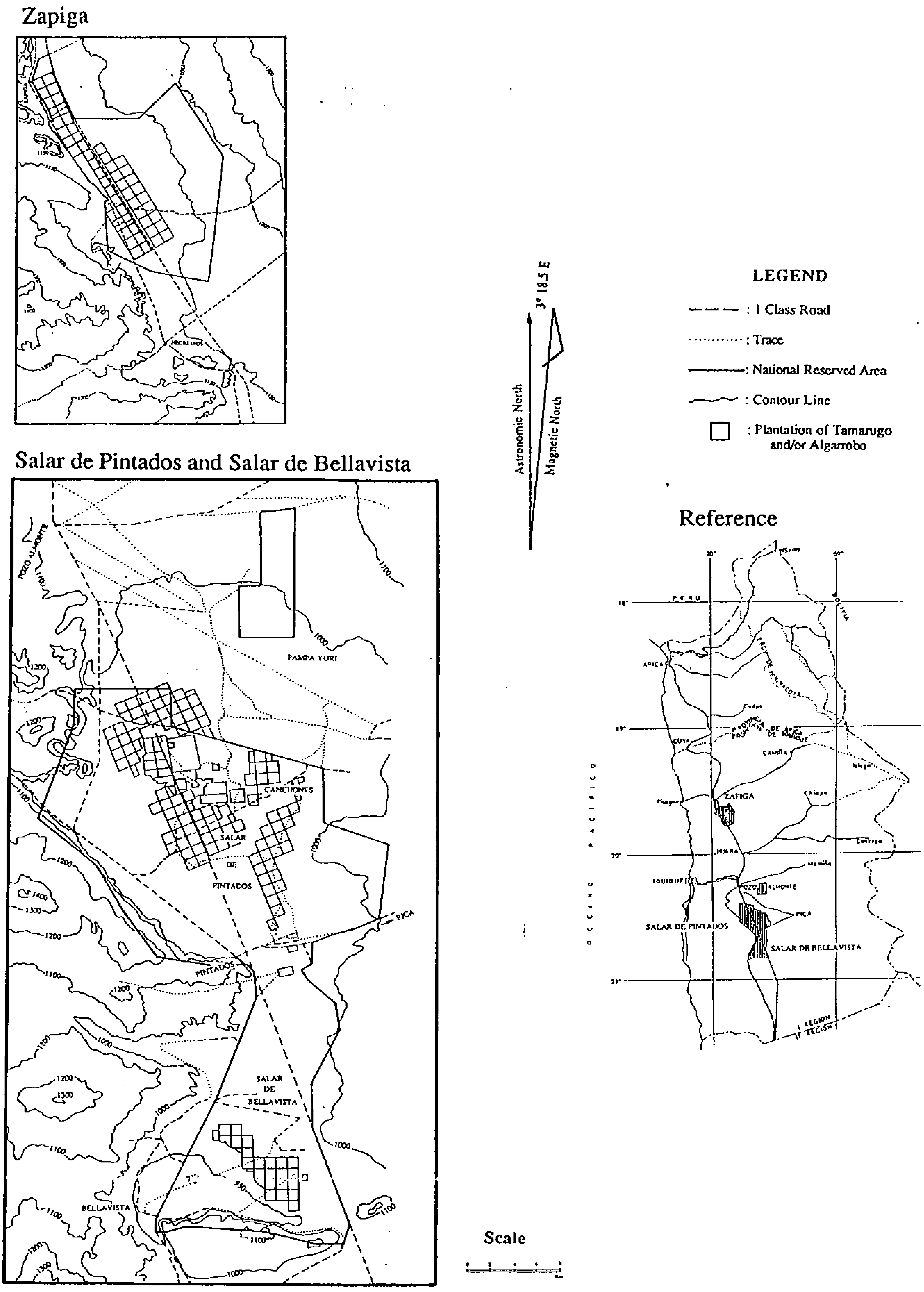
Species	Northern Chile	Salar del Huasco	Share (%)
Chilean Flamingo	15,464	544	3.5
Andean Flamingo	40,747	1,267	3.1
Puna Flamingo	17,268	1,533	8.9
Total	73,479	3,344	4.6

Share of the population of Salar del Huasco to the total population of Northern Chile is also shown in the above table.

Puna Flaming is the most rare species. The total population in the world in 1973 was reported as 15,000. They are all living in Andes Mountains.

3) Nesting

Chickens, nests and eggs of Puna Flamingos were identified by this study. Salar del Huasco provides one of the nesting areas to this rare species.



Zapiga

Salar de Pintados and Salar de Bellavista

Reference

Fig. 5.2.1 National Reserved Area and Tamarugo Plantation

< Area de Reserva Nacional y Plantación de Tamarugo >

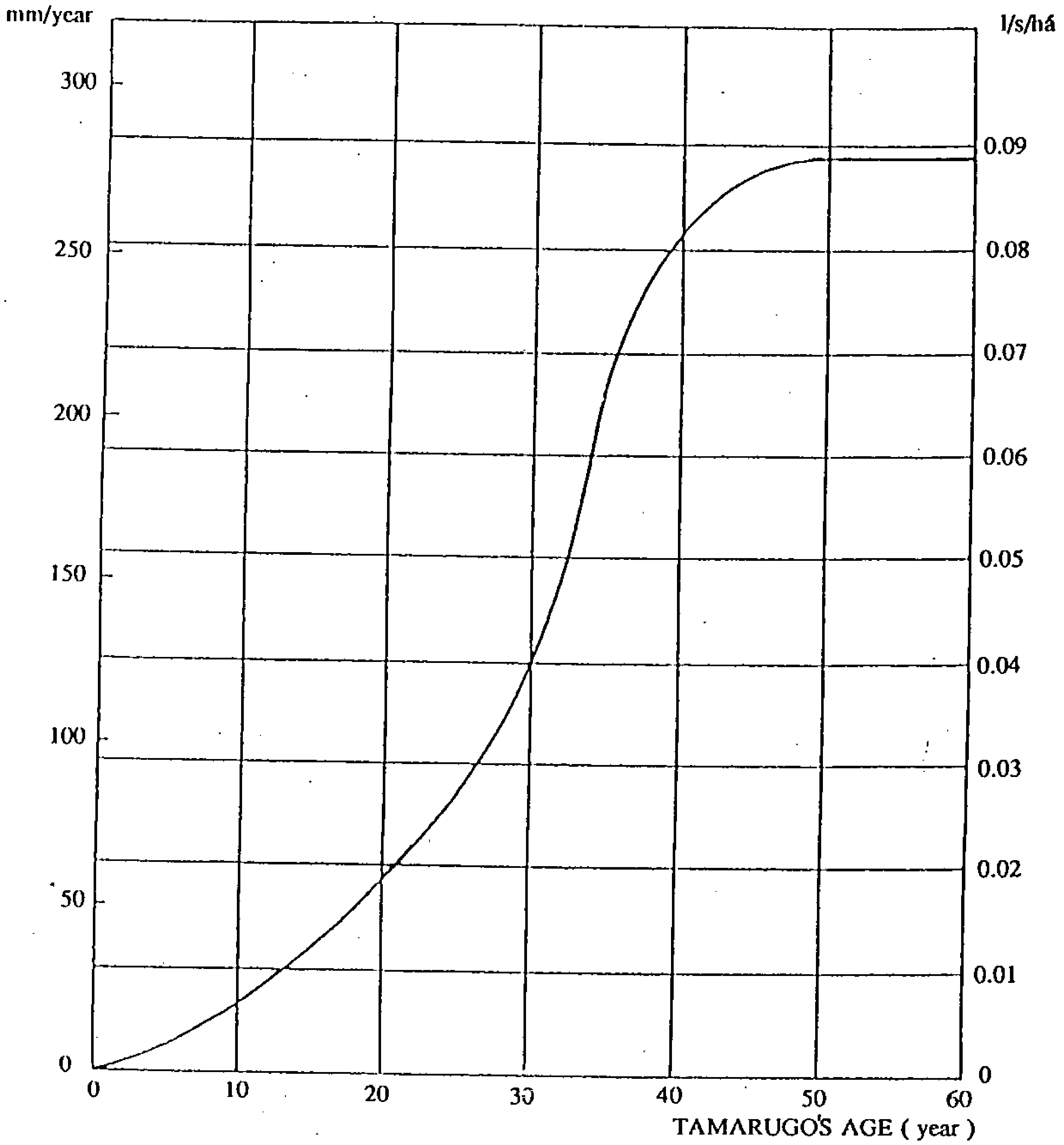


Fig. 5.2.2 Evapotranspiration by Tamarugo Plantations in Pampa del Tamarugal
<Evapotranspiración de las Plantaciones de Tamarugo

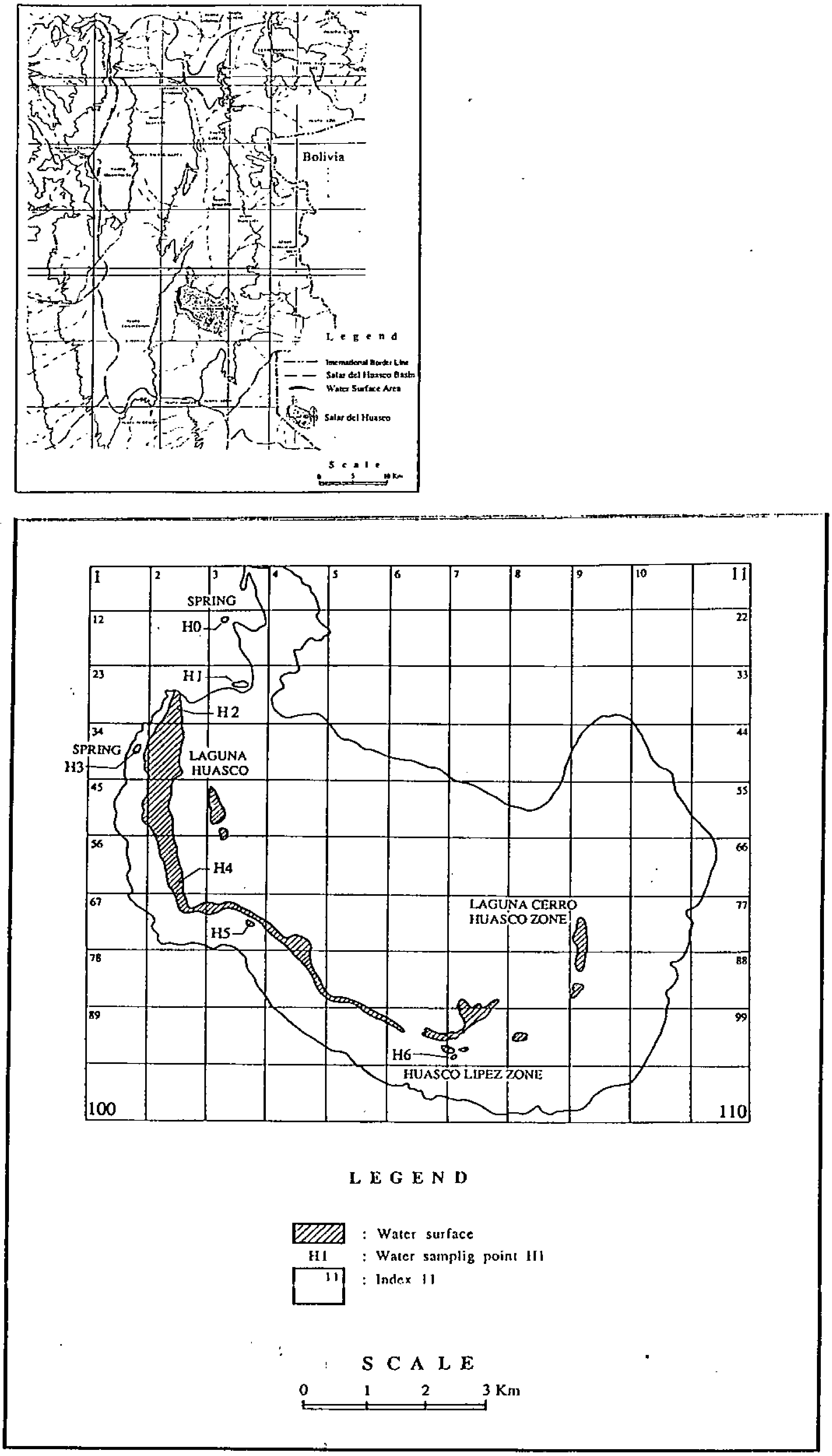


Fig. 5.3.1 Location of Salar del Huasco

< Ubicación del Salar del Huasco >