社会開発調査部報告書

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

EXECUTIVE SUMMARY

MARCH 1995

PACIFIC CONSULTANTS INTERNATIONAL, TOKIO

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).

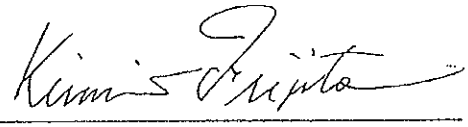
JICA sent to Chile a study team headed by Mr. Naohito MURATA, Pacific Consultants International from March 1993 and March 1995.

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.

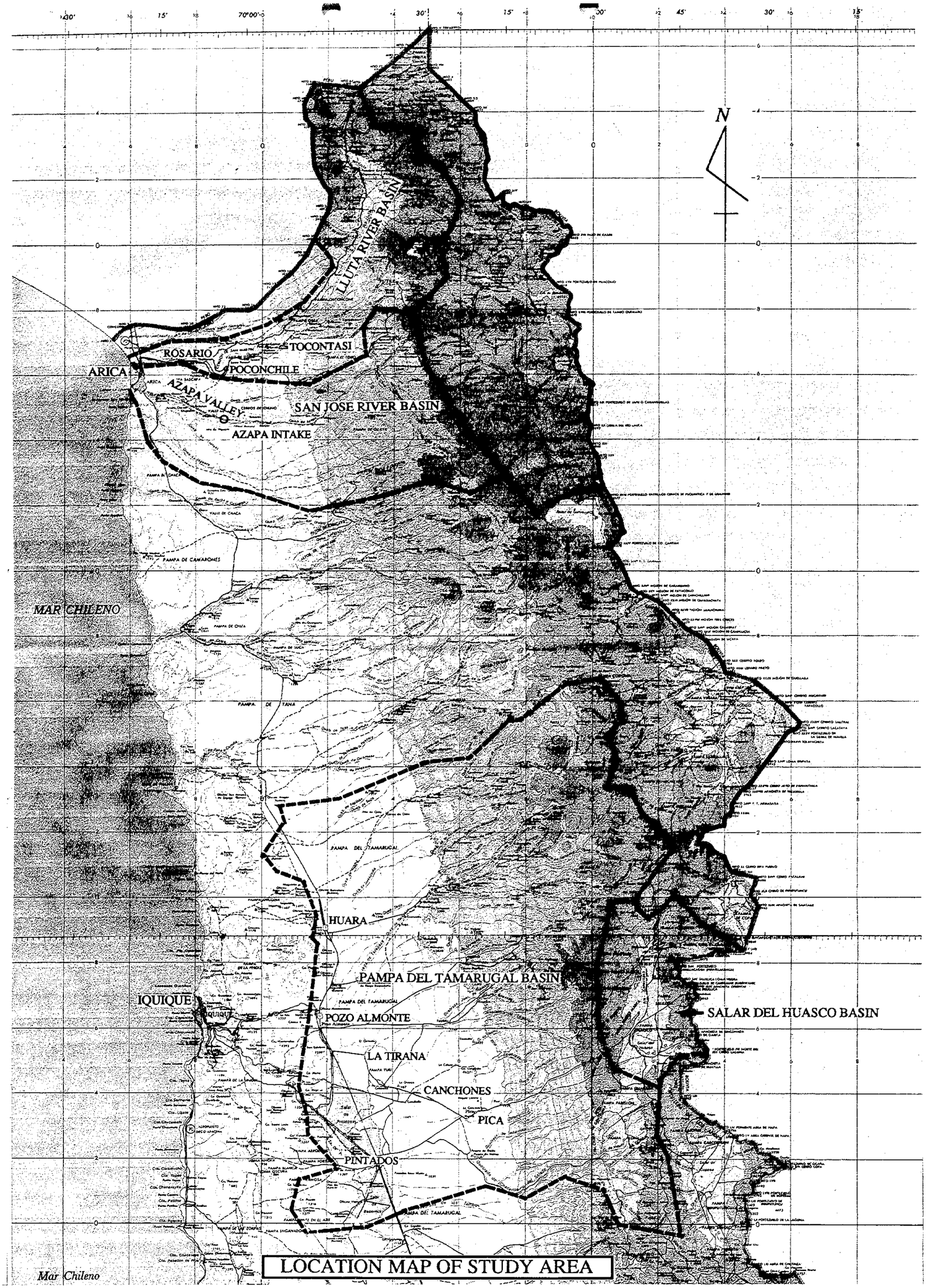
The report consists of the Summary, Main Report, and Supporting Report. The Summary summarizes the results of all studies. The Main Report presents the results of the whole study including analysis of existing conditions, evaluation of the water resources development potential and formulation of water 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,

村田直人

Naohito MURATA
Team Leader



LOCATION MAP OF STUDY AREA

THE STUDY ON THE DEVELOPMENT OF WATER RESOURCES IN NORTHERN CHILE

ABSTRACTS

I. Water Resources Development for Arica City

1. Target Year : 2005

2. Served Area and Population

   (1) Served Area : 1,680 ha

   (2) Served Population : 215,000

3. Water Source

   Groundwater in the Lower Lluta Valley (Rosario ~ Chuilona)

4. Components of the Water Supply Facilities

   (1) Intake Facilities

   Deep Well : ø 12" 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

   Reverse Osmosis Process : 12 units
   Tank : 2 receiving tanks, 2 distribution tanks, etc.
   Wastewater Pipe : ø 350 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

5. Investment Cost

(unit : million Pesos ($))

Direct Construction Cost	25,027
Land Acquisition/Compensation Cost	2,912
Engineering Cost	1,502
Administration Cost	751
Physical Contingency	2,503
Total	32,694

6. Economic Evaluation

The economic internal rate of return is estimated at 11.36%. The project is judged to be economically feasible.

7. Financial Evaluation

The financial internal rate of return is calculated to be 13.06%. The project is judged to be financially viable.

II. Water Resources Development for Iquique City

1. Target Year : 2015

2. Served Area and Population

(1) Served Area : 2,162 ha

(2) Served Population : 273,000

3. Water Source

Groundwater in La Tirana area of Pampa del Tamarugal

4. Components of Water Supply Facilities

(1) Intake Facilities

Deep Well	:	ø 12" 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 site

(5) Land Acquisition

Well-field and Tank Sites : 261 ha

5. Investment Cost

(unit : million Pesos ($))

Direct Construction Cost	38,512
Land Acquisition Cost	262
Engineering Cost	2,311
Administration Cost	1,155
Physical Contingency	3,851
Total	46,091

6. First-stage Project

The first-stage project is targeted for the year 2005 and will serve a population of 213,000. It will complete half of the total project works.

6.1 Major Works

(1) Intake Facilities

Deep Well	:	ø 12" 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

6.2 Land Acquisition

Well-field and Tank Sites : 261 ha

6.3 Investment Cost

(unit : million Pesos ($))

Direct Construction Cost	20,096
Land Acquisition Cost	262
Engineering Cost	1,206
Administration Cost	603
Physical Contingency	2,010
Total	24,177

6.4 Economic Evaluation (First-stage Project)

The economic internal rate of return is estimated to be 17.33%. The project is judged to be economically feasible.

6.5 Financial Evaluation (First-stage Project)

The financial internal rate of return is estimated to be 14.86%. The project is judged to be financially viable.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

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 x 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 $20,868 \times 10^6$ Pesos ($) and $14,138 \times 10^6$ 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: $6,730 \times 10^6$ 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 $11,456 \times 10^6$ 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)

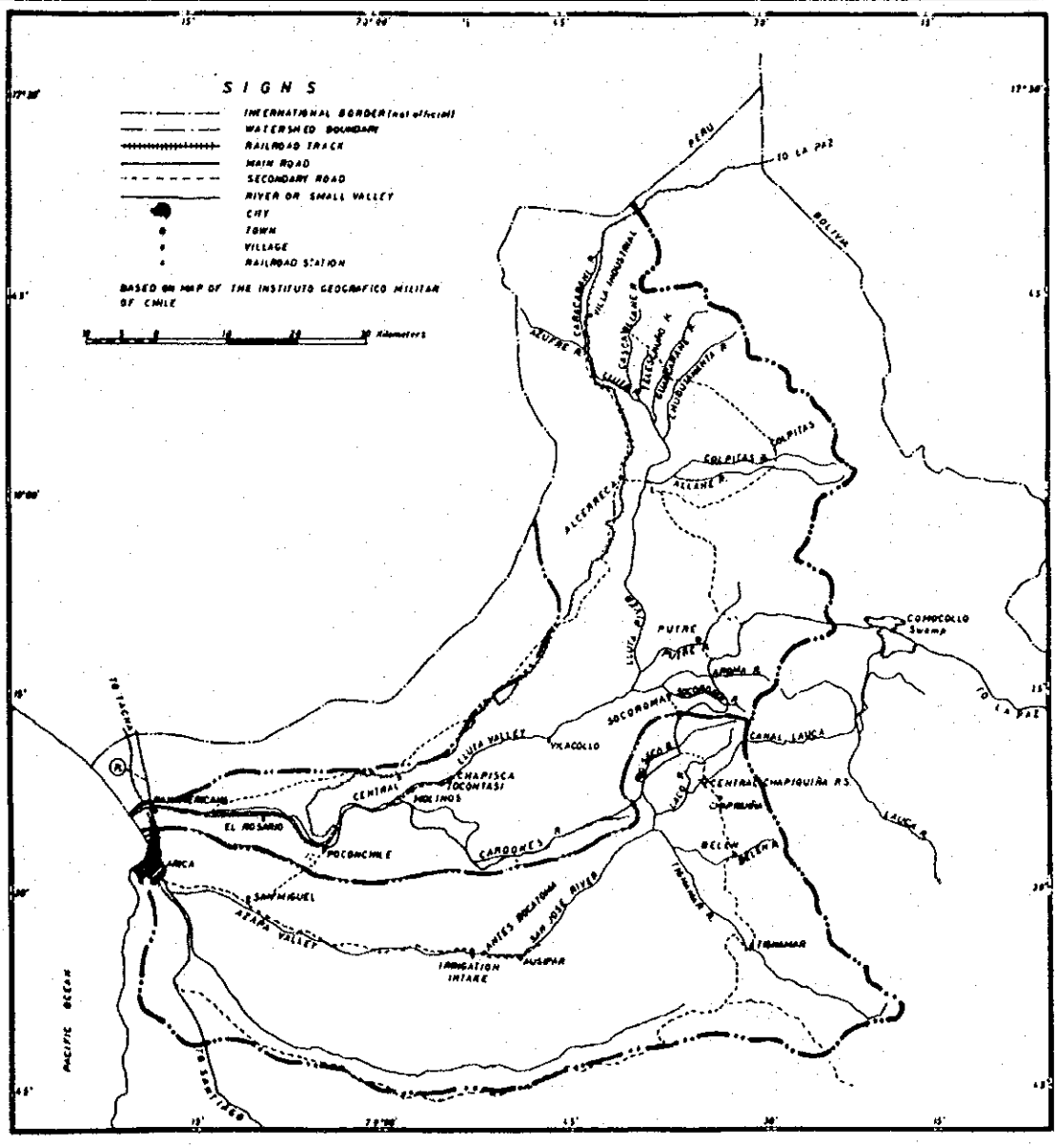
Exchange Rate: US$1.00 = Chilean Pesos $435.00 = Japanese Yen ¥110.00

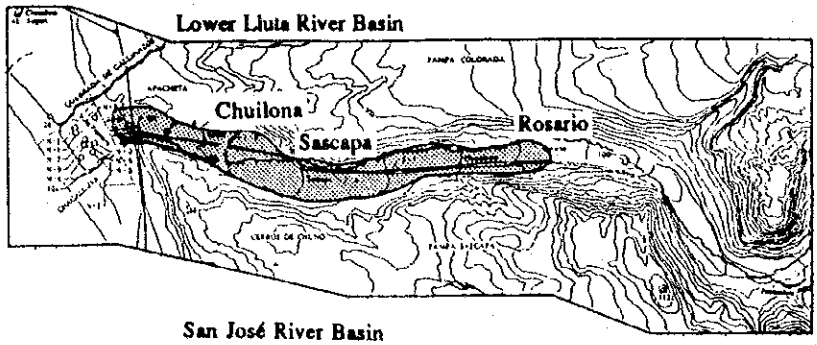
Table 2 Investment Cost for Iquique

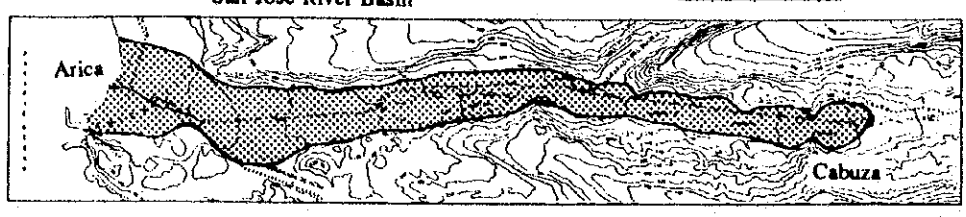
Item	Long-term	First-stage		
	Total (10^3 Pesos $)	F/C (10^3 US$)	L/C (10^3 Pesos $)	Total (10^3 Pesos $)
Direct Construction Cost	38,512,014	36,032	4,422,575	20,096,326
(1) Intake Works	4,075,846	2,532	1,193,663	2,295,144
(2) Transmission Facilities	32,327,643	33,499	2,305,366	16,877,636
i) Transmission 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







Aquifer Area

Fig. 1 San José and Lluta River Basins

<Cuencas de los Ríos San José y Lluta>

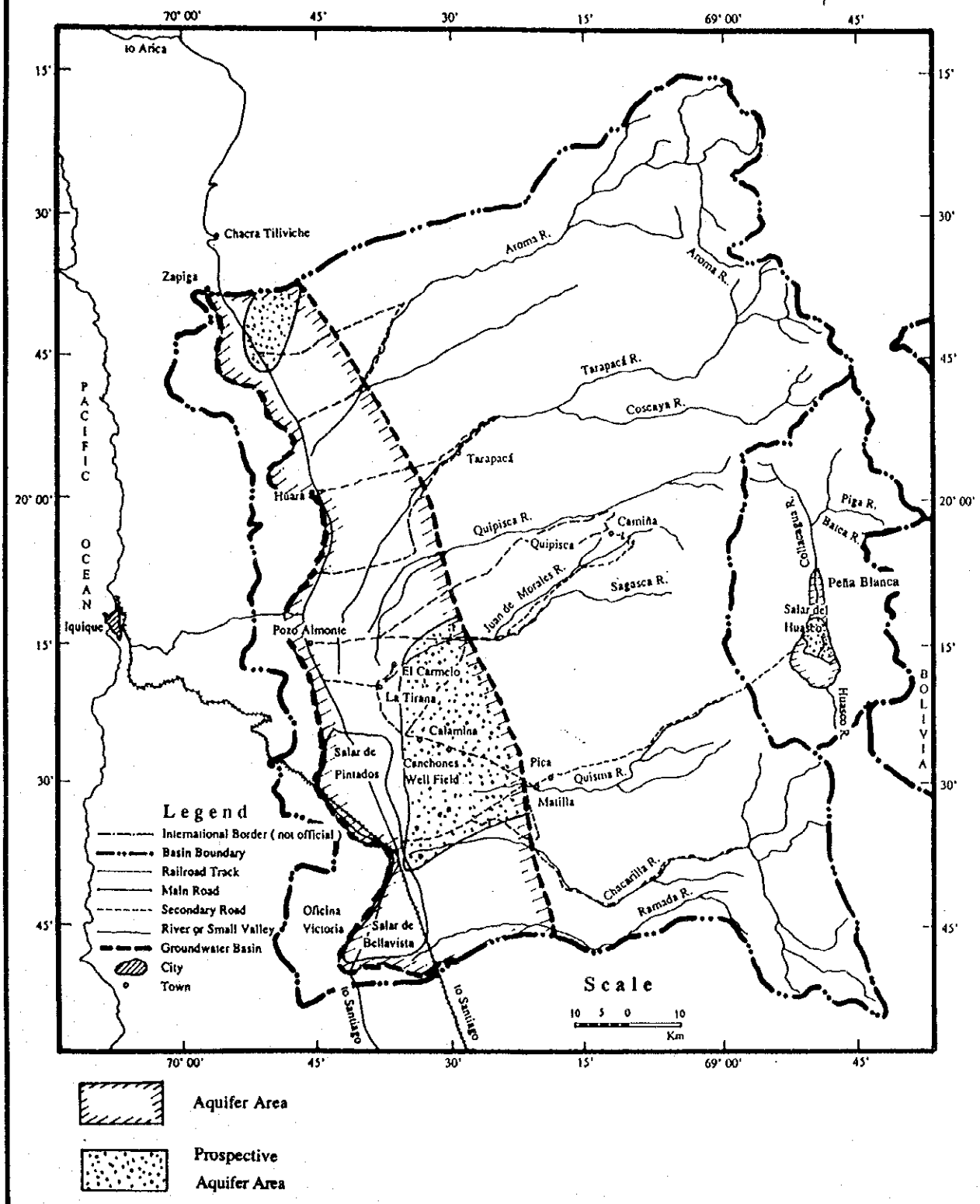


Fig. 2 Pampa del Tamarugal and Salar del Huasco Basins

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

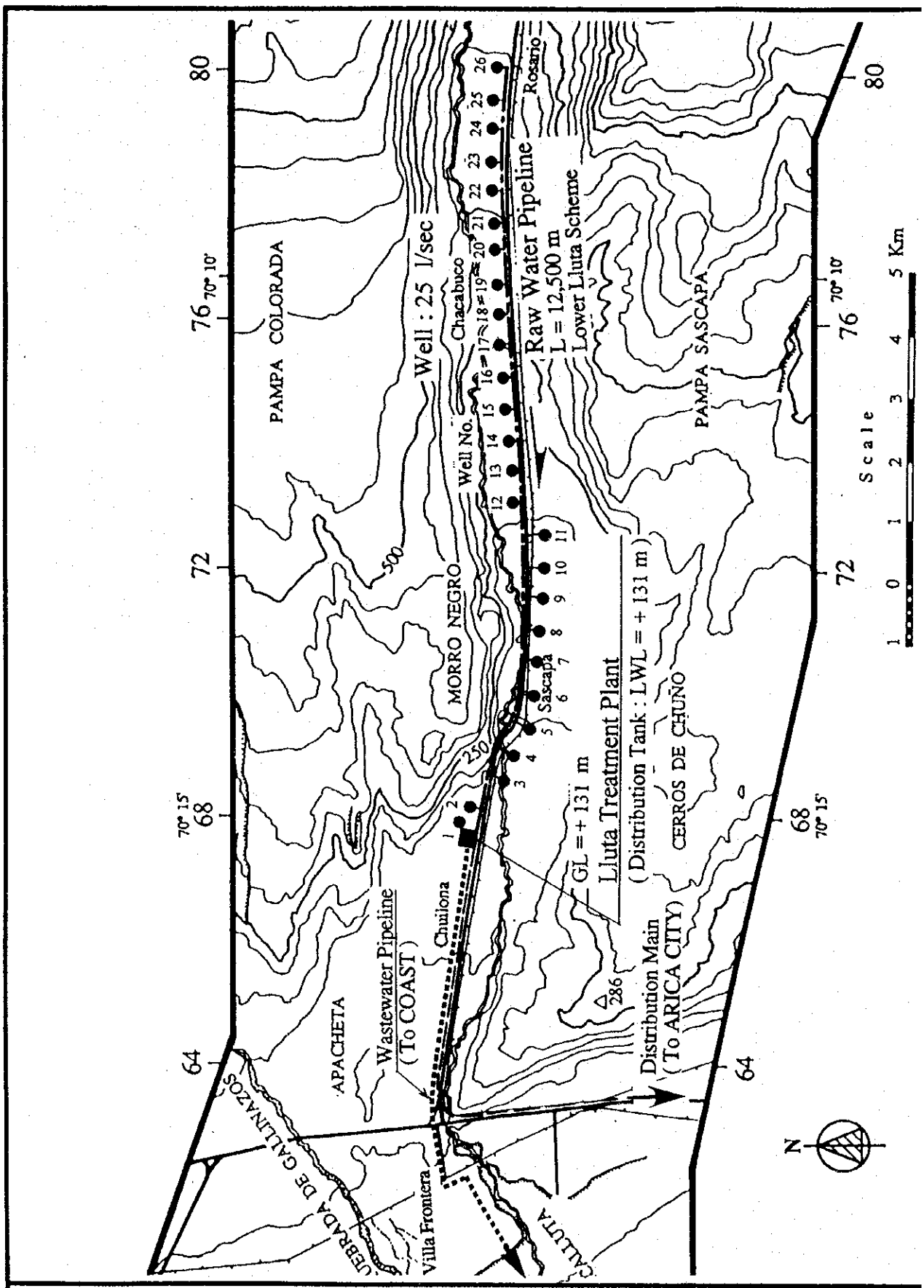


Fig. 3 Water Supply Development for Arica

<Desarrollo de Abestecimiento de Agua para Arica>

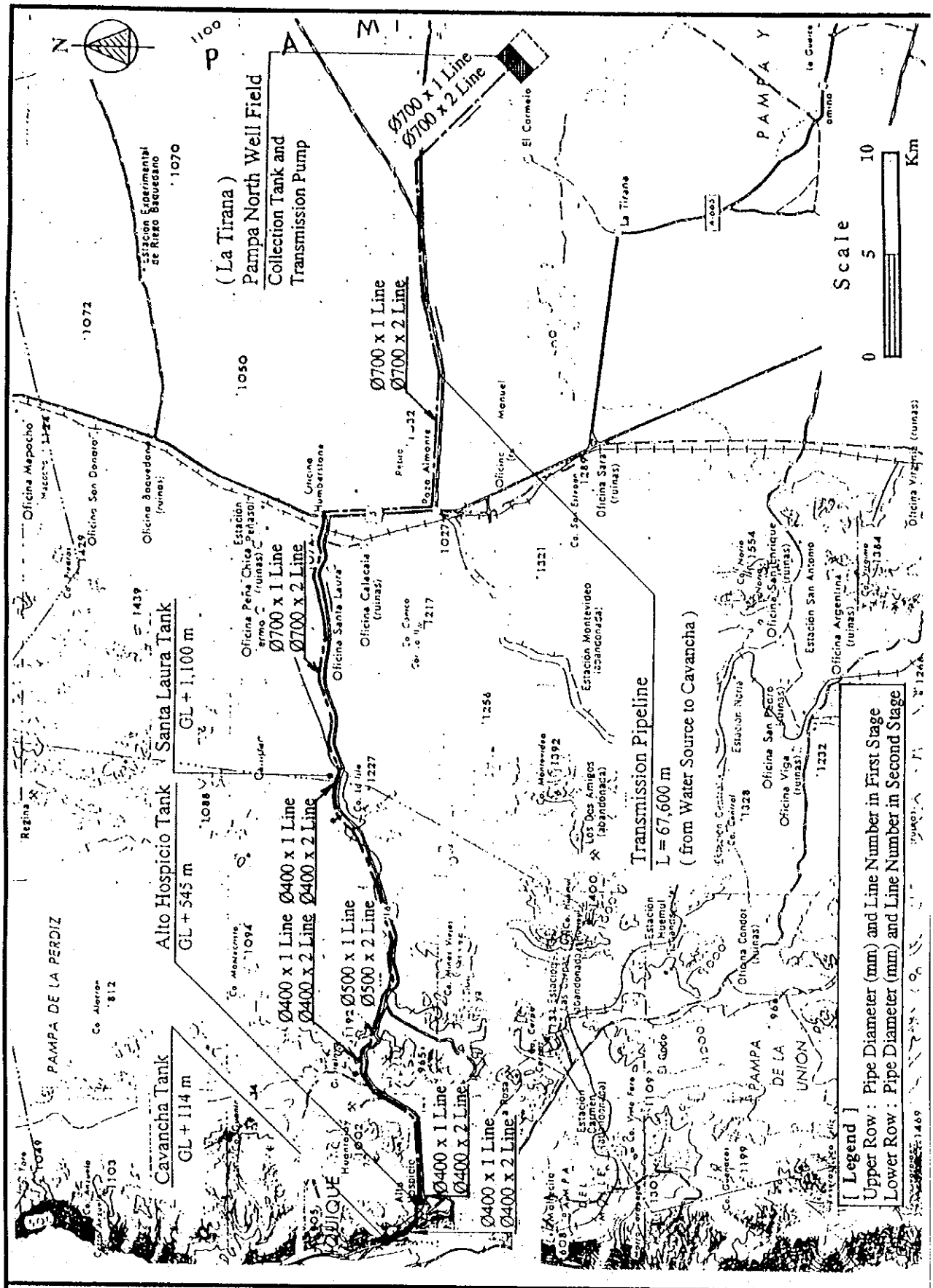


Fig. 4 Water Supply Development for Iquique

<Desarrollo de Abestecimiento de Agua para Iquique>