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THE STUDY
ON
THE DEVELOPMENT OF WATER RESOURCES
IN
NORTHERN CHILE

SUPPORTING REPORT B : GEOLOGY AND GROUNDWATER

MARCH 1995

PACIFIC CONSULTANTS INTERNATIONAL, TOKYO

B-I SAN JOSE RIVER BASIN

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Chapter I. TOPOGRAPHY AND GEOLOGY

1.1 Topography

The JICA Study Team conducted a LANDSAT image analysis, aerial photographs interpretation and field survey in the area, and constructed a Topographical Map (Fig. B-I, 1.1) and a map of River Network (Fig. B-I, 1.2).

The northern part of Chile is divided into five (5) characteristic regions in topography, as shown in Fig. B-I, 1.1.

(1) Littoral Platform (A)

It was formed by the erosion in the western foothills of the coastal hills. It is a narrow region and extend from Iquique up to Morro de Arica, where the hills directly fall into the sea.

(2) Coastal Range (B)

The height and width of the region gradually decrease from Iquique to the north and extinct at Morro de Arica. Beyond this area, the plains of the Andes Mountains directly descend towards the sea.

(3) Intermediate Depression (C)

It is located between the Coastal Range and the Andes Mountains with 1,000 to 2,000 m in height and has gentle slope. It was formed by subsidence of the basement and was filled up by the eroded materials derived from the Andes Mountains to Pampa del Tamarugal. The filling materials of the Pampa are porous and seep the water proceeding from the Andes Mountains. Because of the evaporation of groundwater, saline deposits are widely spreading in the Pampa.

(4) Precordillera (D)

It corresponds to the west foothill of the Andes Mountains, grooved by several deep canyons, some of which have springs. It constitutes the location of many small villages, prehispanic in origin, with terrace cultivation in the foothills.

(5) Altiplano (E)

It forms an almost flat plateau at the top of the Andes Mountains, with 3,500 to 4,500 m in height, where very high and isolated volcanoes are also located. This region was filled up by the thick volcanic materials.

The San José River Basin consists of the parts of Altiplano, Precordillera and above mentioned Intermediate Depression. Drainage patterns of the basin extracted from LANDSAT images which were generated for this study are shown in Table B-I, 1.1. According to the Figures of B-I, 1.1 and 1.2, the San José River is originated at the Altiplano and has a large catchment at the upper stream, and it flows down into the regions of Precordillera and Intermediate Depression. It has a characteristically small catchment at the middle stream.

1.2 Geology

1.2.1 Methodology of Geological Analysis

Geological analysis was carried out by using LANDSAT images and aerial photographs, and field survey in order to clarify the regional hydrogeological conditions of the region. The results of both interpretations were compiled on the maps. They are shown in Fig. B-I, 1.3 and 1.4.

1) Interpretation of LANDSAT Images

For the present study, seven (7) scenes of LANDSAT false color images are used, which were generated using bands of 1, 4 and 5 of Thematic Mapper (TM) data, assigned to blue, green and red, respectively. This band combination has the advantage of emphasizing the color variation of rocks and soils. Details of used LANDSAT TM data are shown in Table B-I, 1.1.

Interpretation of these images which were enlarged to a 1:500,000 scale was conducted in order to extract lithological and structural characteristics on the hydrogeology and to understand large scaled geological structure and regional distribution of each rock units. As for the San José River Basin, four (4) scenes of false color images were used, whose path and row are 001-072, 001-073, 002-072 and 002-073.

2) Interpretation of aerial photographs

Interpretation of Black and white aerial photographs at 1:60,000 scale was followed by the above LANDSAT images interpretation. It allowed to clarify the detailed lithological distribution and geological structures. As for the San José River Basin, 25 sheets of aerial photographs were used, which were acquired in 1976 or 1977.

1.2.2 General Geological Features of the Basin

1) General geology of the Basin

Geology of the San José River Basin is composed of Precambrian (?), Mesozoic and Cenozoic rocks. The interpretation for the basin resulted in the classification of the 12 geological units shown in Fig. B-I, 1.3. Lithology of each units interpreted were discussed with published references which are mainly from Sonia Vogel and Thomas Vila (1980) and Salas, R. et al (1966). Lithological characteristics of each units and their ages are as follows:

Geologic Age	Formation	Lithology	Units
Quaternary	Recent Deposits	alluvial, fluvial, eolian, fan, terrace, beach, recent fluvial and detrital deposits	Qal, Qfl, Qe, Qf, Qt, Qb, Qrf, Qd
	Quaternary Volcanic Rocks	andesitic and trachyandesitic lava and pyroclastics	Qv
	Concordia Formation	unconsolidated gravel, sand, mud and volcanic ash marine deposits	Qc
	El Diablo Formation	Upper: greyish-black conglomerate, consisting mostly of andesite gravel Lower: an alternating bed of greyish-brown fine to coarse grained sandstone with greenish-grey siltstone	Qed,(d)--diatomaceous horizon
Tertiary	Oxaya Formation	Upper: grey, brown and white to pink ignimbritic tuff, rhyolitic and dacitic in composition Middle: greyish breccia intercalated with tuffaceous sandstone Lower: grey andesite intercalated with tuff and ignimbritic tuff	To, (ig)--predominant in ignimbrite
	Azapa Formation	light brown fine to medium grained sandstone intercalated with dark brown claystone, grey siltstone, conglomerate, calcareous rocks, pinkish tuff	Ta
	Chapiquiña Diorite	gray massive diorite. holocrystalline porphyritic	Ti
	(Chapiquiña Group) Lupica Formation	andesitic breccia, tuff, lava: alternated with conglomerate and arkose sandstone, affected by hydrothermal alteration	K-T
	Lluta Diorite	gray diorite with granite, granodiorite. holocrystalline granular	Kil
Cretaceous	(Vilacollo Group) Atajana Formation Sausine Formation	Atajana F.: conglomerate, sandstone, red sandstone and andesitic volcanic rocks Sausine F.: andesitic lava and breccia	J-K
Jurassic	(Arica Group) Los Tarros F. Camaraca F.	Los Tarros F.: brown-grey shale, limestone, grey quartzite, with brown andesite Camaraca F.: andesitic volcanic rocks with marine sedimentary rocks	
Pre-Cambrian (?)	Esquitos de Belen Formation	gneiss and mica schist	PC

(1) Precambrian Unit (PC)

It is distributed in the environs of Belen and Tignamar, and is called the Esquistos de Belen Formation inferred to be Precambrian. The Formation consists of gneiss and mica schists.

(2) Jurassic to Lower Cretaceous Unit (J-K)

It corresponds to Jurassic Arica Group and the Lower Cretaceous Vilacollo Group.

The Arica Group crops out only in the Coastal Range region and is divided into two formations: Camaraca Formation (Middle Jurassic), and Los Tarros

Formation (Upper Jurassic). The lithology of these formations are composed of andesitic volcanic rocks and marine sedimentary rocks.

The Vilacollo Group crops out along the main stream and is constituted by the Atajana Formation and the Sausine Formation. The Atajana Formation consists of conglomerate, sandstone, red siltstone deposited in a continental environment and andesitic volcanic rocks. The Sausine Formation is mainly composed of andesitic lava and breccia.

These formations are intruded by the acidic to basic plutonic rocks of same age in many parts.

(3) Lluta Diorite

It is composed mainly of grey granular holocrystalline diorite accompanied by granite and granodiorite. Phenocrysts are of plagioclase, orthoclase, biotite, amphibole, quartz, sphene, zircon and apatite. Orthoclase and biotite are altered. The rock was formed during the Upper Cretaceous period, because this rock intruded to the Arica Group and the Vilacollo Group and is overlain by the Oxaya Formation.

(4) Upper Cretaceous to Lower Tertiary Unit (K-T)

It corresponds to the Lupica Formation of Chapiquiña Group. Lupica Formation is constituted by a sequence of andesitic volcanic rocks alternated with conglomerate and arkose sandstone. Wide zones of hydrothermal alteration have been developed in this formation.

(5) Chapiquiña Diorite

The Chapiquiña Diorite is composed of porphyritic holocrystalline diorite. Phenocrysts consist of plagioclase, pyroxine and opaque minerals. Alteration of minerals is rare. This rock intrudes to the Lupica Formation of Chapiquiña Group. Thus, the intrusion was occurred during Early Miocene.

(6) Azapa Formation (Lower to Middle Tertiary) (Ta)

It is mainly formed of light-brown fine to medium grained sandstone with intercalation of dark-brown claystone, grey siltstone, conglomerate, calcareous sedimentary rocks and pinkish tuff. The thickness of the formation is variable, and the maximum reaches to 510 m.

(7) Oxaya Formation (Middle to Upper Tertiary) (To, To (ig))

According to Sonia Vogel and Tomas Vila (1980), it is divided into three members with maximum thickness reaching 550 m. It shows a large variation in lithology, both vertical and lateral. The lithology of Oxaya Formation at type-locality in the Pampa is as follows;

The lower member consists of grey andesite with intercalation of tuff and ignimbritic tuff.

The middle member consists of greyish breccia with intercalation of tuffaceous sandstone and tuff. In the San José River, however, conglomerate beds are well developed.

The upper member consists of grey, brown and white to pink ignimbritic tuff, rhyolitic and dacitic in composition, showing a different degree of welding.

(8) El Diablo Formation (Upper Tertiary to Lower Quaternary) (Qed,Qed (d))

According to Sonia Vogel and Tomas Vila (1980), it is divided into following two members;

The lower member consists of an alternating bed of greyish-brown fine grained to coarse sandstone with greenish-grey siltstone. Diatomaceous horizons are intercalated near the base of this member.

The upper member is represented by thick and continuous strata of greyish-black conglomerate which predominantly contains andesite gravels.

(9) Huaylas Formation (Lower Quaternary) (Qhu)

It is distributed in the area between the Altiplano regions and Precordillera and consists of rhyolitic ignimbritic tuff and lacustrine deposits.

(10) Concordia Formation

The Concordia Formation is of marine deposits and distributes in the lower reaches of the San José River and the city area of Arica. The formation is composed of unconsolidated gravel, sand, mud and volcanic ash. The formation never crops out because it is completely overlain by the Recent Units represented by the Fluvial Deposits. The Fluvial deposits has a interfinger relation with this formation in the Azapa Valley.

(11) Quaternary Volcanic Rocks (Qv)

These are widely distributed in the Altiplano region, most of which are andesitic and trachyandesitic in composition.

(12) Recent (Upper Quaternary) Units (Qt, Qf, Qe, Qfl, Qal, Qb, Qrf, Qd)

These are constituted by eight (8) units; terrace deposits (Qt), fan deposits (Qf), eolian deposits (Qe), fluvial deposits (Qfl), alluvial deposits (Qal), beach deposits (Qb), recent fluvial deposits (Qrf) and detrital deposits (Qd). Among the Recent Units, some units are called the Concordia Formation which constitutes the marine terraces. They are supposed to appear in the coastal plain and the lower reaches of rivers such as the San José River and the Lluta River. Beach Deposits appears along the beach from the river mouth of the San José River to the international border with Peru.

Small fans are formed at the outlets of quebradas such as Qda. del Diablo and Qda. de Llosyas. The deposits are rich in fine materials such as tuff and mud.

2) General Geological Structure of the Basin

Many faults of NW-SE direction were extracted from both, LANDSAT images and aerial photographs over the ignimbrite of the Oxaya Formation at the middle part of the basin, located within the Precordillera (Fig. B-I, 1.4). Those faults are probably of Cretaceous or lower Tertiary age and would have been reactivated in upper Tertiary to possibly Quaternary.

On the contrary, in the Intermediate Depression, the Mesozoic and Cenozoic formations form a stable monoclinal structure with gentle dipping towards the west.

1.2.3 Hydrogeology in Azapa Valley

The Study Team constructed a detailed geological map of Azapa Valley (Fig. B-I, 1.5) and a geological profile (Fig. B-I, 1.6) reviewing the existing data (< 1 to <4).

Geology of the Azapa Valley are classified into following seven (7) units;

Recent Fluvial Deposits (Qal)
Recent Beach Deposits (Qb)
Marine Terrace Deposit (Qt)
Fluvial Deposits (Qal)
Fan Deposits (Qf)
Detrital Deposits
Basement Rocks (J-K, K-T, Ta, To)

Six (6) units other than Basement Rocks and Detrital Deposits are considered to be permeable, therefore, aquifers are formed in these units. The Concordia Formation and the Fluvial Deposits are in a relation of interfinger; the former occupies the coastal plain and the lower reaches of the Azapa Valley, and the latter appears in the subsurface of middle to upper reaches of the Valley. Both are the principal aquifers in the area.

Distribution of the aquifers are limited in the coastal plain and the valley of the San José River up to Bocatoma (namely the Azapa Valley). It is considered that the extension of aquifers in the upstream of Bocatoma is small even if the aquifers appear, because the valley decreases its width toward the upstream of Bocatoma.

The aquifers are deposited filling the valley in the impermeable Basement Rocks. Thus, groundwater flows in the aquifers from the upstream to downstream without leaking to the outside of the valley.

Although river system is developed in the San José River basin, no surface water is recognized in the quebradas in the middle to lower reaches except the main stream of the San José River. Therefore, the groundwater is recharged mainly from the surface water of the San José River. In addition to this, fissures developed in the Basement Rocks may supply a certain measure of water to the aquifers.

Hydrogeological descriptions of each geological unit distributed in the area are given below;

1) Basement Rocks

Basement Rocks consist of the Arica Group (Camaraca Formation and Los Tarros Formation), Vilacollo Group (Sausine Formation and Atajana Formation), Chapiquiña Group (Lupica Formation), Azapa Formations, Oxaya Formation and plutonic rocks. These units are lumped together as the basement rocks from the hydrogeological point of view because of their impermeability.

Matrix of the sedimentary rocks in the Basement Rocks are generally filled by the fine materials such as silt, clay and volcanic ash. Fissures and joints are less developed in both sedimentary rocks and igneous rocks (volcanic rocks and plutonic rocks), while they are developed and weathered near the surface of rocks. Considering these conditions, the Basement Rocks are thought to be impermeable in general.

2) Marine Deposits

Marine Terrace was formed on the coastal plain by the eustatic movement. The Marine Terrace Deposits were piled on the terrace and are composed of mainly sand and gravels sometimes intercalated with silts. This unit is one of the aquifers in the city area of Arica. This Marine Terrace Deposits may be included in the Concordia Formation.

3) Fluvial Deposits

The San José River formed the fluvial plain along the both sides of the river. The Fluvial Deposits are piled in this plain and are composed of gravels, sands and silts. The unit is highly permeable, therefore, it is the most important aquifer in the Azapa Valley.

A geological profile (Fig. B-I, 1.6) from Saucache to San Miguel through Pago de Gomez was constructed based on the existing drilling logs. According to this profile, the geological characters of this unit are as follows;

(1) The area from San Miguel to Pago de Gomez

Sand and gravel beds distribute from the surface to a depth of 40 to 50 m. These beds are underlain by mud beds of which thickness is 20 m to 40 m and 60 m in maximum. The mud beds are underlain by fine grained volcanic ash of which thickness is more than 20 m.

(2) The area from San Miguel to Pago de Gomez

Sand and gravel beds distribute from the surface to a depth of 80 to 90 m intercalating with mud bed. The mud bed increases its thickness toward the downstream from Saucache. A more than 20 m thick of mud bed appears under the sand and gravel beds. The bottom of the mud bed has not been confirmed by drilling.

4) Detrital Deposits

Detrital Deposits consist mainly of talus deposits and others formed by land collapses and land slides. Principle units of this talus deposits are formed by gigantic scale of landslide occurred in the Oxaya Formations and deposited keeping their original sedimentary structure; the hydrogeological characteristics are considered same as that of the Oxaya Formation. Other deposits are formed by the land collapse. Matrix of the deposits are filled with very fine sand, silt and clay. Thus, the Detrital Deposits are less permeable.

5) Fan Deposits

The Qda. del Diablo, Qda. de Llosyas, and Qda. de Acha formed the fans at their confluences with the San José River. The Fan Deposits are composed mainly of sand, gravels and silt. Thus, this unit is usually permeable. However, the deposits formed by the Qda. del Diablo are abundant in very fine materials in the matrix and occuply wide and thick impermeable parts in the aquifer. The impermeable parts act as a underground dam which retards the water infiltrated in flood of the San José River.

6) Recent Beach Deposits

Along the coast of the Pacific Ocean, the Recent Beach Deposits are distributed. The deposits consist of sand and gravels. Fine materials are less in the matrix. Thus the permeability is high.

7) Recent Fluvial Deposits

The Recent Fluvial Deposits are distributed along the river channel of the San José River and the Qda. de Acha. The Deposits consist of volcanic ash, mud, gravel and sand. Therefore, it is a important aquifer in the Azapa Valley because of its high permeability.

References

<1: Cuadrangulos Arica y Poconchile, Region de Tarapacá, Carta Geologica de Chile (Escala 1:1,000,000), 1980 for Institute de Investigaciones Geologicas by Sonia Vogel and Thomas Vila

<2: Cuadrangulos Camaraca y Azapa, Provincia de Tarapaca, Carta Geologica de Chile (Escala 1:50,000), 1968 for Institute de Investigaciones Geologicas by Alvaro Tobar B, Ivan Salar Y y Rene F. Kast

<3: Geologia y Recursos Minerales del Departmento de Arica, Provincia de Tarapaca, for Institute de Investigaciones Geologicas, 1966 by Raul Salas O., Rene F. Kast, Francisco Montecinos P. e Ivan Salas Y.

<4: Modelo de Simulacion de las Agua Subterraneas del Valle de Azapa, January 1989 for DGA by Ayala, Cabrera y Asociados Ltda. con la assesoria de IPLA Ltdea.

Table B-I, 1.1 List of Used LANDSAT TM Data.
<Lista de Datos LANDSAT TM Utilizados>

No.	PATH-ROW	ACQUIRED DATE	CLOUD COVER	SCENE CENTER
1	001-072	02/AUG/1987	0 %	S17-21/W068-19
2	001-073	30/MAY/1987	0 %	S18-47/W068-43
3	001-074	27/MAR/1987	0 %	S20-14/W069-04
4	001-075	20/APR/1990	0 %	S21-40/W069-23
5	001-072	10/NOV/1986	0 %	S17-21/W069-55
6	002-073	28/MAR/1985	4 %	S18-47/W070-12
7	002-074	28/APR/1990	8 %	S20-14/W070-31

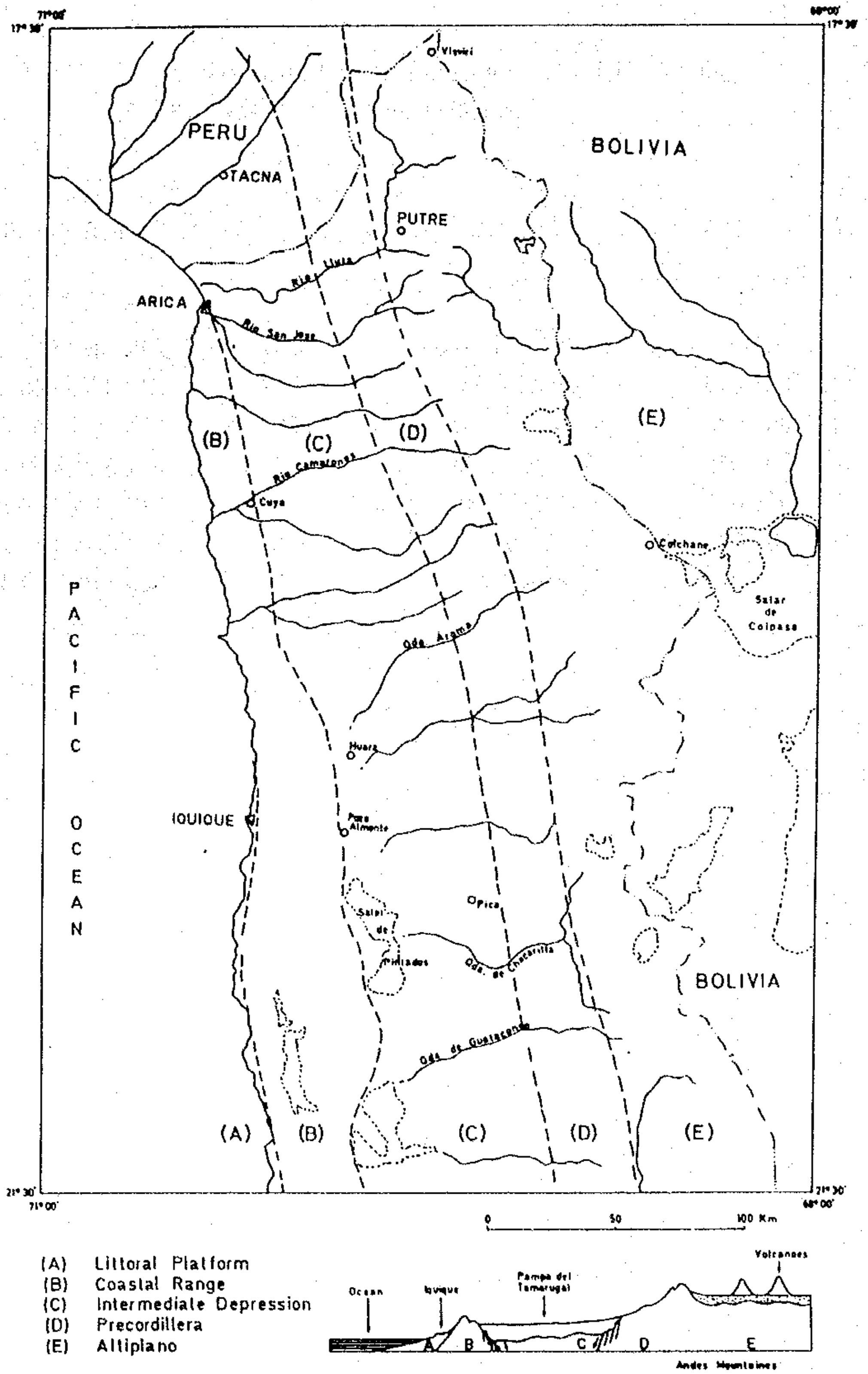


Fig. B-I. 1.1 Topographical Map

< Mapa Topográfico>

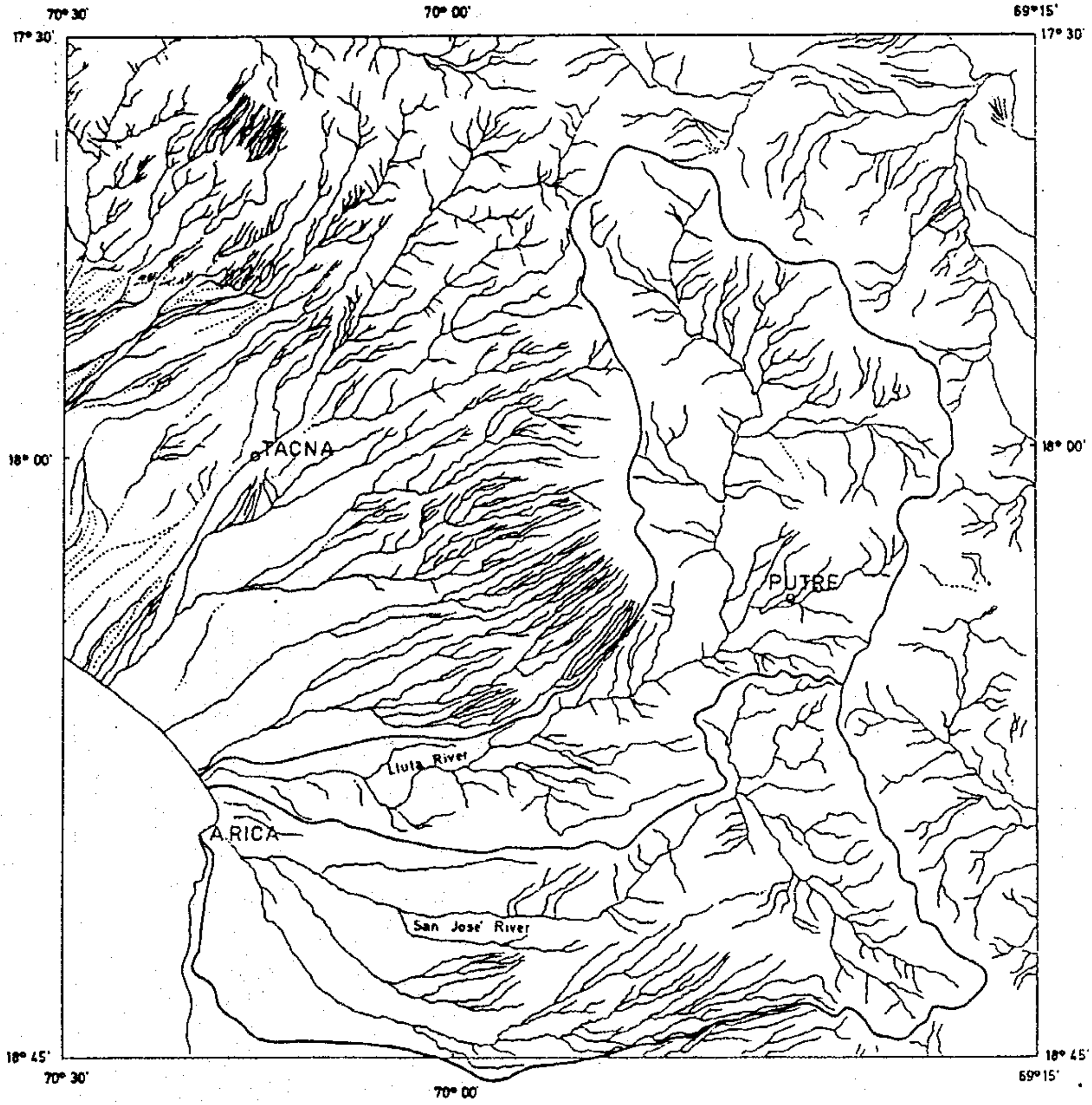


Fig. B-I. 1.2 River Network (Arica Area)
<Sistema Fluvial (Area de Arica)>

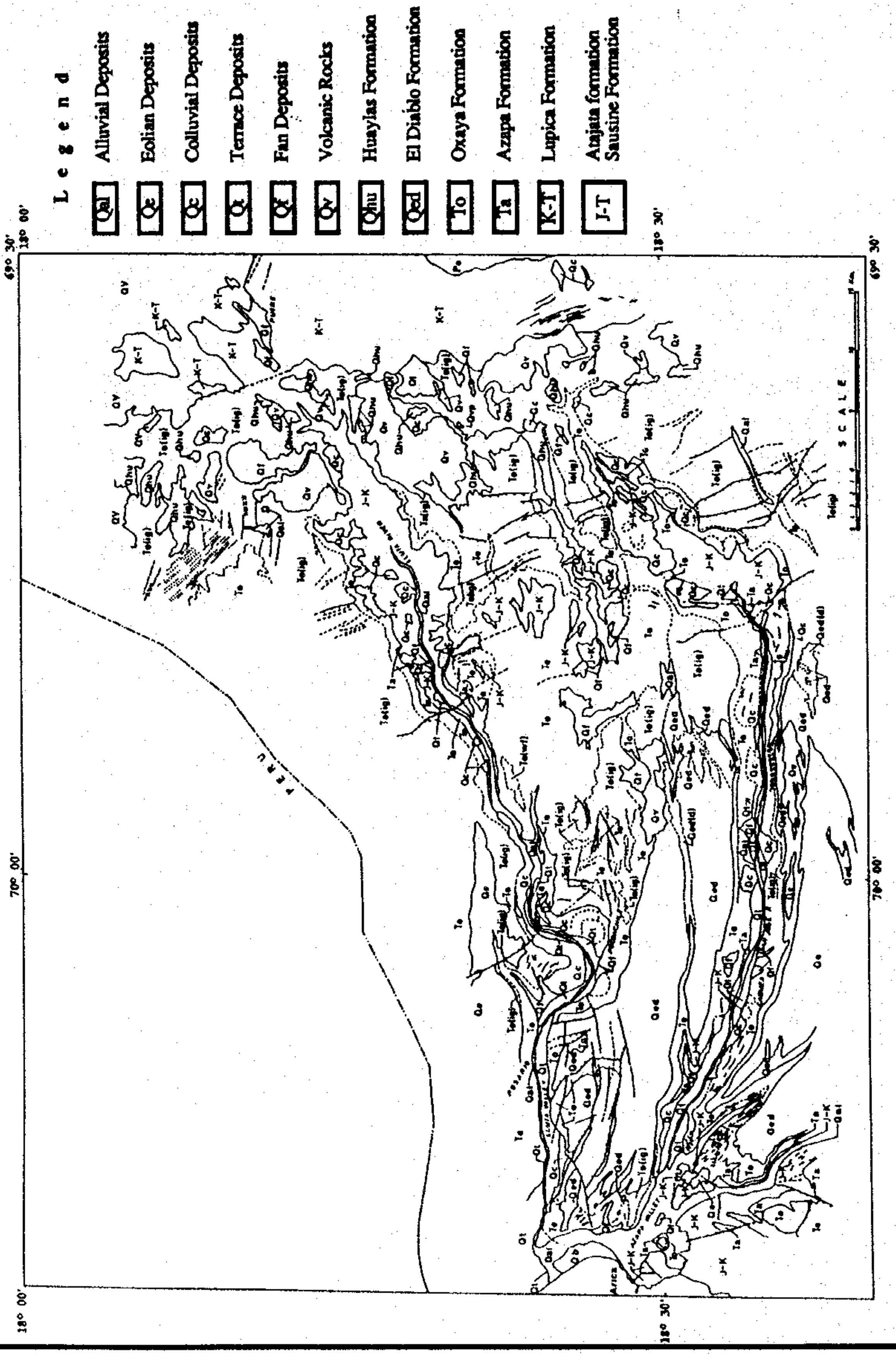


Fig. B-I. 1.3 Geological Map (Arica Area)

< Mapa Geológico (Area de Arica)>

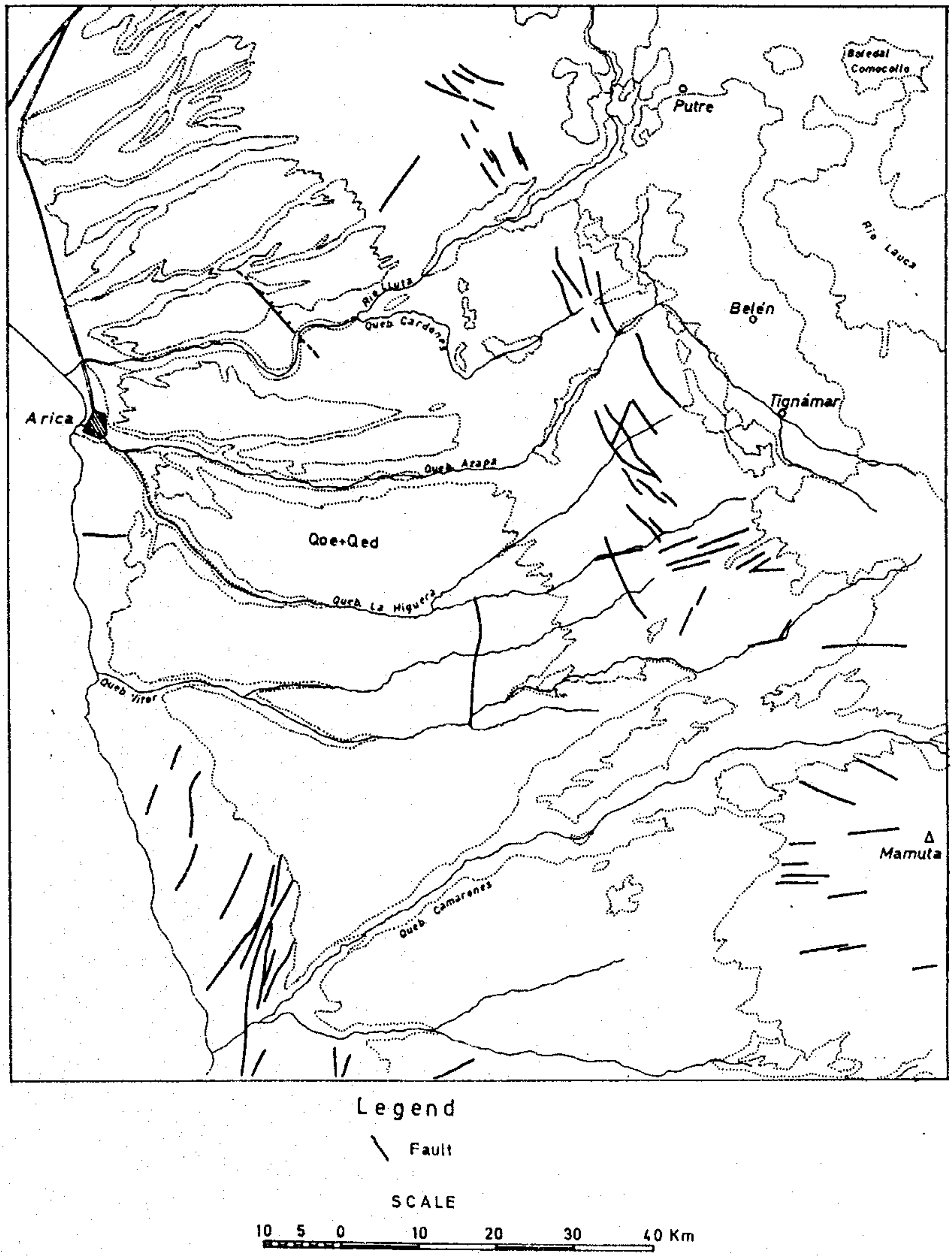


Fig. B-I. 1.4 Geological Structure (Arica Area)
< Estructura Geológica (Area de Arica) >

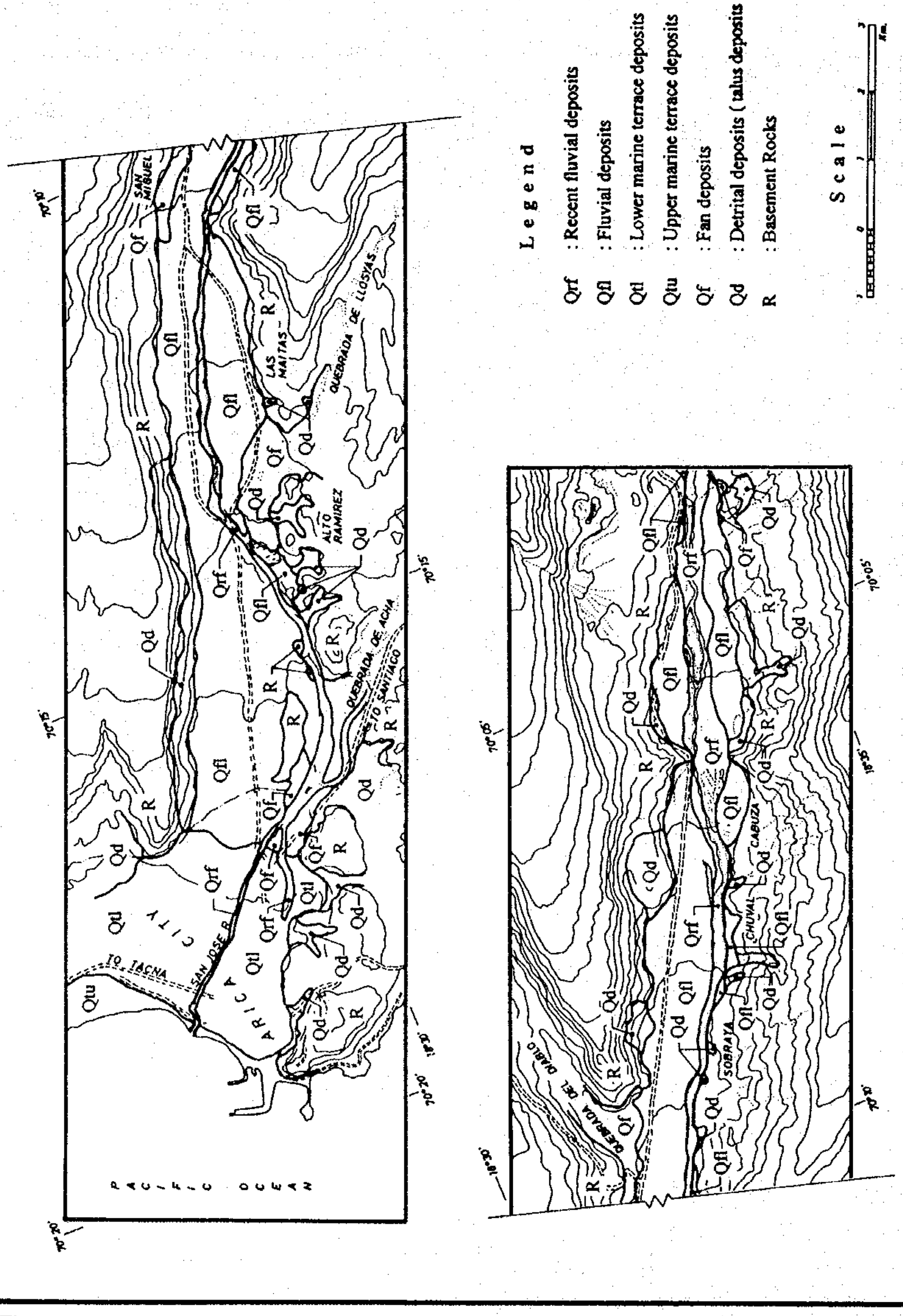


Fig. B-I. 1.5 Geological Map (Azapa Valley)
< *Mapa Geológico (Valle de Azapa)* >

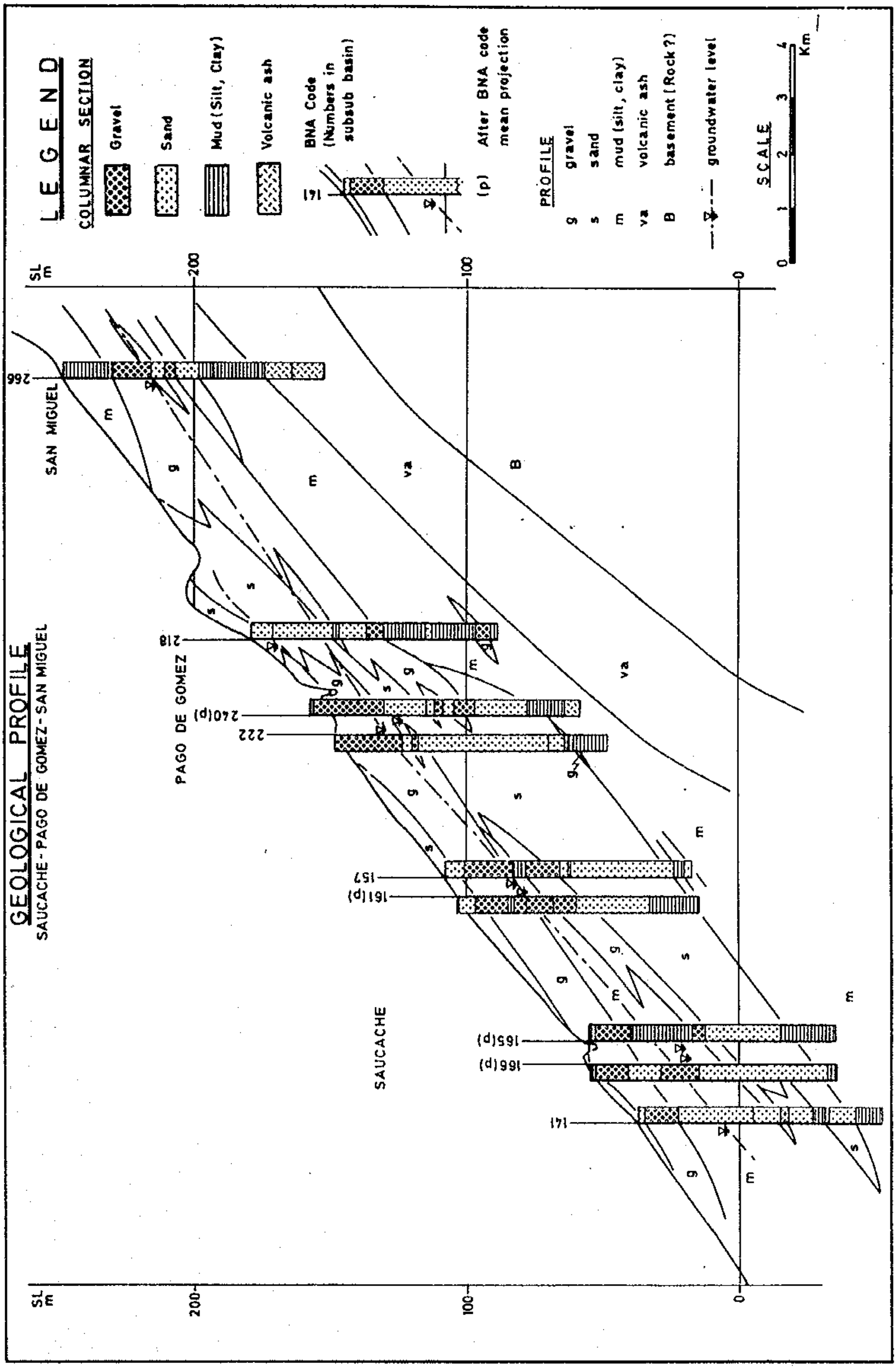


Fig. B-I. 1.6 Geological Profile (Azapa Valley)

< Perfil Geógico (Valle de Azapa)>

Chapter II. AQUIFER OF AZAPA VALLEY

2.1 Inventory of Existing Wells

2.1.1 Well Inventory

Most of the wells existing in the Azapa valley are officially registered to DGA and each well has respective registered number. However different four (4) numbering system were applied to register the wells in past; CORFO code (1969), CORFO code(1975) (<1), DGA code and BNA code (<2). Primarily CORFO code (1969) was used. This system was succeeded to the new system, CORFO code (1975). These systems express the wells by the combination of the coordinates (longitude and latitude) and numbers; for example, "1820-7010 CC-15". Although once DGA made DGA code which expresses the wells by only consecutive numbers such as "DGA-112", this code was not applied to the wells in the Azapa Valley. BNA code is the latest numbering system. This system expresses the wells by consecutive number using the hydrographic basin and sub-basin as follows; "013 10 108-6" (013: hydrographic basin, 10: sub-basin, 108: well No., -6: suffix). At present, DGA has applied both systems, CORFO code (1975) and BNA code, to register and control the wells.

In this report, the wells are expressed by three (3) digits of consecutive numbers using the last three (3) digits of the BNA code like "108" (this No. means "013 10 108-6".

The JICA Study Team established well lists and inventories (as of 1989) based on reviewing existing inventories and field survey (Table B-I, 2.1 and 2.2). The well inventory was prepared in sheets for each well, which gives necessary well data mentioned below to evaluate the groundwater potential around the well. The reviewed inventories are attached to the following reports;

(1) Analisis Critico de la Red de Medición de Niveles de Agua Subterránea 1 Region, October 1987 for DGA by Alamos y Peralta Ingenieros Consultores Ltda.

(2) Modelo de Simulación de las Aguas Subterráneas del Valle de Azapa, January 1989 for DGA by Ayala, Cabrera y Asociados Ltda. Ingenieros Consultores con la asesoris de IPLA Ltda.

(3) Stratigraphic columns prepared by DGA, RIEGO and ESSAT.

There are 371 deep wells and 14 springs (as of 1989) in the Azapa Valley consisting 166 deep wells (sondajes) and 205 dug wells (norias). The wells drilled by the Study Team during phase 2 study are also added. The well lists are shown in Table B-I, 2.1 for deep wells and 2.2 for dug wells. The well inventory is shown in Data Book. The locations of wells are shown in Fig. B-I, 2.1. The well inventories present following items;

(1) Well No.
    a. BNA code No.
    b. CORFO code No. (1975) (Dug wells and springs have not any code No.)
(2) Community name of well location
(3) Location name
(4) Name of owner
(5) Name of constructor
(6) Elevation
    Elevation of well is expressed by the height from the mean sea level (m MSL)
(7) Drilling depth
(8) Depth of well
(9) Specific yield
(10) Date of construction
(11) Static water level (as of De. to Nov., 1993)
    a. BGL (m below the ground level)
    b. MSL (m above the mean sea level)

In addition to these, well inventory cites the following data;

(1) Geostratigraphic column
(2) Well specification (casing & screen design)
(3) Pumping test results (Aquifer constants)
(4) Water quality

2.1.2 Deep Well (Sondaje)

Out of 166 deep wells, 121 deep wells have information on the date of construction and remaining 45 deep wells have no information. The oldest record of deep well is in the year of 1946. The number of deep well started to increase in 1940s, and significant increase of deep well number occurred between 1950 and 1967 as shown in Fig. B-I, 2.2. In this period, 57 deep wells were constructed. Total number of constructed deep wells reached to 100 in 1975 since 1946.

166 deep wells are listed in the list and inventory, however, 14 are abandoned. The purpose of deep well construction (as of 1989) is summarized as follows;

Purpose	No. of wells	Abandoned wells	Total No. of wells
Investigation	8	8	16
Potable	50	2	52
Irrigation	58	3	61
Industry	4	0	1
Others	20	1	21
No data	12	0	11
Total	152	14	166

2.1.3 Dug Well (Noria)

According to the inventory of dug wells, total number of dug wells comes to 205 distributing along the San José river; most dug wells locate between Chugal and Saucache. There are also ten (10) dug wells in the city area of Arica. Nine (9) wells(sondajes) are included in the inventory. Dug wells are used for following purposes (as of 1989);

Purpose	No. of dug wells
potable	37
irrigation	30
industry	2
potable/irrigation	2
potable/industry	1
capped or dried up	25
out of use	74
abandoned	9
no data	25
total	205

Total number of 180 dug wells has information on the date of construction and no information is available on the remaining 25 wells. Information is not available about the construction in 1970s. The oldest dug well in the record was constructed in 1920. Fig. B-I, 2.3 presents the number of construction in each year and increase of dug wells. Dug wells have been continuously constructed since 1920s; several dug wells increased every year.

2.2 Existing Boring Data

2.2.1 Boring Logs

Total of 22 boring logs are available in the area; two (2) logs are for San Miguel area, six (6) logs for Las Animas, seven (7) logs for Pago de Gomez area, seven (7) logs for Saucache area. These data are cited in the Data Book. In addition to these, several data are shown in the existing report <3, although the data present only permeability of strata without lithology.

2.2.2 Pumping Test

Although pumping test was executed on 48 wells at the completion of each deep well, aquifer constants were analyzed for only 10 wells. Therefore, in addition to these data, specific yield was calculated on 48 wells. They are expressed in the Well List (see, Table B-I, 2.1) and Well Inventory of Azapa Valley. Specific yield is given by following formula;

$$Sy = Q / (Ls - Ld)$$

where Sy : specific yield (m^3/day/m or m^2/day)
Q : yield (m^3/day)
Ls : static water level (m)
Ld : dynamic water level (m)

2.3 Configuration of Aquifer

A hydrogeological profile (Fig. B-I, 2.4) and hydrogeological cross sections (Fig. B-I, 2.5 (1) to (4) are provided in addition to the Geological Profile (Fig. B-I, 1.6). They present the figure of aquifers. The aquifer is occurred in the Recent Fluvial deposits, the Lower marine terrace deposits, the Upper marine terrace deposits, the Fluvial deposits and the Fan deposits. They are distributed in the coastal plain and the Azapa Valley up to Cabuza as described in Chapter I, 1.2.2 and 1.2.3. The distance from the coastal area to Cabuza is approximately 25 km.

In the Azapa Valley, the principle aquifers are transferred to the Fluvial Deposits as mentioned above. The estimated total thickness of the aquifer attains a maximum of more than 60 m. However, the aquifer varies markedly in thickness as a result of fluviatile deposition. The extent of the aquifer is controlled by the width of the valley.

Description of aquifers by area are as follows;

(1) Cabuza area

The width of the valley is about 1,200 m. However it becomes narrower at a part and its width is about 600 m. The aquifer is about 50 to 60 m in thickness. Intercalation of permeable layers such as silt and clay are less. As no impermeable layers cover the aquifer in this area, the groundwater is unconfined.

(2) San Miguel area

The width of the valley is about 1,200 m. The total thickness of aquifer is about 50 m including intercalation of impermeable layer due to which the actual thickness decreases to about 35 m. It seems that the aquifer is divided into two (2) parts, upper and lower, by the impermeable layer. However, it is quationable whether the lower part of aquifer is confined or not, because the aquifer is not saturated by groundwater.

(3) Pago de Gomez area

The width of the valley is about 1,200 m. The thickness of the aquifer is about 45 m. Although, impermeable layers appear irregularly in the aquifer, the aquifer is covered by no impermeable layer.

(4) Saucache area

The valley spreads its width up to more than 1,700 m. The aquifer is about 55 m in thickness. Intercalation of impermeable layers are rare. The groundwater in the area is considered to be unconfined.

(5) City area of Arica

The coastal plain is widespread in the area. The impermeable layers are predominant in the deposits of this area. The aquifer is divided by the impermeable layers which reduces its thickness. The lower aquifer is distributed under the sea level, therefore, the aquifer seems to be deteriorated by the sea water.

2.4 Hydrogeological Characteristics of Aquifers

2.4.1 General

As mentioned in 1.2 and 2.3, the aquifer of the Azapa Valley is composed mainly of sand and gravel bed in the different units. The field survey by the Study Team revealed that no hydrogeological discontinuity is recognized among the permeable units and the aquifer of the area is formed by the sequence of the permeable units. The groundwater stored in the aquifer is considered to be originally unconfined.

2.4.2 Pumping Test Result

1) Aquifer Constants

The existing data are concentrated in three (3) areas; San Miguel, Pago de Gomez and Saucache area. A total number of 10 data is available in the Azapa valley, which is shown in the following table.

Area	BNA Code	Test Date	Transmissibility (m3/d/m)	Permeability (cm/sec)	Storativity
San Miguel	266-	20, Jun.,1992	30	7.62 x 10-4	6.09 x 10-1
	265-	21, Aug.,1992	44	1.14 x 10-3	3.68
	Average		37	9.51 x 10-4	2.14 x 10-1
Pago de Gomez	187-6		3,160	9.26 x 10-3	3.22 x 10-4
	157-4		2,820	7.09 x 10-2	3.22 x 10-4
	161-2		3,526	9.72 x 10-2	3.28 x 10-5
	242-	31, Mar, 1992	43	1.11 x 10-1	3.38
	240-	28, May,1992	123	3.18 x 10-3	1.72
	Average		1,934	5.83 x 10-2	1.02
Saucache	166-3		2,075	6.00 x 10-2	6.23 x 10-3
	165-5		1,550	4.98 x 10-2	4.32 x 10-1
	141-B		69	2.12 x 10-3	2.02
	Average		1,231	3.73 x 10-2	8.19 x 10-1
Average (total area)			1,344	3.22 x 10-2	1.18

Note: BNA code of the Azapa Valley is formally expressed as 013 10 xxx-x.

The characteristics of aquifer constants distribution are as follows;

Transmissibility has a wide range from 30 to 3,526 m^3/d/m averaging 1,344m^3/d/m. Transmissibility is rather low in the upper reaches of the valley (San Miguel to Pago de Gomez), 30 to 44 m^3/d/m, and high in the lower reaches of the valley (Pago de Gomez to the city area of Arica), 1,550 to 3,526 m^3/d/m except the well 141-B.

Permeability varies between 7.62x10 $^{-4}$ and 1.11x10^{-1} m^3/d/m, having average of 3.5x10^{-2} m^3/d/m. There is a tendency that Permeability has rather high in Saucache area in the order of 10^{-2}.

Storativity ranges from 3.28x10^{-5} to 3.68, averaging 1.18. The area from San Miguel to Pago de Gomez has high Storativity.

2) Specific Yield

Specific yield is an important factor for evaluation of aquifer, therefore, that of each deep well was calculated based on the pumping test data shown in the Table B-I, 2.1. The results are shown in Table B-I, 2.3 (summarization is shown in the following table) and are presented on a map showing distribution of specific yield (Fig. B-I, 2.6).

unit: $m^3/d/m$

Area	Max.	Min.	Average
Cabuza	786	168	452
Las Riveras	1,080	206	643
San Miguel	2,991	69	722
Pago de Gomez	461	109	243
Saucache	1,080	41	335
City	364	22	158
Total area	2,991	22	351

The average of specific yield is 351 $m^3/d/m$. This value is of ordinary order for the silty sand and gravel bed. The maximum value of 2,991 $m^3/d/m$ is rather high. The values of specific yield vary from place to place reflecting the characteristics of the aquifer. Characteristics of the distribution of specific yield by area are as follows;

(1) Cabuza area

Large values appear in the central part of the valley. It shows that the groundwater mainly flows in the central part of the valley.

(2) Las Riveras to San Miguel area

Contrary to the Cabuza area, large values are unevenly distributed in the southern margin of the valley and are extremely high (2,991 and 1,080 $m^3/d/m$). According to the geological map (Fig. B-I, 1.5), a fan was formed at the outlet of the Qda. del Diablo. This fact suggests that the stream center of groundwater flow is in the southern margin of the valley concentrating towards the narrow part. It is considered that this is caused by the southward spurring of the fine materials derived from the Qda. del Diablo. In addition to this, high specific yield is due to the concentration of groundwater.

(3) Pago de Gomez to Saucache area

Distribution of specific yield shows the ordinary flow pattern; values are large in the center and small in the margin of the valley.

(4) City area of Arica

Specific yield is small in the western part of the city area. However, detail is unclear because of lack of existing data.

2.5 Estimation of Groundwater Storage

Groundwater storage of the Azapa Valley is shown in Table B-I, 2.4 and Fig. B-I, 2.7. These present the estimated groundwater storage in the area from Cabuza to the river mouth of the San José River. Total volume of groundwater storage is estimated as follow;

$$S_{\text{Total Storage}} = 302 \times 10^6 \text{ m}^3.$$

The estimation was made based on the one (1) geological profile and seven (7) geological sections dividing the area into seven (7) zones. Each profile represents following zone;

Zone	Geological section	Major community in the zone
1	(coast line) to sect. A-A	coastal area of Arica city
2	sect. A-A' to B-B'	central area of Arica city
3	sect. B-B' to C-C'	Saucache
4	sect. C-C' to D-D'	Pago de Gomez
5	sect. D-D' to E-E'	Pago de Gomez, Las Maitas
6	sect. E-E' to F-F	San Miguel
7	sect. F-F' to G-G'	Las Riveras, Cabuza

Conditions applied in the estimation are as follows;

(1) Climate condition will be constant during the estimated period.

(2) The extent of the estimation is limited to the area from the city area of Arica to Cabuza, because no stratigraphic column of well is available toward the upper reaches from Cabuza.

(3) Groundwater stored below the sea level is not included in the storage.

(4) Estimation is made on the groundwater stored in permeable and semi-permeable beds. Although groundwater is stored in impermeable beds, it is not considered as prospective one.

(5) Effective porosity of aquifer is assumed to be 30 % as a whole, considering the materials which compose the aquifer.

References

<1: Catastro de Pozos de la Pampa del Tamarugal, 1975 by CORFO.

<2: Banco Nacional de Aguas, 1983 for DGA by Cristian Juricic V., Dario Mosca R. and Brahim Nazarala G.

<3: Análisis Crítico de la Red de Medición de Niveles de Agua Subterránea 1 Region, October 1987 for DGA by Alamos y Peralta Ingenieros Consultores Ltda.

<4: Modelo de Simulación de las Aguas Subterráneas del valle de Azapa, January 1989 for DGA by Ayala, Cabrera y Asociados Ltda. Ingenieros Consultores con la asesoris de IPLA Ltda.

Table B-I, 2.1 (1) List of Deep Well (Azapa Valley)

<Lista de Sondajes (Valle de Azapa)>

BNA CODE		CORFO CODE (1975)			COMMUNITY	LOCATION NAME	NAME OF OWNER	CONSTRUCTOR	ELEVATION (mASL)	DRILLING DEPTH (m)	WELL DEPTH (m)	SPECIFIC YIELD (m2/d)	DATE OF CONST-RUCTION
		LAT.-LONG.		NO.									
013 10	136-1	1820	7010	CA 1	ARICA	CHINCHORRO NORTE	CORFO	CORFO - 414	10.00	300	-		63/08
013 10	139-8	1820	7010	CC 1	ARICA	AP SAUCACHE	DOS	-	40.00	-	-	206.3	65/11
013 10	140-K	1820	7010	CC 2	ARICA	ESTADIO MUNICIPAL	JUNTA ADELANTO	CORFO-389	38.86	67	67	92.6	72/12
013 10	141-8	1820	7010	CC 3	ARICA	AP RETEN ESTADIO	DOS 714	CORFO-685	37.00	136	136	166.2	65/10
013 10	142-6	1820	7010	CC 4	ARICA	AP CANCHA TUCAPEL	DOS 715	CORFO-643	20.00	110	110	230.1	65/10
013 10	143-4	1820	7010	CC 5	ARICA	AP ESTADIO USA EMPL	DOS	DOS-	24.00	109	109	168.1	65/11
013 10	135-3	1820	7010	CC 6	ARICA	CEMENTERIO ARICA	CORFO	CORFO-478	23.68	33	33		72/12
013 10	144-2	1820	7010	CC 7	ARICA	EMBOTELLADORA ANDINA	EMBOT ANDINA	BONACI	28.00	-	-		64/04
013 10	145-0	1820	7010	CC 8	ARICA	ENDESA	ENDESA	CORFO-386	22.81	45	45	30.0	61/05
013 10	146-9	1820	7010	CC 9	ARICA	CHINCHORRO	CORFO	CORFO-472	4.10	30	30		64/01
013 10	147-7	1820	7010	CC 10	ARICA	PLANTA AP SAN JOSE	DOS	DOS-	8.00	-	84	98.4	
013 10	148-5	1820	7010	CC 11	ARICA	REGIMIENTO RANCAGUA	EJERCITO CHILE	CORFO-383	21.23	38	38	22.3	73/01
013 10	149-3	1820	7010	CC 12	ARICA	UNIVERSIDAD DE CHILE	CORFO	CORFO-475	6.00	30	30		64/01
013 10	150-7	1820	7010	CC 13	ARICA	CASINO ARICA	CORFO	CORFO-471	5.58	30	30		63/12
013 10	151-5	1820	7010	CC 14	ARICA	HOTEL PACIFICO	DIREC DE RIEGO	RIEGO-	4.00	30	30		54/09
013 10	133-7	1820	7010	CC 15	ARICA	AVDA. TARAPACA	JUNTA ADELANTO	CORFO-1232	23.54	50	50		73/05
013 10	126-4	1820	7010	CC 16	ARICA	AVDA AZOLA	JUNTA ADELANTO	CORF-1233	33.47	50	50		73/05
013 10	227-	1820	7010	CC 17	ARICA	ACDA. P. AGUIRRE CERDA	JUNTA ADELANTO	CORFO-1234	30.15	60	60		73/06
013 10	152-3	1820	7010	CC 18	ARICA	AVDA. CHACABUCO	JUNTA ADELANTO	CORFO-1235	14.64	50	50		73/06
013 10	131-0	1820	7010	CC 19	ARICA	LOS DUENDES	JUNTA ADELANTO	CORFO-1237	46.80	80	80		73/06
013 10	213-9	1820	7010	CC 20	ARICA	UNIVERSODA DE NORTE		D.R.	49.50	-	-		
013 10	214-7	1820	7010	CC 21	ARICA	HOSPITAL			25.00	-	-		
013 10	153-1	1820	7010	CD 1	ARICA	PAGO DE GOMEZ	MARIO FIGUEROA	-	117.00	-	50		55/
013 10	154-K	1820	7010	CD 2	ARICA	PAGO GOMEZ ALGODONAL	S.NADER JORRAT	-	108.87	-	47		58/
013 10	155-8	1820	7010	CD 3	ARICA	PAGO GOMEZ ALGARROBA	S NADER JORRAT	-	109.84	-	50		67/
013 10	156-8	1820	7010	CD 4	ARICA	CONSULADO ITALIANO	JANIS KANEPA	-	109.86	-	39		66/
013 10	157-4	1820	7010	CD 5	ARICA	AP. ALGODONAL	DOS 491	DOS-491	106.89	105	105	83.4	62/05
013 10	158-2	1820	7010	CD 6	ARICA	AP. AZAPA	DOS 492	DOS-492	111.03	-	-		
013 10	159-0	1820	7010	CD 7	ARICA	AP. AZAPA	DOS 40	RIEGO-	108.30	57	57	102.0	47/09
013 10	160-4	1820	7010	CD 8	ARICA	AP. AZAPA	DOS 48	RIEGO-	110.25	55	55	682.1	47/08
013 10	161-2	1820	7010	CD 9	ARICA	AP AZAPA	DOS 434	-	103.83	62	62	170.4	60/04
013 10	162-0	1820	7010	CD 10	ARICA	PAGO DE GOMEZ	SUC NEVERMAN		100.19				
013 10	163-9	1820	7010	CD 11	ARICA	AP AZAPA	DOS 186	CAS	103.00	79	79	115.5	
013 10	106-K	1820	7010	CD 12	ARICA	PARCELA ALGODONAL	J W HULES	CORFO-452	90.44	96	96		70/09
013 10	164-7	1820	7010	CD 13	ARICA	MOTEL AZAPA	UHRCEK		86.00				80/
013 10	165-5	1820	7010	CD 14	ARICA	AP SAUCACHE	DOS 568	CORFO-406	54.99	110	110	448.0	62/04
013 10	166-3	1820	7010	CD 15	ARICA	AP SAUCACHE	DOS 650	DOS 650	54.40	85	85	1080.0	63/10
013 10	167-1	1820	7010	CD 16	ARICA	AP SAUCACHE	DOS 569	CORFO-407	50.00	110	110	505.5	62/05
013 10	138-0	1820	7010	CD 17	ARICA	AP SAUCACHE	DOS	CORFO-434	47.23	69	69		60/
013 10	128-0	1820	7010	CD 18	ARICA	OLIVARERA AZAPA	SOCOAGRO	CORFO-512	46.25	83	83	41.1	71/01
013 10	130-2	1820	7010	CD 19	ARICA	OLIVARERA AZAPA	SOCOAGRO	CORFO-334	44.31	78	78	227.4	72/11
013 10	132-9	1820	7010	CD 20	ARICA	VIDRIERIA ARGENTINA	CORFO	CORFO-1084	31.82	59	59		71/
013 10	168-K	1820	7010	CD 21	ARICA	REFINADORA DE AZUFRE	CORFO	CORFO-1061	35.00	58	58		71/
013 10	169-8	1820	7010	CD 22	ARICA	QUEBRADA ACHA	JUNTA ADELANTO	CORFO-1214	71.28	110	110		73/10
013 10	170-1	1820	7010	CD 23	ARICA	LA VERBENA	JUNTA ADELANTO	CORFO-1236	59.58	70	70		73/06
013 10	110-8	1820	7010	CD 24	ARICA	SAUCACHE	JUNTA ADELANTO	CORFO-1203	67.35	110	110		73/06
013 10	111-6	1820	7010	CD 25	ARICA	AVDA. BALMACEDA	JUNTA ADELANTO	CORFO-1229	57.72	60	60		73/07
013 10	118-3	1820	7010	CD 26	ARICA	AVDA. LOA	JUNTA ADELANTO	CORFO-1230	41.03	50	50		73/07
013 10	119-1	1820	7010	CD 27	ARICA	AVDA. GONZALO CERDA	JUNTA ADELANTO	CORFO-1231	43.08	50	60		73/07
013 10	171-K	1820	7010	CD 28	ARICA	QUEBRADA ACHA	JUNTA ADELANTO	CORFO-1273	74.43	100	100	474.1	73/09
013 10	172-8	1820	7010	CD 29	ARICA	QUEBRADA ACHA	JUNTA ADELANTO	CORFO-1274	67.46	105	105		73/09
013 10	137-K	1820	7010	CD 30	ARICA	QUEBRADA ACHA	JUNTA ADELANTO	CORFO-1262	67.93	106	106	388.8	73/12
013 10	108-6	1820	7010	CD 31	ARICA	QUEBRADA ACHA	JUNTA ADELANTO	CORFO-1252	73.99	100	100	167.8	73/12
013 10	109-4	1820	7010	CD 32	ARICA	ALGODONAL	JUNTA ADELANTO	CORFO-1296	92.28	102	102	90.0	74/04
013 10	229-	1820	7010	CD 33	ARICA	AP AZAPA	DOS	HIDROSAM	112.00	90	90	293.9	87/
013 10	230-	1820	7010	CD 34	ARICA	AP AZAPA	DOS	HIDROSAM	109.38	90	90	137.4	87/
013 10	231-	1820	7010	CD 35	ARICA	AP AZAPA	DOS	HIDROSAM	103.53	90	90	238.3	87/
013 10	232-	1820	7010	CD 36	ARICA	AP AZAPA	DOS	HIDROSAM	110.89	90	90	490.9	87/
013 10	244-	1820	7010	CD 37	ARICA	LOTEO ALGODONAL	YUSEFF M. SIU-ANTUM		106.11	45			81/
013 10	245-	1820	7010	CD 38	ARICA	PARCELA 26 ALGODONAL	P. CESPEDES		108.75				84/
013 10	246-	1820	7010	CD 39	ARICA	PARCELA 13 ALGODONAL	K. JOOMG K.		101.25	48			73/
013 10	247-	1820	7010	CD 40	ARICA	PARCELA 16 ALGODONAL	ENRIQUE BORQUEZ		105.00				87/
013 10	248-	1820	7010	CD 41	ARICA	PARCELA 24 ALGODONAL	JORGE BORQUEZ		104.50				
013 10	249-	1820	7010	CD 42	ARICA	PARCELA 30 ALGODONAL	BARBATO-NUNEZ-QUINT		101.39				
013 10	250-	1820	7010	CD 43	ARICA	PARCELA 20 ALGODONAL	PETRONEO GRECO		100.00				
013 10	251-	1820	7010	CD 44	ARICA	ALGODONAL	MARIO KOTESKY		91.38	50			83/
013 10	252-	1820	7010	CD 45	ARICA	SAUCACHE	MARIO CHANG	CHANG	80.80	50			83/
013 10	253-	1820	7010	CD 46	ARICA	EL PEDREGAL-ACHA	EJERCITO DE CHILE		71.43	100			73/
013 10	254-	1820	7010	CD 47	ARICA	AZAPA 3190	SOTO		56.67				
013 10	255-	1820	7010	CD 48	ARICA	SAUCACHE	MARIO CHANG	CHANG	72.70	40			
013 10	256-	1820	7010	CD 49	ARICA	SAUCACHE	MARIO CHANG	CHANG	80.30	50			83/
013 10	257-	1820	7010	CD 50	ARICA	AZAPA 4120	A. WORM		76.87				
013 10	258-	1820	7010	CD 51	ARICA	OCURICA Y LEOMOR	NEVERMAM	NEVERMAM	98.00	37.8			86/
013 10	261-	1820	7010	CD 52	ARICA	LA PORTRICA	T. NUNEZ		117.50				
013 10	262-	1820	7010	CD 53	ARICA	TOURIST RANCH	H. LAGOS		117.50	30			86/
013 10	263-	1820	7010	CD 54	ARICA	ACEITUNAS PUCARA	PRIETO		93.43	43			87/
013 10	264-	1820	7010	CD 55	ARICA	PARCELA JUAN MARCELO	JULIO PANIAGUA		85.71				87/
013 10	173-8	1820	7010	DC 1	ARICA	PAGO GOMEZ STA LUCIA	SUC YANULAQUE	-	126.86	60	-		58/
013 10	174-4	1820	7010	DC 2	ARICA	PAGO GOMEZ	HUGO MOZO	-	128.22	51	51		52/
013 10	175-2	1820	7010	DC 3	ARICA	PAGO GOMEZ	S. NADER JORRAT	RIEGO-1062	129.95	73	73		56/07
013 10	121-3	1820	7010	DC 4	ARICA	CINCO OLIVOS	JUNTA ADELANTO	CORFO-1308	126.70	110	110	108.0	74/07
013 10	122-1	1820	7010	DC 5	ARICA	CINCO OLIVOS	JUNTA ADELANTO	CORFO-1317	127.80	110	110		74/07
013 10	215-5	1820	7010	DC 6	ARICA	LAS PALMERAS	E. YANULAQUE		161.71	40	-		64/
013 10	242-	1820	7010	DC 7	ARICA	PAGO DE GOMEZ	ABUD GUTIERREZ		130.00	38			
013 10	120-9	1830	7000	AA 1	ARICA	CHUNGAL SANTA PABLA	ISIDORO ANDIA	RIEGO-	323.21	52	-		58/03
013 10	115-8	1830	7000	AA 2	ARICA	CERRO MORENO	AMADEO CARBONE	RIEGO-	314.54	45	45		56/05
013 10	112-4	1830	7000	AA 3	ARICA	DIRECCION DE RIEGO	DIREC DE RIEGO	RIEGO-	306.01	31	30		
013 10	113-2	1830	7000	AA 4	ARICA	LAS RIVERAS MADRID	DIREC DE RIEGO	RIEGO-	291.65	-	-	1080.0	73/04
013 10	101-8	1830	7000	AA 5	ARICA	LAS RIVERAS MADRID	DIREC DE RIEGO	RIEGO	289.40	105	-		
013 10	216-3	1830	7000	AA 6	ARICA	LAS RIVERAS	D.O.S.	CELZAC-1678	280.00	25	25	205.7	80/03
013 10	233-	1830	7000	AA 7	ARICA	CHUNGAL SANTA PABLA	ISIDORO ANDIA		324.14				
013 10	176-0	1830	7000	AC 1	ARICA	CHUNGAL SANTA GEMA	SUC BARRIENTOS	RIEGO-1073	345.98	24	-	23.7	56/03
013 10	225-	1830	7000	AC 2	ARICA	FACUNDO GUTIERREZ		RIEGO-1072	365.30	38	38		56/01
013 10	177-9	1830	7000	AD 1	ARICA	CABUZA 1C	DIREC DE RIEGO	RIEGO-	440.00	-	-	403.2	53/05
013 10	178-7	1830	7000	AD 2	ARICA	CABUZA 5E	DIREC DE RIEGO	RIEGO-	432.00	52	52		

Table B-I, 2.1 (2) List of Deep Well (Azapa Valley)

<Lista de Sondajes (Valle de Azapa)>

SNA CODE		CORFO CODE (1975)				COMMUNITY	LOCATION NAME	NAME OF OWNER	CONSTRUCTOR	ELEVATION (mASL)	DRILLING DEPTH (m)	WELL DEPTH (m)	SPECIFIC YIELD (m3/d)	DATE OF CONSTRUCTION
		LAT.-LONG.		NO.										
013 10	100-0	1830	7000	AD	3	ARICA	CABUZA 1A	DIREC DE RIEGO	RIEGO-	432.87	57	-	785.5	73/05
013 10	118-7	1830	7000	AD	4	ARICA	CABUZA 3F	DIREC DE RIEGO	RIEGO-	433.81	71	71	777.6	
013 10	117-5	1830	7000	AD	5	ARICA	CABUZA 2B	DIREC DE RIEGO	RIEGO-	434.03	137	137	168.0	53/10
013 10	179-5	1830	7000	AD	6	ARICA	CABUZA G	DIREC DE RIEGO	RIEGO-	433.23	55	-		57/05
013 10	180-9	1830	7000	AD	7	ARICA	CABUZA 9H	DIREC DE RIEGO	RIEGO-	434.34	-	-		
013 10	181-7	1830	7000	AD	8	ARICA	CABUZA 4D	DIREC DE RIEGO	RIEGO-	434.82	39	39		64/01
013 10	182-5	1830	7000	AD	9	ARICA	CHUNGAL	S. QUINA TRUFFA	RIEGO-	382.04		-		
013 10	183-3	1830	7000	AD	10	ARICA	SOBRAYA	CORFO	CORFO-470	-	300	-		64/10
013 10	184-1	1830	7000	AD	11	ARICA	SOBRAYA	CORFO	CORFO-573	-	90	-		
013 10	185-K	1830	7000	AD	12	ARICA	SOBRAYA	CORFO	CORFO-594	-	84	84		66/10
013 10	226-	1830	7000	AD	13	ARICA	ESCUELA CHITITA M 28	I. MUNICIPALIDAD ARICA		-		-		
013 10	186-8	1830	7010	AB	1	ARICA	AP AZAPA	DOS 184	CAS-	112.18	67	67	183.8	59/11
013 10	187-6	1830	7010	AB	2	ARICA	AP AZAPA	DOS 47	RIEGO-	111.50	45	45	363.8	47/09
013 10	188-4	1830	7010	AB	3	ARICA	AP AZAPA	DOS 185	CAS-	112.75	53	53	182.3	
013 10	189-2	1830	7010	AB	4	ARICA	HACIENDA BUENA VISTA	R DEFLIPPES	CORFO-304	-	83	-		
013 10	190-6	1830	7010	AB	5	ARICA	HACIENDA BUENA VISTA	R DEFLIPPES	CORFO-552	97.97	110	110	52.3	68/01
013 10	191-4	1830	7010	AB	6	ARICA	HACIENDA BUENA VISTA	R DEFLIPPES	CORFO-415	100.00	36	-		62/02
013 10	192-2	1830	7010	AB	7	ARICA	HACIENDA BUENA VISTA	R DEFLIPPES	RIEGO-	97.74	52	39		46/06
013 10	193-0	1830	7010	AB	8	ARICA	HACIENDA BUENA VISTA	R DEFLIPPES	CORFO-416	80.00	105	70	84.4	73/01
013 10	217-1	1830	7010	AB	9	ARICA	HACIENDA BUENA VISTA	R DEFLIPPES	RIEGO	92.00	29	-		58/04
013 10	224-4	1830	7010	AB	10	ARICA	HDA. S.JUAN DE OCURRIR			121.25		-		
013 10	267-	1830	7010	AB	11	ARICA	AP AZAPA	DOS	HIDROSAN	111.00	90	90		87/
013 10	228-	1830	7010	AB	12	ARICA	AP AZAPA	DOS	HIDROSAN	113.33	92	92		87/
013 10	243-	1830	7010	AB	13	ARICA	HACIEMOR BUENA VISTA	CONTRERAS		90.00				
013 10	194-9	1830	7010	AD	1	ARICA	QUEBRADA ACHA	CORFO	CORFO-450	-	88	-		63/10
013 10	195-7	1830	7010	BA	1	ARICA	LAS MAITAS VIOLETA	RICARDO FERNAN	-	192.95		-		
013 10	103-5	1830	7010	BA	2	ARICA	LAS MAITAS VIOLETA	CORFO	CORFO-378	188.00	341	341	28.1	73/01
013 10	196-5	1830	7010	BA	3	ARICA	LAS ANIMAS	HUGO MOZO	RIEGO-1097	178.69	51	51		58/04
013 10	197-3	1830	7010	BA	4	ARICA	FUNDO LAS ANIMAS	HUGO MOZO	CORFO-370	181.81	175	175	108.9	73/03
013 10	107-8	1830	7010	BA	5	ARICA	LAS ANIMAS	A GARDILCIC	RIEGO-1083	180.70	45	45		56/09
013 10	125-6	1830	7010	BA	6	ARICA	PAGO GOMEZ SAN ELIAS	JUSEFF NADER	RIEGO-1086	151.90	50	50		57/03
013 10	123-K	1830	7010	BA	7	ARICA	PAGO GOMEZ SAN ELIAS	JUSEFF NADER	RIEGO-	154.00	50	-		68/
013 10	198-1	1830	7010	BA	8	ARICA	PAGO GOMEZ SAN ELIAS	HUGO MOZO	RIEGO-1042	140.77	51	45		53/10
013 10	199-K	1830	7010	BA	9	ARICA	LAS PALOMAS	REINALDO ORDON	CORFO-1002	135.29	45	45	180.0	71/01
013 10	104-3	1830	7010	BA	10	ARICA	LAS VARGAS	CARLOS BUNEDER	CORFO-389	131.77	68	68	460.8	61/10
013 10	105-1	1830	7010	BA	11	ARICA	PAGO GOMEZ L. PALOMAS	CARLOS BUNEDER	RIEGO-1028	133.98	46	46		52/02
013 10	200-7	1830	7010	BA	12	ARICA	LAS MACHORRAS	REINALDO ORDON		126.26	46	46	288.0	73/04
013 10	201-5	1830	7010	BA	13	ARICA	COLONIA BELLAVISTA	COLO BELLAVISTA	RIEGO-1015	124.12		-		
013 10	202-3	1830	7010	BA	14	ARICA	REINALDO ORDONEZ	JUNT A ADELANTO	CORFO-1213	176.86	111	-		
013 10	203-1	1830	7010	BA	15	ARICA	PAGO GOMEZ SAN JUAN	ESTEBAN GARDIC	RIEGO-1080	127.84	50	-		56/08
013 10	210-4	1830	7010	BA	16	ARICA	PAGO GOMEZ LO ANDRADE	ERNESTO LOMBAR		-		-		
013 10	211-2	1830	7010	BA	17	ARICA	PAGO GOMEZ LA GONDOLA	RAIMUNDO CENTE		132.29		-		54/
013 10	218-K	1830	7010	BA	18	ARICA	LAS ANIMAS	D.O.S. 1216	CELZAC-1436	178.80	90	-		78/11
013 10	219-8	1830	7010	BA	19	ARICA	LAS CARMENES	R. BLAMEY		182.59		-		59/
013 10	220-1	1830	7010	BA	20	ARICA	PAGO GOMEZ L. PALOMAS	S. ORDONEZ		134.64		-		
013 10	221-K	1830	7010	BA	21	ARICA	PLANTA P. GOMEZ	DOS 1113	CELZAC-1365 P	148.84	87	-	256.9	
013 10	222-8	1830	7010	BA	22	ARICA	PLANTA P. GOMEZ	DOS 1114	CELZAC-1367 P	148.00	100	-	380.2	
013 10	223-6	1830	7010	BA	23	ARICA	PLANTA P. GOMEZ	DOS 1142	CELZAC-1372 P	150.95	97	-		75/
013 10	237-	1830	7010	BA	23	ARICA	VIDOVAGORA	BEZMALINOVIC		181.56				86/
013 10	238-	1830	7010	BA	23	ARICA	VIDOVAGORA	BEZMALINOVIC		173.93				86/
013 10	239-	1830	7010	BA	23	ARICA	PONGO	CARLOS MOZO		147.19				
013 10	240-	1830	7010	BA	23	ARICA	PAGO DE GOMEZ	A.BUNEDER		158.00				
013 10	241-	1830	7010	BA	23	ARICA	OLIVO	DOS		180.00				
013 10	259-	1830	7010	BA	23	ARICA	SAN AGUSTIN	PALZA		198.13	50			
013 10	204-K	1830	7010	BB	1	ARICA	LAS RIVERAS	AMADEO CARBON	RIEGO-1076	278.00	45	45		56/06
013 10	134-5	1830	7010	BB	2	ARICA	COLONIA JUAN NOE	COLONIA J. NOE	CORFO-372	261.45	80	80	69.1	73/03
013 10	205-8	1830	7010	BB	3	ARICA	COLONIA JUAN NOE	COLONIA J. NOE	RIEGO-1016	249.05	50	50	2990.8	47/05
013 10	206-6	1830	7010	BB	4	ARICA	COLONIA JUAN NOE	COLONIA J. NOE	RIEGO-1023	248.46	48	48	762.4	51/10
013 10	207-4	1830	7010	BB	5	ARICA	COLONIA JUAN NOE	COLONIA J. NOE	RIEGO-1026	247.48	51	51	86.4	61/11
013 10	102-7	1830	7010	BB	6	ARICA	COLONIA JUAN NOE	COLONIA J. NOE	RIEGO-1029	247.87	49	49	275.9	52/03
013 10	208-2	1830	7010	BB	7	ARICA	COLONIA JUAN NOE	COLONIA J. NOE	RIEGO-1032	252.38	55	55	506.1	52/06
013 10	114-0	1830	7010	BB	8	ARICA	PARCELA 16	COLONIA J. NOE	RIEGO-1036	230.59	50	50	363.8	52/07
013 10	209-0	1830	7010	BB	9	ARICA	LAS MAITAS SANTA ANA	JUAN FOCACIC	BONACI-	218.87		-		
013 10	124-8	1830	7010	BB	10	ARICA	LAS MAITAS	F MARINI	RIEGO-1081	205.49	47	46		58/10
013 10	212-0	1830	7010	BB	11	ARICA	LAS MAITAS	EDO. CHONG		207.94	60	-		50/
013 10	265-	1830	7010	BB	12	ARICA	SAN MIGUEL	DOS 1472		248.00				
013 10	266-	1830	7010	BB	13	ARICA	SAN MIGUEL	DOS 1471		248.33				
013 10	234-	1830	7010	BB	14	ARICA	COLONIA JUAN NOE	COLONIA JUAN NOE		262.50				
013 10	235-	1830	7010	BB	15	ARICA	PUEBLO SAN MIGUEL	DOS	AP.RURAL	255.00				86/
013 10	236-	1830	7010	BB	16	ARICA	VIVERO SAN MIGUEL	MANUEL CABRERA		251.87				86/
013 10	260-	1830	7010	BB	17	ARICA	LAS ANIMAS	ROXANA GANCILIC		199.57				

SOURCE: < 1 and <2

Table B-I, 2.2 (1) List of Dug Well (Azapa Valley)

<Lista de Noria (Valle de Azapa)>

NO.	LOCATION	NAME OF OWNER	CONSTRUCTOR	USE	ELEVATION (m ASL)	DEPTH (m)	STATIC LEVEL(m)	DYNAMIC LEVEL(m)	YIELD (l/sec)	DATE OF CONSTRUCTION
1	ARICA NORTE	PLAYA CHINCHORRO		AB	(10,0)		1,23			
2	ARICA NORTE	PLAYA CHINCHORRO		AB	8,9		0,80			
3	ARICA NORTE	PLAYA CHINCHORRO		P	(3,0)	2,00	1,02		M	
4	ARICA NORTE	PLAYA CHINCHORRO		P	(3,0)	3,00	2,09		M	
5	ARICA NORTE	PLAYA CHINCHORRO		P	(3,1)	1,90	1,23		M	
6 *	ARICA		GALLO	SU	3,0					
7 *	CERRO CHUNO	CHUNO	O.PEREZ	SU	(30,0)					1920
8 *	CERRO CHUNO	ENAMI	ENAMI	SU	(20,0)					
9	ARICA NORTE	BARRIO INDUSTRIAL	CORMET	SU	24,5	28,70	18,44			
10	ARICA NORTE	BARRIO INDUSTRIAL	EDELNOR	TA	2,3					
11	ARICA NORTE	RIO SAN JOSE	PAREDES	TA						1989
12	ARICA VELASQUEZ	HOTEL EL PASO	H.EL PASO	R	(7,0)	9,00	5,33			
13 *			MARIA GALINDO		(6,0)					
14	KM 4,0 P.GOMEZ	HIJUELA 14	ALVARADO	SU	(118,7)		S			1963
15	KM 4,0 P.GOMEZ	LA PORTADA	T.NUNEZ	SONO 261	(118,4)		23,33			
16	KM 4,0 P.GOMEZ	MARAVILLA	M.SALAS	SU	(116,7)	12,00	S			
17 *			CANEPA							
18	KM 3,3 P.GOMEZ	OCURICA Y LEONOR	NEVERMAN	TA	(102,2)					
19	KM 4,0 P.GOMEZ	LA PORTADA	T.NUNEZ	SU	(113,8)		S			1968
20	KM 2,5 SAUCACHE	SAN GABRIEL	S.CAVALAN	SU	95,8					1964
21	KM 2,5 SAUCACHE	ACEITUNAS PUCARA	PRIETO	SONO 263	(92,8)					
22	KM 2,5 SAUCACHE	COLCHAGUA	SUC. LY	SU	(90,5)	30,00	S			1967
23	KM 2,5 SAUCACHE	COLCHAGUA	SUC. LY	SU	(89,3)	20,00	S			
24	KM 2,5 SAUCACHE	ESTADIO ITALIANO	COM.ITALIANA	R	(86,9)					
25	KM 2,5 SAUCACHE	VILLA VERONA	H.PERI	TA						1964
26	KM 2,0 SAUCACHE	JUAN MARCELO	J.PANIAGUA	SONO 264	(83,7)		20,53			
27	KM 2,5 SAUCACHE	OCURICA Y LEONOR	NEVERMAN	TA	(90,0)					1958
28	KM 2,5 SAUCACHE	OCURICA Y LEONOR	NEVERMAN	TA	(88,0)					1944
29	KM 2,5 SAUCACHE	LOS MOLINOS	T.TORO	TA	(86,8)					1964
30	KM 2,5 SAUCACHE	LOS MOLINOS	T.TORO	AB						
31	KM 2,5 SAUCACHE	LOS MOLINOS	T.TORO	TA						
32	KM 1,5 SAUCACHE	PARCELA SAN LUIS	D.DEVOTO	SU	(76,1)		S			1940
33	KM 1,5 SAUCACHE	PARCELA SAN LUIS	D.DEVOTO	SU	(76,3)		S			1938
34	KM 1,0 SAUCACHE	PARCELA SAN LUIS	D.DEVOTO	TA	75,8					
35	KM 1,5 SAUCACHE	AZAPA 4120	A.WORM	SONO 257			28,40			
36	KM 1,5 SAUCACHE	AZAPA 4160	R.AGUIRRE	R	(76,6)	40,00	26,56		2,00	1970
37	KM 1,5 SAUCACHE		SUC.SANCHEZ	AB	(78,4)					1950
38	KM 2,0 SAUCACHE	CHABELITA	C.CRIGNOLA	SU	(82,5)	30,00	24,45			1960
39	KM 1,5 SAUCACHE		M.CHANG	SONO 256	81,3	50,00	25,09			
40	KM 2,0 SAUCACHE		CORA	TA						
41	KM 0,5 SAUCACHE		RUIZ							
42	KM 1,0 SAUCACHE	VILLA OLGUITA	COLEGIO ALEMAN	SU	(70,6)	50,00	33,88			1965
43	ARICA SAUCACHE	QUEBRADA LA HIGUERA	ALVARADO	SU	62,3	30,00	S			1960
44	CERRO CHUNO	RENATO ROCA 1999	YPFB	SU	36,0	27,00	18,86			1961
45	ARICA NORTE	BARRIO INDUSTRIAL	PEREZ		30,0					
46	KM 7,0 LAS ANIMAS	LAS CARMENES	RINA BLANEY	SU	(168,0)	18,00	7,79			
47	KM 6,5 PAGO GOMEZ	LOS ALAMOS	SUC.FERNANDEZ	SU	(152,6)	20,00	10,55			1925
48	KM 6,5 PAGO GOMEZ	EL GALLITO	J.CESPEDES	R	(153,5)	23,00	13,83			1958
49	KM 6,5 PAGO GOMEZ	PONGO	CARLOS MOZO	AB	(150,9)	15,00	S			1960
50	KM 6,5 PAGO GOMEZ	LAS PALMERAS	E.YANULAQUE	R-P	(157,2)	38,00	10,88		8,00	1964
51	KM 6,0 PAGO GOMEZ	EL TRIANGULO	A.CORVACHO	R	(140,1)	30,00	21,56		38,00	1960
52	KM 6,0 PAGO GOMEZ	EL SAUCE	J.CESPEDES	AB	138,1	44,00	21,04			1965

Table B-I, 2.2 (2) List of Dug Well (Azapa Valley)

<Lista de Noria (Valle de Azapa)>

NO.	LOCATION	NAME OF OWNER	CONSTRUCTOR	USE	ELEVATION (m ASL)	DEPTH (m)	STATIC LEVEL(m)	DYNAMIC LEVEL(m)	YIELD (l/sec)	DATE OF CONSTRUCTION
53	KM 5,0 PAGO GOMEZ	EL LAUREL	FERNANDEZ	SU	(133,4)	26,00	23,08			
54	KM 4,5 PAGO GOMEZ	EL LAUREL	FERNANDEZ	P	(130,8)	36,00			26,75	1936
55	KM 4,5 PAGO GOMEZ		A.GUTIERREZ	SOND 242			21,72			
56	KM 4,5 PAGO GOMEZ	JUAN DE C.	BRAZ							
57	KM 4,5 PAGO GOMEZ	SANTA HELEDINA	A. SALINAS	AB	(130,5)		22,57			
58	KM 4,0 PAGO GOMEZ	ALGODONAL	YUSSEF NADER BU-ANT.	SU	(123,2)		S			
59	KM 4,0 PAGO GOMEZ	MIRANDA	SUC.SALAS	SU	122,1	40,00	23,82			
60	KM 4,5 PAGO GOMEZ	STA JUANA	J.HENRIQUEZ	TA						
61	KM 4,5 PAGO GOMEZ	STA JUANA	J.HENRIQUEZ	SU	(122,6)	37,00	23,12			1945
62	KM 16,5 CHUGAL	ROCO	PASCUAL ROCO	R	334,1	29,00	9,49		19,20	1952
63	KM 16,0 CHUGAL	DAVID	RAMOS-MOLINA	I	330,1	20,00	11,20		0,20	1965
64	KM 15,5 LAS RIVERAS	CERRO MORENO	LIDO CARBONE	P	(311,6)	20,00	5,25		0,60	1936
65	KM 15,0 LAS RIVERAS	CERRO MORENO	S.LOMBARDI	TA	300,0					
66	KM 14,5 LAS RIVERAS	CERRO MORENO	H. ANDIA	SU	301,6		4,42			1960
67	KM 13,5 LAS RIVERAS	SAN FELIPE	TALENTE	TA	293,5					1960
68	KM 13,5 LAS RIVERAS	SAN EDUARDO	R.CENTELLA	TA	292,0		S			
69	KM 13,5 LAS RIVERAS	LAS RIVERAS	SAJAMA	TA	293,3		S			1940
70	KM 13,5 LAS RIVERAS	SAN FELIPE	KU	TA	296,7		S			1944
71	KM 18,0 CHUGAL	CHUGAL	BALUARTE	TA	371,0					1955
72	KM 18,0 CHUGAL	SAN JUAN	J.CHOVAN	TA	372,5					1961
73	KM 17,5 CHUGAL	SAN MANUEL	GUTIERREZ	SU	(366,1)		10,14			1964
74	KM 17,5 CHUGAL	LA TARA	A. ESTORAICA	SU	(359,4)		10,89			
75	KM 17,5 CHUGAL	LA TARA	M.MELGAR	R	(361,5)		11,49			
76	KM 17,5 CHUGAL	SAN MARCOS	H.ROJAS	SU	354,1	28,00	12,64			1964
77	KM 17,5 CHUGAL	EL OLIVO	J. LOMBARDI	R	(353,8)	32,00	10,82		40,00	1949
78	KM 18,0 CHUGAL	STA. INES	J. LOMBARDI	R	363,0		12,25			
79	KM 20,0 CABUZA	STA. FILOMENA	H.STAGNARO	P	392,9	25,00	23,18		M	
80	KM 8,5 ALTO RAMIREZ	LA CUCANA	CHONG	TA	196,9					1959
81	KM 8,5 LAS MAITAS	SAN AGUSTIN	PALZA	SOND 259			21,30			
82	KM 8,0 ALTO RAMIREZ	LA EXOTICA	SUC. OSORIO	SU	190,0	35,00	16,92			1966
83	KM 8,0 ALTO RAMIREZ	LAS CADENAS	ALICIA PONCE	P	(186,4)	20,00	13,61			1940
84	KM 7,5 LAS ANIMAS	CRUZ BLANCA	S. FLORES	TA						
85	KM 7,5 LAS ANIMAS	LAS ANIMAS	J. YUCRA	P	186,4	30,00	19,94			1958
86	KM 7,0 ALTO RAMIREZ	LAS CADENAS	ALICIA PONCE	SU	(166,5)	8,00	S			
87 *	LAS MAITAS	SAN FERNANDO	OSORIO							
88	KM 17,0 CHUGAL	LA YARA	ENRIQUE CHANG	P	(337,9)	23,00	11,45			1946
89	KM 7,0 ALTO RAMIREZ	LA AURORA	BUITANO	SU	158,6	35,00				1944
90	KM 6,5 PAGO GOMEZ	LAS ANIMAS	YANULAQUE	R-SU	(155,3)	20,00	9,64			1960
91	KM 6,5 PAGO GOMEZ	LA PALMA	SUC ZABALA	SU	157,7	18,00	8,88			1946
92	KM 6,5 PAGO GOMEZ	LAS ANIMAS	YANULAQUE	SU	(155,6)	17,00	9,52			
93	KM 6,5 PAGO GOMEZ		CARLOS MOZO	SOND 239			18,66			
94	KM 6,5 PAGO GOMEZ		CARLOS MOZO	TA						
95 *	PAGO GOMEZ	SAN ELIAS	Y. NADER BU-ANTUN							
96	KM 6,5 PAGO GOMEZ	HACIENDA PIEMONTE	LOMBARDI	SU	(153,7)	31,00	17,76			1964
97	KM 6,5 PAGO GOMEZ	HACIENDA PIEMONTE	LOMBARDI	TA						
98	KM 6,5 PAGO GOMEZ	HACIENDA PIEMONTE	LOMBARDI	R	153,5	55,00	23,67		50,00	1967
99	KM 6,5 PAGO GOMEZ	HACIENDA PIEMONTE	LOMBARDI	R	154,8	77,00	22,12		8,00	1948
100	KM 7,0 ALTO RAMIREZ	NOVA ITALIA	LOMBARDI	R	(145,2)	63,00	27,30			1946
101	KM 7,0 ALTO RAMIREZ	NOVA ITALIA	LOMBARDI	TA						
102	KM 6,0 PAGO GOMEZ	LA PALMA	IBARRA	P	142,9	42,00	30,85		1,70	1945
103	KM 5,8 PAGO GOMEZ	LO ANDRADE	LOMBARDI	SU	(138,5)	30,00	S			1944
104	KM 4,5 PAGO GOMEZ	SAN JUAN DE OCURRIR	M. GARDILIC	SU	(122,0)	25,00	S			1950
105	KM 13,0 SAN MIGUEL	AGRADECIDA	M. CARBONE	P	201,4	17,00	5,23		5,60	1959
106 *	LAS RIVERAS	BUEN RETIRO	LOMBARDI	TA						
107	KM 13,5 LAS RIVERAS	LAS RIVERAS	E. CHONG	SU	278,7		4,70			1950
108	KM 13,0 SAN MIGUEL	SAN FCO.DE ASIS	I.BALUARTE	TA	271,6		0,54			
109	KM 12,0 LOS ALBARRACI	SAN JUAN	FOCACCI	SU	270.3	37.00	4.38			

Table B-I, 2.2 (3) List of Dug Well (Azapa Valley)

<Lista de Noria (Valle de Azapa)>

NO.	LOCATION	NAME OF OWNER	CONSTRUCTOR	USE	ELEVATION (m ASL)	DEPTH (m)	STATIC LEVEL(m)	DYNAMIC LEVEL(m)	YIELD (l/sec)	DATE OF CONSTRUCTION
110	KM 12,0 LOS ALBARRACI		BERETTA							
111	KM 12,5 SAN MIGUEL	SAN FRANCISCO	DANTE NOCE	AB	266,8	20,00	30,00			1945
112	KM 12,5 SAN MIGUEL	PARCELA 36 Y 37	A. CENTELLA	SU	(269,0)	20,00	17,65			1963
113	KM 11,0 LOS ALBARRACI	SAN LORENZO	FOCACCI	AB	248,3	10,00	S			
114	KM 11,5 LOS ALBARRACI	LA RINCONADA	GUTIERREZ	SU	236,9	33,00	18,34			1964
115	KM 10,5 LAS MAITAS	LA HUERTA	FOCACCI	SU	(226,6)	67,00	28,33			1948
116	KM 10,5 LAS MAITAS	LA HUANCA	E.ALMONTE	AB	228,2	20,00	S			1943
117	KM 10,5 LAS MAITAS	LA HUANCA	SAUL OVIEDO	P	220,9	36,00	23,04		1,50	1987
118	KM 10,5 LAS MAITAS	SAN.ISIDRO	SUC. ISHIHARA	SU	(221,0)	38,00	22,59			1942
119	KM 9,0 LAS ANIMAS	PARCELA 30	A. TORRES	SU	(203,5)	20,00	18,04			
120	KM 8,5 LAS ANIMAS		ROXANA GARDILIC	SOND 260	199,5		18,36			
121	KM 8,5 LAS ANIMAS		TORRES							
122	KM 12,0 SAN MIGUEL		COLONIA J. NOE		250,3					
123	KM 13,0 SAN MIGUEL	SAN FCO.DE ASIS	I. BALUARTE	P	274,9	12,00	4,56		1,70	1986
124	KM 15,0 LAS RIVERAS	QUEBRADA DEL DIABLO	M. CARBONE	R	302,4	11,00	9,52		4,00	
125	KM 14,0 LAS RIVERAS	PARCELA 1	MARIA SOTO	P	(286,1)	12,00	1,00			
126	KM 15,8 LAS RIVERAS	LAS RIVERAS	A. CARBONE	P	(317,8)	17,00	6,52			1983
127	KM 15,5 LAS RIVERAS	CHIRINOS	CHIRINOS	P	(317,9)		5,65			
128	ARICA CHINCHORRO	LAS DUNAS	DOROTEA SORTA	P	(4,5)		2,04			
129	ARICA CHINCHORRO	RESTAURANT B. COJO	DOROTEA SORTA	P	(4,5)	2,50	1,58			
130	ARICA CHINCHORRO	RESTAURANT B. COJO	DOROTEA SORTA	P	(4,5)	3,00	1,46			1958
131	ARICA CHINCHORRO	LAS DUNAS	DOROTEA SORTA	SU	(4,5)		1,40			
132	ARICA CHINCHORRO	LAS DUNAS	CLINICA VETERINARIA	SU	(4,5)		1,22			
133	KM 17,0 CHUGAL	PLANTA TOMATIN	LOMBARDI	I	(352,2)	14,00	12,04		7,00	
134	KM 17,0 CHUGAL	PLANTA TOMATIN	LOMBARDI	SU	(350,0)	10,00	S			
135	KM 16,0 CHUGAL	SAN ANTONIO		SU	(327,4)	12,00	9,62			1985
136	KM 2,5 SAUCACHE	COLEGIO SAN JORGE	COLEGIO	SU	(89,8)	50,00	22,70			1984
137	KM 2,5 SAUCACHE		R. OHACO	R	(92,7)		23,60			
138	KM 2,5 SAUCACHE			P	(94,6)					
139	KM 3,3 PAGO GOMEZ	OCURICA Y LEONOR	NEVERMAN	SU	(101,7)		24,73			
140	KM 3,5 ALGODONAL	PARCELA 25 Y 33	C. CESPEDES	R	(105,1)	40,00	24,77		8,50	
141	KM 3,5 ALGODONAL	PARCELA 43	C. FOCACCI	P	(107,7)	32,00		24,84	0,80	
142	KM 3,5 ALGODONAL	LOTEO ALGODONAL	PAUL BIRO	P	(107,6)	28,00	24,06		1,00	
143	KM 3,5 ALGODONAL	LOTEO ALGODONAL	PAUL BIRO	P	(108,0)	30,00	24,27		1,50	
144	KM 3,5 ALGODONAL	LOTEO ALGODONAL	VELEZ	SU	(105,1)		23,88			
145	KM 3,5 ALGODONAL	LOTEO ALGODONAL	S. DONOSO	P	(102,6)	38,00	23,10		1,70	
146	KM 3,0 ALGODONAL	PETORCA 5809	C. RAMIREZ	P	(98,5)	40,00	29,26		3,00	
147	KM 3,0 ALGODONAL	PARCELA 19	E. LEIVA	SU	(95,1)	25,00	S			
148	KM 3,5 ALGODONAL	PARCELA 48	D. CROSSA	SU	(104,6)	16,00	S			
149	KM 3,5 ALGODONAL	PARCELA 49	G. VICENCIO	R	(105,8)	35,00	24,70		1,00	
150	KM 3,5 ALGODONAL		P. BEOVIC	SU	(101,0)		24,76			
151	KM 3,5 ALGODONAL	PARCELA 28	R. CORTES	R	(95,0)	25,00	21,71			
152	KM 3,5 ALGODONAL				(100,1)		24,08			1988
153	KM 3,5 ALGODONAL	PARCELA 29	ANDRES	P	(99,0)					
154	KM 3,5 ALGODONAL		V. SABA	P	(101,8)					
155	KM 3,5 ALGODONAL	PARCELA 23	OTTO KOCH	SU	(104,8)	14,00	S			
156	KM 3,5 ALGODONAL	CENTRO ESPANOL	COM. ESPANOLA							
157	KM 3,0 ALGODONAL	LAS CANAS 2198	M. PEREZ	P	(94,9)	35,00	28,26		2,00	
158	KM 3,0 ALGODONAL	COMBARBALA 2036	PIO LOPEZ	R	(99,0)	38,00			1,50	
159	KM 3,0 ALGODONAL	PARCELA 2	A. SOLARI	R	(100,0)	35,00	30,45		5,50	
160	KM 2,5 SAUCACHE		R. CASTRO	R	(96,0)	34,00	25,40		1,50	
161	KM 2,5 SAUCACHE	LOS ITALIANOS 2090	MARCO A.AGUIRRE	R	(89,8)	32,00	22,41			
162	KM 2,5 SAUCACHE	LOS ITALIANOS 2110	E.AUTRAN	R	(88,2)	30,00		22,98	1,00	
163	ARICA SAUCACHE	PANAMERICANA 2831	M.CALVANESE	SU	(61,4)	25,00	S			
164	KM 2,0 CAMPO VERDE	PARCELA 419	C.NORAMBUENA	P	(82,0)		24,92			1986
165	KM 2,0 CAMPO VERDE	PARCELA 6	LOBERA	SU	(77,3)		25,68			1986
166	KM 2,0 CAMPO VERDE	PARCELA 8	NARDAKOLSKI	SU	(76,3)	20,00				1986

Table B-I, 2.2 (4) List of Dug Well (Azapa Valley)

<Lista de Noria (Valle de Azapa)>

NO.	LOCATION	NAME OF OWNER	CONSTRUCTOR	USE	ELEVATION (m ASL)	DEPTH (m)	STATIC LEVEL(m)	DYNAMIC LEVEL(m)	YIELD (l/sec)	DATE OF CONSTRUCTION
167	KM 2,0 CAMPO VERDE		F. BRITO	SU	(78,3)					1988
168	ARICA SAUCACHE	ROTONDA AZAPA	B. AROS	SU	(60,3)	16,00	S			
169	ARICA SAUCACHE	ROTONDA AZAPA	HOTEL P.DE ASTURIAS	SU	(59,5)		34,13			1987
170	ARICA SAUCACHE	CAMPUS SAUCACHE	U. DE TARAPACA	SU	(46,0)	28,00	S			
171	KM 45,0	ESCUELA ALBODONAL	SERME ARICA	P		53,00	S		0,80	
172	KM 30,0 CASAGRANDE	PARCELA AZAPA	EJERCITO DE CHILE	P		12,00	4,00		5,00	
173	KM 30,0 CASAGRANDE	PARCELA AZAPA	EJERCITO DE CHILE	SU			5,30			
174	ARICA NORTE	PLAYA CHINCHORRO		SU	(3,0)	2,00	1,00			
175	ARICA NORTE	BARRIO INDUSTRIAL	GENERAL MOTORS	P-I	(26,2)			22,54		
176	ARICA NORTE	BARRIO INDUSTRIAL	BOTTAI HNOS.	I	(28,3)		22,05		4,20	
177	ARICA VELASQUEZ	HOTEL EL PASO	HOTEL EL PASO	R	(5,9)		3,81			
178	ARICA VELASQUEZ	HOTEL EL PASO	HOTEL EL PASO	R	(6,0)	8,00	3,75			
179	ARICA CENTRO	LAVANDERIA MODERNA	LAVAND. MODERNA	I	(11,7)		7,95		2,00	
180	KM 2,5 SAUCACHE	SAN GABRIEL	S. CAVALAN	R-P	(96,0)		22,67		1,50	
181	KM 2,5 SAUCACHE	LOS MOLINOS	T. TORO	R	(82,1)	30,00	22,20		3,30	
182	KM 2,5 SAUCACHE	LOS MOLINOS	T. TORO	R	(86,0)	25,00	24,07			
183	KM 2,5 SAUCACHE	AVICOLA DONOSO	DONOSO	SU	(83,0)		24,72			
184	KM 1,5 SAUCACHE	PARCELA SAN LUIS	D. DEVOTO	R	(77,0)	39,40	29,44			
185	KM 2,5 SAUCACHE	VILLA PAULITA	S. PELISARE	SU	(85,5)	30,00	21,17			1986
186	KM 1,5 SAUCACHE	SAUCACHE	MONTALVO	SU	(77,6)		27,60			1980
187	KM 2,5 CAMPO VERDE	PARCELA 8-STA. CLARA	H. HERNANDEZ	SU	(85,5)	27,00	21,65			1986
188	KM 2,0 CAMPO VERDE	PARCELA 2	GERARDO DIAZ	R	(74,3)	32,00	25,09			1986
189	KM 4,5 PAGO GOMEZ	STA. MELEDINA	ABULEME	P	(130,6)	27,00	22,98		1,00	1987
190	KM 4,5 PAGO GOMEZ	LA HUERTECITA	J. HORTA	SU	(128,7)	27,00	23,02			1986
191	KM 4,5 PAGO GOMEZ	LA HUERTECITA	F. DURAN	R	(128,5)	27,00	22,80		1,00	1986
192	KM 15,0 LAS RIVERAS	CERRO MORENO	SERAFINA LOMBARDI	R	(301,3)		2,08		8,30	1984
193	KM 7,0 ALTO RAMIREZ	PARCELA 22	E. AVACA	P	(165,2)	10,80	4,05			
194	KM 7,0 LAS ANIMAS	LAS CARMENES	RINA BLANEY	SU	(161,5)		7,65			
195	KM 20,0 CABUZA	STA.IRENE SUR	F. CONDORI	SU	(412,1)	25,00	19,52			1989
196	KM 5,5 PAGO GOMEZ	OLIVAR WEGUELIN	HUGO MOZO	SU	(140,6)	33,00	25,95			1987
197	KM 6,5 PAGO GOMEZ	ALAMEDA	SUC.FERNANDEZ	SU	(154,7)	10,00	S			
198	KM 5,0 PAGO GOMEZ	LAS PALMAS	F. ROQUE	P	(145,0)		4,90			
199	KM 4,5 PAGO GOMEZ		OVANDO	SU	(125,2)					
200	KM 4,5 PAGO GOMEZ		OVANDO	SU	(125,6)	18,00	S			
201	KM 13,0 SAN MIGUEL	SAN JOSE	A. CARBONE	SU	(279,0)	10,00	5,79			
202	KM 13,5 LAS RIVERAS	LADERA IZQUIERDA	M. CABRERA	SU	(285,0)		7,46			1988
203	KM 10,5 LAS MAITAS	ESCUELA 69	SERME ARICA	P	(226,7)	39,00	24,16		0,30	1983
204	KM 11,0 LOS ALBARRAC		E. CUESTA	P	(241,6)	30,00	18,07		3,00	1983
205	KM 15,0 LAS RIVERAS	LOTE AB	M. MADRID	R	(303,0)	18,00	1,52		12,00	1980

Nomenclature used :

*	Without location in the plan
P	Drinking
I	Industrial
SU	Out of use
AB	Abandoned
R	Irrigated
TA	Covered or fallen down
S	Dry
N	By hand / with bucket

(Modelo de Simulacion de las Aguas Subterraneas del valle de Azapa, January 1989 for DGA by Ayala, Cabrera y asociados Ltda. Ingenieros Consultores con la asesoris de IPLA Ltda.)

Table B-I, 2.3 Distribution of Specific Yield (Azapa Valley)

<Distribución de Escrrímiento Específico (Valle de Azapa)>

B.N.A CODE	PUMPING RATE (l/s)	DYNAMIC WATER LEVEL(m)	STATIC WATER LEVEL(m)	SPECIFIC YIELD (m3/d/m)	DROW-DOWN (m)
135-3	-	25.2	22.7		2.5
145-0	6	29.9	16.6	39.0	13.3
147-7	45	54.0	14.5	98.4	39.5
148-5	2.4	29.8	20.5	22.3	9.3
157-4	22	49.9	27.1	83.4	22.8
159-0	24.8	39.0	18.0	102.0	21.0
160-4	52.7	22.3	14.2	562.1	8.1
161-2	29	35.7	21.0	170.4	14.7
163-9	11.5	33.1	24.5	115.5	8.6
186-8	20	30.4	21.0	183.8	9.4
187-6	40	25.3	15.8	363.8	9.5
188-4	23	31.4	20.5	182.3	10.9
190-6	23	59.8	21.8	52.3	38.0
193-0	24.7	64.0	38.7	84.4	25.3
106-K	-	33.1	31.7		1.4
165-6	70	38.0	24.5	448.0	13.5
166-3	50	37.0	33.0	1080.0	4.0
167-1	55	36.4	27.0	505.5	9.4
128-0	7	58.8	44.1	41.1	14.7
130-2	6	44.7	42.8	227.4	1.9
171-K	45	52.5	44.3	474.1	8.2
137-K	45	54.5	44.5	388.8	10.0
108-6	20	58.3	48.0	167.8	10.3
109-4	25	50.2	26.2	90.0	24.0
229-	50	40.2	25.5	293.9	14.7
230-	45	54.8	26.5	137.4	28.3
231-	40	39.0	24.5	238.3	14.5
232-	50	32.7	23.9	490.9	8.8
121-3	30	39.3	15.3	108.0	24.0
113-2	35	8.1	5.3	1080.0	2.8
216-3	20	14.8	6.4	205.7	8.4
177-9	28	42.0	36.0	403.2	6.0
100-0	40	36.2	31.8	785.5	4.4
117-5	35	48.0	30.0	168.0	18.0
103-5	19	73.3	10.3	26.1	63.0
197-3	30	34.3	10.5	108.9	23.8
199-K	20	37.8	28.2	180.0	9.6
104-3	32	37.0	31.0	460.8	6.0
200-7	27	31.1	23.0	288.0	8.1
221-K	55	36.0	17.5	256.9	18.5
222-8	55	31.0	18.5	380.2	12.5
134-5	20	45.0	20.0	69.1	25.0
205-8	45	18.3	17.0	2990.8	1.3
206-6	45	24.8	19.7	762.4	5.1
207-4	19	41.0	22.0	86.4	19.0
102-7	38	32.2	20.3	275.9	11.9
208-2	41	31.5	24.5	506.1	7.0
114-0	40	22.0	12.5	363.8	9.5

NOTE: COMPILED FROM WELL INVENTORY

Table B-I, 2.4 Estimation of Groundwater Storage (Azapa Valley)

<Estimación de Reservas de Agua Subterraneas (Valle de Azapa)>

DEPTH (m BSWL)	ZONE 1 (COAST-SECT.A) (x million m3)		ZONE2 (SECT. A-B) (x million m3)		ZONE3 (SECT. B-C) (x million m3)		ZONE4 (SECT. C-D) (x million m3)		ZONE5 (SECT. D-E) (x million m3)		ZONE6 (SECT. E-F) (x million m3)		ZONE7 (SECT. F-G) (x million m3)		TOTAL (COAST-SECTION G) (x million m3)	
		SUM		SUM		SUM		SUM		SUM		SUM		SUM		SUM
0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
10	0.26	0.26	2.25	2.25	12.70	12.70	18.70	18.70	13.90	13.90	8.35	8.35	18.90	18.90	75.06	41.15
20	0.00	0.26	0.00	2.25	5.34	18.04	12.50	31.20	10.20	24.10	4.00	12.35	9.38	28.28	41.42	82.57
30	0.00	0.26	0.00	2.25	5.98	24.02	12.80	44.00	10.10	34.20	5.30	17.65	9.84	38.12	44.02	126.59
40	0.00	0.26	0.00	2.25	8.05	32.07	14.40	58.40	11.20	45.40	9.33	26.98	16.20	54.32	59.18	185.77
50	0.00	0.26	0.00	2.25	7.97	40.04	14.90	73.30	7.59	52.99	4.39	31.37	12.70	67.02	47.55	233.32
60	0.00	0.26	0.00	2.25	8.61	48.65	11.60	84.90	2.55	55.54	0.00	31.37	2.93	69.95	25.69	259.01
70	0.00	0.26	0.00	2.25	4.55	53.20	4.71	89.61	0.00	55.54	0.00	31.37	0.00	69.95	9.26	268.27
80	0.00	0.26	0.00	2.25	0.00	53.20	0.00	89.61	0.00	55.54	0.00	31.37	0.00	69.95	0.00	268.27
90	0.00	0.26	0.00	2.25	0.00	53.20	0.00	89.61	0.00	55.54	0.00	31.37	0.00	69.95	0.00	268.27
100	0.00	0.26	0.00	2.25	0.00	53.20	0.00	89.61	0.00	55.54	0.00	31.37	0.00	69.95	0.00	268.27
TOTAL	0.26		2.25		53.20		89.61		55.54		31.37		69.95		302.18	

NOTE: "BSWL" means below the static water level in 1993.

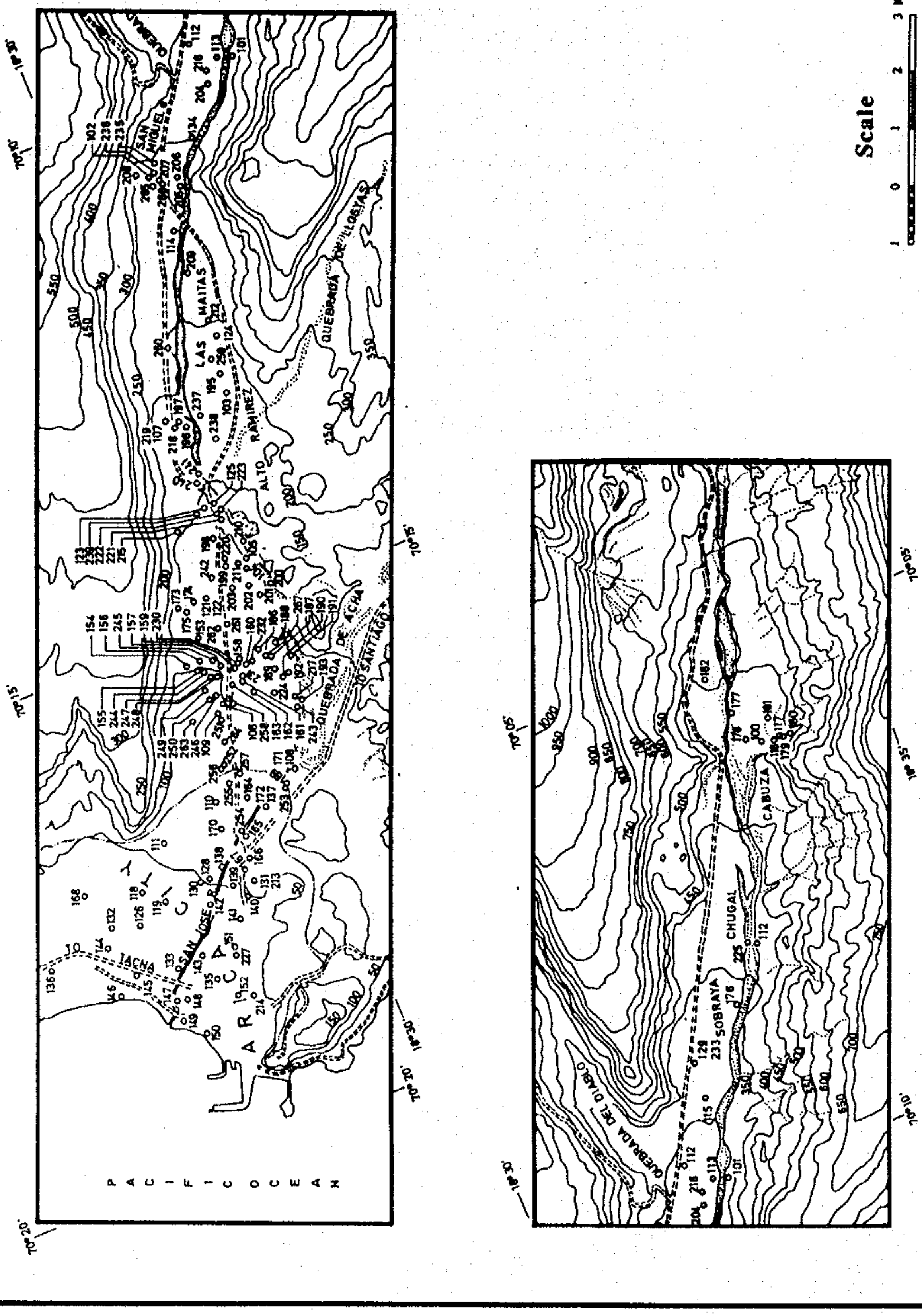
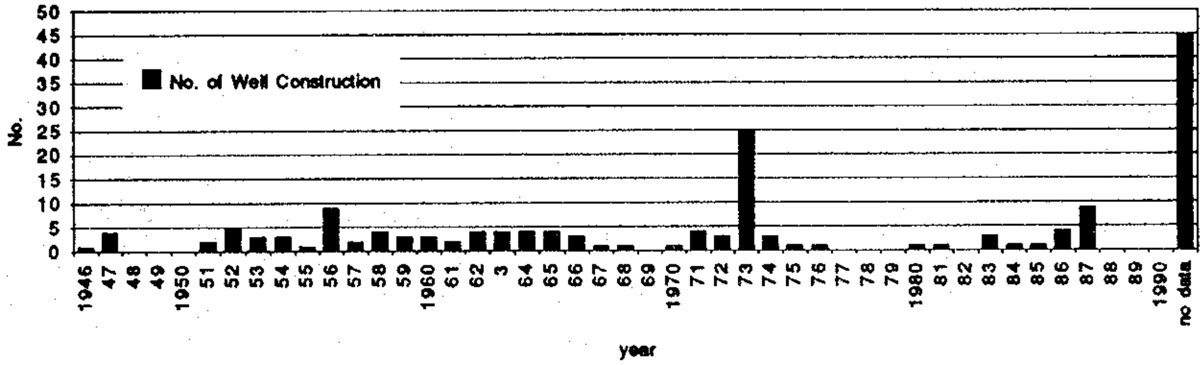


Fig. B-I. 2.1 Well Locations (Azapa Valley)

< Ubicación de Sondajes (Valle de Azapa) >



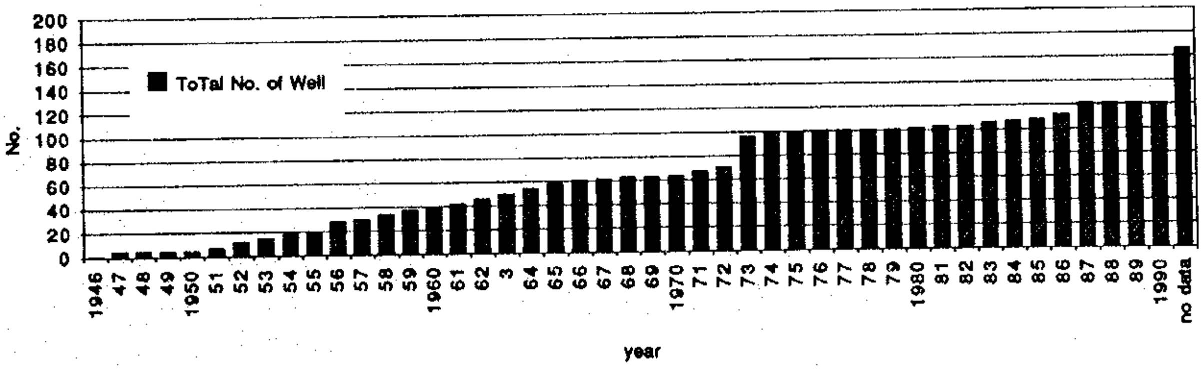
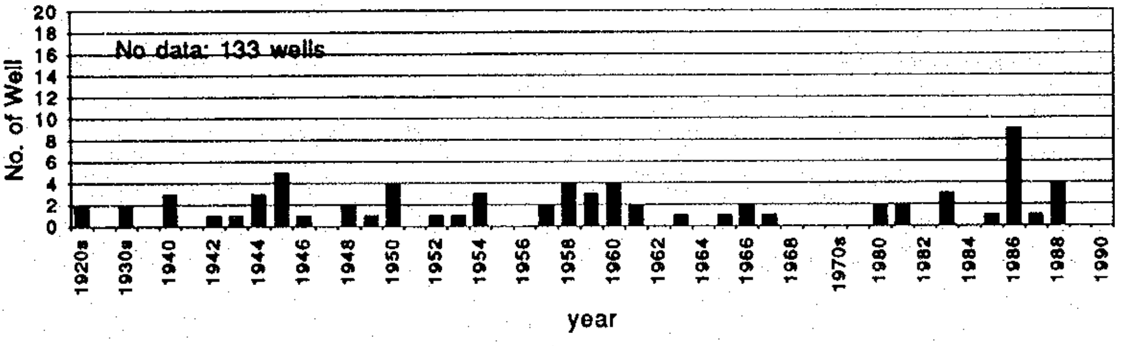


Fig. B-I. 2.2 Well Construction (Azapa Valley)

< Construcción de Sondajes(Valle de Azapa)>

DUG WELL CONSTRUCTION



INCREASE THE NUMBER OF DUG WELLS

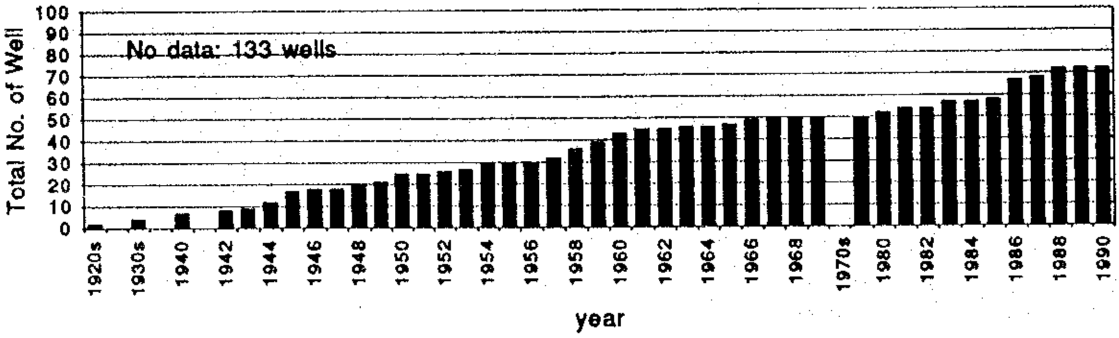


Fig. B-I. 2.3 Dug Well Construction (Azapa Valley)
< Construcción de Noria <Valle de Azapa)>

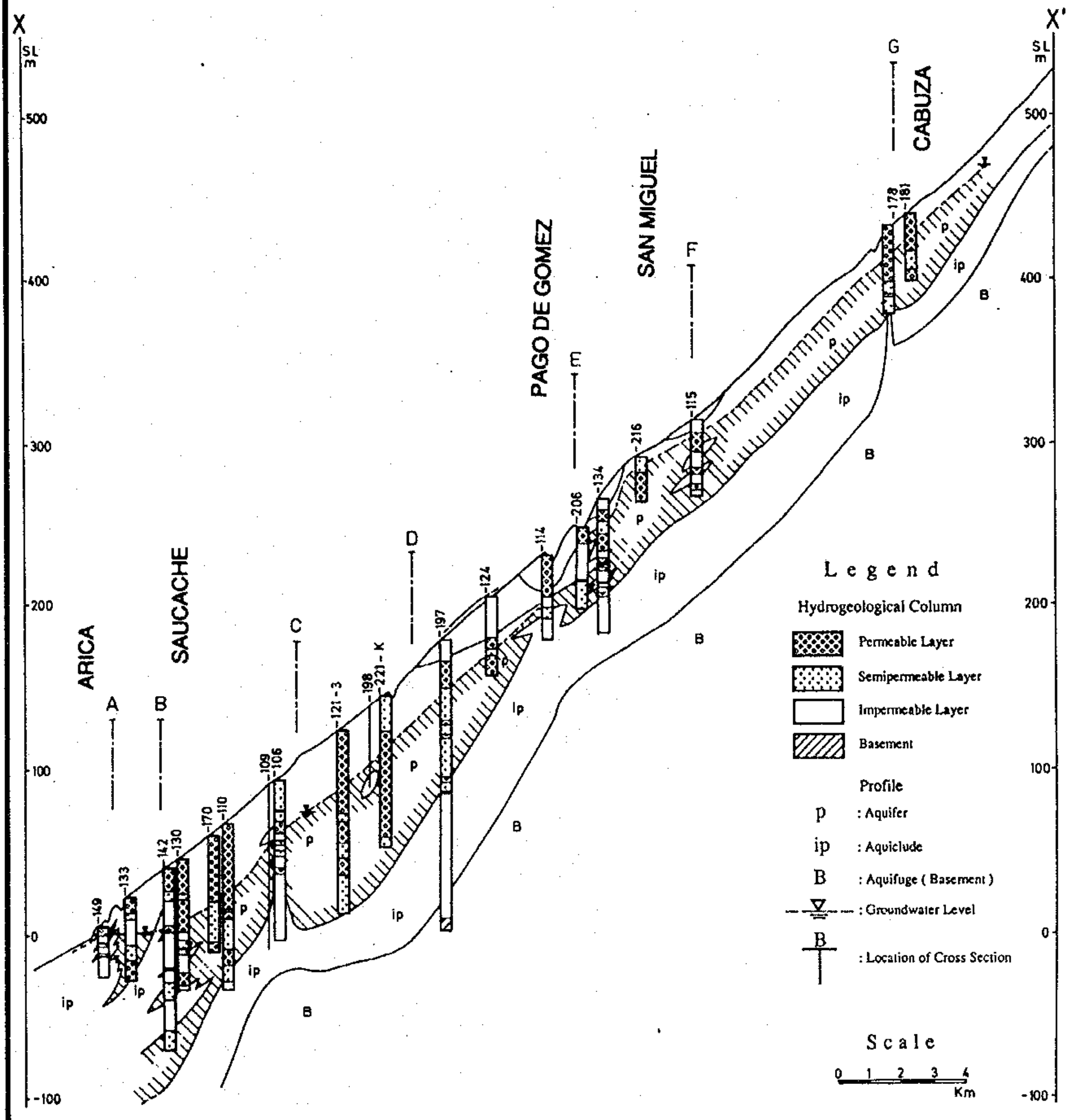


Fig. B-I. 2.4 Hidrogeological Profile (Azapa Valley) (X-X')
< Perfil Hidrogeológico(Valle de Azapa) (X-X')>

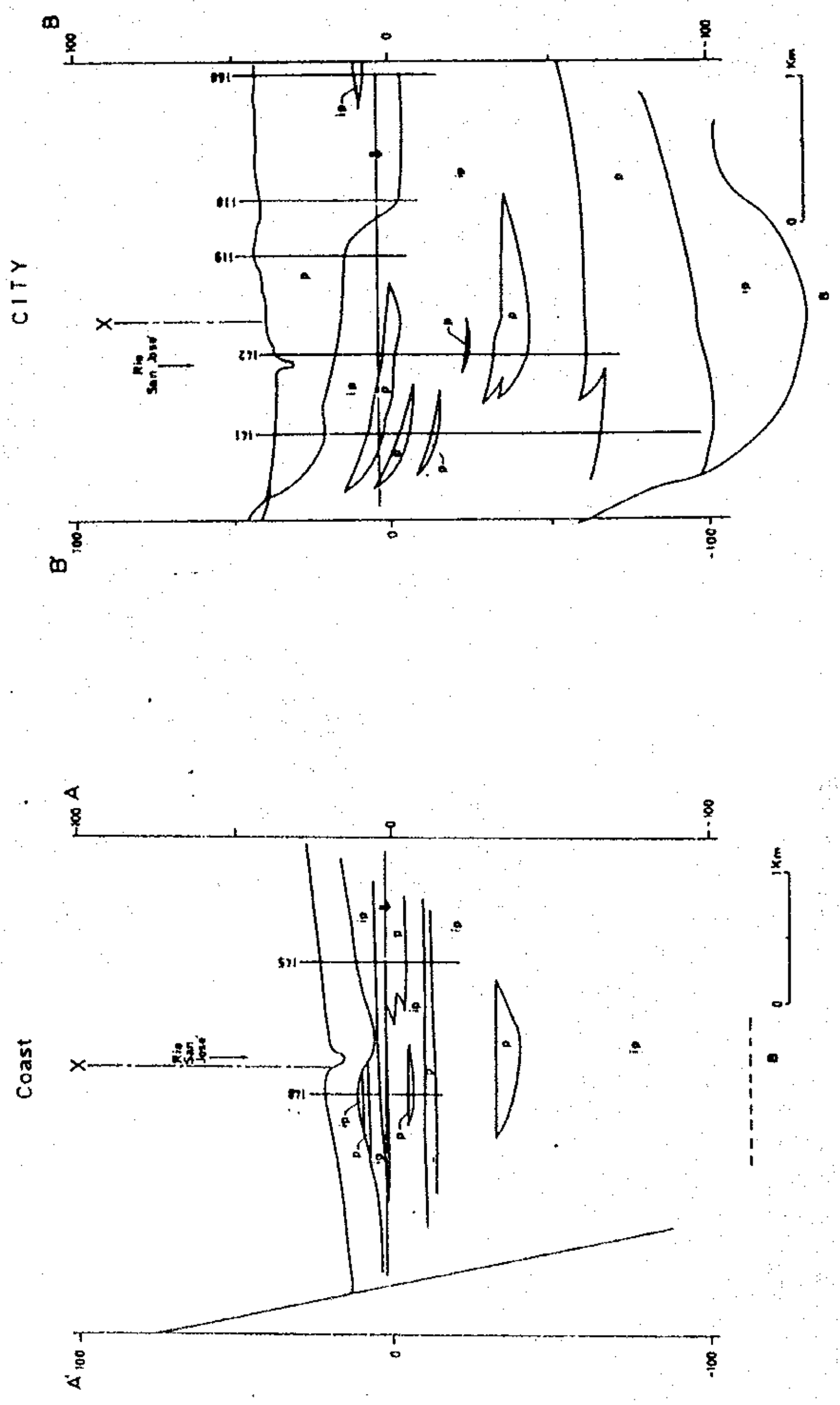


Fig. B-I. 2.5 (1) Hydrogeological Cross Section (Azapa Valley)
< Sección de Cruce Hidrogeológico (Valle de Azapa) >

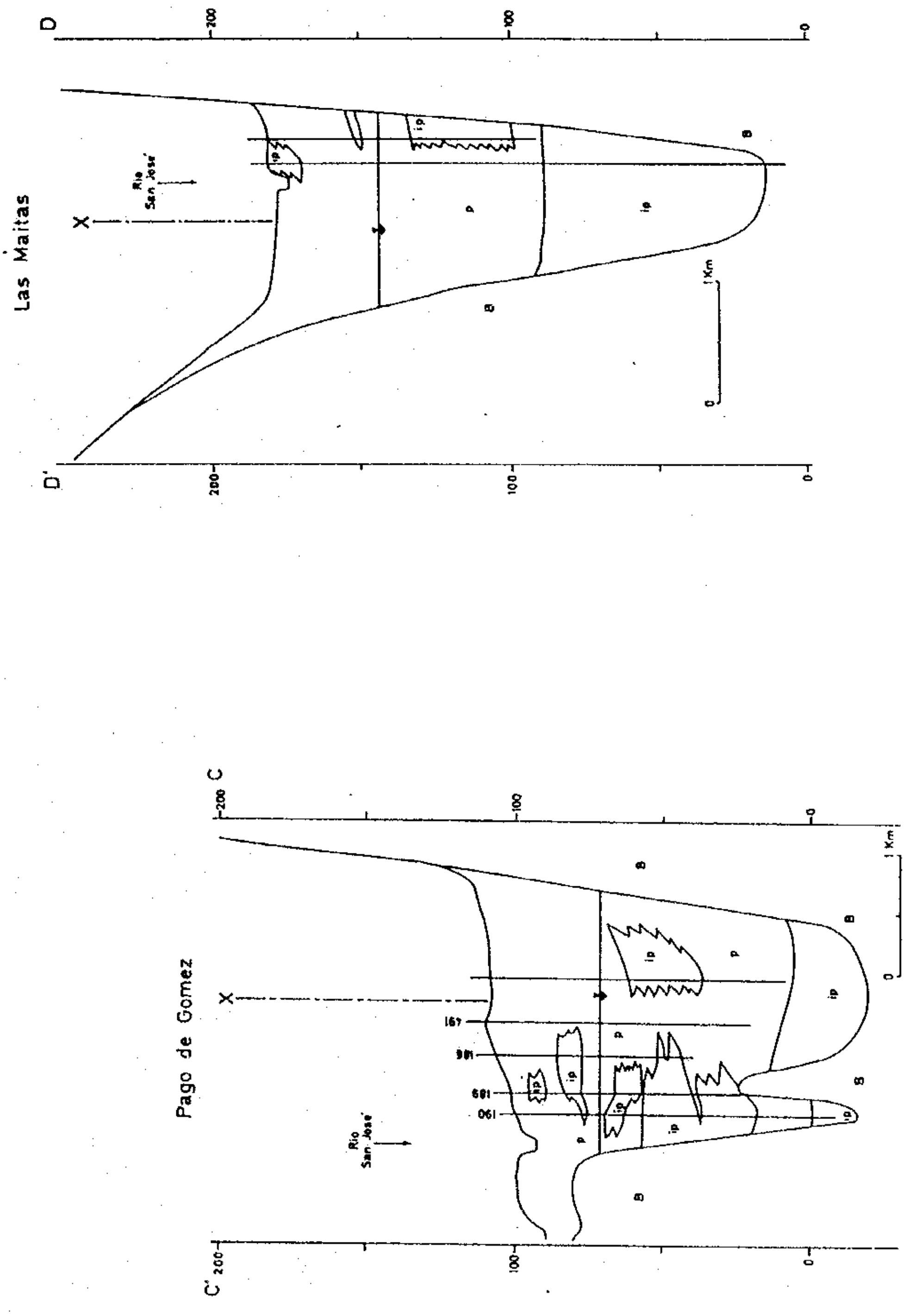


Fig. B-I. 2.5 (2) Hydrogeological Cross Section (Azapa Valley)
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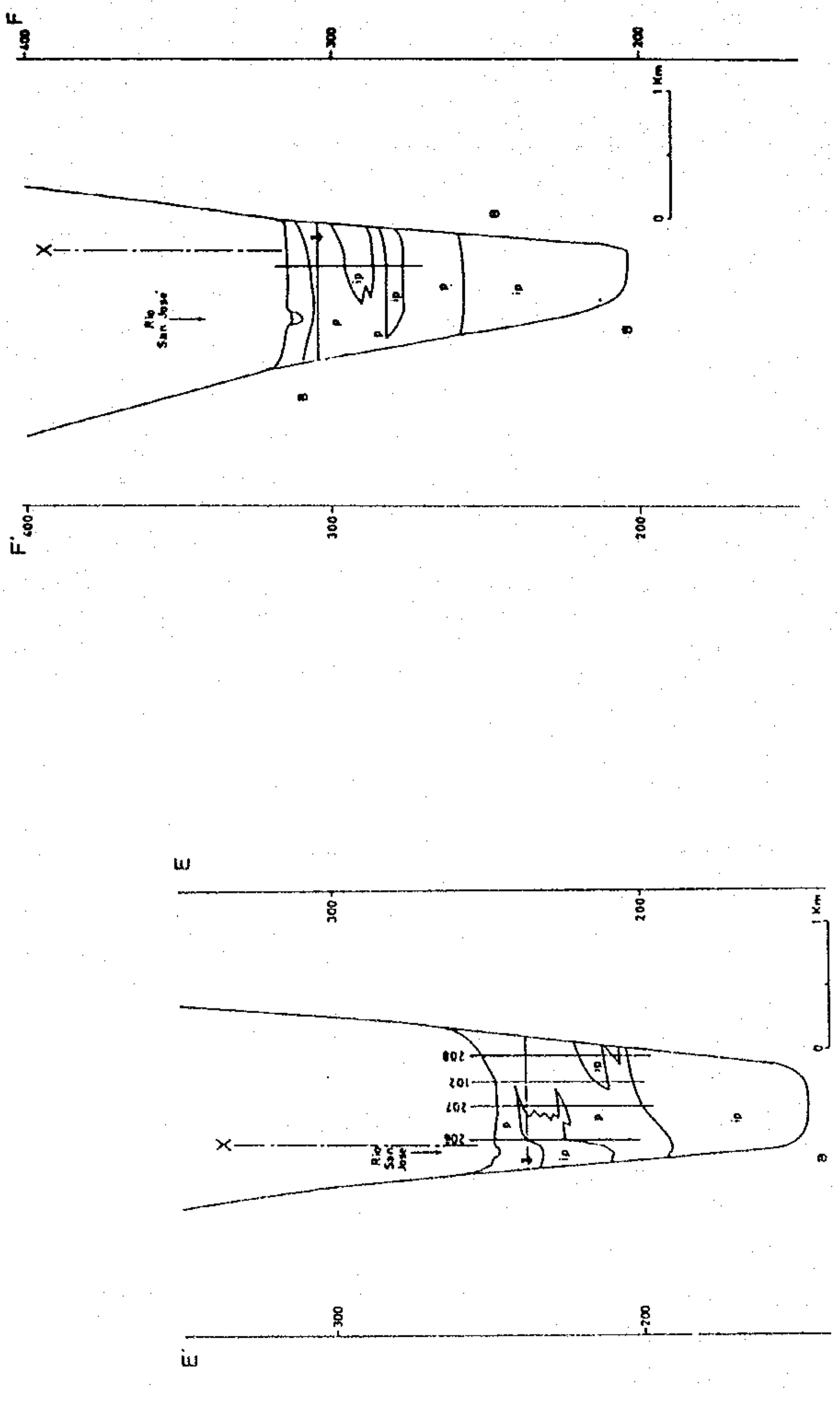

Fig. B-I. 2.5 (3) Hydrogeological Cross Section (Azapa Valley)
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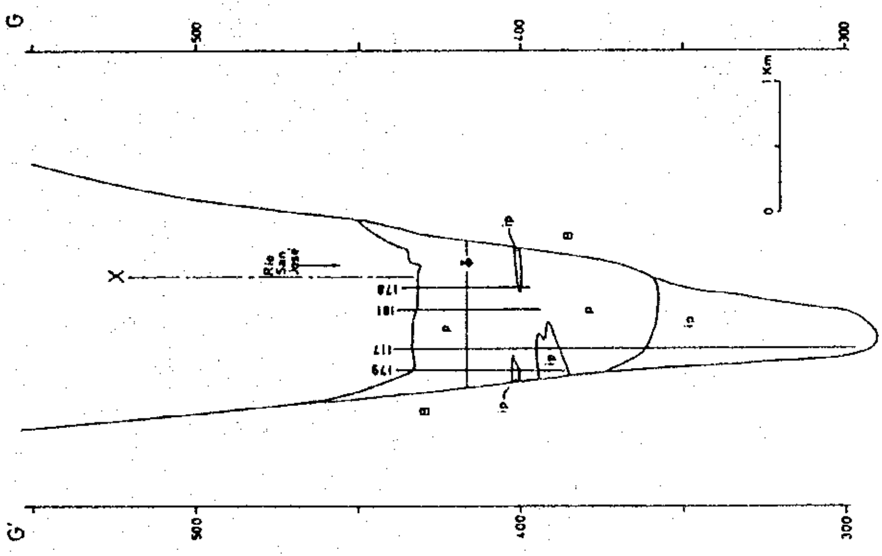

Fig. B-I. 2.5 (4) Hydrogeological Cross Section (Azapa Valley)

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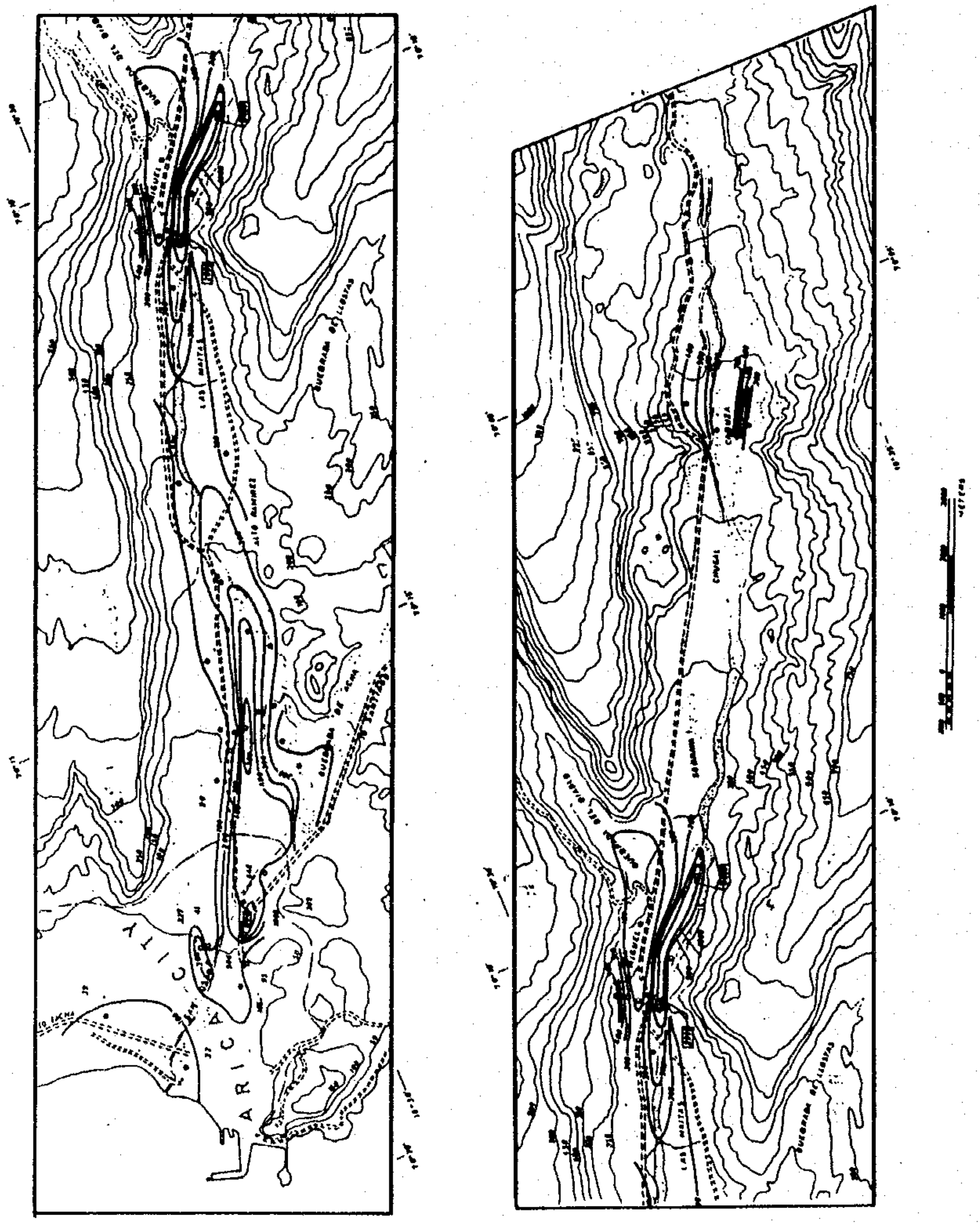

Fig. B-I. 2.6 Distribution of Specific Yield

<Distribución de Escurrímiento Especifico>

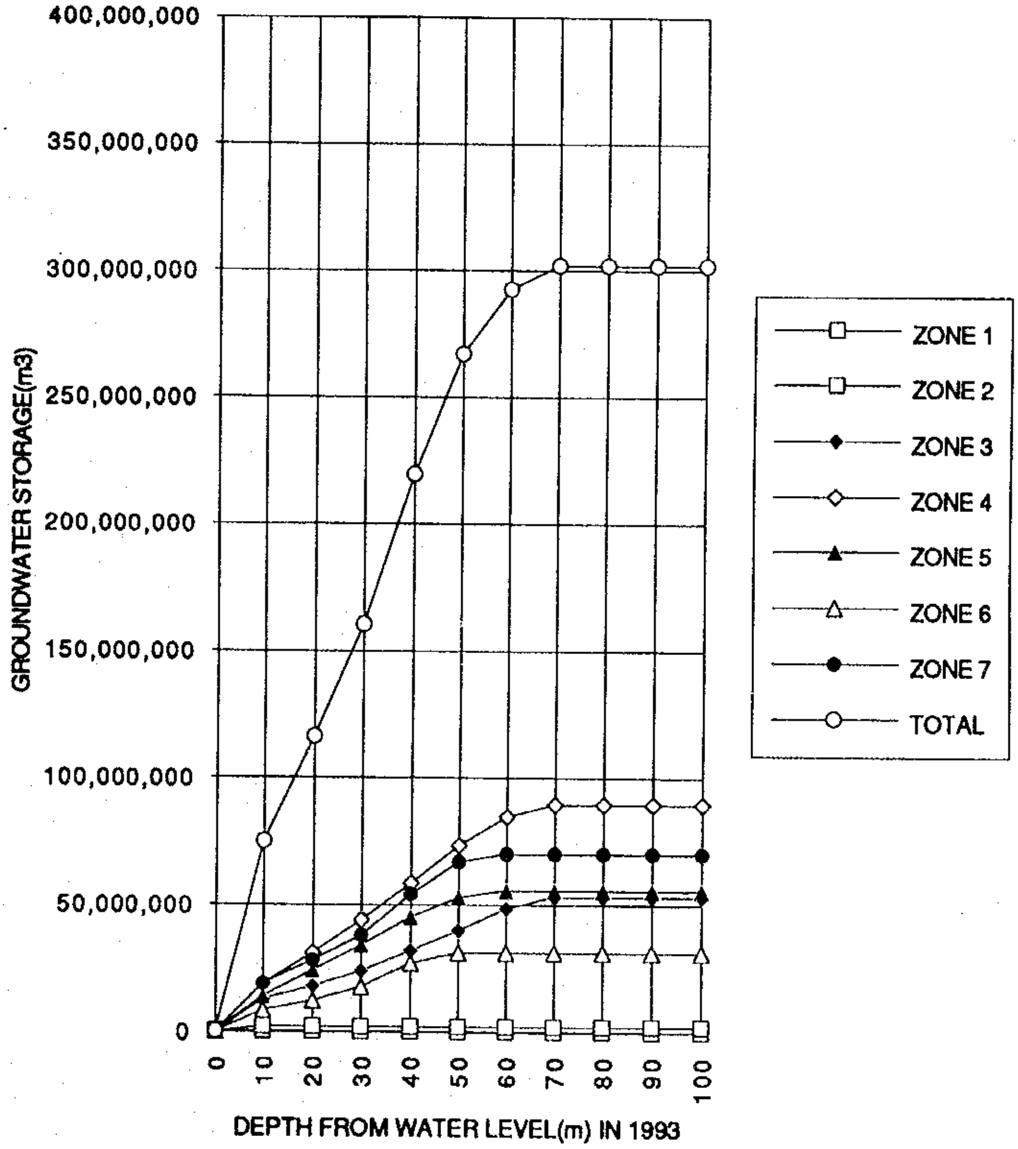

Fig. B-I. 2.7 Estimation of Groundwater Storage (Azapa Valley)

< Estimación de Reservas de Agua Subterránea (Valle de Azapa) >

Chapter III. GROUNDWATER EXTRACTION

3.1 Existing Groundwater Extraction

Groundwater in the Azapa Valley is extracted mainly from following three (3) types of wells including spring;

- ESSAT Well
- Other Wells
- Spring

3.1.1 ESSAT Wells

ESSAT extracted 17,292x$10^3$$m^3$ (503 l/sec) of groundwater in both Azapa Valley and Arica city area in 1992 (See Chapter I, Supporting Report C). In addition to this, 10 wells were drilled in 1993 to increase the groundwater production; six (6) wells in Arica city area and four (4) wells in the Azapa Valley, yielding 227 l/sec of groundwater. Thus, the total yield of ESSAT wells increased up to 730 l/sec by the end of 1993.

3.1.2 Other Wells

There was no data on the groundwater extraction through the wells in the area except ESSAT wells. Therefore, to clarify the groundwater extraction, field interviews were carried out in the area by the JICA Study Team and DGA during phase 2 study (1993). The result revealed that there are 343 wells; 167 wells are in operation and 176 wells are not in operation. Extraction rates from each wells are as follows;

Water Use	Number of Wells	Extraction Rate (m^3/yr)
Irrigation	122	9,536,336
Domestic	30	1,366,328
Industrial	3	125,691
Others	12	201,626
Total	167	11,229,981

source: field interview by DGA and the Study Team in 1993.

In addition to this, there are springs in the valley and a total yield of these reaches to 73.4 l/sec (2,302,128 m^3/yr).

3.1.3 Groundwater Extraction in Azapa Valley

As mentioned above, total groundwater extraction in the valley is summarized in the following table.

Water Use	Extraction Rate (l/sec)	Extraction Rate (m^3/yr)	%
ESSAT Wells (Q_E)	730	23,021,280	63.0
Irrigation (Q_R)	302	9,536,336	26.1
Domestic (Q_D)	43	1,366,328	3.7
Industrial (QI)	4	125,691	0.3
Others	6	201,626	0.6
Spring Water (Q_S)	73	2,302,128	6.3
Total	1,203	36,553,389	100.0

Source: ESSAT and field interview by DGA and Study Team.

Total extraction is estimated to be approximately 36.6 million m^3/year (1,203 l/sec). ESSAT wells yield a 63 % of groundwater and wells for irrigation yield 26 %. Other extractions are rather small.

3.2 Observed Groundwater Level of Existing Wells

3.2.1 Static Water Level

Observation of the static water level has been executed by DGA on selected wells. Based on this result, contour maps of static water level (as of Oct., 1993) is prepared as shown in Fig. B-I, 3.1 and 3.2. The maps show static water level above the mean sea level (MSL) and below the ground level (BGL), respectively.

Static water level is about 280 m at San Miguel and gently decreases toward the lower reaches of the San José River. The levels are 200 m at Las Maitas, 120 m at Pago de Gomez, 20 to 100 m at Saucache and less than 10 m in the city area.

Gradient of groundwater table is 22/1000 in the area between San Miguel and Las Maitas, and increases to 32/1000 at Pago de Gomez toward the city area. After reaching to the city area, water table becomes gentle, 4/1000.

Extraction of groundwater is large in Pago de Gomez and Saucache area, therefore, it causes change of groundwater table.

3.2.2 Dynamic Level

Dynamic water level of each well was examined by the pumping test at the completion of well construction. 48 data are available. The results are shown in Table B-I, 3.1 which presents static water level, draw-down and specific yield as well as dynamic water level. These wells are divided into three (3) categories by degree of drawdown as follows;

Drawdown (m)	Cabuza	Las Riveras	San Miguel	Pago de Gomez	Saucache	City	Total
less than 10	2	1	4	3	11	2	23
10 - 20	1	0	2	2	8	1	14
more than 20	0	0	1	3	6	1	11
total	3	1	7	8	25	4	48

Degree of draw-down is almost within 10 m in Cabuza and Las Riveras in the upper reaches of the valley. It increases toward the down stream. In Saucache, six (6) wells, out of 11 wells, show large degree of draw-down which are more than 20 m.

The wells of small drawdown generally show high specific yield except the city area. The wells of large drawdown is mainly located in the Pago de Gomez and Saucache area. It is supposed that high concentration of wells causes large degree of drawdown in these area.

3.2.3 Historical Variation

Historical variation of each well is shown in Table B-I, 3.2 (1) to (10) and Fig. B-I, 3.3 (1) to (4). Fig. B-I, 3.4 presents the variation of groundwater level of selected wells and flow rate of the San José River during flood period. Following characteristics are recognized on the variation of groundwater level;

a) Generally, the water levels have been decreased gradually, although the levels are recovered to a certain degree during the floods of the San José River. As shown in Fig. B-I, 3.4, the periods of the rising and declination of water level are in concordance with the periods of occurrence of floods in the San José River. Floods of the San José River cause the rising of the groundwater level in the area. After rising, the water level continues to fall down up to the next occurrence of flood.

b) Range of the water level variation is large in Cabuza area and it generally becomes smaller toward the lower reaches of the San José River; its range is about 20 m in Cabuza area and about 15 m in Saucache area.

c) Static water level shows different behavior in Las Riveras area; water level is shallow and its variation is small; once water level is risen by recharging from the flood water of the San José River, the water table keeps the risen level for a long period.

d) Variation of water level is not clear in the city area of Arica because of the lack of long term observation record. Static water level is high around 1964, 1977 and 1987, and is low around 1967, 1984 and present.

e) Rising of water level in 1987 is apparent in San Miguel area, however, it is not so clear in Pago de Gomez and Saucache area.

f) The degree of drawdown of water level is large in the lower reaches of the San José River.

Considering the hydrogeological characteristics of the area, the features described above suggest following;

a) The groundwater in the basin is recharged directly by the surface water of the San José River especially during the flood period.

b) The fact mentioned above b) is caused by fine materials such as silt and clay deposited in the valley. These fine materials are derived from the Qda. del Diablo and make the aquifer less permeable near the confluence area with San José River. These materials act like a dam constructed under the ground. It is like a dam up effect due to the spur of the Qda. del Diablo.

c) Apparent drawdown is caused by over exploitation of groundwater in the lower reaches of the San José River through a lot of wells and dug wells.

3.3 Groundwater Quality

3.3.1 Existing Data

Groundwater quality data are available on 61 wells in the Azapa Valley. Main data sources are the analysed data of ESSAT and the existing report entitled Analisis Critico de la Red de Medicion de Niveles de Agua Subterránea 1 Region, October 1987 for DGA by Alamos y Peralta Ingenieros Consultores Ltda. In addition to these, DGA reported the increase of salinity based on the conductivity data on the groundwater in the Azapa Valley (<3).

The number of well distribution by area (as of 1989) is as follows;

(1) Cabuza area : 5
(2) Las Riveras area : 4
(3) San Miguel area : 4
(4) Pago de Gomez area : 14
(5) Saucache area : 22
(6) City area : 12
Total : 61

3.3.2 Groundwater Quality of Existing Wells

1) Results of Groundwater Quality Analysis

Table B-I, 3.3 (1) to (2) show the groundwater quality data after averaging to avoid the instability of data and to easily understand the tendency of water quality, because water quality analysis was not executed periodically. The characteristics of water quality are as follows;

a) Most TDS values exceed 500 ppm, therefore, groundwater in the Azapa Valley is classified as brackish water. 12 wells in total exceed the TDS value standard (WHO). Out of 12 wells, six (6) wells are in the city area of Arica. The number of well that exceeds the TDS standard decreases toward the upstream of the San José River. No well exceeds the standard in the Cabuza area.

b) TDS value shows extremely high at the well 168-K located in the Saucache area. This well is located downstream of the Qda. Encantada. There was a salt mine in the upper reaches of this quebrada. This fact suggests that the groundwater in downstream of the quebrada is influenced by the salty water derived from the salt mine.

c) The values of Boron (B) content are available on 24 wells. (B) contents are generally high.

d) Arsenic (As) contents are generally within the standard (0.01 ppm: WHO).

2) Composition of Major Ions

The composition of major anions and cations is plotted in the trilinear diagram (Fig. B-I, 3.5). Only one (1) well (No. 107) lies in the zone 1. This type of groundwater is classified as carbonate hardness type which is the normal type of groundwater. Most wells lie in the central part of zone 3 concentrating in a small area. This type of groundwater is classified as non carbonate hardness type which is deteriorated by the groundwater originated from volcanoes. The wells (149, 150 and 168) fall at the edge of zone 3. These wells show an increase of (Cl+SO4) contents. This means that the groundwater in these wells are deteriorated by saline water because well No. 149 and 150 are located near the coastal area and well No. 168 is located in the downstream side of the salt mine.

The groundwater in the Azapa Valley is generally influenced by the water of volcanic origin and the influence of saline water is added near the coastal area.

3) Relation between TDS Value and EC

Fig. B-I, 3.6 shows the relationship between TDS values analyzed by recurrence analysis and EC values measured by salinometer or other equipment. The both values have a good correlation expressed by the following formula;

$Y = 0.6848\,X + 91.38$ (A)

where, X: measured value of EC, Y: TDS value

4) Relation between Cl Content and EC Value

Fig. B-I, 3.7 shows the relationship between Cl contents analyzed in laboratories and EC values measured by equipment. The relationship is expressed by the following equation based on the result of recurrence analysis;

$$Y = 0.2653\,X - 158.7 \qquad (B)$$

where, X: measured value of EC, Y: Cl contents

3.3.3 Historical Variation

Salinity of groundwater shows historical variation as shown in Fig. B-I, 3.8 (1) to (3). Salinity is expressed by TDS values in this figure. TDS values increased as a whole, comparing the values in 1960s, 1970s and 1980s. Variations of the contents (increase and decrease) are recognized especially in 1970s. These variations are considered to be caused by the variation of groundwater level depending on the floods of the San José River.

Increase of conductivity in Azapa Valley is reported in <3 and <4 by DGA. Fig. B-I, 3.9 shows the variation of conductivity measured on the spring water and groundwater in the valley since 1960. Conductivity is less than 1,500 ms/cm in all the springs up to 1970; especially less than 1,000 ms/cm in San Miguel. Increase was suddenly occurred between 1985 and 1990 in the whole springs increasing to more than 1,500 ms/cm. The rate of increase is about twice during 1970 and 1990. The reports mentioned that these increase of salinity was caused by agricultural chemicals used in the Azapa Valley as well as the upper reaches of the San José River.

Although it is difficult to predict precisely the future increase of salinity in the groundwater, an estimation was made by correlative analysis on the average EC value under the assumption that the increase of salinity continues with the same condition as present. Increasing of salinity is given by following formula;

$$Y = 37.3\,X - 72{,}408$$

where, Y: EC , X : year

Results of estimation are shown in Fig. B-I, 3.10.

It shows that salinity will increase up to 2,200 ms/cm in 2000 and 2,600 ms/cm in 2010. These correspond to 425 mg/l and 530 mg/l respectively, converting into Cl contents by formula (B). It is a 10.5 mg/l/year of increasing rate. However, considering the decreasing of groundwater level in the valley, it will be happened in future that the increase of salinity will suddenly become much greater than the estimation.

Groundwater of the valley also indicates similar tendency to that of the springs.

3.3.4 Evaluation of Groundwater Quality

Groundwater quality is shown in Table B-I, 3.3 (1) to (2). Permissible value for drinking water is shown partly as follows;

	pH	Cl	SO_4	Mg	As	Cu	Fe	$N\text{-}NO_3$	$N\text{-}NH_3$
		(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)
Permissible Values	6.0-8.5	250	250	125	0.05	1.0	0.3	9.0	0.5

Water Quality Standard is referred in Appendix A, 5 of Supporting Report A.

The results are as follows;

a) Cl is higher than permissible values at several wells mainly in the lower reaches.

b) SO_4 and NO_3 sometimes exceed permissible values.

c) Boron (B) is higher than permissible values at most of well.

d) As is less than permissible values.

3.4 Evaluation of Groundwater Development Potential

Water balance of the Azapa Valley is estimated by equations as follows;

$$\Delta S = Q_{Ausipar} - (O + I + E)$$
$$E = D + E_{Others}$$

Here, ΔS stands for the groundwater storage increment/deficit, $Q_{Ausipar}$ for surface runoff at Ausipar, O for the surface water outflow to the sea, I for the consumption of irrigation use, E for the exploitation rate from the groundwater, D for the domestic use in Arica City and E_{Others} for the others consumption (such as industrial use and individual drinking use, etc.).

Each item in the equations are estimated as follows;

$Q_{Ausipar}$: 34,721,000 m^3 (1,101 l/s : see Supporting Report A, Chapter 1)
O : 4,699,000 m^3 (see Supporting Report A, Chapter 1)
I : 24,810,000 m^3 (see Supporting Report C, Chapter 2)
D : 18,330,000 m^3 (see Supporting Report C, Chapter 1)
E_{Others} : 675,000 m^3 (see Supporting Report C, Chapter 2)

The water balance of the Azapa Valley is shown as below

$$\begin{aligned} \Delta S &= Q_{Ausipar} - (O + I + D + E) \\ &= 34{,}721{,}000 - (4{,}699{,}000 + 24{,}810{,}000 + 14{,}823{,}000 + 675{,}000) \\ &= -10{,}286{,}000{,}000 \ (m^3) \end{aligned}$$

This results indicate that groundwater exploitation in the area exceeds the recharge rate from the San José River and its deficit is balanced by consuming the groundwater storage. If this amount of groundwater is consumed every year, following equation comes into being;

$$S/\Delta S = n \text{ (years)}$$

where S : total storage of groundwater
n : life of aquifer

S is estimated to be 302 x 10^6 m^3 (see Chapter 2). Thus,

$$n = 302 \times 10^6 \, m^3/(10{,}286 \times 10^3 \, m^3) = \mathbf{29.4} \text{ (years)}$$

This means that most groundwater storage will be consumed within about 30 years if all the conditions continue during this period. The water balance in Azapa Valley was roughly estimated; the groundwater resources will be comsumed during about 30 years. However, the results show severe condition for future groundwater extraction in the Azapa Valley. Therefore, groundwater protection is necessary instead of further development in the Azapa Valley.