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JAPAN INTERNATIONAL COOPERATION AGENCY(JICA)

DIRECTORATE GENERAL OF WATER
MINISTRY OF PUBLIC WORKS
THE REPUBLIC OF CHILE

THE STUDY
ON
THE DEVELOPMENT OF WATER RESOURCES
IN
NORTHERN CHILE

MAIN REPORT

MARCH 1995

PACIFIC CONSULTANTS INTERNATIONAL, TOKYO

In this report, project costs are estimated based on March 1994 prices with an exchange rate of US$1.00 = Chilean Pesos ($) 435.00 = Japanese Yen ¥110.00

PREFACE

In response to a request from the Government of Republic of Chile, the Government of Japan decided to conduct a master plan and feasibility study on the Development of Water Resources in Northern Chile and entrusted the study to the Japan International Cooperation Agency (JICA).

JICA sent to Chile a study team headed by Mr. Naohito MURATA, Pacific Consultants International from March 1993 and March 1995.

The team held discussions with the officials concerned of the Government of Chile, and conducted field surveys at the study area. After the team returned to Japan, further studies were made and the present report was prepared.

I hope that this report will contribute to the promotion of the project and to the enhancement of friendly relations between our two countries.

I wish to express my sincere appreciation to the officials concerned of the Government of Republic of Chile for their close cooperation extended to the team.

March 1995

Kimio Fujita
President
Japan International Cooperation Agency

THE STUDY ON THE DEVELOPMENT OF WATER RESOURCES IN NORTHERN CHILE

March 1995

Mr. Kimio Fujita
President
Japan International Cooperation Agency

LETTER OF TRANSMITTAL

Dear Sir,

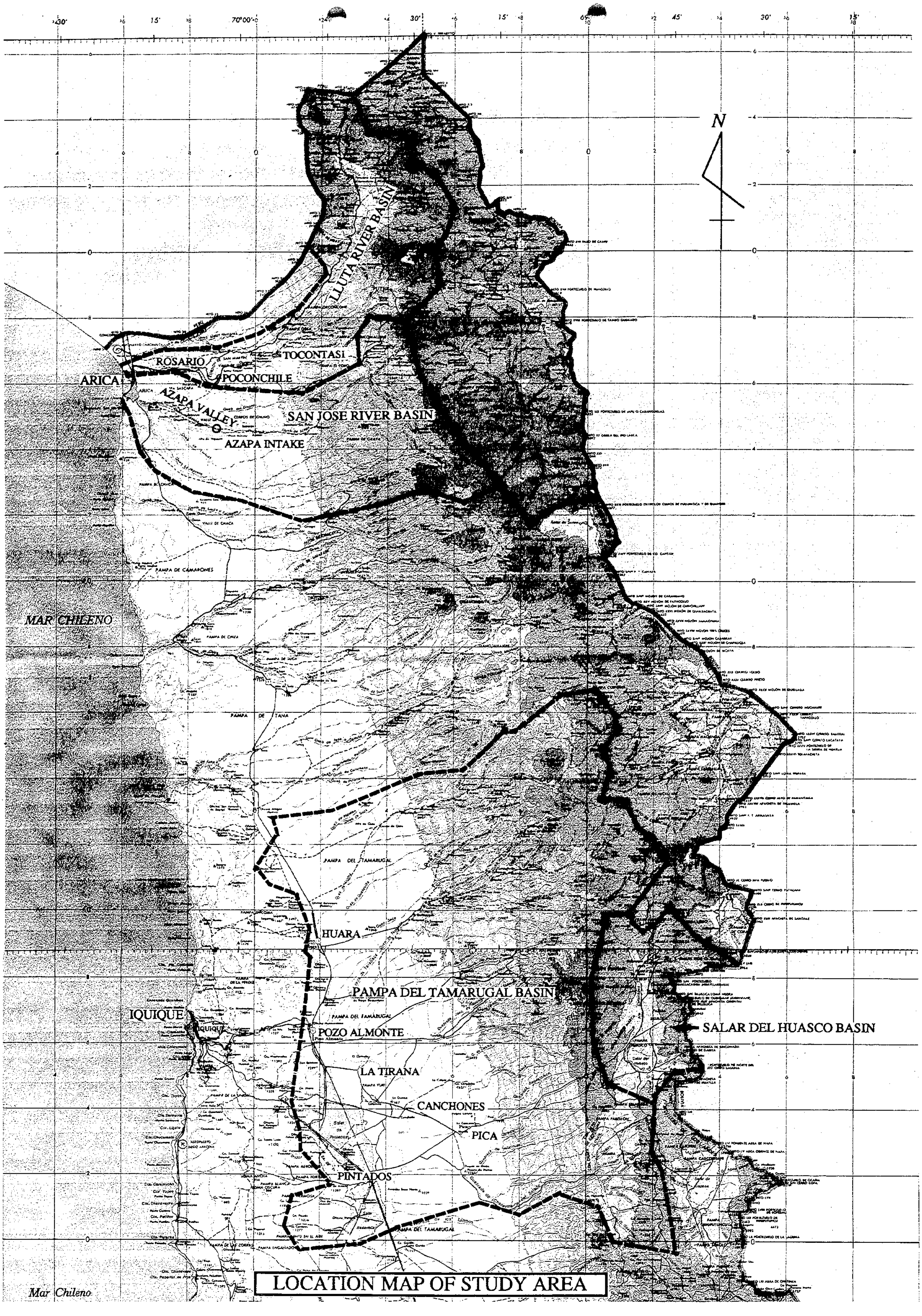
We are pleased to submit the final report entitled "THE DEVELOPMENT OF WATER RESOURCES IN NORTHERN CHILE". This report has been prepared by the Study Team in accordance with the contract signed on 25 March 1993, 14 September 1993 and 8 June 1994 between Japan International Cooperation Agency and Pacific Consultants International.

The report consists of the Summary, Main Report, and Supporting Report. The Summary summarizes the results of all studies. The Main Report presents the results of the whole study including analysis of existing conditions, evaluation of the water resources development potential and formulation of water resources development plan for water supply to Arica and Iquique cities. The Supporting Report describes in detail the technical aspects of the entire study. In addition, a Data Book has been prepared and submitted herewith.

All members of the Study Team wish to express grateful acknowledgments to the personnel of your Agency, Ministry of Foreign Affairs, and Embassy of Japan in Chile, and also to officials and individuals of the Government of Chile for their assistance extended to the Study Team. The Study Team sincerely hopes that the results of the study will contribute to the improvement of the water supply condition and the social and economic development in Arica and Iquique cities.

Yours faithfully,

Naohito MURATA
Team Leader



LOCATION MAP OF STUDY AREA

SUMMARY

SUMMARY

I. Background

Arica and Iquique cities, the economical centers of Region I (Tarapacá Región), have been realizing a remarkable economical development in recent years with a support of the national policy "Duty-Free Zone". The population of Arica city has increased from 88,000 in 1970 to 169,000 in 1992 and is expected to grow further to 265,000 in 2015. Similarly, population of Iquique city has risen from 64,000 in 1970 to 153,000 in 1992 and is projected upto 273,000 in 2015.

However, both cities are suffering from severe water shortages. The population increase in the future will further worsen the circumstances of water supply in both cities.

On the other hand, the potential water resources existing in the proximity of the two (2) cities are only San José and Lluta River Basins for Arica city and Pampa del Tamarugal and Salar del Huasco Basins for Iquique city.

Hence, the water resources development of the above basins is awaited to meet the increasing water demand of Arica and Iquique cities.

The objectives of the Study are as follows:

(1) To evaluate the water resources potential of the Study Area

(2) To formulate the water resources development plan for water supply to Arica and Iquique cities.

The Study Area covers the four (4) basins as shown in Location Map.

II. Water Resources, Water Use and Environments

2.1 San José River Basin

1) Water Resources

The San José River covers a drainage basin of 3,187 km^2. The precipitation of the Basin concentrates on the uppermost Andes Mountain areas with an elevation of 4,000~5,000 m. Some water is diverted from the Lauca River

Basin adjacent to the east to supplement the indigeneous water resources of San José River.

The annual average flow rate of the River is estimated to be 1,101 l/s of which 149 l/s spills over to the sea at the time of floods. The remaining 952 l/s is consumed for drinking, irrigation and other purposes or infiltrates into the ground to recharge groundwater in Azapa Valley located in the lower reaches of the River.

There exists a large groundwater aquifer of unconfined type with a total storage of 302 million m^3 in Azapa Valley. It extends 22 km from Cabuza to the sea coast. The aquifer is mainly formed of Fluvial Deposits. The size and hydrogeological constants are summarized below.

Width (m)	Thickness (m)	Permeability (cm/sec)	Specific Yield (l/s/m)
600 ~ 1,700	45 ~ 60	3.22×10^{-2}	4.92

The groundwater table has gradually lowered since 1977 due to the excessive extraction. The draw-down in the recent 15 years has reached 30 m in the downstream reaches of Azapa Valley.

The groundwater quality has also been worsening in the recent years. The existing water quality of TDS is in the range of 519 mg/l and 2,835 mg/l, exceeding the permissible limit of drinking use (1,000 mg/l) in many wells, specially in the downstream reaches of the Valley.

For the drainage basin and aquifer area, see Fig. 1.

2) Water Use

The whole municipal water of Arica city is supplied by extracting the groundwater of Azapa Valley including the city area. The production capacity of the water sources was 503 l/s until 1993. However, it was increased to 730 l/s based on the temporarily granted water rights at the end of 1993 in view of the serious water shortage in Arica city.

In Azapa Valley, the farmlands of 3,213 ha is irrigated for cropping of fruits (1,694 ha), vegetables (1,393 ha) and pasture (126 ha). The irrigation water is taken from the River through Azapa Canal, being supplemented by spring water and groundwater.

Further, some amount of groundwater is extracted for individual domestic, industrial and other uses in Azapa Valley.

The water used in Azapa Valley including the city area is not all really consumed. A considerable amount of the extracted water recharges the groundwater for re-use. The existing water extraction and real consumption are summarized below.

	Extraction (l/s)	Real Consumption (l/s)
Municipal Water of Arica City	730	639
Irrigation in Azapa Valley	1,269	787
Other Uses in Azapa Valley	53	21
Total	2,052	1,447

3) Water Resources Development Potential

The water balance of Azapa Valley shows a deficit of 495 l/s, as described below.

Inflow to Azapa Valley	1,101 l/s
Outflow to Sea	-149 l/s
Real Water Consump. in Azapa Valley	-1,447 l/s
Balance	-495 l/s

Hence, the groundwater storage of Azapa Valley will gradually decrease in the future. The remaining life is estimated to be approximately 20 years if the existing water uses continue.

Moreover, the groundwater quality will become worse according as the draw-down of the water level in future.

No further water resources development of San José River Basin is expected.

2.2 Lluta River Basin

1) Water Resources

The Lluta River covers a drainage basin of 3,378 km^2. The precipitation of the Basin concentrates on the uppermost Andes Mountain areas with an altitude of 4,000~5,000 m . The river flow rate at Tocontasi/Chapisca station (upper end of Lower Lluta Valley) 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

A groundwater aquifer with a total storage of 107 million m^3 is identified in the Fluvial Deposits of Lower Lluta Valley. The aquifer extends 18 km from Rosario to Panamericana. It is composed of shallow aquifer of unconfined type and deep aquifer of confined type of which the deep one is considered as prospective for development. The size and hydrogeological constants of the deep aquifer are summarized below.

Width (m)	Thickness (m)	Permeability (cm/sec)	Specific Yield (l/s/m)
800 ~ 3,000	50 ~ 100	3.63×10^{-3}	1.72

Both the river water and groundwater of Lower Lluta Valley are much contaminated by the pollutants originating from the upper tributaries; Azufre and Colpitas Rivers. The major water contaminants observed, are summarized below.

	TDS (mg/l)	Cl (mg/l)	B (mg/l)	Fe (mg/l)	As (mg/l)
River Water	1,051	323	10.7	3.8	0.31
Deep Groundwater	3,289	949	21.9	1.5	0.029
Permissible Limit of Drinking Use	1,000	250	(5.0)	0.3	0.05

Note: ( ) : assumed

For the drainage basin and aquifer area, see Fig. 1.

2) Water Use

The existing water use in Lower Lluta Valley is only agricultural one. The farmlands of 2,784 ha is irrigated for cropping of maize (1,698 ha), pasture (684 ha) and vegetables (402 ha) mostly by the river water. The groundwater extraction is negligibly small.

The river water is repeatedly used while flowing down to the river mouth. The average river water extraction and real consumption for irrigation in the downstream reaches of Tocontasi/Chapisca are estimated to be 1,925 l/s and 894 l/s respectively.

3) Water Resources Development Potential

The river water is fully used for irrigation in dry season. Hence, the groundwater of Lower Lluta Valley is considered as the only prospective water source for the water supply development of Arica city.

The groundwater development shall be within the limit of recharge volume considering that the groundwater storage is not large. The groundwater is recharged by the surplus river water exceeding over the existing irrigation use.

The yearly average groundwater recharge potential is estimated to be 542 l/s. However, the groundwater development potential is reduced to 450 l/s in consideration to the constraints caused by the irrigation use and limitation of the installation density of production wells.

2.3 Pampa del Tamarugal Basin

1) Water Resources

The Pampa del Tamarugal Basin covers a hydrologically closed area of 18,005 km^2. The ground elevation of the Basin ranges from 1,000 m at Pampa del Tamarugal to 4,000~5,000 m at Andes Mountains. Precipitation of the Basin concentrates on the upper Andes Mountains.

Several rivers originating from Andes Mountains recharge the groundwater of Pampa del Tamarugal and no water flows out of the Basin. The total annual average flow rate of the rivers is estimated to be 976 l/s.

Apart from the recharge by the river water, the aquifer of Pampa del Tamarugal is recharged by the underground inflow from Salar del Huasco and other neighbouring basins. The estimated underground inflow is 289 l/s. Hence, the total groundwater recharge by the river water and underground inflow is 1,265 l/s.

The groundwater aquifer is of unconfined type and formed of Altos de Pica Formation. It extends 130 km in north-south direction from Zapiga to

Bellavista and has a total storage of 26,908 million m^3. The size and hydrogeological constants are shown below.

Width (km)	Thickness (m)	Permeability (cm/sec)	Specific Yield (l/s/m)
13 ~ 46	60 ~ 225	5×10^{-3}	2.37

The water of the Basin is imbalanced to some degree. The groundwater table has been lowering at a rate of 7 cm/year on an average in the recent years.

The groundwater is contaminated in the western part of the aquifer 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 central-eastern part of the aquifer is suitable for drinking use without treatment.

The drainage basin and aquifer area is shown in Fig. 2.

2) Water Use

The whole municipal water of Iquique city is supplied from Pampa del Tamarugal by extracting the groundwater at the Canchones well-field 70 km east from the city. The existing average water production is estimated to be 547 l/s. The requirement for the water sources in Pampa del Tamarugal will increase according to the population growth of the city in the future.

The domestic water of seven (7) local towns is supplied from the groundwater in Pampa del Tamarugal. The future water demand will also increase according to the population growth of the towns.

The farmlands of 580 ha in the Basin are irrigated by river water and groundwater at present. These farmlands are expected to expand to 1,040 ha by the year 2015.

Four (4) mines are supplied mining water from the rivers and underground at present. Number of the mines is projected to increase to 28 mines by the year 2015.

The water used within Pampa del Tamarugal is not all really consumed but a considerable portion of the extracted water is returned to the aquifer for re-use.

The existing and future water demand and real consumption by water use category are estimated as follows.

	Existing (1992)		Future (2015)	
	Demand (l/s)	Real Consump. (l/s)	Demand (l/s)	Real Consump. (l/s)
Iquique Municipal Water	547	547	1,062	1,062
Water Use in the Basin	645	340	1,684	1,034
Domestic Water	117	47	134	54
Irrigation Water	459	249	597	406
Mining Water	69	44	953	574
Total	1,192	887	2,746	2,096

3) Environments

Three (3) districts with a total area of 101,000 ha in Pampa del Tamarugal are designated as National Reserved Area. The Tamarugo trees covering a total area of 24,000 ha are distributed in the National Reserved Area at present. The Tamarugo tree area will expand to 25,000 ha in 2015.

The Tamarugo trees consume a large amount of groundwater. The existing evapotranspiration of the trees is estimated to be 1,019 l/s. It is projected to increase to 1,523 l/s in 2015.

4) Water Resources Development Potential

The total of the real water consumption and evapotranspiration of the Tamarugo trees exceeds the total groundwater recharge. Hence, the groundwater storage of the aquifer will gradually decrease in the future.

The total reduction of the groundwater storage during 23 years until 2015 is estimated to be 986 million m^3 or 3.7% of the existing groundwater storage of 26,908 million m^3.

Groundwater development potential of Pampa del Tamarugal is considered large enough to meet the future water demand. Its development is restricted by quality rather than by quantity. Hence, the potential groundwater suitable for the water supply development of Iquique city is identified in the central-eastern part of the aquifer (see, Fig. 2).

2.4 Salar del Huasco Basin

1) Water Resources

The Salar del Huasco Basin covers a closed drainage basin of 1,712 km^2 with an elevation ranging from 3,800 m at Salar del Huasco to 5,000 m at Andes Mountains. All the surface water infiltrates into underground to recharge the groundwater aquifer in Salar del Huasco plains. No surface water flows out of the Basin. However, some portion of the groundwater discharges to the aquifer of Pampa del Tamarugal through the geological fissures.

Salar del Huasco covers a total area of 29 km^2 composed of water area (2 km^2) and wet land (27 km^2). The water depth is less than 20 cm.

The water balance of the Basin is shown below.

Annual average surface water	:	809 l/s
Evaporation of lake areas	:	575 l/s
Groundwater discharge to Pampa del Tamarugal	:	234 l/s

The groundwater aquifer of unconfined type is identified in the Collacagua Formation of Salar del Huasco plains. It extends over an area of 126 km^2 and has a total storage of 465 million m^3. The thickness varies from 130 m to 210 m. The aquifer constants are estimated to be 2.60×10^{-3} cm/sec in permeability and 0.99 l/sec/m in specific yield.

The groundwater quality is good as a whole except Mn and Fe. The contents of Mn and Fe are as shown below.

	Mn (mg/l)	Fe (mg/l)
Water Quality	0.61 ~ 1.40	4.30 ~ 18.0
Permissible Limit for Drinking Use	0.1	0.3

Water treatment is necessary before using it for drinking purpose.

For the drainage basin and aquifer area, see Fig. 2.

2) Water Use

There exists no water use in the Basin.

3) Environments

The most important environmental factor in the Basin is the ecology of flamingos. Three (3) species of flamingos; Chilean Flamingo, Andean Flamingo and Puna Flamingo, are identified in the Salar del Huasco areas. Approximately 3,300 population of the flamingos were observed in this Study.

Puna Flamingo is the most rare species living only in Andes Mountains. The population observed in the Salar del Huasco was approximately 1,500 equivalent to around 10% of the total population of Andes Mountains.

4) Water Resources Development Potential

The hydrologically sustainable development volume of the groundwater is estimated to be 575 l/s at the most.

However, any amount of groundwater extraction will reduce or dry up the lake areas to keep the hydrological balance of the Basin. As a result it may cause adverse effects on the ecology of the flamingos.

Therefore, further detailed environmental impact assessments are necessary to conclude the water resources development potential of the Basin.

III. Municipal Water Supply Development for Arica City

3.1 Water Demand

1) Existing Water Supply Service

The municipal water of Arica city is supplied by ESSAT; the sanitary service corporation of Region I. The existing water supply system covers about 1,680 ha of the urbanized area of the city, serving the entire population of the city of 169,000.

The city had suffered from severe water shortages until the end of 1993 when the Emergency Water Supply Project was completed. The water production capacity was increased from 503 l/s to 730 l/s by the above-mentioned project based on the temporarily granted water rights. At present, the water of 730 l/s is constantly supplied from 45 deep wells located in Azapa Valley and city area throughout the year.

The water supply service of the city was limited to 10.5 ~ 15.0 hours per day before the completion of the Emergency Water Supply Project. It is now temporarily relaxed.

The existing water loss of the distribution system is large. It is estimated to be approximately 40% of the produced water.

The water tariff is composed of fixed charge and variable charge. The existing normal variable charge is 140.02 pesos/m^3 as of 1994.

2) Future Water Demand

The water demand of the city will increase in the future according to the growth of population and improvement of living standards. On the other hand, reduction in the water loss will be achieved based on the program of ESSAT. The estimated future served population, water loss and water demand (average production basis) are shown below.

	Served Population	Water Loss (%)	Water Demand (l/s)
1995	178,087	40	779
2005	214,524	30	840
2015	265,375	30	1,091

3.2 Short-term Development Plan

1) Development Capacity

The Lower Lluta groundwater development can provide the raw water of 425 l/s on daily average basis by the drilling of 26 deep wells. However, a special treatment of the raw water by Reverse Osmosis (RO) method is necessary to remove a high content of TDS and boron (B). The production of the treated water is estimated to be 319 l/s on daily average basis, by assuming the recovery efficiency of the treatment as 75%. The remaining concentrated water is wasted.

On the other hand, temporarily increased water production of 227 l/s in Azapa Valley will be canceled after completion of the Lower Lluta groundwater development to conserve the groundwater of Azapa Valley. Hence, the integrated water supply capacity (822 l/s) of the Azapa and Lower Lluta systems will meet the water demand of the city only upto the year 2003.

The water production capacity (daily maximum) of the short-term development plan (Lower Lluta development plan) are shown below.

Raw Water	553 l/s (48,000 m^3/day)
Treated Water	414 l/s (36,000 m^3/day)
Wastewater	139 l/s (12,000 m^3/day)

2) Water Supply Development Facilities

The groundwater of the Lower Lluta Valley is developed by 26 deep wells installed between Rosario and Chuilona. All the well water is transferred through a transmission pipeline of 12.5 km to a treatment plant by gravity.

The treatment plant of RO method is constructed on the land of 3.8 ha in Chuilona. The treated water is supplied to the northern part of Arica city through the distribution tanks attached with the treatment plant. On the other hand, the wastewater is directly discharged to the sea through a drainage pipe of 8,750 m by gravity.

The proposed major construction works are shown below.

(1) Intake Works
  Deep Well : ø12" x (120~150 m) x 26 wells
  Pump : 26 submersible pumps
(2) Transmission Main
  Pipeline : ø(150~500 mm) x 1 line x 12,500 m
  Tank : 4 pressure-break tanks
(3) Treatment Plant
  RO : 12 units
  Tank : receiving tank (2 units), distribution tank (2 units), etc.
  Wastewater Pipe: ø350 mm x 1 line x 8,750 m
(4) Land Acquisition
  Treatment Plant : 3.8 ha
(5) Compensation Works (Reconstruction of Irrigation System)
  Head Works : 1 site
  Irrigation Canal : 77.6 km

Location and route of the proposed facilities are shown in Fig. 3.

3) Project Cost and Implementation Program

The total investment cost, consisting of direct construction cost, land acquisition cost, engineering cost, administration cost and physical contingency amounts to 32,694 million pesos ($) at 1994 prices with a foreign currency of 48,177 thousand US$ and a local currency of 11,737 million pesos ($). Its break-down is shown in Table 1.

The total annual operation and maintenance cost (O&M cost) including electric consumption cost, chemical consumption cost, personnel cost and repair cost, at the stage of full operation is estimated to be 1,257 million Pesos ($) at 1994 prices.

The Project will be completed within three (3) years from 1996 to 1998. The detailed design and land acquisition will be completed within 1996. The construction work including direct construction works and compensation works will be completed in the period of 1997 and 1998. It will be commissioned in 1999 and will reach the full operation in 2003.

3.3 Project Evaluation

1) Economic Evaluation

The present values of benefits and costs of the Project are estimated to be 18,574 x 10^6 Pesos ($) and 20,148 x 10^6 Pesos ($) respectively, assuming a discount rate of 12% based on the guideline of MIDEPLAN (Ministry of Planning). The economic profitability is evaluated in terms of Net Present Value (NPV), Benefit Cost Ratio (B/C) and Economic Internal Rate of Return (EIRR) as shown below.

NPV: -1,574 x 10^6 Pesos ($), B/C: 0.92, EIRR: 11.36%

The NPV is a little negative and EIRR is a bit smaller than the percentage of 12% requested by the guideline of MIDEPLAN.

According to the sensitivity analysis, it would be necessary to reduce the proposed investment cost by 10.35% or to lower the assumed discount rate (12%) down to 11.36% in order to make NPV non-negative.

However, this project is considered profitable in case that such intangible benefits as the improvements of sanitary/hygienic conditions and living standards in Arica city are taken into account.

2) Financial Evaluation

The financial profitability of the Project is evaluated in terms of Net Present Value (NPV) and Financial Internal Rate of Return (FIRR).

NPV is calculated to be 7,199 x 10^6 Pesos ($) under the following conditions.

Average Water Tariff : 154 Pesos ($)/$m^3$ at the end of 1994. It will increase at a rate of 16% per year.

Discount Rate: 12% (based on the guideline of MIDEPLAN)

Then, FIRR is estimated at 13.06%.

3) Environmental Impact Assessment

A private land of 3.8 ha shall be acquired for construction of the treatment plant. No negative impact is anticipated concerning the land acquisition since the land is now idle.

The construction works will cause no significant public nuisances of vibration, noise, dust, traffic disturbance, etc. since the construction sites are sparsely inhabited and the traffic volume of the related highways is small.

The project plans to extract the groundwater within the extent of its potential recharge. The existing groundwater table will be maintained on a long-term average basis although it may seasonally or yearly fluctuate.

However, lowering of the groundwater level in dry period will accelerate the groundwater recharge of the river water. It may cause some negative impacts on the existing river water extraction for irrigation use. Hence, the proposed project includes the reconstruction of the existing irrigation system necessary to cope with this problem.

No adverse impact on the existing wells is anticipated since they are far from the proposed well sites.

IV. Municipal Water Supply Development for Iquique City

4.1 Water Demand

1) Existing Water Supply Service

The municipal water of Iquique city is also supplied by ESSAT. The existing water supply system covers 2,162 ha of the city, serving the entire population of the city of 153,000.

The whole water of the city is extracted from 12 deep wells of the Canchones well-field in Pampa del Tamarugal and transferred through two (2) transmission pipelines of 75.3 km length each to Cavancha distribution tank located on the eastern hill of the city.

In 1992, water of 547 l/s on daily average basis was supplied to the city. On the other hand, the water production capacity of the existing system is estimated to be 680 l/s. The demand on the daily maximum basis is going to exceed the existing production capacity.

The existing water loss of the distribution system is estimated to be approximately 40% of the production.

The water tariff is composed of fixed charge and variable charge. The existing normal variable charges are 233.44 Pesos ($)/m^3 for off season and 230.82 Pesos ($)/m^3 for peak season as of 1994.

2) Future Water Demand

The future served population, water loss and water demand (average production basis) are estimated in the same way as Arica city and are shown below.

	Served Population	Water Loss (%)	Water Demand (l/s)
1995	165,236	40	708
2005	213,356	30	807
2015	272,605	30	1,062

4.2 Long-term Development Plan

1) Development Capacity

The long-term development plan is targeted for the year 2015. The water production demand of the city for the year 2015 is estimated to be 1,381 l/s on daily maximum basis. On the other hand, the existing production capacity is 680 l/s. Hence, the additional production capacity of 701 l/s shall be developed.

2) Water Supply Development Facilities

The planned water source is the groundwater in the eastern neighbourhood of La Tirana in Pampa del Tamarugal. The water quality is suitable for drinking use with no treatment. The groundwater is extracted by 16 deep wells and is collected in the collection tanks, proposed in the well-field. The well-field covers an area of 260 ha.

The water is transferred by two (2) transmission pipelines of 67.6 km length each from the collection tank to Cavancha distribution tank via Alto Hospicio tank. The major part of the pipelines runs along the existing highways.

The water is pumped up by the transmission pump installed in the well-field to cross over the coastal mountain ranges.

The proposed major construction works are as follows.

(1) Intake Works
- Deep Well : ø12" x 200 m x 16 wells
- Pump : 16 submersible pumps
- Collection Pipe: ø (250~800 mm) x 9,750 m

(2) Transmission Pump
- Pump : 5 units x 1 site

(3) Transmission Main
- Pipeline : ø (400~700 mm) x 2 lines x 67,600 m

(4) Tank
- Collection Tank : 2 units x 1 site
- Transmission Tank : 2 units x 2 sites
- Pressure-break Tank : 2 units x 3 sites
- Distribution Tank : 4 units x 1 sites

(5) Land Acquisition

Well-field and Tank Sites: 261 ha

Location and route of the proposed facilities are shown in Fig. 4.

3) Project Cost

The total investment cost, consisting of direct construction cost, land acquisition cost, engineering cost, administration cost and physical contingency amounts to 46,091 million Pesos ($) at 1994 prices. Its break-down is shown in Table 2.

4.3 First-stage Development Plan

1) Development Capacity

The first-stage development plan is targeted for the year 2005. The water production demand for the year 2005 is estimated to be 1,049 l/s on daily maximum basis. The additional production capacity of 369 l/s shall be developed.

2) Water Supply Development Facilities

The first-stage plan covers exactly half of the works proposed in the long-term plan. However, required land till long term plan will be acquired in the first stage.

The proposed major works are as follows.

(1) Intake Works

Deep Well : ø12" x 200 m x 8 wells

Pump : 8 submersible pumps

Collection Pipe : ø(250~800 mm) x 5,750 m

(2) Transmission Pump

Pump : 3 units x 1 site

(3) Transmission Main

Pipeline : ø(400~700 mm) x 1 line x 67,600 m

(4) Tank

Collection Tank : 1 unit x 1 site

Transmission Tank : 1 unit x 2 sites

Pressure-break Tank : 1 unit x 3 sites

Distribution Tank : 2 units x 1 site

(5) Land Acquisition

Well-field and Tank Sites : 261 ha

Location and route of the facilities are shown in Fig. 4.

3) Project Cost

The total investment cost, consisting of direct construction cost, land acquisition cost, engineering cost, administration cost and physical contingency amounts to 24,177 million Pesos ($) at 1994 prices with a foreign currency of 41,024 thousand US$ and a local currency of 6,331 million Pesos ($). Its break-down is shown in Table 2.

The total annual O&M cost including electric consumption cost, chemical consumption cost, personnel cost and repair cost at the full operation stage is estimated to be 614 million Pesos ($) at 1994 prices.

The Project will be completed within three (3) years from 1996 to 1998. The detailed design and land acquisition will be completed within 1996. The direct construction works will be completed within the years of 1997 and 1998. It will be commissioned in 1999 and will reach the full operation in 2005.

4.4 Project Evaluation

1) Economic Evaluation

The present values of benefits and costs of the Project are estimated to be 20,868 x 10^6 Pesos ($) and 14,138 x 10^6 Pesos ($) respectively by assuming a discount rate of 12% based on the guideline of MIDEPLAN. The economic profitability is evaluated in terms of NPV, B/C and EIRR as follows.

NPV: 6,730 x 10^6 Pesos ($), B/C: 1.48, EIRR: 17.33%

2) Financial Evaluation

The financial profitability of the Project is evaluated in terms of NPV and FIRR.

NPV is calculated to be 11,456 x 10^6 Pesos ($) under the following conditions.

Average Water Tariff : 278 Pesos (\$)/m^3 at the end of 1994. It will increase at a rate of 12% per year.

Discount Rate: 12% (based on the guideline of MIDEPLAN)

Then, FIRR is estimated at 14.86%.

3) Environmental Impact Assessment

The land acquisition of 261 ha is necessary for construction of the well-field and tanks. No negative impact is anticipated concerning the land acquisition since the land is idle and mostly owned by the government.

The construction works will cause no significant public nuisances of vibration, noise, dust, traffic disturbance, etc. since most of the construction sites are in the dessert and the traffic density of the related highways is small.

The existing groundwater table will be lowered in future by such various water developments as municipal water of Iquique city, domestic water of local towns, irrigation water and mining water. The total draw-down by the proposed project and other water developments after 100 years is estimated as follows.

- by 25 ~ 30 m in the most seriously affected area
- by less than 15 m in most part of the aquifer area
- by less than 15 m in the existing Tamarugo tree area

The six (6) existing shallow wells will be affected by the above lowering of the groundwater table. They shall be deepened or reconstructed in the future.

Roots of the Tamarugo trees generally reach a depth of 25~30 m to absorb the groundwater. Hence, no significant impact on the Tamarugo trees is anticipated.

V. Recommendations

1) The proposed Lower Lluta water supply development will satisfy only a short-term water demand of Arica city. Additional water resources developments to meet the long-term water demand should be studied.

2) The groundwater of Azapa Valley will be exhausted in not far future if the existing water uses continue. The management of the water resources and water uses in Azapa Valley and Arica city should be strengthened.

3) A proper water treatment process must be applied for the existing raw water in Canchones in future.

4) Based on available data, the groundwater quality in La Tirana area of Pampa del Tamarugal is suitable for drinking use without treatment. However, it is recommended to re-confirm the water quality of the proposed well-field in La Tirana area by drilling a test well, prior to determining the detailed location of the well-field.

5) The existing monitoring system of groundwater in Azapa Valley, Lower Lluta Valley and Pampa del Tamarugal must be strengthened.

Table 1 Investment Cost for Arica

Item	F/C (10^3 US$)	L/C (10^3 Pesos $)	Total (10^3 Pesos $)
Direct Construction Cost	42,080	6,722,117	25,027,108
(1) Intake Works	7,153	1,700,006	4,811,728
(2) Transmission Facilities	1,470	118,258	757,702
(3) Treatment Plant	29,597	4,112,572	16,987,214
(4) Distribution Networks	3,850	633,281	2,312,464
(5) Electric Transmission Line	0	158,000	158,000
Land Acquisition Cost	0	2,912,000	2,912,000
(1) Land Acquisition	0	12,000	12,000
(2) Compensation Works	0	2,900,000	2,900,000
Engineering Cost	1,782	726,456	1,501,626
Administration Cost	0	750,813	750,813
Physical Contingency	4,315	625,678	2,502,711
Total	48,177	11,737,064	32,694,258

Note: Cost: as of March 1994, excluding Value Added Tax (IVA)

Exchange Rate: US$1.00 = Chilean Pesos $435.00 = Japanese Yen ¥110.00

Table 2 Investment Cost for Iquique

Item	Long-term	First-stage		
	Total (10^3 Pesos $)	F/C (10^3 US$)	L/C (10^3 Pesos $)	Total (10^3 Pesos $)
Direct Construction Cost	38,512,014	36,032	4,422,575	20,096,326
(1) Intake Works	4,075,846	2,532	1,193,663	2,295,144
(2) Transmission Facilities	32,327,643	33,499	2,305,366	16,877,636
i) Transmission Pumps	1,873,190	3,126	151,091	1,510,912
ii) Transmission Pipeline	29,081,203	30,373	1,468,050	14,680,499
iii) Tanks	1,373,250	0	686,225	686,225
(3) Distribution Networks	1,950,525	0	765,546	765,546
(4) Electric Transmission Line	158,000	0	158,000	158,000
Land Acquisition Cost	262,000	0	262,000	262,000
Engineering Cost	2,310,721	1,528	541,100	1,205,780
Administration Cost	1,155,360	9	602,890	602,890
Physical Contingency	3,851,201	3,465	502,408	2,009,633
Total	46,091,296	41,024	6,330,973	24,176,629

Note: Cost: as of March 1994, excluding Value Added Tax (IVA)

Exchange Rate: US$1.00 = Chilean Pesos $435.00 = Japanese Yen ¥110.00

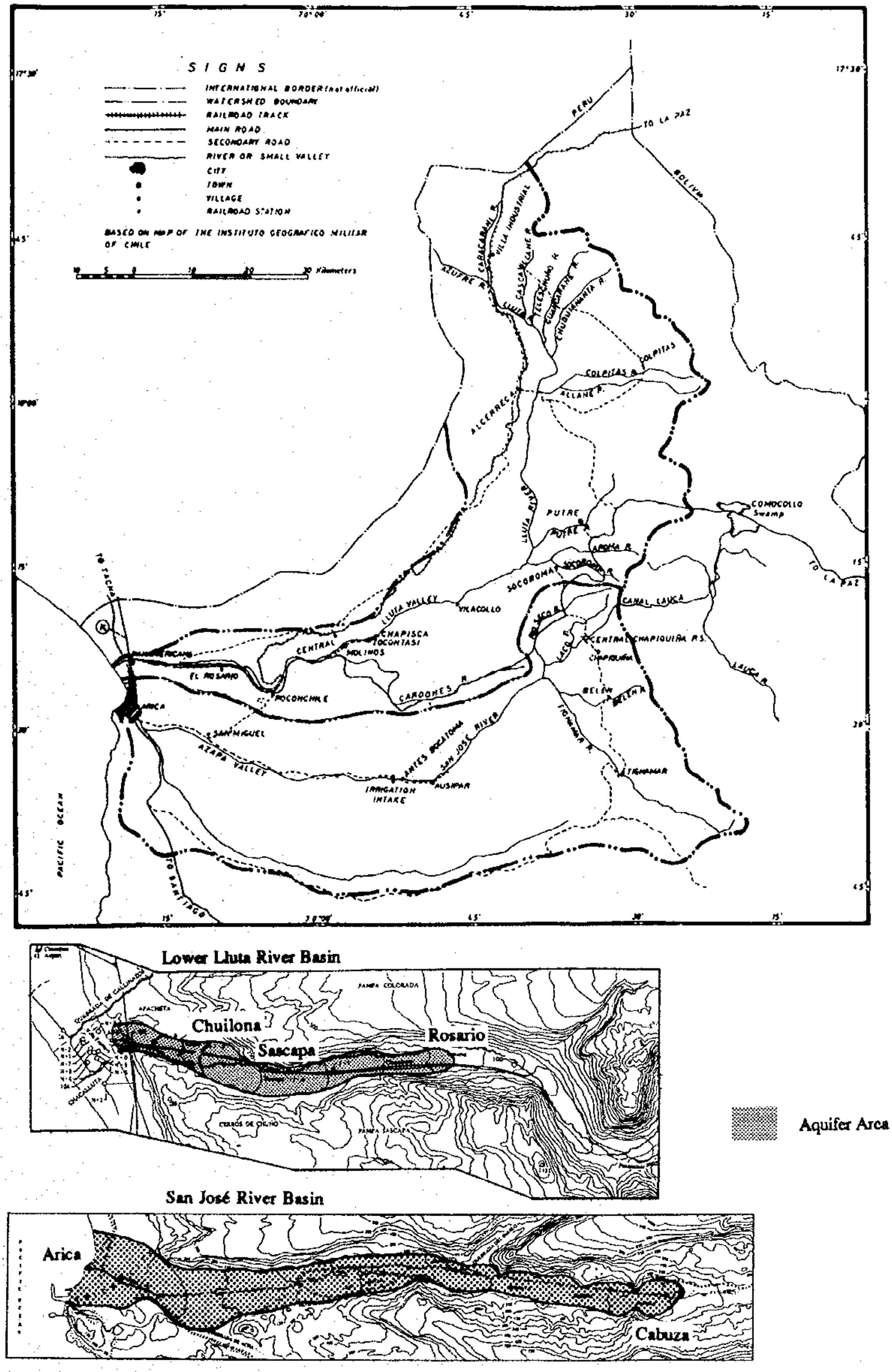


Fig. 1 San José and Lluta River Basins

<Cuencas de los Ríos San José y Lluta>

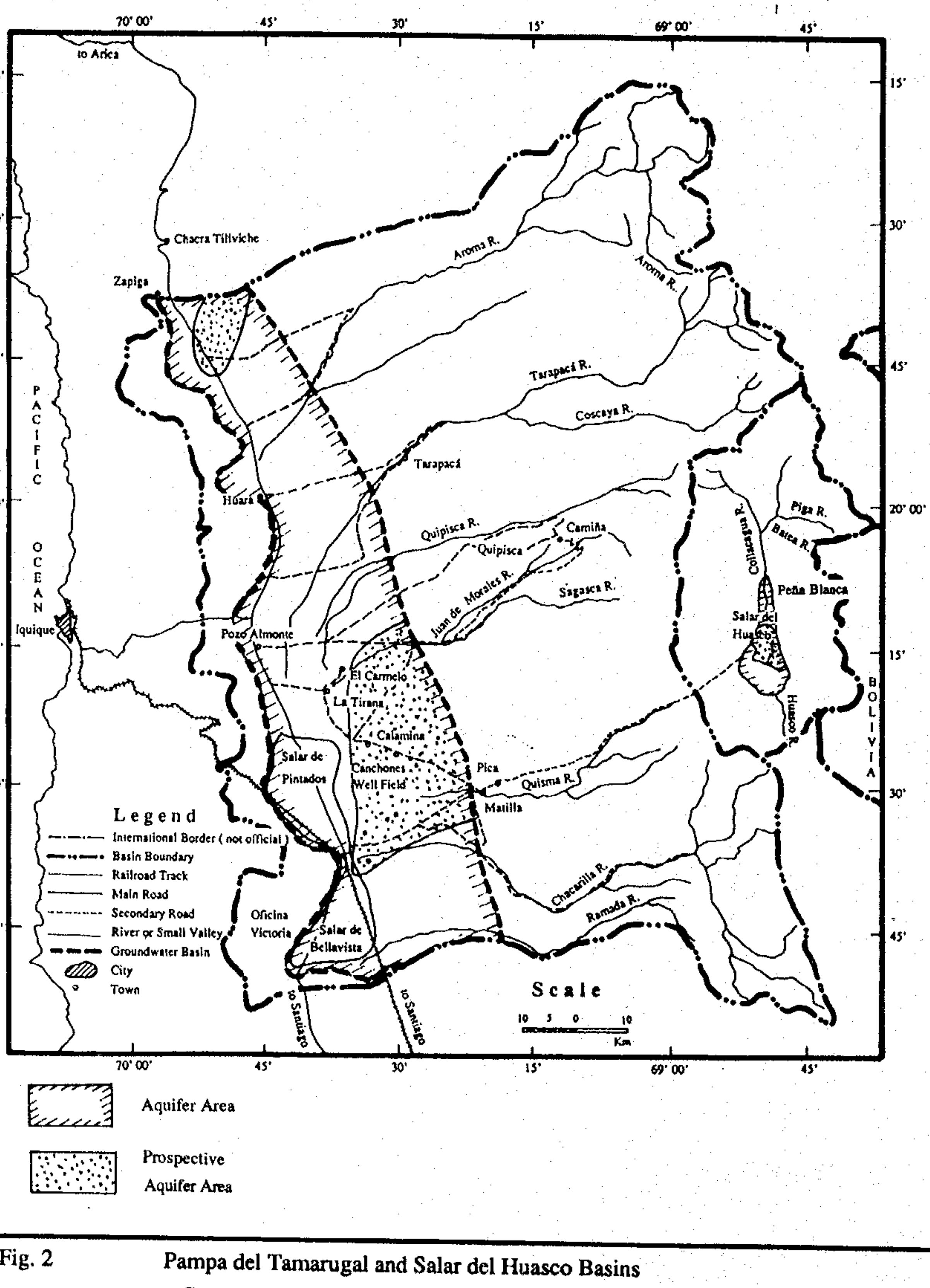


Fig. 2 Pampa del Tamarugal and Salar del Huasco Basins

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

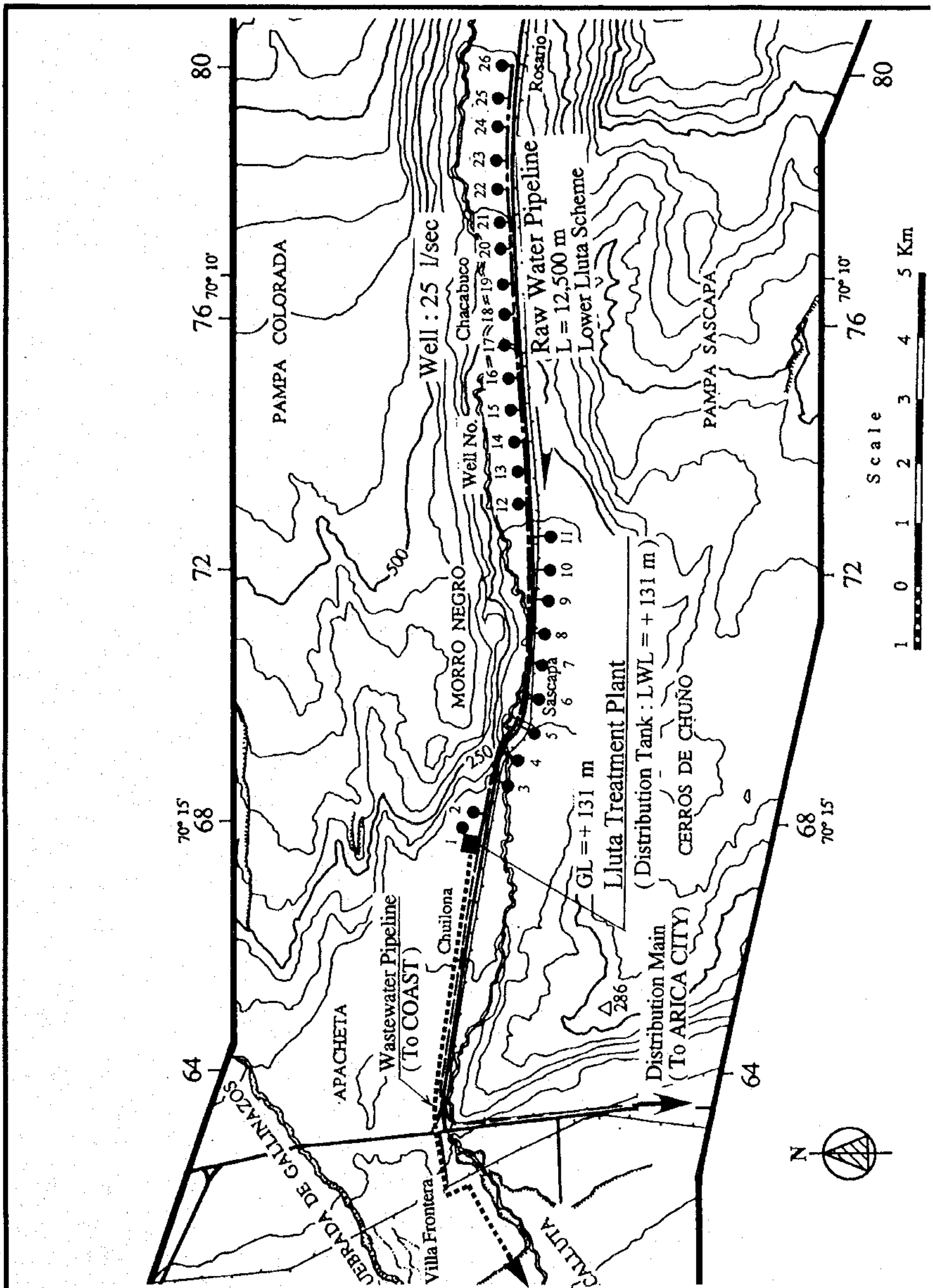


Fig. 3 Water Supply Development for Arica

<Desarrollo de Abestecimiento de Agua para Arica>

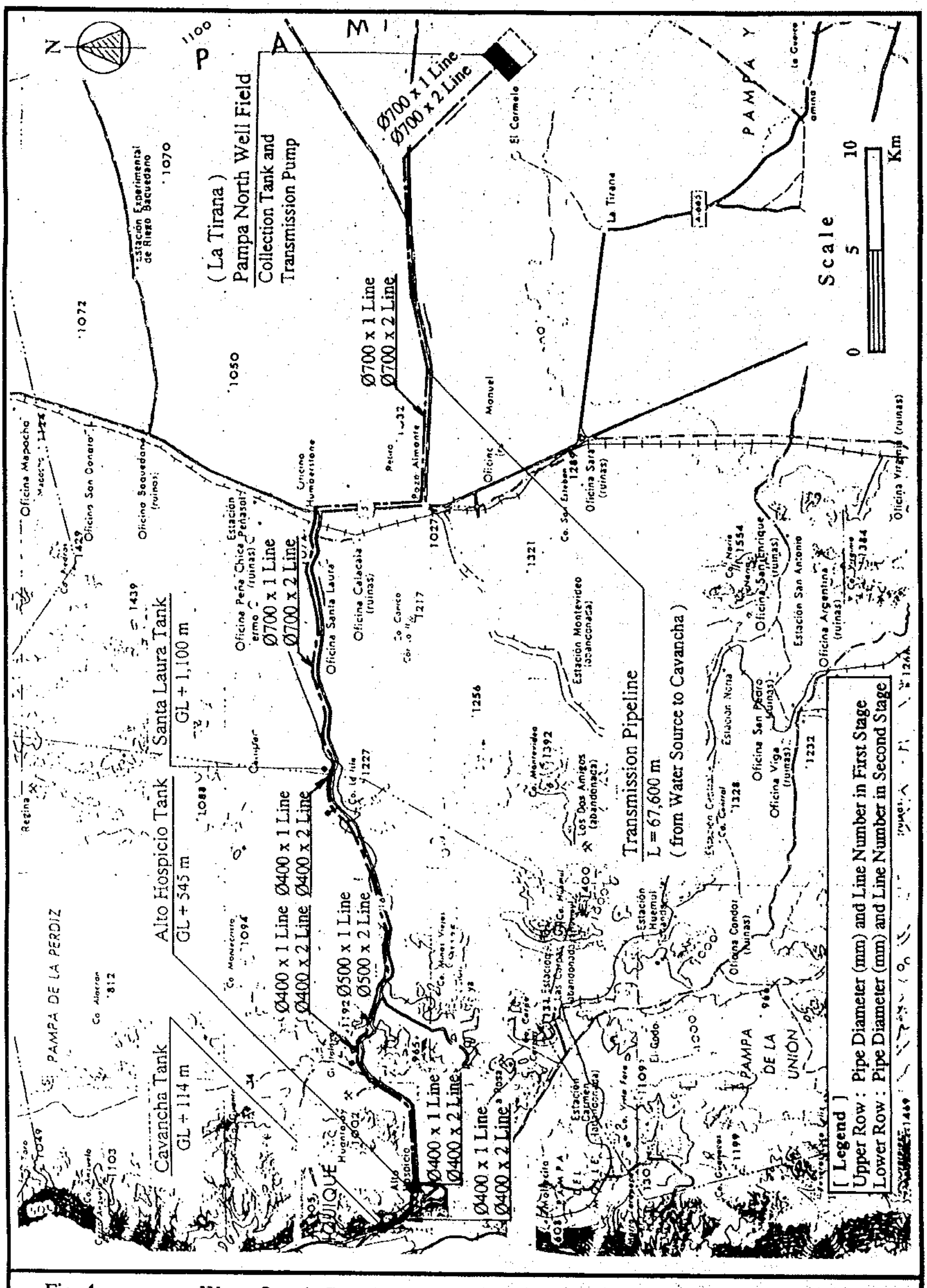


Fig. 4 Water Supply Development for Iquique

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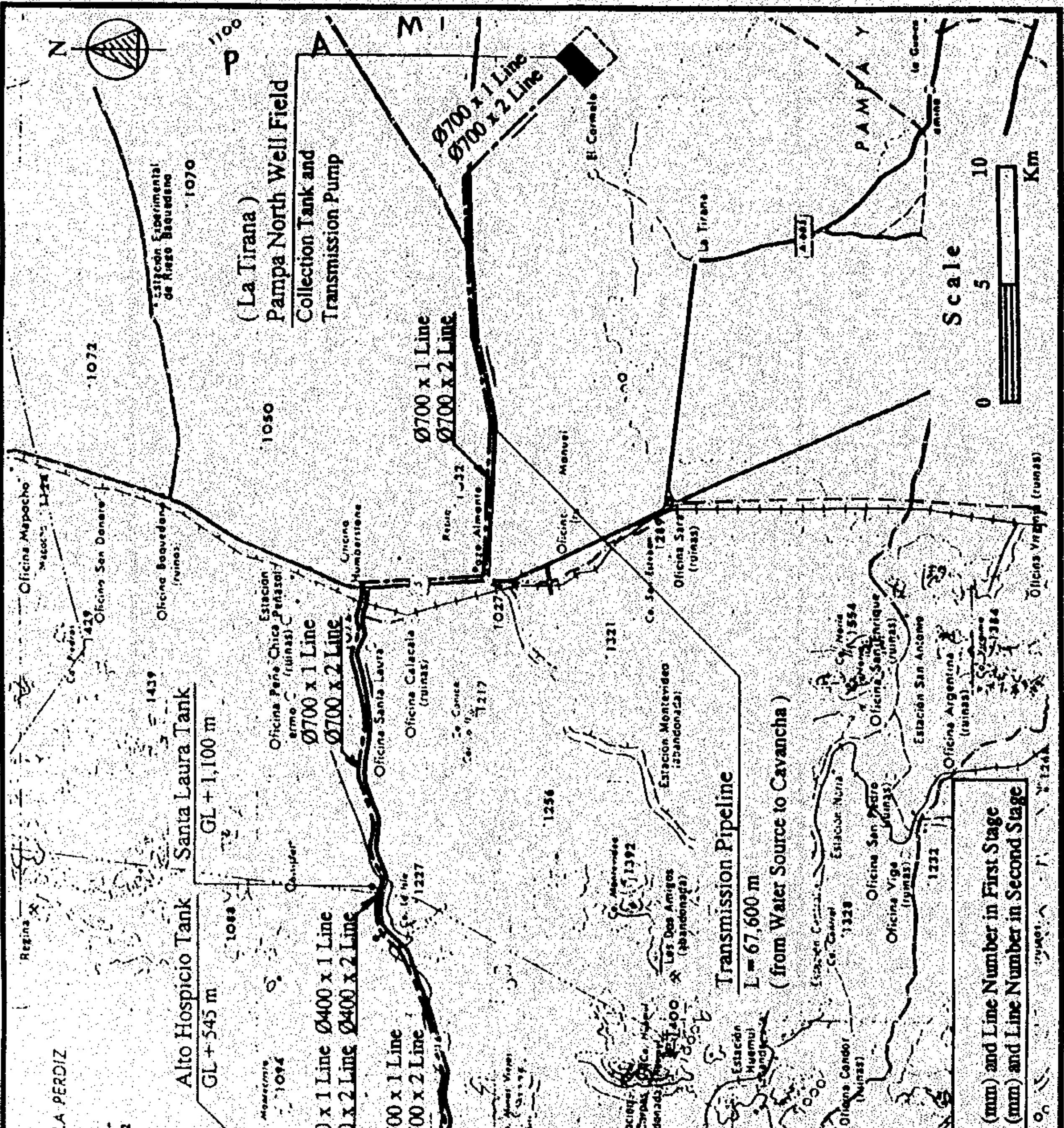

Fig. 4 Water Supply Development for Iquique

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ABBREVIATION

acc.	: acción (a kind of water right)
ACP	: Asbestos Cement Pipe
B/C	: Benefit Cost Ratio
BGL	: below the ground level
BNA	: Banco Nacional de Aguas
CAPPTA	: Corporación Agrícola Proyect Pampa del Tamarugal
CITES	: Convention on International Trade in Endangered Species of Wild Fauna and Flora
CONAF	: Cooperación Nacional de Forestal
DGA	: Dirección General de Aguas
EC	: Electric Conductivity
EDR	: Electrodialysis Reverse
EIRR	: Economic Internal Rate Return
ENAP	: Empresa Naciónal de Petróleo
ESSAT	: Empresa de Servicios Sanitarios de Tarapacá
GL	: Ground Level
HWL	: High Water Level
Irr.	: Irrigation
IVA	: Impuesto al Valor Agregado (Value Added Tax)
JICA	: Japan International Cooperation Agency
MIDEPLAN	: Ministerio de Planificación y Cooperación
MOP	: Ministerio de Oblas Públicas
MSL	: Mean Sea Level
NPV	: Net Present Value
O&M	: Operation and Maintenance
PCI	: Pacific Consultants International
Qda.	: Quebrada (small river)
RO	: Reverse Osmosis
SIMOP	: Simulación de Oblas Publicas
sp.	: species
TDS	: Total Dissolved Solid
TEM	: Transient Electro-Magnetic
U.S.A	: United States of America

CHAPTER I INTRODUCTION

Chapter I INTRODUCTION

1.1 Background of the Study

Region I (Tarapacá Región) covers the northernmost area of 58,700 km^2 of Chile, bordering the territories of Peru on the north and Bolivia on the east, and facing the Pacific Ocean on the west (See, Location Map). In its eastern fringe areas, Andes Mountain Ranges with an elevation of 4,000-5,000 m run in the north-south direction.

The Region had a total population of 341,000 in 1992, of which 322,000 or 94% is concentrated in the two (2) major cities of Arica and Iquique cities, located in the coastal area. These cities, especially Iquique city, have been realizing a remarkable economical development in recent years with a support of the national policy of "Duty-Free Zone". The population of Arica city has increased from 88,000 in 1970 to 169,000 in 1992 and is expected to grow further to 265,000 in 2015. Similarly, population of Iquique city has risen from 64,000 in 1970 to 153,000 in 1992 and is projected up to 273,000 in 2015.

The whole water demand of Arica city depends on the groundwater of San José River Basin at present. However, the city has been suffering from a severe water shortage in recent years. The whole water of Iquique city is supplied by extracting the groundwater of Pampa del Tamarugal located far east of the city. However, the water demand of the city is exceeding the existing water supply capacity. The population increase in the future will further worsen the circumstances of the water supply in both cities.

The water resources of the Region are very scarce due to its dry climate. Precipitation is limited on Andes Mountain areas. The coastal area receives no rainfall throughout the year. The potential water resources existing in the proximity of the two (2) cities are only San José and Lluta River Basins for Arica city and Pampa del Tamarugal and Salar del Huasco Basins for Iquique city (See, Location Map).

Therefore, the water resources development of the above basins is awaited to meet the increasing water demand of Arica and Iquique cities.

1.2 Study Area

The Study Area was determined in the Scope of the Study agreed upon between the governments of both countries on 10 November, 1992. It covers San José River Basin (3,187 km^2) and Lluta River Basin (3,378 km^2) for the water supply to Arica city, and

Pampa del Tamarugal Basin (18,005 km^2) and Salar del Huasco Basin (1,712 km^2) for the water supply to Iquique city.

The surface water of San José and Lluta River Basins originates from The Andes Mountains (their uppermost reaches) with an altitude of 4,000-5,000 m and finally enters Pacific Ocean at Arica city. However, most of it is already consumed for irrigation, drinking and other purposes, or infiltrates into underground in their lower reaches before reaching the sea. Then, the groundwater is considered as the main potential water resources to be developed for these basins.

Pampa del Tamarugal and Salar del Huasco Basins are both hydrologically closed. The surface water originating from The Andes Mountains (their uppermost reaches) of 4,000-5,000 m height finally infiltrates into underground in the downstream flat plains of the basins. No water flows out from the basins. The elevation of the flat plains in Pampa del Tamarugal and Salar del Huasco Basins are about 1,000 m and 3,800 m respectively. The groundwater is also considered as the main potential water resources to be developed for these basins.

1.3 Objectives of the Study

The objectives of the Study are defined in the above-mentioned agreement as follows.

(1) To evaluate the potential water resources, mainly groundwater of the Study Area

(2) To formulate the water resources development plan, mainly related to groundwater, for water supply to Arica and Iquique cities

(3) To conduct technology transfer to the Chilean counterpart personnel.

1.4 Implementation of the Study

The Directorate General of Water Resources (Dirección General de Aguas: DGA) of the Ministry of Public Works (Ministerio de Obras Publicas: MOP) was assigned as the counterpart executing agency of the Government of Chile, while the Japan International Cooperation Agency (JICA) was assigned as the official agency responsible for the implementation of the technical cooperation program of the Government of Japan.

The Study was carried out by the Japanese consultant team retained by JICA and Chilean counterpart staff.

The Study was conducted from March 1993 to March 1995. The members involved in the Study are listed below.

(1) JICA Advisor

Mr. Yasuo MUKAI

(2) JICA Study Team

Mr. Naohito MURATA	Team Leader
Mr. Yasumasa YAMASAKI	Deputy Team Leader/Hydrogeologist
Dr. Chaisak SRIPADUNGTHUM	Hydrologist
Dr. Shuichi KUDO	Water Quality Analyst/Hydrogeologist
Mr. Masatane KATO	Geophysical Survey Expert
Mr. Takenobu SUZUKI	Environmental Expert
Mr. Norifumi YAMAMOTO	Groundwater Simulation Expert
Mr. Yoshiaki SHIBATA	Remote Sensing Expert
Mr. Yuichi HATA	Drilling Expert (A)
Mr. Makoto KUSAKABE	Drilling Expert (B)
Mr. Hideki YAMAZAKI	Water Facility Planner
Mr. Hiroaki MIYAKOSHI	Water Facility Designer/Cost Estimator
Mr. Dennis HARIS	Water Demand
Dr. Jorge TOKESHI	Economic/Financial Analyst
Dr. Katsuhito YOSHIDA	Coordinator

(3) Counterparts of Chile

Mr. Angel Silva	Chief of Counterparts, DGA
Mrs. Fernanda Rojas	DGA
Mr. Luis Rojas	Dirección de RIEGO
Mr. MIguel Silva	DGA, 1 Región
Mr. Arturo Beltrán	DGA, 1 Región
Mr. Domingo Aguirre	DGA, 1 Región
Mr. Conrado Popp	ESSAT

1.5 Composition of the Report

This report consists of four (4) volumes : Summary Report, Main Report, Supporting Reports and Data Book. The Main Report presents the summarized results of all the studies. In Chapter II through IV, the basic information for the Study are described. Water supply and demand balance of both Arica and Iquique cities are described in Chapter V. From Chapter VI to Chapter VII, the water supply development plans of both cities are presented. Chapter VIII deals with the recommendations and further studies.

Detailed study results are described in the Supporting Reports and Data Book. The contents of the Supporting Reports are as follows;

A. Surface Water
B. Geology and Groundwater
C. Water Use
D. Municipal Water Supply Development
E. Environment
F. Project Economy and Finance

CHAPTER II WATER RESOURCES POTENTIAL

Chapter II WATER RESOURCES POTENTIAL

2.1 San José River Basin

2.1.1 General Features of Basin

The San José River covers a drainage basin of 3,187 km^2. Precipitation of the Basin concentrates on the Andes Mountain areas with an elevation of 4,000 - 5,000 m. Average annual precipitation gradually increases from zero in the downstream reaches to 200 mm in the uppermost areas. The major upstream tributaries, indigenous water sources of the Basin are Laco, Seco and Tignamar rivers.

The indigenous water resources of the Basin is small. Hence, the Lauca Canal to divert the Lauca River (international river flowing to Bolivia across the border) was constructed in 1962 to increase the available water in the downstream reaches of the San José River.

The water diverted from Lauca River is discharged at Central Chapiquina, after generating hydro-electric power. After joining the indigenous water of San José River, it further flows down the San José Main River to the irrigation intake of the Azapa Canal and finally enters the Pacific Ocean at Arica city.

The water drawn from the intake irrigates the farmland of 3,213 ha of Azapa Valley along with spring and groundwater available in the Valley.

Azapa Valley is provided with a large groundwater aquifer. The municipal water of Arica city is entirely supplied from this groundwater.

The river system of the Basin is shown in Fig. 2.1.

2.1.2 Surface Flow Rate

1) Inflow to Azapa Valley

The surface flow rate of San José River has been observed at Ausipar/Antes Bocatoma gauging stations by DGA since 1967. This flow rate includes the diverted water from the Lauca River. On the other hand, the data of the diverted water is available at Central Chapiquina hydro-electric power station also since 1967.

Ausipar/Antes Bocatoma stations catch the all water of their upstream basins including both surface water and groundwater since the river beds at their stations are formed of impermeable basement rocks. The groundwater in the upstream basins appears in the river as surface water before reaching the stations. Hence, the surface flow observed at Ausipar/Antes Bocatoma is regarded as the total inflow water to Azapa Valley.

The monthly average flow rate at Ausipar/Antes Bocatoma ranges from 694 l/s in October to 2,272 l/s in February with an annual average of 1,101 l/s. The monthly average diverted water at Central Chapiquina is comparatively constant. It is in the range of 752 l/s in June and 879 l/s in January, averaging 796 l/s. The balance of the flow rates at Ausipar/Antes Bocatoma and Central Chapiquina is the indigenous flow rate of the Basin.

The annual average flow rates of the San José River Basin are summarized as follows:

Lauca Diverted Flow Rate	:	796 l/s
Indigenous Flow Rate	:	305 l/s
Flow Rate at Ausipar/Antes Bocatoma	:	1,101 l/s

2) Overflow to Sea

Floods of the San José River usually occur in January and February. A large portion of those floods infiltrate into the river beds to recharge the groundwater of the Azapa Valley. However, some remaining portions spill over to the sea.

Average annual discharge to the sea is estimated to be 149 l/s or 13.5% of the flow rate at Ausipar/Antes Bocatoma.

For location of the gauging stations, see Fig. 2.1.

2.1.3 Surface Water Quality

Surface water quality of San José River has been observed at Antes Bocatoma by DGA since 1967. All the water quality parameters other than As and Fe are below the permissible limits for drinking use in Chile. Average concentration of As and Fe at Antes Bocatoma are shown below, in comparison with those at Lauca Canal.

	As (mg/l)	Fe (mg/l)
Lauca Canal	0.087	0.268
Antes Bocatoma	0.080	1.399
Permissible Limit	0.050	0.3

2.1.4 Hydrogeology of Azapa Valley

Geology of Azapa Valley are classified into seven (7) units as described below.

(1) Basement Rocks

The Basement Rocks consist of Arica Group Formation, Vilacollo Group Formation, Chapiquina Group Formation, Azapa Formation and Plutonic Rocks. These Formations are impermeable.

(2) Marine Terrace Deposits

The Marine Terrace Deposits were formed on the coastal plain by eustatic movement. These Deposits are mainly composed of sands and gravels sometimes intercalated with silt. They form one of the aquifers in the city area of Arica.

(3) Fluvial Deposits

The San José River formed a fluvial plain along the River. The Fluvial Deposits composed of gravel, sand and silt are piled in this plain. This unit is highly permeable. Thus, it is one of the most principal aquifers in Azapa Valley.

(4) Detrital Deposits

The Detrital Deposits mainly consist of talus and other deposits formed by land slides/land collapses. Principal units of the talus deposits keep their original sedimentary structures. The other deposits are piled with the matrix filled by fine materials. Thus, the Detrital Deposits are less permeable.

(5) Fan Deposits

The Qda. Diablo, Qda. Llosyas and Qda. Acha formed fans at the confluences with San José River. The Fan Deposits are mainly composed of sand, gravel and silt. This unit is generally permeable.

(6) Recent Beach Deposits

The Recent Beach Deposits consisting of sand and gravel are distributed along the sea coast, forming a beach. The permeability of the Deposits is high.

(7) Recent Fluvial Deposits

The Recent Fluvial Deposits are distributed along the channels of San José River and Qda. Acha. The Deposits consist of volcanic ash, mud, sand and gravel. The permeability of this unit is generally high and therefore, it is considered one of the important aquifers in Azapa Valley.

Geological map and geological profile of Azapa Valley are shown in Fig. 2.2 and Fig. 2.3 respectively.

2.1.5 Aquifer

1) Configuration of Aquifer

Location and size of the aquifers in Azapa Valley and Arica city area were estimated based on the existing geological map and boring data.

The aquifers are located in the Recent Fluvial Deposits, Fluvial Deposits, Fan Deposits and Marine Terrace Deposits. The principal aquifers of Azapa Valley are formed in the Fluvial Deposits. On the other hand, those of Arica city area are contained in the Marine Deposits.

The prospective aquifers of these areas extend over 22 km from the sea coast to Cabuza in Azapa Valley. No large potential aquifers are identified in the upstream reaches of Cabuza.

Width of the aquifer is the maximum at the top layer of the aquifer. It is equivalent to the width of the Valley. It gradually decreases from the top layer to the bottom layer of the aquifer. The bottom of the aquifer is generally located in the center of the Valley.

The configurations of aquifers by region are summarized below.

(1) Cabuza Area

The width of the aquifer is 600-1,200 m. The thickness is 50-60 m. Intercalation of such impermeable layers as silt and clay into the aquifer is little.

(2) San Miguel Area

The aquifer is divided into two (2) layers : upper layer and lower layer by an intercalated impermeable layer. The aquifer width is 1,200 m. The total thickness of the two (2) aquifers including the impermeable layer of 15 m is estimated to be 50 m.

(3) Pago de Gomez Area

The width and thickness of the aquifer are 1,200 m and 45 m respectively. Irregular impermeable layers are put into the aquifer.

(4) Saucache Area

The aquifer width reaches more than 1,700 m. The aquifer thickness is estimated at 55 m. Impermeable layers are rarely identified in the aquifer.

(5) Arica City Area

The aquifer of this area spreads in the Marine Terrace Deposits. Impermeable layers are predominant in this deposits. The aquifer is divided by impermeable layers, resulting in reduction of the net aquifer thickness. The lower aquifer is distributed under the sea water level.

The longitudinal profile of the aquifers are shown in Fig. 2.4.

2) Hydrogeological Characteristics of Aquifer

Major portion of the aquifers in this area are formed of the Fluvial Deposits in Azapa Valley and Marine Terrace Deposits in Arica city area. The aquifers are composed of a sequence of permeable units, however, they are in an unconfined state.

Hydrogeological constants of the aquifer are evaluated based on the existing available data. The average transmissibility, permeability and specific yield by region are summarized below.

	Transmissibility (m³/d/m)	Permeability (cm/sec)	Specific Yield (l/s/m)
Cabuza	-	-	5.23
Las Riveras	-	-	7.44
San Miguel	37	9.51×10^{-4}	8.36
Pago de Gomez	1,934	5.83×10^{-2}	2.81
Saucache	1,231	3.73×10^{-2}	3.88
City Area	-	-	1.83
Average	1,067	3.22×10^{-2}	4.92

Specific yield is the most important constant in evaluation of the groundwater potential. The value of the constant ranges from 1.83 l/s/m in Arica city area to 8.36 l/s/m in San Miguel with an average of 4.92 l/s/m. This average value of 4.92 l/s/m is considered as an ordinary one for the aquifers composed of sand and gravel mixed with silt.

3) Estimated Groundwater Storage

The major aquifer of this area extends from the coastal area of Arica city to Cabuza of Azapa Valley. The aquifer in the upstream reaches of Cabuza is considered negligibly small. The aquifer existing under the sea water level in the city area is also considered unavailable.

The total groundwater storage is estimated to be 302 million m^3 with the following break-down.

Zone	Section	Storage ($10^6 m^3$)	Area
1	Coast to A-A'	0.26	Coastal Arica City
2	A-A' to B-B'	2.25	Central Arica City
3	B-B' to C-C'	53.20	Saucache
4	C-C' to D-D'	89.61	Pago de Gomez
5	D-D' to E-E'	55.54	Pago de Gomez, Las Maitas
6	E-E' to F-F	31.37	San Miguel
7	F-F' to G-G'	69.95	Las Riveras, Cabuza
Total		302.18	

For location of the sections, see Fig. 2.2 and Fig. 2.4.
In the above estimation, effective porosity of the aquifers was assumed as 30%.

2.1.6 Groundwater Level and Quality

1) Existing Groundwater Extraction

The groundwater of Azapa Valley and Arica city area is extracted from 206 wells. The existing groundwater extraction was estimated based on the interviews with the users which was conducted in this Study.

Furthermore, spring water is extracted from five (5) springs for irrigation use in Azapa Valley. The existing spring water extraction was observed in this Study.

The results of the interviews and discharge observation are summarized as follows.

	Nos. of Well/Spring	Extraction (l/s)
Groundwater		
Arica Municipal	39	730.0
Irrigation	122	302.0
Individual Domestic	30	43.0
Industrial	3	4.0
Others	12	6.4
Spring Water		
Irrigation	5	73.0
Total	211	1,158.4

2) Groundwater Level

Static groundwater level of Azapa Valley and Arica city area has been observed at the selected wells by DGA since 1962.

The groundwater table has gradually lowered since 1977. It once recovered to some extent due to the recharge of the floods of San José River occurred during 1984 to 1988. Thereafter, it has drawn down again.

The draw-down during 15 years from 1977 to 1992 in the representative wells are shown below.

Well Location	Draw-down (m)
San Miguel (upstream)	3
Las Maitas	15
Pago de Gomez	20
Saucache	30

San Miguel (upstream) is located at the upstream of the confluence of Qda. Diablo. Draw-down of the groundwater table at San Miguel (upstream) is small. It is considered due to the dam-up effects of the impermeable spur from Qda. Diablo.

For the historical variation of the groundwater table in the representative wells, see Fig. 2.5.

The longitudinal profile of the existing groundwater table is shown in Fig. 2.4.

3) Groundwater Quality

Data of the groundwater quality are available for 61 wells located in Azapa Valley and Arica city area from ESSAT and DGA. The above wells are widely distributed from the city area to Cabuza.

(1) Existing Groundwater Quality

The salient features of the existing groundwater quality are shown below.

(i) The critical parameters of the existing groundwater quality of this area are TDS, SO_4, Cl and NO_3. On the other hand, As, B and other parameters are generally good for drinking use.
(ii) The contents of TDS, SO_4, Cl and NO_3 are summarized below.

	TDS	SO_4	Cl	NO_3
Range (mg/l)	519-2,835	117.1-861.3	71.3-577.6	0.0-113.1
Average (mg/l)	913	253.2	154.2	9.6
Permissible Limit (mg/l)	1,000	250	250	10.0

Note : This table was prepared from Supporting Report B, Table B-I, 3.3. In this preparation, the data of the well Number 168-K was excluded because it is affected by a special contamination source.

(iii) In all the wells, B is less than 1.8 mg/l and As is smaller than the permissible limit of 0.05 mg/l.

(2) Historical Variation

Salinity of the groundwater in the lower reaches of Azapa Valley and Arica city area has been increasing during the recent years. DGA has studied for the historical variation of Electric Conductivity of the several springs located in the middle and lower reaches of Azapa Valley. The average Conductivity of the springs during the recent years are roughly estimated as follows.

	1975	1986	1987	1990	1991
EC (mmho/cm)	1,300	1,500	1,600	1,800	1,900

It is projected to increase to 2,200 mmho/cm in 2000 and 2,600 mmho/cm in 2010.

On the other hand, EC value can be converted into TDS by using the following relationship established for this area based on the existing available data.

$$Y = 0.6848\,x + 91.38$$

where, X : EC value (mmho/cm)
Y : TDS Value (mg/l)

The future TDS value of the spring water is estimated at 1,097 mg/l in 2000 and 1,869 mg/l in 2010 respectively.

Conductivity of the well water in the lower Azapa Valley and city area also shows a similar increasing tendency.

2.2 Lluta River Basin

2.2.1 General Features of Basin

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 - 5,000 m. Precipitation of the Basin is limited in the upper mountain areas. Average annual precipitation gradually increases from zero in the lower Lluta Valley to 350 mm in the Andes Mountains.

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.

The river water is extracted at 80 locations in the Lluta Valley of 65 km distance between Vilacollo and Panamericana for irrigation of the farmlands of 2,784 ha extending along the Lluta River. River water extraction in the upstream reaches of Vilacollo is negligibly small.

The groundwater extraction is limited to the lowermost area of the Lluta Valley. A small quantity of groundwater is pumped up by approximately 10 wells for irrigation and industrial uses.

For the river system of the Lluta River Basin, see Fig. 2.1.

2.2.2 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.2.4.

The water sources of the Lluta River are limited to the following upstream tributaries (see, Fig. 2.1).

(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 1~3, 1993. The results are shown below.

River	Flow Rate (l/s)	Share (%)	Exceedence Probability of Flow Rate in June (%)
Caracarani (at Humapalca)	394	33	50
Azufre	76	6	
Eastern Slope Tributaries	334	29	
Sub-total (Caracarani at Alcerreca)	(804)	(68)	50
Colpitas	231	19	95
Putre & Others	360	31	
Loss	-211	-15	
Lluta (at Chapisca)	1,184	100	95

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

2) Surplus Surface Flow Rate

There are approximately 2,500 ha of irrigated farmlands 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 (l/s)	3,744	906	643	248	1,385
80% Drought (l/s)	520	390	409	76	349
90% Drought (l/s)	340	274	348	63	256

For the monthly flow rate, See Supporting Report A, Table A,2.4.

2.2.3 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 River is much contaminated by the water of the upstream tributaries of Azufre and Colpitas. The pollutants mainly originate from natural contamination sources. 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.

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 River) are summarized in Table 2.2.

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. 2.6 (1) and Fig. 2.6 (2) respectively.

The results are summarized below.

(1) Azufre River

(i) Pollution loads of As and B in Azufre River gradually increases downward until A-8 point. However, they decrease to a great degree between A-8 point and A-5A point although the flow rate increases in this stretches. Thereafter, they increase again between A-5A point and A-3 point (river mouth of Azufre), despite that the flow rate decreases in this reaches.

The flow rate and pollution loads by river section are shown below.

River Section	A-8	A-5A	A-3
Flow Rate (l/s)	48	119	74
As Content (mg/l)	6.75	0.01	5.21
As Load (g/s)	0.324 (83.9%)	0.001 (0.3%)	0.386 (100%)
B Content (mg/l)	28.93	6.82	27.87
B Load (g/s)	1.389 (67.4%)	0.812 (39.4%)	2.062 (100%)

(ii) The largest contamination sources exist in the river reaches between A-5A and A-3. The pollution loads is considered to spring from the river beds because the tributaries joining the river between the two (2) sections had no surface water during the observation time.

The pollution load production from the river beds between A-5A and A-3 shares 99.7% for As and 60.6% for B of the total pollution loads at the river mouth of Azufre.

(iii) Bypassing the existing river channel between A-5A and A-3 is considered as one of the prospective projects for reduction of As and B of Azufre River.

(2) Colpitas River

(i) The major portion of As and B 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 (load at C-3 point) is 66.1% for As and 58.4% for B as shown below.

River Section	C-10	C-3
Flow Rate (l/s)	74	346
As Content (mg/l)	2.08	0.67
As Load (g/s)	0.154 (66.1%)	0.233 (100%)
B Content (mg/l)	61.79	22.61
B Load (g/s)	4.572 (58.4%)	7.823 (100%)

(ii) Construction of an evaporation reservoir of the river water at C-10 point is considered as one of the prospective projects for reduction of As and B of Colpitas River.

2.2.4 Hydrogeology of Lluta Valley

Geology of the Lower Lluta Valley 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, are less developed in the lower layer. Therefore, they are 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 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) Detrital Deposits

Detrital 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 with a large quantity of fine materials.

Geological map of the Lower Lluta Valley is shown in Fig. 2.7.

2.2.5 Geological Survey

Electromagnetic surveys and boring tests were conducted in this study for the Lower Lluta Valley between Panamericana and Chacabuco to supplement the existing geological data.

1) Electromagnetic (TEM) Survey

The TEM surveys were performed for 30 stations set on five (5) survey lines. Location of the survey lines and stations are shown in Fig. 2.8.

Geoelectric profiles along the five (5) survey lines were drawn based on the observed apparent resistivity curve at each station. They are shown in Fig. 2.9.

The geology of the survey area is classified into three (3) to four (4) layers in terms of apparent resistivity. The thickness and resistivity of each layer are summarized below.

Layer	Thickness (m)	Resistivity (ohm-m)
1st Layer	5-70	28-300
2nd Layer	50-250	11-30
3rd Layer	70-190	29-96
4th Layer		< 9.8

The 2nd layer existing in all the five (5) lines is considered as prospective aquifer.

2) Boring Test

Four (4) wells including two (2) test wells (J-A, J-B) and two (2) observation wells (J-1, J-2) were drilled along the TEM survey lines. For their locations, see Fig. 2.8.

The results of the boring tests are summarized in Table 2.3. The table shows borehole depth, dimensions of casing and screen pipes, geological features of the identified aquifers and resistivity of well logging, compared with that of TEM survey. For columnar sections of the four (4) wells, see Fig. 2.10 and Fig. 2.11.

Further, pumping tests including step drawdown test, constant discharge test and recovery test were executed for the above four (4) wells.

The results of the pumping tests are summarized in Table 2.4. The table shows pumping data by constant test, aquifer constants and well capacity.

2.2.6 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. 2.10 and Fig. 2.11.

(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. Both thickness and width of the aquifer 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. 2.12.

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 basically of confined type. However, the impermeable layer overlying the aquifer is discontinuous in some places. In such places, the aquifer becomes semi-confined.

The deep aquifer is considered to be recharged by the surface water of Lluta River mostly from the upstream reaches of Chacabuco. This is because the deep aquifer is covered by an impermeable tuff layer in the downstream reaches of Chacabuco, although the tuff layer disappears in some places. 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)	Storativity	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^{-4}	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. 2.7.

Storativity is generally small; from 6.60×10^{-6} to 8.54×10^{-4}, averaging 3.35×10^{-4}. This order of storativity means the aquifer is confined one.

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 from 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 as described below.

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 of deep aquifer is estimated to be 107 million m^3 with the following break-down by zone.

Zone No.	Section	Storage ($10^6 m^3$)
1	A-A' to B-B'	14.5
2	B-B' to C-C'	23.6
3	C-C' to D-D'	23.7
4	D-D' to E-E'	13.8
5	E-E' to F-F'	31.3
Total		106.9

For location of the sections, see Fig. 2.7.

In the above estimation, effective porosity of the aquifer was assumed as 20%.

2.2.7 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 1993, October 1993 and February 1994.

The water quality exceeds the permissible limit of drinking water in some water quality elements. Such elements are TDS, Na, SO_4, Cl, 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.

Element	Groundwater Shallow	Groundwater Deep	Surface Water Tocontasi/Chapisca	Permissible Limit
TDS	3,522	3,289	1,051	1,000
Na	503	529	198.9	200
SO4	919	852	310	250
Cl	1,110	949	323	250
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. 2.13.

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.

2.3 Pampa del Tamarugal Basin

2.3.1 General Features of Basin

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 ground elevation of the Basin ranges from 1,000 m at Pampa del Tamarugal to 4,000-5,000 m at Andes Mountains.

Precipitation of the Basin concentrates on the upper mountains. The average annual precipitation of the Basin gradually increases from zero in Pampa del Tamarugal to 200 mm in the highest mountain areas.

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 flows down toward Salar de Bellavista.

Surface water of some of the above rivers is extracted for irrigation use of 275 ha in the river valleys. Groundwater of Pampa del Tamarugal is pumped up for drinking use of Iquique city and seven (7) local towns, for irrigation use of 305 ha and for four (4) mines.

For the basin system, see Fig. 2.14.

2.3.2 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, 3.2.

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 rivers of the Study Area and its neighboring areas: Lluta, San José, Vitor, Camarones, Tana, Tarapacá, Chacarilla and Loa rivers. It is as follows.

$$R = 1{,}423.17 f + 23.52$$

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 Coefficient	Yearly Average Flow Rate (l/s)
Aroma	1,746	102	0.055	310
Tarapacá	1,716	104	0.056	318
Quipisca	846	82	0.041	89
Sagasca	971	71	0.033	72
Quisma	298	70	0.032	21
Chacarilla	1,221	89	0.046	159
Ramada	244	49	0.016	7
Total	7,042			976

This total run-off of the seven (7) rivers of 976 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			

2.3.3 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. 2.15.

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.

2.3.4 Geological Survey

Electromagnetic surveys and boring tests were executed in this study for the whole area of Pampa del Tamarugal to supplement the existing geological data.

1) Electromagnetic (TEM) Survey

The TEM surveys were conducted for 100 stations placed on eight (8) survey lines. Location of the survey lines and stations are shown in Fig. 2.16.

Geoelectric profiles along the eight (8) survey lines were prepared based on the observed apparent resistivity curves at the respective stations. They are shown in Fig. 2.17.

Geology of the survey area is classified into three (3) to four (4) layers in terms of apparent resistivity. The thickness and resistivity of each layer are summarized below.