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JAPAN INTERNATIONAL COOPERATION AGENCY (JICA)

NATIONAL DIRECTION OF BASIC SANITATION (DINASBA)
SUB-SECRETARIAT OF URBAN DEVELOPMENT
NATIONAL SECRETARIAT OF POPULAR PARTICIPATION
MINISTRY OF HUMAN DEVELOPMENT
THE REPUBLIC OF BOLIVIA

THE STUDY ON GROUNDWATER DEVELOPMENT IN RURAL AREAS IN THE REPUBLIC OF BOLIVIA

FINAL REPORT

SUMMARY

June 1996

ENVIRONMENTAL TECHNOLOGIC CONSULTANT CO., LTD.
SUMIKO CONSULTANTS CO., LTD.

THE REPUBLIC OF BOLIVIA
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PREFACE

In response to a request from the Government of the Republic of Bolivia, the Government of Japan decided to conduct a study on Groundwater Development in Rural Areas and entrusted the study to the Japan International Cooperation Agency (JICA).

JICA sent to Bolivia a study team headed by Mr. Kenichi Takashima, Environmental Technologic Consultant Co., Ltd., and composed of staff members of Environmental Technologic Consultant Co., Ltd. and SUMIKO Consultants Co., Ltd., (three times between October 1994 and March 1996.)

The team held discussion with the officials concerned of the Government of Bolivia, 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 the Republic of Bolivia for their close cooperation extended to the team.

June 1996

Kimio Fujita
President
Japan International Cooperation Agency

June 1996

Mr. Kimio Fujita
President
Japan International Cooperation Agency
Tokyo, Japan

Dear Mr. Kimio Fujita,

Letter of Transmittal

We are pleased to submit you the final report of the Study on Groundwater Development in Rural Areas in the Republic of Bolivia.

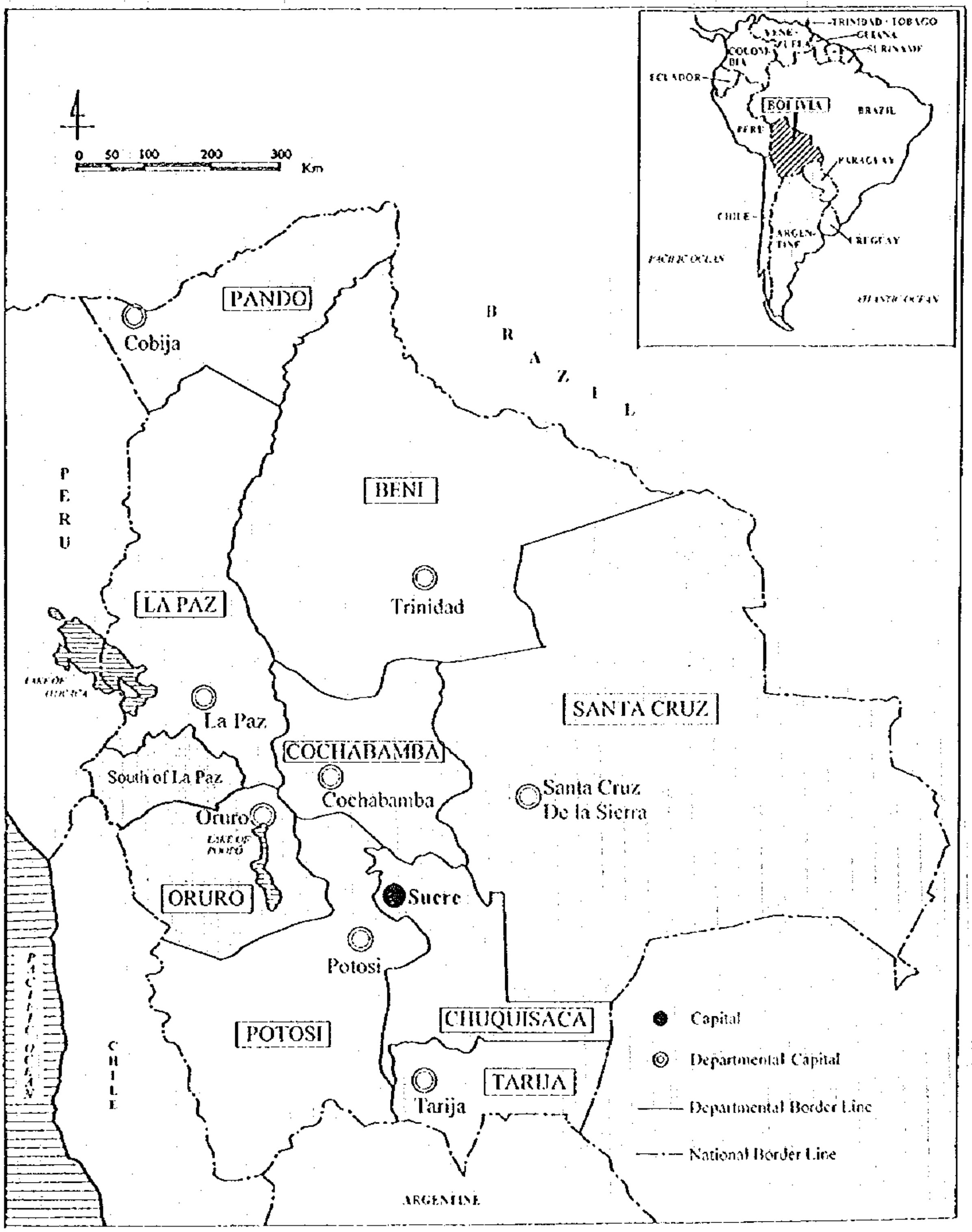
The study was conducted by Environmental Technologic Consultant Co., Ltd. and SUMIKO Consultants Co., Ltd. under a contract to JICA for 21 months from October 1994. We had conducted the field study three times to hold discussions with officials concerned in Bolivia and to carry out field surveys, developing water supply database for the Departments of Chuquisaca, Oruro, Tarija, Santa Cruz and four Provinces of La Paz with their close cooperations and formulating the regional groundwater development strategies based on the database. We had also carried out pilot projects including test well drilling, construction of the water supply facilities, operation and management education and sanitary education.

We wish to take this opportunity to express our sincere gratitude to your Agency, the Ministry of Foreign Affairs and other officials concerned. We would also like to express our deep gratitude to the Ministry of Human Development, five Prefectures and authorities concerned as well as the Embassy of Japan in Bolivia and the JICA Bolivia Office for close cooperations and assistance extended to us throughout our field study.

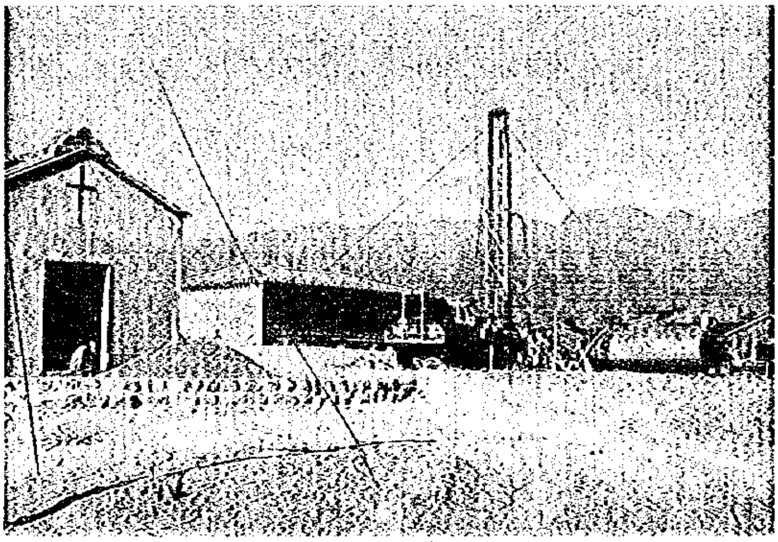
Finally, we hope that this report will contribute to promotion of groundwater development and improvement of public health and living conditions in rural areas in the Republic of Bolivia.

Very truly yours,

Kenichi Takashima 高島健一
Team Leader
The Study on Groundwater Development in
Rural Areas in the Republic of Bolivia

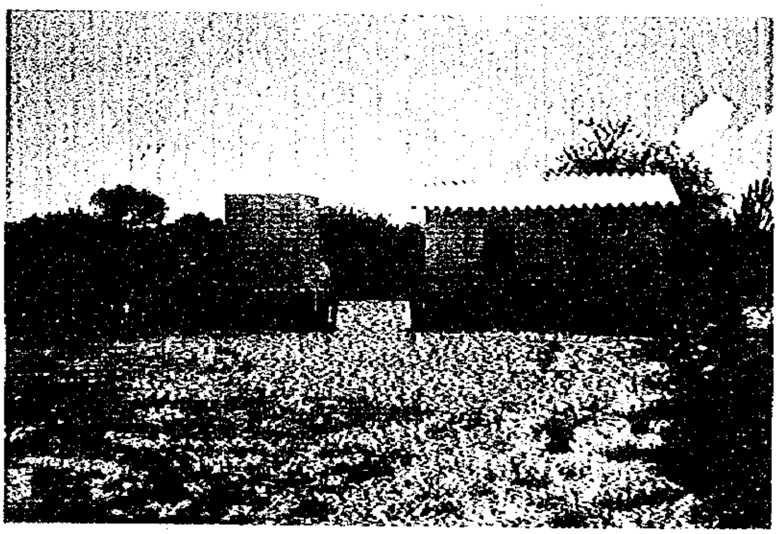


Location Map of the Study Area



Test well drilling (La Chosa)

Pumping test (Patacamaya)



Water supply facility of pilot project (Campo León)

SUMMARY OF THE PROJECT

1. Outlines of the Study

The Study on Groundwater Development in Rural Areas was conducted to formulate the regional groundwater development strategies by Department based on the water supply database. The water supply database was built up for the Study Area that includes four Departments (i.e. Chuquisaca, Oruro, of Tarija, Santa Cruz), and the Southern Part of Department of La Paz, and then based on this water supply database, the strategies for development of groundwater in the Study Area were formulated. Furthermore, the feasibility studies on water supply development project had been also conducted through the implementation of four pilot projects at four water supply blocks which were selected from each Department in the Study Area with the exception of La Paz.

2. Water Supply Condition in the Study Area.

The Study Area covers an area of 532,361 km^2 large, and a total population of 2,570,000 in which the population of departmental capitals are included (INE 1992 Census). In other words, the Study Area accounts for 48.5% of the national wide area, and 40.1% of the total national population.

The Study was conducted on a Departmental basis, but data was collected for the water supply block, which is the smallest unit of community or locality for a water supply system. A water supply block was defined as a community, besides the departmental capital, with a population of over 120 for the Department of Santa Cruz, and as community with a population of over 50 for the other four Departments. According to the water supply database, the number of water supply blocks in the Study Area is 4,265, and its total population is 1,400,000 approximately.

Table 1 shows the outline of the water supply condition of each Department in the Study Area. The water supply coverages of urban area and rural area of the Study Area are calculated to be 82% and 23% respectively. Beside, there are 3,020 blocks, or 71% of the total, which has not existing water supply system.

Table 1 Current Water Supply Circumstance in the Study Area

Department	Population	Current water supply coverage (%)			Number of blocks classified by current water supply coverage			
		Urban area	Rural area	Total	>=60%	<60%	No existing system	Total
Chuquisaca	289,129	88.5	16.4	19.6	131	135	957	1,223
S. of La Paz	126,277	26.0	16.4	17.0	51	39	672	762
Oruro	137,448	63.3	21.3	33.0	62	129	353	544
Tarija	200,158	88.8	36.8	54.8	158	133	220	511
Santa Cruz	652,135	83.8	26.4	51.5	221	186	818	1,225
Total	1,405,147	81.7	23.3	40.5	623	622	3,020	4,265

Note: Based on the water supply database. Urban area consists of cities with population of 2,000 or more.

In Bolivia, the shortage of drinking water supply in rural area is serious, comparing with the ones in urban area. A majority part of the communities in rural area has not any kind of water supply system, and is in serious shortage of water.

The main cause of the lag of water supply service in rural area is assumed to be the difficulty in the development of water resource. Up to now, the main sources of water that had been developed in rural area are surface water or groundwater from shallow aquifer, whose produce quantity is insufficient and quality is doubtful generally. Numerous communities with existing water supply system have to face with inevitable water shortage in the dry season every year.

The development of groundwater in the Study Area is lag due to the lack of equipment, financial resource, technique, etc. though its potential is high. It is assumed that the development of groundwater is indispensable to meet the needs of drinking water supply of inhabitants in rural communities.

3. Water Supply Database

Water Supply Database was built up to compile, process and manage a large amount of information relevant to the socioeconomic situation, water supply condition, sanitary condition, existing water supply systems, existing wells, etc. in each water supply blocks.

It consists of 254 numeric data fields, and data on 4,265 water supply blocks, 890 water supply systems, 808 existing wells had been input. Beside, it also stores 12 kinds of graphic data such as the road network map, administrative map, etc. Among them, 175 pieces of well geographical column maps are included.

4. Groundwater development strategies

During the Study, the groundwater development strategies had been formulated, aiming at the stabilization of drinking water supply services in rural area. Through this formulating process, the target water supply coverages of each Department had been determined, the case study on several project implementation strategies, project types had been carried out, and based on these results, the implementation plan had been formulated, with a list of appropriate blocks selected for the project implementation.

1) Targets

The strategy target year had been determined to be the year 2000 (i.e. in five years period, from 1996). Following, the target water supply coverages in rural area and in urban area of each Department had been determined separately, after examined the project scale that can be carried out in five years period. The target water supply coverages are given as 89% for the urban area and as 38% for the rural area, making an average of 54% for the Study Area in total. Given that the current average water supply coverage of the Study Area stands at 40.5%, this target marks a 13.5% increase.

2) Selected projects

Table 2 shows the outline of the project with the blocks selected as the most appropriate communities for the implementation plan. For five Departments in the Study Area there are 456 blocks, with 255,785 beneficiaries in total. This number of beneficiaries marks 16% of total population of the Study Area in the target year. Beside, it is assumed that for five Departments, 9 sets of drilling rig are required to make able the project implementation in five years period.

Table 2 Outline of the Proposed Project

	Population (in 2000)	Target water supply coverage (%)			Number of blocks	Number of benefici-aries	Required number of rigs
		Urban area	Rural area	Total			
Chuquisaca	312,073	90	30	33	98	57,295	2
S.of La Paz	119,750	80	30	34	46	19,957	1
Oruro	139,800	80	40	51	72	31,009	1
Tarija	245,262	90	50	65	85	35,128	2
Santa Cruz	794,792	90	40	62	155	112,396	3
Total	1,611,677	89	38	54	456	255,785	9

Note: The number of rigs are as required for each Department to complete the drilling works in 5 years period.

3) Organizations responsible to the project implementation

It is assumed that the individual prefectural governments should be the organizations responsible for the implementation of drilling works, and the prefectural governments or the municipal agencies are responsible for the construction of water supply facilities. Furthermore, it is assumed that once the water supply had been completed, its operation and maintenance should be carried out by the cooperatives formed by the beneficiaries in the individual communities, under the jurisdiction and instructions of the competent prefectural government.

4) Estimation of project cost

As shown by Table 3, it is assumed that the total project cost for all five Departments is US$ 71.30 million, of which US$ 39.50 million should be shared by external finance, while US$ 31.80 million should depend on Bolivian domestic financial sources. The procurement of drilling equipment, and the cooperation in conducting the drilling works in one year term to instruct the Bolivian technicians on the utilize of drilling equipment, are proposed to be financed by foreign countries or international organizations through no-compensation financial aids.

Table 3 Estimated Project Cost

(Unit: million US dollars)

Department	Investment Amount			Breakdown of Project Cost			
	Foreign Funds	Domestic Funds	Total	Procurement of Rig	Water Supply Equipment	Drilling Work	Water Supply Work
Chuquisaca	9.0	6.9	15.9	7.8	3.2	2.0	2.9
S. of La Paz	4.5	3.0	7.5	4.1	1.4	1.0	1.0
Oruro	5.7	4.4	10.1	4.2	2.3	2.0	1.6
Tarija	9.0	5.4	14.4	7.8	2.7	2.1	1.8
Santa Cruz	11.3	12.1	23.4	9.6	4.9	3.3	5.6
Total	39.5	31.8	71.3	33.5	14.5	10.4	12.9

(Note) The rigs shall be procured and the drilling work for the 1st year shall be carried out with foreign funds. The drilling work for the next year onward shall be carried out by the Bolivian side. The cost relating to water supply equipment consists of the procurement of casing, screening materials, water pump, generator.

5) Project implementation plan

Development priority of the water supply blocks is assumed to lay in the blocks with bigger population, lower coverage and easier drilling work. Based on this proposition, the implementation plan has been formulated, in such a manner that the project is started from the area which covers many first priority blocks and with easy access conditions, and gradually extended to the surrounding areas, in order to obtain the most efficient drilling works, and transportation of drilling machines, while taking into consideration the parity of annual investments during the period of project implementation. Table 4 shows the schedule of the drilling works that had been prepared as a main part of the implementation plan.

Table 4 Stage Plan of Drilling Works

		1st Year	2nd Year	3rd Year	4th Year	5th Year	Total
Chuquisaca	No. of blocks	19	28	20	20	11	98
	Total drilling depth (m)	1,300	2,050	2,300	3,000	2,950	11,600
S. of La Paz	No. of blocks	7	14	9	9	7	46
	Total drilling depth (m)	450	1,000	1,350	1,450	1,200	5,450
Oruro	No. of blocks	16	19	16	13	8	72
	Total drilling depth (m)	1,950	1,900	2,400	2,050	2,100	10,400
Tarija	No. of blocks	14	19	21	16	15	85
	Total drilling depth (m)	1,550	2,600	2,450	2,900	3,250	12,750
Santa Cruz	No. of blocks	20	36	40	39	20	155
	Total drilling depth (m)	2,100	4,350	4,600	4,500	5,100	20,650
Total	No. of blocks	76	116	106	97	61	456
	Total drilling depth (m)	7,350	11,900	13,100	13,900	14,600	60,850

Note: The drilling works are to be completed in five years for each departments.

5. Project Feasibility Study

The study on the feasibility of the water supply development project had been carried out by means of the geophysical prospecting surveys, test borings at 9 locations, and pilot projects at 4 communities. Through 4 pilot projects, the water supply facilities are constructed to test the installation feasibility of water supply system, and conduct experiments on the education of operation and maintenance of water supply system, and on the education of sanitation subjected to the inhabitants in rural communities of Bolivia.

The results of the study on the four communities of the pilot projects are summarized in Table 5, in which, the results of drilling test are also shown. The results show that at all four communities, the productivity of the test well is beyond the needs of the community.

Table 5 Outlines of Pilot Project Communities and Test Well Drilling

Department	Community	Population (persons)	Drilling depth (m)	Yield (l/sec)	Static water level (m)	Dynamic water level (m)
Chuquisaca	Campo Leon	237	411	2.25	190.0	282.9
Oruro	Corque	1,558	100	2.00	6.5	26.1
Tarija	La Chosa	371	127	7.55	(artesian)	-
Santa Cruz	San Carlos	480	260	10.00	57.5	93.0

Through the pilot projects, the water supply plan using the drilling test wells had been made, construction cost, operation and management cost had been calculated, and were used to examine the feasibility of the water supply plan.

The construction cost of these water supply systems were extremely beyond the financial ability of the inhabitants concerned. And it is considered that such construction cost should be financed by public investment funds.

Even at Campo Leon, where the economical condition is worst comparing with other communities, the cost required for the daily operation and maintenance of the water supply system is within the tariff payment ability of the inhabitants. Consequently, it is assumed that the daily operation and maintenance of the water supply system can be maintained with the self-help efforts of the inhabitants. But, for the sustainability of the water supply system in long term, the external supports are assumed to be important, and it appears the need to establish the maintenance and management systems with the combined supports of prefectural government, municipal agency, and private companies concerned as well.

6. Recommendation

1) The groundwater development project should be implemented as soon as possible, to fill the needs of drinking water in daily life of rural inhabitants, improve their living standard, and stabilize their public welfare. The government and the prefectural governments should confer with related agencies about the responsibility-sharing, the cooperation system and the raising funds, in order to promote a quick implementation of the project.
2) The Bolivian government and the prefectural governments do have the will and the ability to implement the project continuously in long term. The implementation of the project is assumed to be feasible, because the Bolivian government, the prefectural governments, the municipal agencies would be able to bring out the project by their own financial ability, if they have obtained the international cooperation in procuring of drilling equipment and technical transfer. The reorganization of local government is ongoing now, and it is expected that the works will be transferred smoothly from ex-CORDES to prefectural governments, and the UNASBAs (Unit of Basic Sanitation) will be strengthened appropriately.

After all, the project implementation is assumed to be totally reasonable, either in terms of project operation, project maintenance and project management.

3) The main targets of this project are the dispersed communities in rural area, and it is assumed that the prefectural government should take responsibility to bring out the project. The prefectural governments should strengthen the project implementation organization, ensuring personnel required, improve their technical ability, establish the financial foundation, etc., in order to perform the adequate and efficient implementation of the project.

4) Efforts should be done to conduct appropriate explanations to the inhabitants concerned on the meaning of the project and on their considerable responsibility, to promote their participation in the project implementation. Once the water supply system had been installed, the beneficiaries should take responsibility in the system operating and maintaining, under the jurisdiction and instructions of the competent prefectural government. Prefectural governments should promote the education program on sanitation and maintenance of the water supply system toward the inhabitants in rural communities, and strengthen the supporting systems to help inhabitants in managing and maintaining the water supply systems, and ensure the sustainability of these systems. The women's participation in the management and maintenance of the water supply systems should be promoted in order to strengthen the organization of managing and maintaining these systems.

5) Furthermore, an information system should be established to manage the information on the water supply conditions in rural communities, and supervise the progress of the water supply project implementation. More efforts are required to update the water supply database, extend its use to the departments standing outside of the Study Area, utilize it in formulating the water supply plans, and in the management of groundwater development project.

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Conversion Rate (March 1996)

1 US Dollar =	105 Yen
1 US Dollar =	5.0 Bolivianos
1 Boliviano =	21 Yen

CHAPTER 1 INTRODUCTION

1.1 Background of the Study

During the "Ten Years of International Water Supply and Sanitation" (1981~1990), propounded by the United Nations, the Government of the Republic of Bolivia (hereinafter referred to as "the Government of Bolivia") has made efforts to expand water supplies and sanitation and to improve water quality and water services. However, due to delays in the furnishing of infrastructure in rural areas, adequate results have not been obtained and public health problems such as high infant mortality rates and cholera epidemic are yet to be solved.

Under such circumstances, the Government of Bolivia formulated the "National Development Plan for Water Supply and Sanitation" in 1991. This plan is aimed at raising the water supply coverage in rural areas, where measures have been delayed, from 30% to 60% by the year 2000 under the slogan of "Water for All".

The Government of Bolivia reorganized the previous division of the Ministry of Urban Affairs into the National Direction of Basic Sanitation (DINASBA), National Secretariat of Urban Affairs of the Ministry of Human Development and appointed DINASBA as the agency responsible for the promotion of the above-mentioned National Development Plan. In the meantime, the Government has deemed that the implementation of projects be promoted by Regional Development Corporations of the respective Departments as part of the decentralization program. Close connections between the central and regional governments and the strengthening of each organization are therefore being desired.

Given such background, the Government of Bolivia has requested the Government of Japan on August 1992, the formulation of a groundwater development plan in relation to the above-mentioned National Development Plan. In response to the request, Japan International Cooperation Agency (JICA) has dispatched the preparatory study team in December 1993. Both countries agreed to conduct the Study on Groundwater Development in Rural Areas (hereinafter referred to as "the Study") and concluded the Scope of Work (S/W) on December 13, 1993. The Study was commenced in October 1994 and ended in June 1996.

1.2 Objectives of the Study

The objectives of the Study are as follows.

1) To build up a water supply database for the Departments of Chuquisaca, Tarija, Santa Cruz and Oruro and the southern part of the Department of La Paz and to formulate groundwater development strategies up to the year 2000 with development priorities attached thereto.

2) To conduct feasibility studies on water supply for the pilot projects to be implemented at four (4) water supply blocks. One representative water supply block is selected from each Department with the exception of the Department of La Paz. In the case where one water supply facility can supply water for plural water supply blocks, the plural water supply blocks are regarded as one water supply block.

3) To perform technology transfer to the Bolivian counterpart personnel through the Study in order to raise the levels of water supply planning, servicing of water supply facilities, furnishing of project implementation systems for fee collection, etc., operation and maintenance of water supply facilities, groundwater development technologies, etc.

1.3 Study Area

The Study Areas covers the rural areas in the Departments of Chuquisaca, Tarija, Santa Cruz and Oruro, and the southern part of the Department of La Paz. The southern part of the Department of La Paz consists of four (4) Provinces; Aroma, Gualberto Villarroel, Pacajes, and José Manuel Pando. The total area is 532,361 km^2 and the total population excluding departmental capital cities is 1,472,427 in 1992.

The Study was conducted on a Departmental basis but the data was collected for the water supply block, which is the smallest unit of community or locality for a water supply system. A water supply block was defined as a community, besides the capital city of a Department, with a population of over 120 for the Department of Santa Cruz and as community with a population of over 50 for the other four(4) Departments. The total number of water supply blocks amounts to 4.265 according to the water supply database.

Table 1-3-1 shows the outline of each Department in the Study Area.

Table 1-3-1 Outlines of the Study Area

Department		Chuqui-saca	South of La Paz	Oruro	Tarija	Santa Cruz	Total
Area(km^2)		51,524	19,005	53,588	37,623	370,621	532,361
Total Population[1]		453,756	125,343	340,114	291,407	1,364,389	2,575,009
	Capital	131,769	-	183,422	90,113	697,278	1,102,582
	Others	321,987	125,343	156,692	201,294	667,111	1,472,427
No. of Provinces		10	4	16	6	15	51
No. of Sections		27	20	30	11	46	134
No. of Cantons		116	139	153	184	118	710
No. of WSB[2]		1,223	762	544	511	1,225	4,265

Note : *1) Population is based on the INE 1992 Census*

2) WSB = Water Supply Block

1.4 Scope and Schedule of the Study

The Study was carried out through the following three (3) phases:

Phase I: Formulation of Regional Groundwater Development Strategies in Each Department

A water supply database was built up in order to facilitate the formulation of regional groundwater development strategies of each Department in the Study Area. Based on the database, regional groundwater development strategies was formulated with development priorities attached thereto for each water supply block. Upon classifying the water supply blocks according to characteristics, four (4) pilot projects was selected as models to carry out the feasibility study in Phase II and Phase III.

Phase II: Detailed Study for the Pilot Projects

Studies concerning the feasibility of water source development was carried out for the pilot projects selected in Phase I. Education for the technology transfer of operation and maintenance techniques for water supply facilities and experimental health education of residents was also carried out for the purpose of stable supplying of sanitary water.

Phase III: Formulation of Water Supply Projects Relevant to the Pilot Projects

Based on the results of the Study in Phase II, water supply plans, that take the environment and the role of women in development (WID) into consideration, was formulated along with the operation and maintenance program and health education programs to enable sustainable development. Furthermore, these projects was fed back to the groundwater development strategies.

Figure 1-4-1 shows the time schedule of the entire Study.

The Study at Bolivia had been conducted during the periods from October 1994 to March 1995, and from June 1995 to January 1996.

The Regional Development Corporations (CORDES) of the respective Department were responsible for the data collection and data input in Phase I, under the instruction of the Study Team. Based on the collected data, the data analysis and the formulation of groundwater development strategies had been conducted. Numerous workshops had been held in order to improve the abilities of the CORDES on the water supply planning, the operation and management of the water supply system, etc. as a part of the technology transfer.

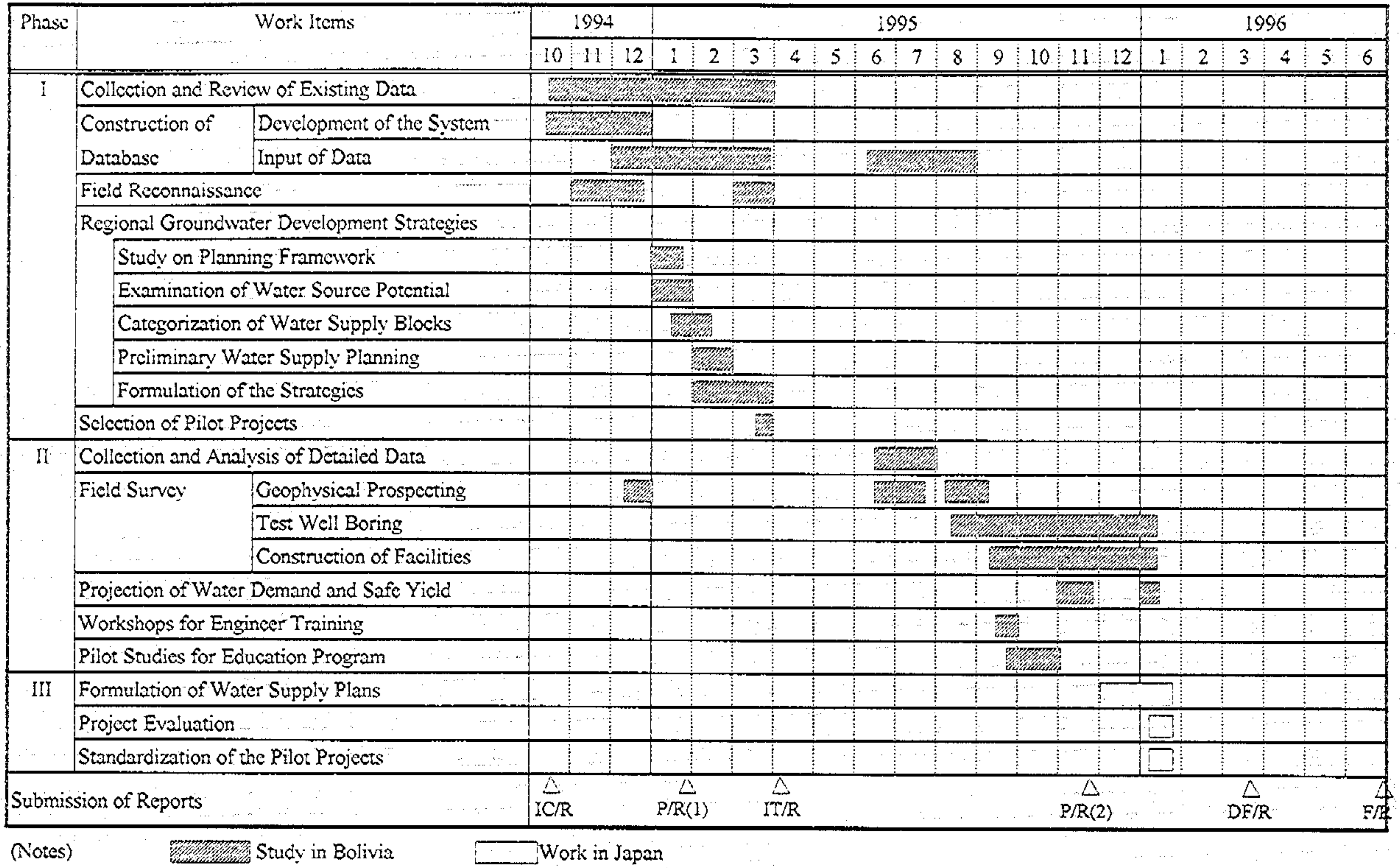

Figure 1-4-1 General Work Schedule of the Study

1.5 Study Organization

The official agency of the Japanese side for conducting the Study is Japan International Cooperation Agency (JICA). JICA had appointed Environmental Technologic Consultants Co., Ltd. (ETC) and Sumiko Consultants Co., Ltd. (Sumiko) as consultants to carry out the Study.

The JICA Study Team consists of thirteen (13) members as follows.

Name	Field in Charge
Kenichi Takashima	Team Leader
Hirotaka Nishimoto	Hydrological and Geological Analysis
Masao Odagaki	Water Quality Analysis/ Environmental Consideration
Takao Ogawa	Geophysical Prospecting/ Geological Analysis
Hiroatsu Narita	Water Supply Planning/ Operation and Maintenance Planning
Guido J. Acurio	Social Analysis/ WID Consideration
Masanori Ito	Organizational and Institutional Analysis / Sanitary Education
Norio Mochizuki	Economic and Financial Analysis
Nguyen My Tuan	System Engineer
Takeshi Sijimaya	Well Boring Advisor
Akio Chida	Well Boring Advisor
Toshimitsu Ozeki	Well Boring Advisor
Michihiro Ohkoshi	Well Boring Advisor

The counterpart agencies in Bolivia were the National Direction of Basic Sanitation (DINASBA) on behalf of the National Secretariat of Urban Affairs of the Ministry of Human Development, and five Regional Development Corporations (CORDES) in each Department. The CORDES have been integrated to the Prefectures in January 1996.

The Bolivian counterpart personnels are as follows.

DINASBA (National Direction of Basic Sanitation)

Ing. Jorge Calderón Monterde	Project Manager
Arq. Emira Mérida	Coordinator
Ing. Jose Luis Panozo	Sanitary Engineer/Sociologist
Ing. Yamil Maire	Hydrogeologist
Ing. Reynaldo Gonzales	System Engineer
Tec. Luis Ojopi	System Engineer
Sra. Maria del Rosario Cabrera	System Engineer
Lic. Max Paredes	Economist
Lic. Maria E. Godoy	Economist
Ing. Luis Chumacero	Sociologist

Chuquisaca (CORDECH)

Ing. Alfred Zelada E.	Coordinator
Ing. Jorge Fiengo	Hydrogeologist/ Geophysicist
Ing. Jorge Fraija	System Engineer/ SocioEconomist
Ing. Ignacion Ramirez	Well Boring Supervisor
Lic. Ramiro Martinez T.	SocioEconomist
Ing. Ricardo Gonzales	Coordinator (ex)

La Paz (CORDEPAZ)

Ing. Ricardo Quisbert	Coordinator/Water Supply Engineer
Ing. Alfredo Arias	Geologist
Ing. Ricardo Anda	System Engineer
Tec. Luis Mejia	System Engineer
Arq. Samuel Vasquez	Socioeconomist
Ing. Sergio Valdivia	Coordinator (ex)

Oruro (CORDEOR)

Ing. Mario Ramirez V.	Coordinator/Water Supply Engineer.
Ing. Marco Antonio Roses	Water Supply Engineer/Sanitary Engineer
Ing. Abel Sangueza	Hydrogeologist/ Geophysicist /Well Boring Supervisor.
Ing. Rene Leyva	Water Supply Engineer
Lic. Adolfo Morales	Sociologist
Ing. Wilfredo Rossel Crespo	System Engineer

Tarija (CODETAR)

Ing. Roberto Mérida	Coordinator/ Geophysicist / Well Boring Supervisor.
Ing. Hernan Villena	Water Supply Engineer/Hydrogeologist
Lic. Marina Reyes	Sociologist/Economist
Tec. Carlos Martinez	System Engineer
Ing. Pedro Dubravcic	Coordinator (ex)

Santa Cruz (CORDECRUZ)

Ing. Milton Berbetti A.	Coordinator/Hydrogeologist
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CHAPTER 2 OUTLINES OF THE STUDY AREA

2.1 Socio-economic Conditions

1) Outline of Bolivia

Bolivia is a landlocked country with the total area of 1,099,000 km^2 located in the central part of the South American Continent. Its main industries are agriculture and mining. According to 1992 INE Census, the total national population was 6.42 million. The ratio of population in urban area accounts for 58% of total national population, and urbanization is ongoing. Population in 1995 is estimated to be approximately 7.4 million. The GDP of the 1993 fiscal year was $900 per person, which means that the country is one of the poorest countries in South America.

2) Outline of the Study Area

The Study Area covers an area equivalent to 48.5% of the Bolivian land space. According to the INE 1992 Census, the population of the Study Area is 2,575,009 (40.1% of the total national population). The population of 4 provinces of Southern Part of La Paz accounts to 16% of the total population of Department of La Paz.

According to the water supply database which had been built up by the Study, the number of water supply blocks in the Study Area is 4,265. Among them, number of big cities with population of 2,000 or more is 60 block, number of medium cities with population between 500 to 1,999 is 271, and number of small cities with population of 499 or less is 3,934.

3) Land Use

Located in the central part of the South American Continent, Bolivia is a land-locked country bordered by Brazil in the north and east, Peru in the West, and by Paraguay and Argentina in the south. Its national territory is approximately 1.1 million square kilometers. In terms of the country's geographic and social-economic conditions, it can be divided into the following three zones: 1) the highland of the Altiplano; 2) an undulated hill zone; and 3) and the plains in the eastern parts of the country.

1) The highland of the Altiplano accounts for 38% of the national territory and 53% of Bolivia's population. This part of the country is home to agricultural activities concentrating on potato farming. Practically all of Bolivia's metal mining operation, one of the main industrial sectors of the nation, is distributed in this region.

2) The undulated hill zone accounts for 13% of the national territory and 27% of the nation's population. As most part of this area is mountainous, the cities and towns are located in the relatively large plateaus or in the plains stretching between mountains. It is a traditional agricultural zone with little rainfall and small plowing land areas per farming household.

3) The plains in the eastern parts of the country occupies 59% of the national territory and is home to 20% of the nation's population. Thanks to the favorable natural relief and clement climatic conditions, this part has a flourishing agricultural and forestry industry. It also commands oil and natural gas deposits.

The Landsat pictures showing the land use patterns for the Bolivian territory indicate that there are about 34,600 square kilometer of arable land, equivalent to 3.1% of Bolivia's territory. Pasture land total 266,500 square kilometers (24.3%), and forest-covered land 556,700 square kilometers (50.6%), while the non-arable land mass total 178,000 square kilometers (16.2%). In the highland and undulated-hilly regions, the land is cultivated on the crop rotation system of farming so that a considerable part of the land is left fallow at any one time, with the seasonally cultivated farming land amounting to 78% of the total farming land area. The crops grown on a large area scale include, in the order of importance, maize, potato, rice, barley, wheat, Soy bean, sugar cane, and quinua. In the eastern plains, the land is widely cultivated by the slash-and-burn method of farming.

Much of the grassland consists of the pampas distributed in the eastern plains. These areas are mostly water-logged in the rainy and dry land in the dry season so that they can only be used as natural pastures.

The forest coverage is marked by the tropical rain forests spreading in the northern Amazon regions and the subtropical dry forests spread over part of the undulated terrain if the Departments of Tarija and Chuquisaca. The forests have a relatively sparse density of upright trees. The highlands of the Altiplano have practically no forest coverage while the eastern plains are witnessing a progressive decline in their forest coverage.

2.2 Organizational System

Bolivian administrative organizations are classified to the state, prefecture (Departamento), county (Provincia), section (Seccion), Canton, city (Municipality), and town (Comunidad) or village (Localidad).

In the central government, the National Secretary of Urban Affairs (SNAU) of the Ministry of Human Development is in charge of the administration of water supply sector, and the National Direction of Basic Sanitation (DINASBA) of SNAU is in charge of the making of plans relating to this water supply sector. In February, 1992, the Government of Bolivia issued the "National Development Plan for Water Supply and Sanitation (Agua Para Todos)", aiming at raising the water supply coverage to 80% in the urban area and to 60% in the rural area by 2000. However, as a result of reorganization, in November, 1995, the National Secretary of Urban Affairs (SNAU) was reorganized to be the Sub-Secretary of Urban Development of the National Secretary of Public Participation. Figure 2-2-1 shows the organizational chart of the central government agencies concerned.

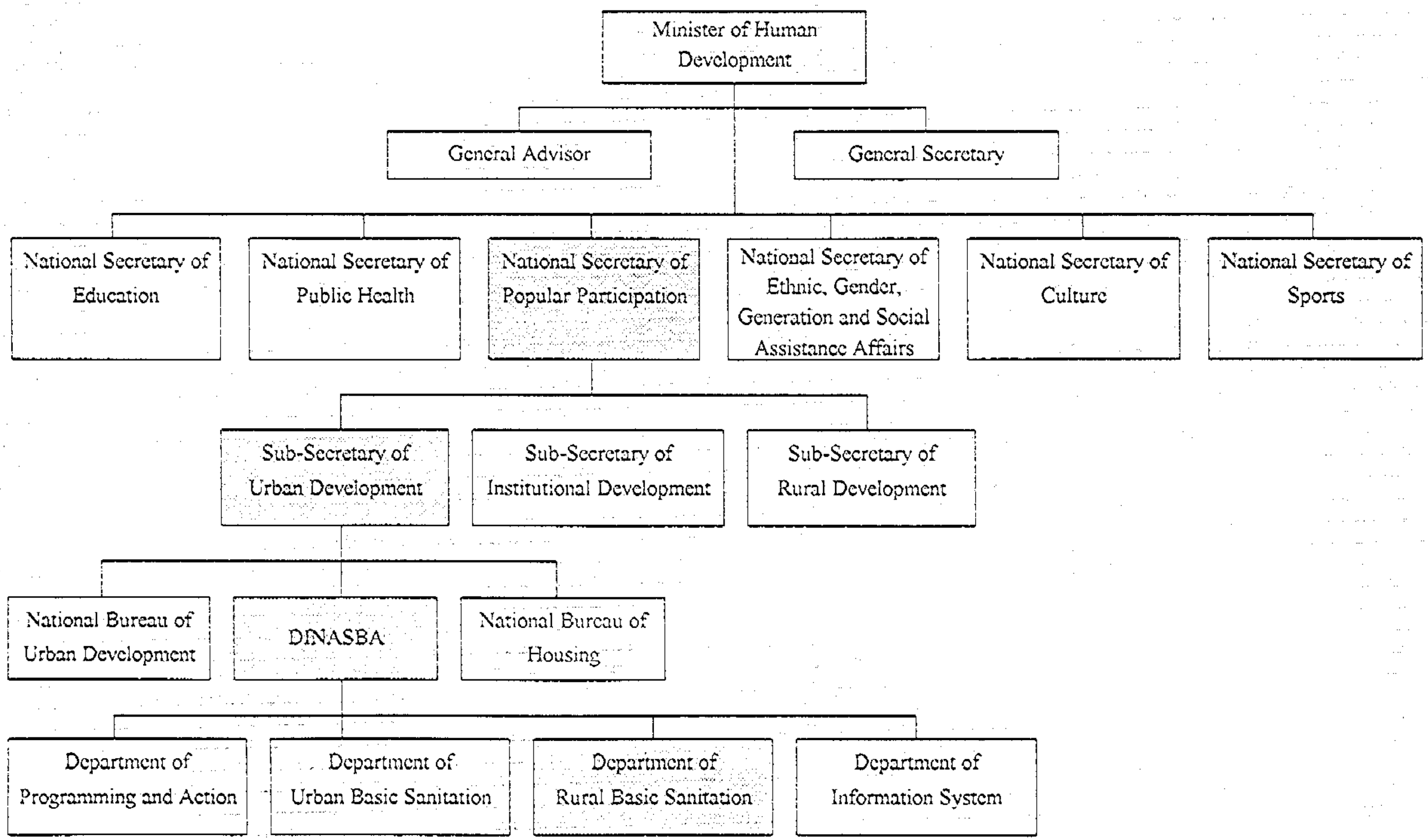


Figure 2-2-1 Organizational Chart of the National Entity Responsible for the Study (Since October 2, 1995)

The Municipals are now in charge of the water supply services in local areas of Bolivia. However, until now, the Regional Development Corporations (CORDES) had taken the main roles in the planning of water supply systems and in the construction of water supply facilities, in the rural communities. The Regional Development Corporations, an organization with a staff of 300 to 600 persons, had had the duties to manage the public investment in each Department and reinforce the Municipalities, Comunidads and Localidads inside its authority territory. These CORDES were disorganized as the result of the Decentralization Act, which was issued in July, 1995, and came into effect since January 1, 1996. The property and a part of the personnel of former CORDES was transferred to prefectural agencies (Prefectura), and the prefectural governments became the entities those have responsibility for all works handed over from the former CORDES.

Figure 2-2-2 shows the organizational chart of the prefectural government in relation with the water supply sector.

And effected by the Law of Popular Participation (issued on April 20, 1994), the financial resources for the implementation of water supply projects in rural area had been changed. Instead of being determined under the control of the central government as previous, a part of the national income are destined to Municipalities according to the size of population of Seccions. Consequently, the Municipality has become to be able to make public investments on its own judgment, and the amount of investments to water supply projects tends to increase. In addition, it is expected that linking between prefectural government and the regional agencies concerned, which is one of main subjects of the Decentralization Act, will be strengthened.

Maintenance and management of water supply systems in rural communities are conducted by Water Committees or Public Service Cooperatives organized by residents. Generally, the monthly collectable water tariff is about 5 to 20 bolivianos per household. In some communities where there are not any existing water supply system nor suitable water sources, the inhabitants have to paid 5 to 10 bolivianos for purchase of water by means of water supply wagons.

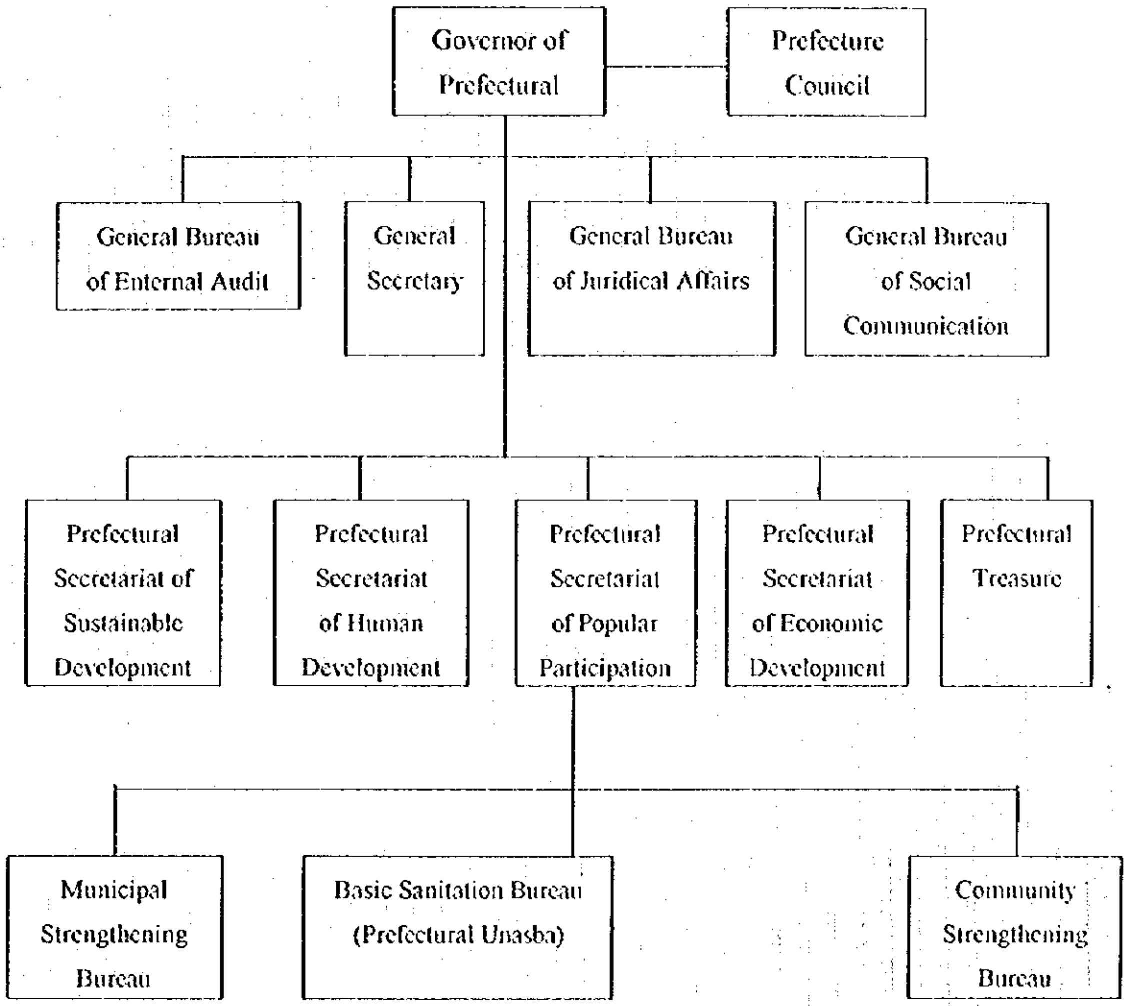


Figure 2-2-2 Organizational Chart of Prefectural Goverament in Relation with the Water Supply Sector

2.3 Present Situation of Water Supply

Table 2-3-1 shows the number of water supply blocks and distribution of population classified by the water supply coverage in the Study Area. The current water supply coverage in the whole Study Area excluding the prefectural capitals is 40.5%. While the water supply coverage in the urban cities with population of 2,000 or more is 81.7%, in the rural communities with population of 1,999 or less, the coverage reaches only 23.3%. And the number of blocks with no water supply system is 3,020 which accounts for 71% of the total number of blocks.

Table 2-3-1 Number of Water Supply Blocks and Distribution of Population Classified by the Water Supply Coverage

	Water Supply Coverage								
	>=60%		1 ~ 59%		0%		Total		
	Number of blocks	Popula-tion	Number of blocks	Popula-tion	Number of blocks	Popula-tion	Number of block	Population	Served Popula-tion
Chuquisaca	131	54,502	135	43,779	957	190,848	1,223	289,129	56,627
S.of La Paz	51	19,249	39	20,868	672	86,160	762	126,277	21,466
Oruro	62	43,434	129	43,443	353	50,571	544	137,448	45,382
Tarija	158	113,689	133	40,228	220	46,241	511	200,158	110,300
Santa Cruz	221	356,029	186	86,638	818	209,468	1,225	652,135	335,885
Total	623	586,903	622	234,956	3,020	583,288	4,265	1,405,147	569,660

Note: According to water-supply database. Excluding prefectural capitals.

According to the water supply database, the current water supply coverage and served population in Chuquisaca are 19.6% and 232,500, in southern part of La Paz are 17.0% and 102,800, in Oruro are 33.0% and 92,000, in Tarija are 54.8% and 90,500 and in Santa Cruz are 51.5% and 316,200, respectively.

In communities with no water supply system, the inhabitants are usually using the shallow dug wells, spring water, puddle, rainwater, etc. as water sources. However, most of them are not suitable for drinking water, generally. In communities with water supply system, the current main water sources are well in Altiplano, and in the northern part of Santa Cruz, or surface water in mountainous-hilly areas.

The present situation of water shortage in rural communities differs according to its natural characteristics such as type of dependable water source, distance to the water source, precipitation, etc. However, in many areas, the absolute shortage of safe and good quality drinking water is serious.

In short, it can be said that such insufficient water supply services result from (1) natural and geographical conditions, (2) delay in development of water sources, (3) shortage of technique, personnel and funds related to the operation and management of existing water supply systems, and so on.

Water development and water supply project in the rural areas of Bolivia have been pursued by the former Regional Development Corporations of each Department and the Public Service Authorities such as municipalities, with the cooperation of various countries, international agencies, and non-government organizations (NGO). These projects have included shallow wells, springs, and river-bed water. However, these projects are sporadically and located at some particular areas, so that the supply quantity is deficient in absolute terms.

Financial resources of projects carried out inside the country are generally borrowed from national investing institutions such as the National Fund for Regional Development (FNDR) or the Fund for Social Investment (FIS). According to data provided by the World Bank, construction cost of water supply facilities carried out in the past is around $80 per beneficiary.

There are only two Departments, i.e. Department of Chuquisaca and Department of Oruro, own drilling machine and equipment. However, these are outdated and of low performance, and are not efficient. Other Departments do not own any kind of drilling equipment, and have to depend on private constructors, and can not push forward the groundwater development projects continuously.

CHAPTER 3 WATER SUPPLY DATABASE

3.1 Objectives and Preparation Methods

The objectives of the Water Supply Database are to organize and accumulate basic data on water supply and groundwater development planning in the areas targeted by the plan and to be put to use for the formulation of groundwater development strategies for each Department. Population and other general socioeconomic information, circumstances of existing water supply systems, data on existing wells, etc. were gathered in a computer and arranged in the database, using water supply blocks with a population of 50 or more (water supply blocks with a population of 120 or more in the case of Santa Cruz) as the minimum unit.

In preparing the database, the Study Team provided guidance on program development and on methods of data collection and input, and the former CORDES carried out the collection and input of data.

The water supply blocks were set in reference of the community divisions in the 1992 census and on the basis of 1/50,000 scale topographical maps. The number of water supply blocks in the areas targeted by the plan amounted to a total of 4,265 for the 5 Departments. The input data are mainly based on the 1992 census and existing materials possessed by each Department and insufficient data were supplemented and confirmed through field studies.

With regard to computer operating methods and data input/renewal/processing methods, an operation manual for the database was prepared and technical guidance was provided to DINASBA and the counterparts of each Department through workshops, seminars, etc.

3.2 Outline of the Database

1) Data Items

Table 3-2-1 shows the contents of the database. Numerical data are comprised of 254 items and are arranged in 8 data tables. Although general socioeconomic data, data on water supply circumstances, and data on sanitation circumstances are based on the 1992 census results, since much of the data were not tabulated in water supply block units, hearing, etc. were carried out in the field studies to confirm and correct the data upon input. A large part of the data on existing water supply systems were collected through field studies. For the well data, the data possessed by each Department, as well as those possessed by well drillers, aid agencies of various nations, and NGO's, were input. There are 12 types of graphic data and among these, the administrative district maps for Department, Provincia, and Canton were prepared by the CORDES of each Department and the locations of water supply blocks are indicated in the Canton maps. The other maps were input with the scale of the original map being maintained.

Table 3-2-1 Contents of the Data Tables and Data Fields in Water Supply Database

Classification		Table	No. Field	Contents
Numeric Data	General Socio-Economic Data	C*_BNAME.DB	5 fields	Block code, block name, established year, area, etc.
		C*_SOCI.DB	17 fields	Population and number of household in 1976 and 1992, and in recent year; number of local administrative office, school, bank, airport, hospital; etc.
		C*_EJPOB.DB	11 fields	Estimated population from 1995 to 2010, by rural area and urban area.
	Sanitation Data	C*_SANI.DB	15 fields	Number of sanitation toilet and not, by mean of treatment method, by rural area and urban area
	Water Supply General Data	C*_WTRS.DB	11 fields	Type of water source, level of service, water abstracting method, water usage, water quality and method of treatment, seasonal production status, production capacity, served population, etc.
	Data on the Existing Water Supply System Level II	C*_WSB2.DB	64 fields	Data on the Water Supply System Level II (Area of service, number of faucet, served population, served family, technical informations such as lengh of pipe, number and capacity of tank, etc.; informations on operation status such as operation time, water quality, supply interruption frequency, etc.; informations on management system such as tarif structure, number of management staff, annual expenditure, annual income, etc.)
	Data on the Existing Water Supply System Level III	C*_WSB3.DB	116 fields	Data on the Water Supply System Level III (Same as System Level II, but in more detail)
	Well Data	C*_WELL.DB	15 fields	Depth, diameter, construction year, statistic level, transmissibility, aquifer information, production status, map of geographic column, etc.
Total		8 tables	254 fields	

Note) [*] is the Code of Department in concern. 1 for Dept. of Chuquisaca, 2 for Dept. of La Paz, 4 for Dept. of Oruro, 6 for Dept. of Tarija, and 7 for Dept. of Santa Cruz.

Graphic Data				
	1. Canton Distric Map	726maps	7. Geological Map	32 maps
	2. Province District Map	50 maps	8. Topographical Map	32 maps
	3. Department District Map	5 maps	9. Land Use Map	32 maps
	4. Well Geographic Column Map	175 maps	10. Administrative Boundary Map	32 maps
	5. Road Network Map	18 maps	11. Hydrogeological Map	18 maps
	6. Hydrographic Map	32 maps	12. Natural Environmental Map	24 maps
	Total 12 kinds, 1,176 maps			

2) Number of Input Data and Configuration of the Database

General socioeconomic data, sanitation circumstances data, water supply circumstances data, and existing water supply systems data were organized according to each of the total of 4,265 water supply blocks in the Study Area. A total of 890 existing water supply systems data were input in the database, covering 71.5% of the 1,245 blocks in which some form of water supply system were presumed to exist from the water supply circumstances data (i.e. blocks for which the current water supply coverage exceeds 0%). There are total of 808 well data with 175 of them accompanying well column map.

As shown in Figure 3-2-1, the numerical data are tabulated according to the Department, Province, and Canton levels.

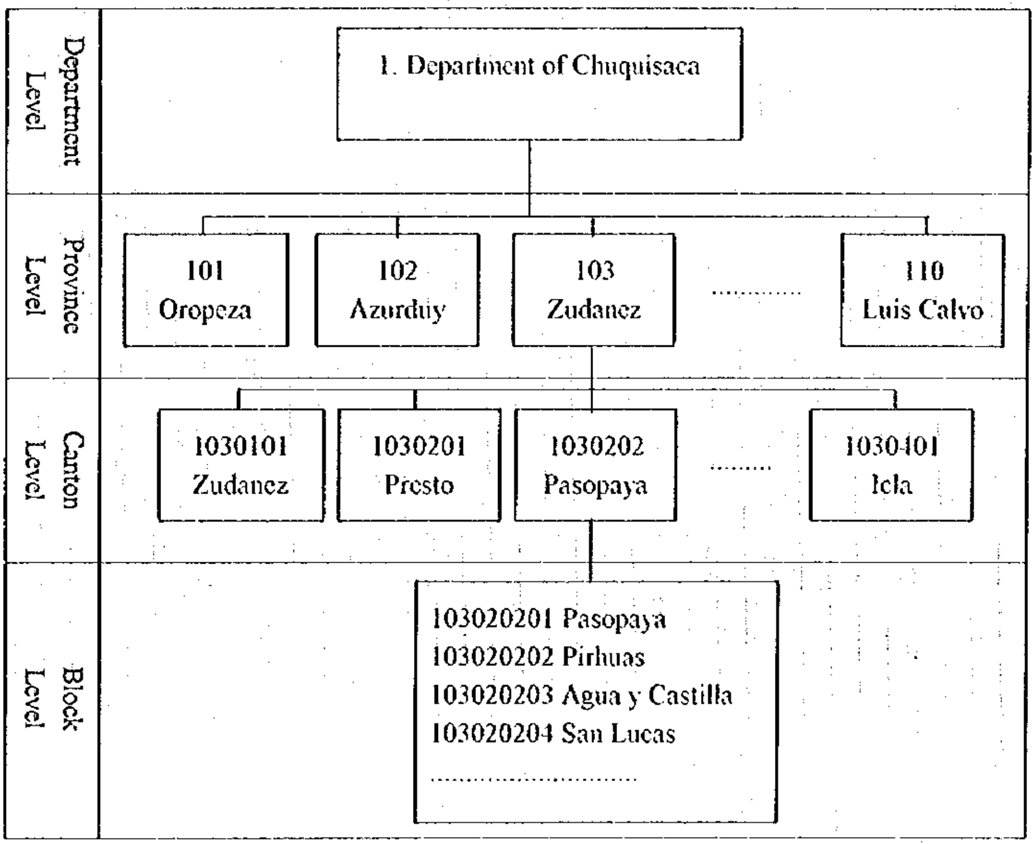


Figure 3-2-1 Levels of Data (In case of Chuquisaca, as an example)

3) Database Program and Methods of Use

The database operation program (BADAA) was developed in Spanish using the database application software naming "Paradox for Windows". The computer equipment are comprised of an IBM personal computer, printer, hard disk, scanner, etc. and one set each were provided to DINASBA and each of the 5 Departments.

Figure 3-2-2 shows an outline of the BADAA program flowchart. Cross reference access of graphic data and numerical data are enabled though interactive operation with the computer and the data can be easily converted for use in a spreadsheet program. The database can be used for various analyses in accordance with the computer environment of the user and has been utilized in the formulation of the groundwater development strategies for each Department.

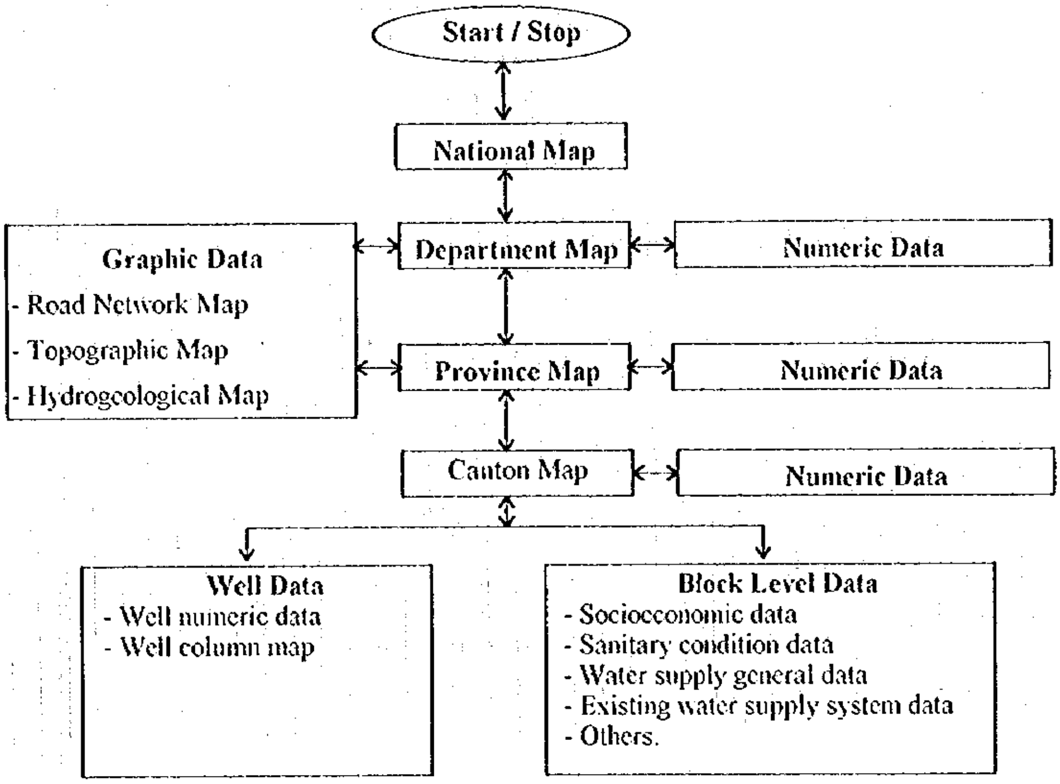


Figure 3-2-5 The Principal Flow-Chart of the Water Supply Database Program

CHAPTER 4 HYDROGEOLOGICAL INVESTIGATION

4.1 Natural Conditions

4.1.1 Topography and Geology

Land area of Bolivia is divided topographically into the seven zones; namely, ① La Cordillera Occidental, ② El Altiplano Andino, ③ La Cordillera Oriental, ④ Las Seranias Sub-Andinas, ⑤ La Llanura Chaco-Beniana, ⑥ Las Seranias Chiquitanas, and ⑦ El Escudo Central. The zonal divisions are shown in Figure 4-1-1 and the geological distribution in the Study Area is shown in Figures 4-1-2.

1) Cordillera Occidental (Complejo Volcanico)

A mountainous zone with altitudes of 4,000 to 6,000m and with a distribution of Quaternary Period volcanoes.

2) Altiplano Andino (Altiplano)

This zone is located between the mountain ranges of "Cordillera Occidental" and "Cordillera Oriental" and comprises a gradual plateau with altitudes of 3,700 to 4,000m. A series of expansive lakes continue from Lake Titicaca at the northern boundary with Peru to Lake Poopo at the southern part and Uyuni Salt Pan, in which salts have accumulated, is formed at the southern part. This plateau has a closed river basin in which the Desaguadero River flows out from Lake Titicaca and into Lake Poopo.

3) Cordillera Oriental (Cadena Montanosa)

This zone is mainly comprised of a mountainous zone with altitudes of 4,000 ~ 6,000m and with mountainous valleys branching out from this mountain zone. In the valley areas with altitudes of 1,800~4,000m,steep valleys have developed and there is also a distribution of nearly flat and relatively spacious basins.

The mountainous part of this zone is a steep area comprised of hard rock (Paleozoic strata, igneous rock) and with poor vegetation due to the low progress of soil formation. As the altitude decreases, the rainfall increases, soil formation progresses somewhat, and the vegetation becomes richer. Mountain basins are located in areas with altitudes of 3,800 to 1,800m and unsolidified Quaternary deposits are distributed in such areas. The Cochabamba basin, the basin in the vicinity of Potosi, the basin in the vicinity of Tarija, etc. have traditionally been agricultural zones.

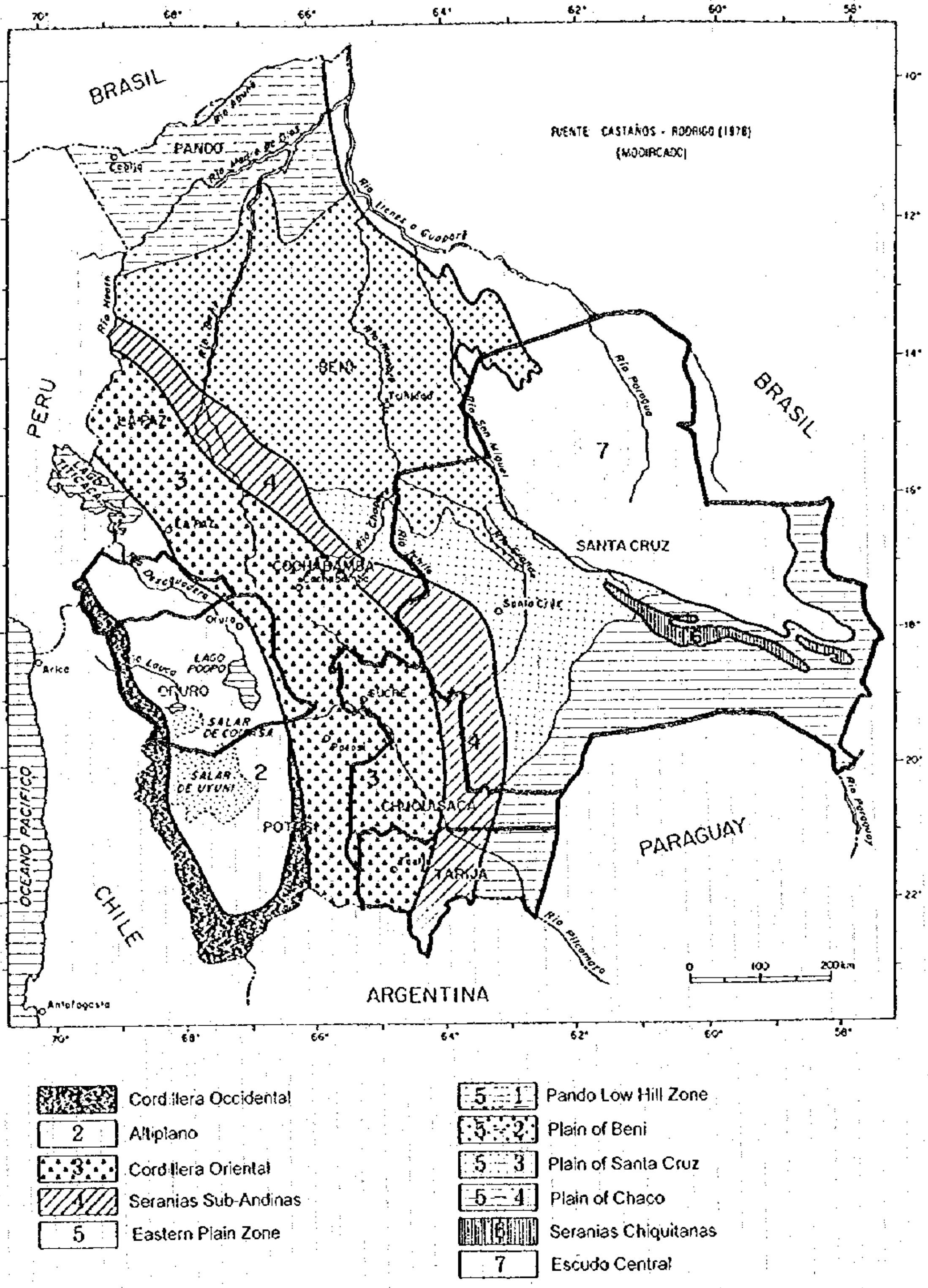


Figure 4-1-1 Topographical Zonal Divisions of the Republic of Bolivia

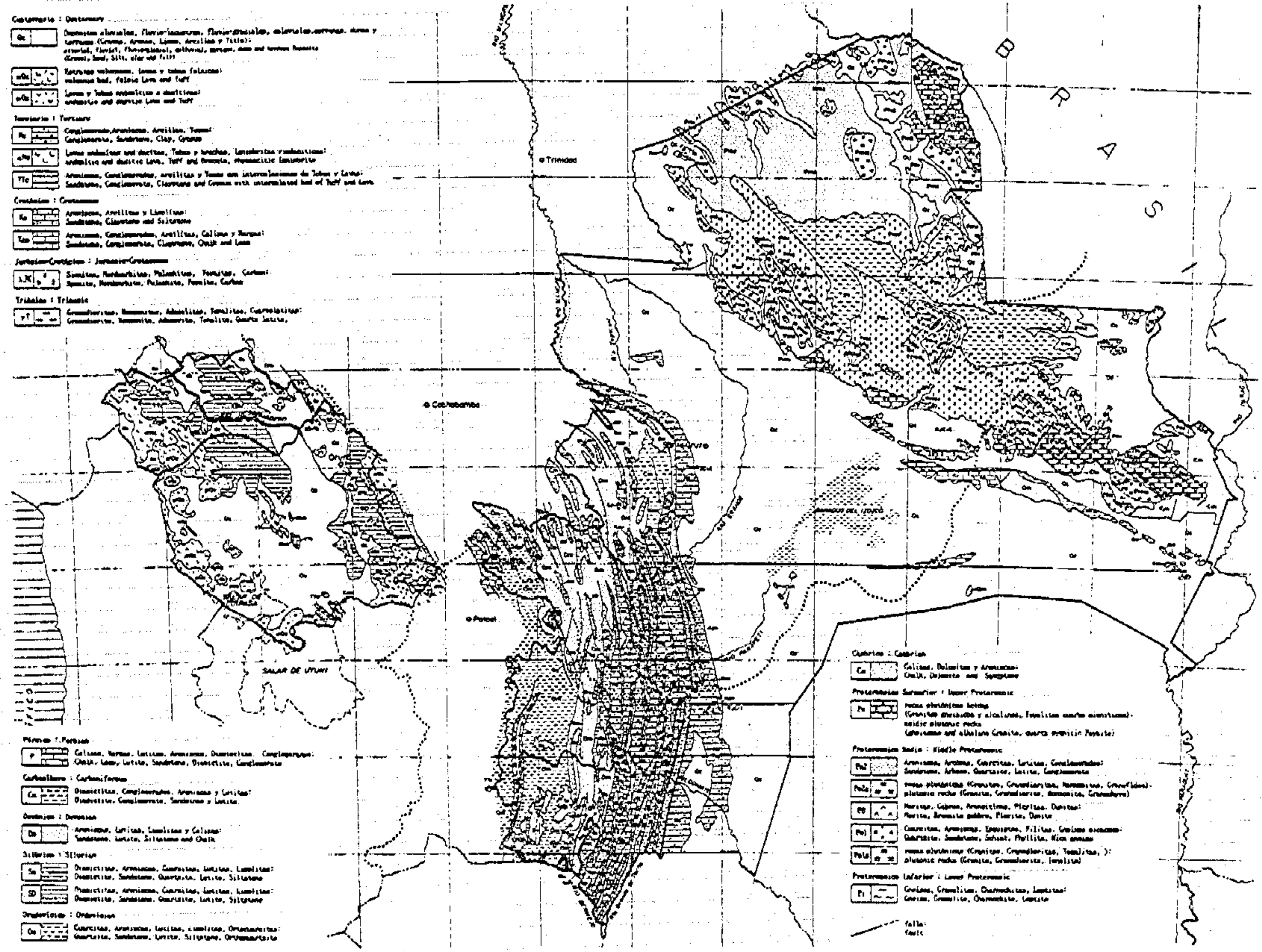


Figure 4-1-2 Geological Distribution of the Study Area

4) Seranias Sub-Andinas (Zona Sub-Andina)

This zone is a mountainous zone with altitudes of 1,000 to 2,000m that is rather gradual in comparison to the Cordillera zones. The stratum of the era from the Devonian to Mesozoic and the Tertiary deposits are distributed side by side in the direction of north and south, showing complex structure of fold. The rocks have weathered to some extent and the valley has been eroded by rivers to form a slender basin plain.

5) Llanura Chaco-Beniana

This is a nearly flat plain filled with unsolidified Quaternary deposits.

(1) Low Hill Zone (Pando)

This landform, located in the western part of the Department of Pando, is characterized by low hills eroded by small rivers.

(2) Plain of Beni

This is a vast plain that stretches along the Amazon river basin in the Department of Beni and the northern part of the Department of Santa Cruz. It is characterized by an extremely gradual incline and a significant part of this plain becomes submerged and turns into a marsh in the rainy season.

(3) Pedimental Plain Zone

A low hilly pediment in the northern area at the part of transition from the Plain of Santa Cruz and Plain of Beni to the foothills of the Andes. This zone has high rainfall and is rich in forest resources.

(4) Plain of Chaco

The plain of Chaco is a vast plain which extends from the southern part of the Department of Santa Cruz, through the eastern lowlands of the Departments of Chuquisaca and Tarija, and to Paraguay. The precipitation is low and the vegetation is sparse.

6) Seranias Chiquitanas (Sierras Chiquitanas)

This zone is a low mountainous area that continues along the rim of "Escudo Central" and is characterized by Paleozoic geology of the Silurian and Devonian periods.

7) Escudo Central (Escudo Cristalino)

A gently undulating plateau which belongs to the Itenez river basin. Though comprised of hard stratum of the Pre-Cambrian era, which is the same geological structure as that of the central plateau of Brazil, the weathering of rocks is quite advanced.

Bolivian lands are often classified into the three general zones of ① Altiplano zone, ② hill zone, and ③ valley zone based on geographical and socioeconomic conditions. The "Cordillera Oriental" and "Seranias Sub-Andinas" zones are collectively included in the valey zone while the "Seranias Chiquitanas" and "Escudo Central" zone are included in the plain zone.

4.1.2 River Basins

The river basins of Bolivia can be largely classified into the Altiplano basin (area: 145,081 km^2), the Amazon river basin (area: 724,000 km^2), and the La Plata river basin (area: 229,500 km^2) which respectively comprise 13.2%, 65.9%, and 20.9% of the total land area of the nation (Figure 4-1-3).

The Altiplano is a closed river basin with a total area of 190 thousand square kilometers and which is sandwiched by the Andes mountain range at the eastern and western sides. This river basin extends over the southeastern part of Peru and the Departments of La Paz, Oruro, and Potosi. It inclines gradually from north to south, with the altitude in the vicinity of Uyuni Salt Pan being the lowest.

The major rivers of the Amazon river basin include the Madre de Rios river, Beni river, Mamore river, Itenez river, etc. The Mamore river divides into the Rio Grande river, Ichiro river, etc. and the Itenez river divides into the Paragua river, San Miguel river, etc.

The Pilcomaya river, Bermejo river, and Paraguay river are among the rivers in the La Plata river basin.

The river basin divisions zones in the Study Area are as shown according to Department in Table 4-1-1. The southern part of La Paz and Oruro are located in the Altiplano while Tarija is located in the La Plata river system. The watershed between the La Plata and Amazon river systems runs through Chuquisaca and the southern part of Santa Cruz.

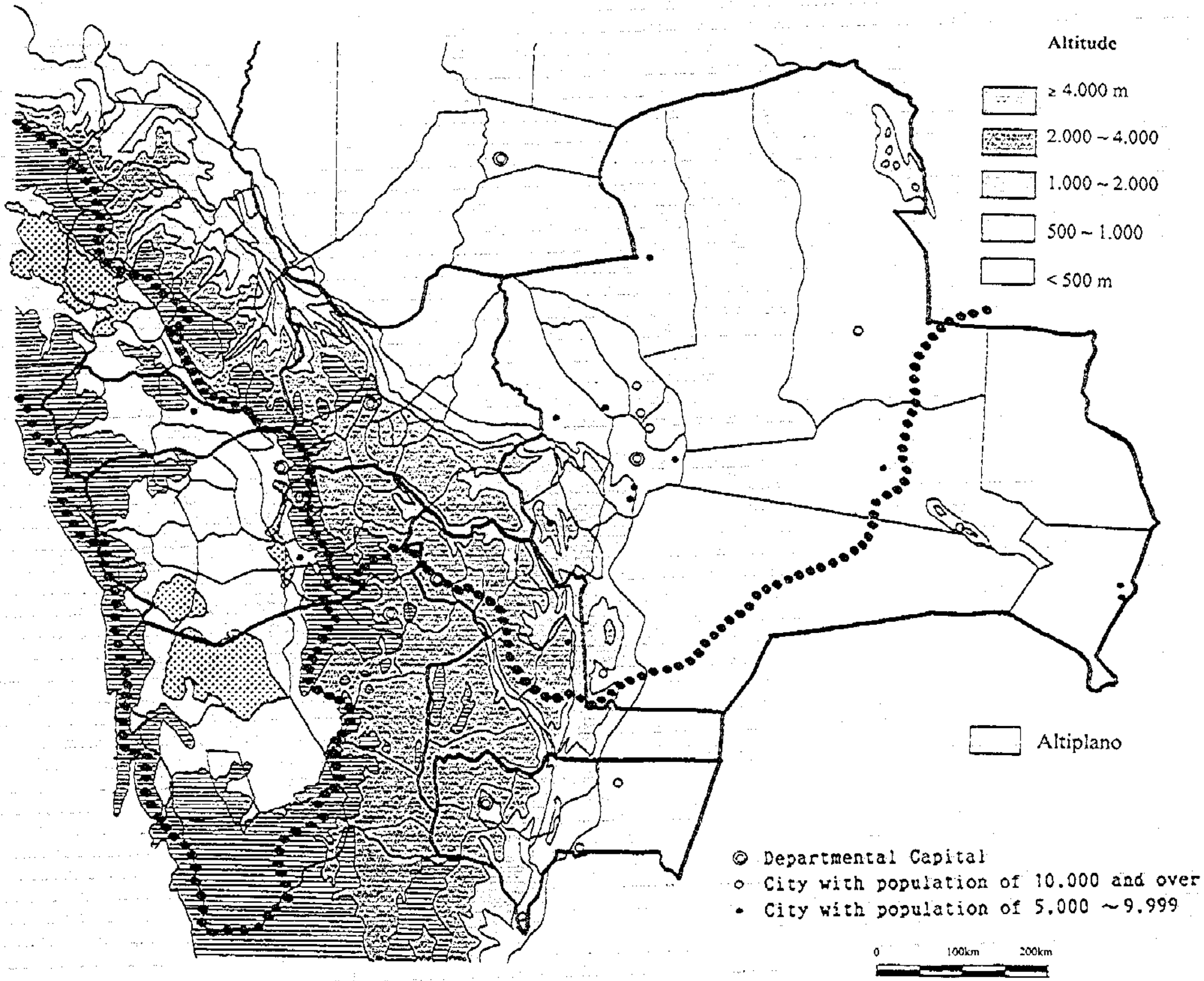


Figure 4-1-3 The River Basins of the Republic of Bolivia

Table 4-1-1 Areas of the River Basin Divisions in the Study Area

(Unit: square kilometers)

River basin Division		Chuqui-saca	South of La Paz	Oruro	Tarija	Santa Cruz	Total
Altiplano	Lake Titicaca		583				583
	Lake Poopo		18,422	22,973			41,395
	Coipasa Salt Pan			23,247			23,247
	Uyuni Salt Pan			3,125			3,125
	Subtotal		19,005	49,345			68,350
Amazon	Madre de Rios river						
	Beni river						
	Mamore river	22,634		2,270		97,567	122,471
	Itenez river					151,757	151,757
	Subtotal	22,634		2,270		249,324	274,228
La Plata	Bermejo river				11,623		11,623
	Pilcomaya river	28,893		1,973	25,785	2,100	58,751
	Paraguay river					119,197	119,197
	Subtotal	28,893		1,973	37,408	121,297	189,571
Total		51,527	19,005	53,588	37,408	370,621	532,149

4.1.3 Meteorology

Although Bolivia is located in the tropical to subtropical zone in terms of latitude, its climate varies in a complex manner due to vertical and spatial topographical variations presented by the plateau zone with altitudes of approximately 4,000m,the hill zone with altitudes of 1,000 to 3,000, and Llanura Chaco-Beniana with altitudes of 200 to 500m. In terms of seasons, the dry season and the rainy season can be distinguished clearly, with the dry season continuing from April to October and the rainy season continuing from December to March of the subsequent year. The characteristics of the climates of the Study Area are as follows.

1) Altiplano

The climate of the Altiplano zone is a cool, dry climate with an annual mean temperature of 10° C and an annual mean precipitation of about 120~350 mm. During the winter, there is hardly any rain and there are times when freezing occurs. In general, the rainfall is lower at the western part of the Altiplano.

2) Valley Zone

This zone is represented by Sucre, Tarija, etc. The precipitation is low in general and there are parts which receive hardly any rain during the dry season (May to August). The annual mean temperature ranges from 20 to 30° C and the annual precipitation is about 500~700 mm.

3) Plain Zone

This zone can be divided into a humid area in northern part of the 18~19-degrees-south-latitude, in which Santa Cruz City is located, and a dry zone called the Chaco region. Although the former area is characterized by an annual mean temperature of 22° C and an annual precipitation of 1,000~1,500 mm, there are years in which drought occurs and causes damage. The latter area has a hot dry climate with an annual mean temperature of 22~26° C and an annual precipitation of 500~1,000 mm, the rainfall being low from June to September.

Figure 4-1-4 shows the precipitation distribution of the Study Area and Figure 4-1-5 shows the monthly variations in precipitation at the major observation points.

Table 4-1-2 shows the water balance calculated for each Department based on the distribution maps for annual precipitation and evapotranspiration. The annual precipitation of the entire Department is 40 billion tons for Chuquisaca, 6.7 billion tons for the southern part of La Paz, 11 billion tons for Oruro, 30 billion tons for Tarija, and 470 billion tons for Santa Cruz. The evapotranspiration is greater than the precipitation in the southern part of La Paz and Oruro and it is presumed that there is inflow of groundwater from neighboring upstream areas of the Altiplano.

Table 4-1-2 Water Balance in the Study Area

(Unit: mm/year)

	Chuquisaca	South of La Paz	Oruro	Tarija	Santa Cruz
Precipitation	780	352	212	800	1,284
Evapotranspiration	620	366	296	593	997
Infiltration · Runoff	160	▲ 14	▲ 84	207	287

(Note) The average value for each Department was calculated on the basis of the river basin areas of the corresponding river basins and the precipitation and evapotranspiration distribution maps.

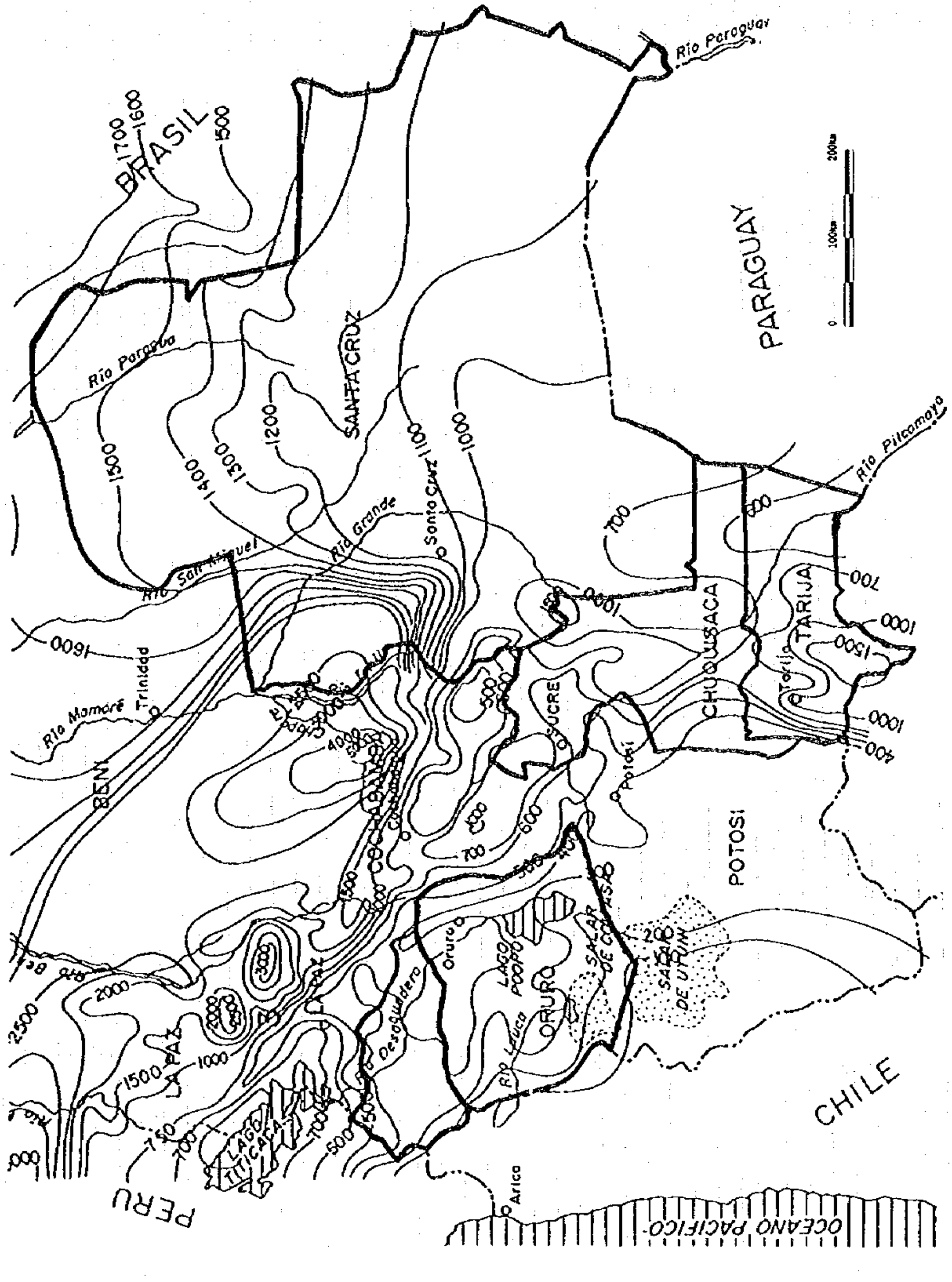
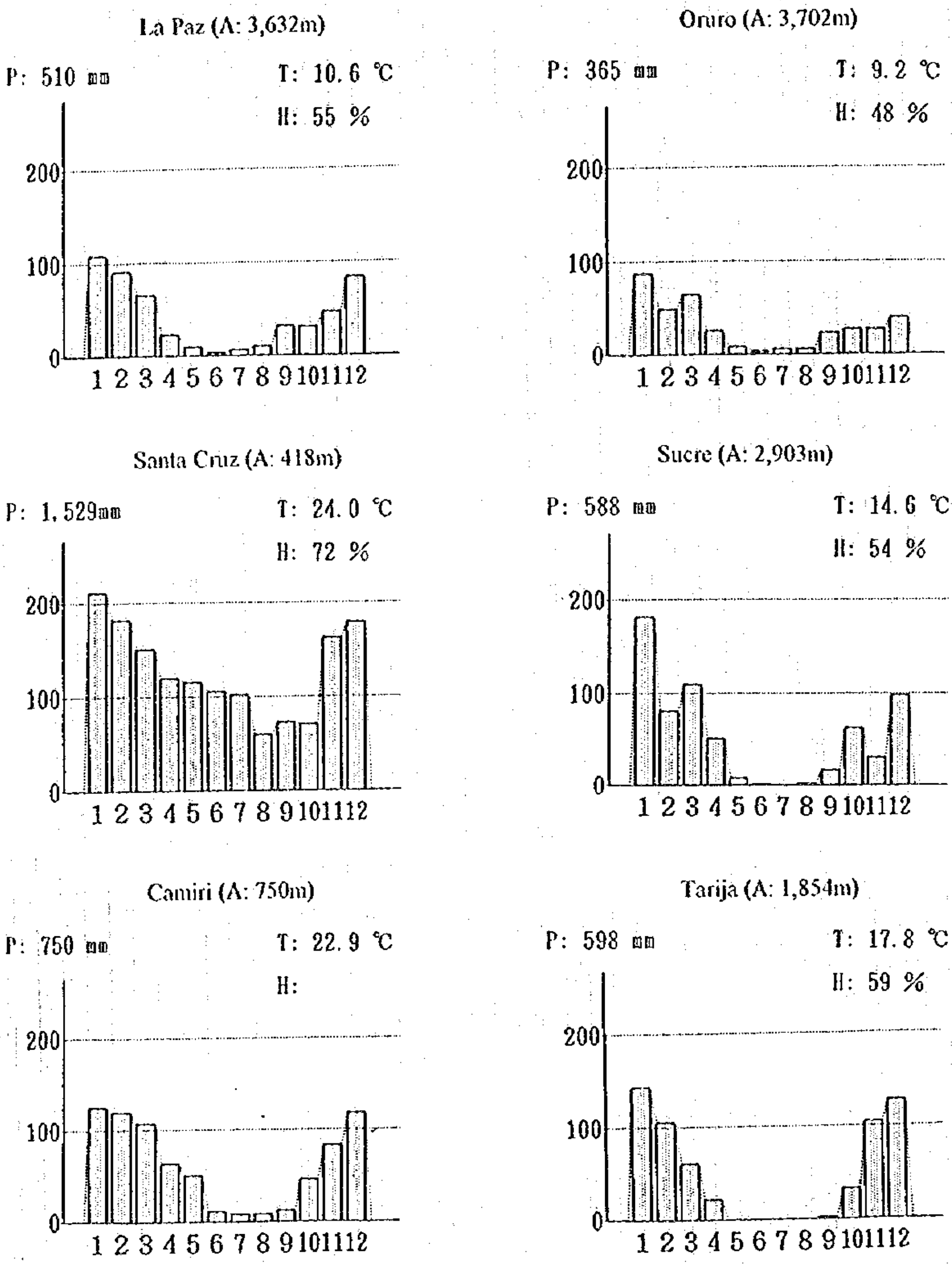


Figure 4-1-4 Precipitation Distribution of the Study Area



Note: *A: Altitude* *P: Annual Precipitation* *T: Annual Mean Temperature*
H: Annual Mean Humidity

Figure 4-1-5 Monthly Variations in Precipitation at Major Points of the Study Area

4.2 Field Survey

4.2.1 Geophysical Prospecting

1) Survey Methods

Geophysical prospecting was carried out in order to study the geological structure and conditions of groundwater existence in the Study Areas and to select test boring points. Geophysical prospecting is a method of measuring the apparent specific resistance of the strata by inserting electrodes into the ground and the present survey was carried out using the specific electrical resistance method and the electromagnetic sounding method.

The vertical sounding (VES) method using the Schulumberger electrode array was adopted as the specific electrical resistance method while the TEM method, which makes use of transient phenomena, was used as the electromagnetic prospecting method.

The survey points are shown in Figure 4-2-1. Vertical sounding was performed at a total of 204 points in the Altiplano, valley zone, plain zone, and a part of the Chaco region. The TEM method was used at 101 points in the Chaco region where the aquifer depth was deep. Measurements were made to depths of 100~200m in the Altiplano and 100~250m in the valley and plain zones. Depths of up to 500m were probed in the Chaco region.

2) Survey Results

The results of the above survey show that the strata, such as the sand layer, gravel layer, sandstone, etc., which comprise promising aquifers, have a specific resistance of 30~80 Ω·cm. The depth distribution of presumed aquifers is shown in Figure 4-2-2. Hereinafter, a stratum which exhibits a specific resistance corresponding to a promising aquifer shall be referred to as an "aquifer."

The aquifer depth in the Altiplano is generally deep in areas where the lake deposit layer is deep and relatively shallow at the foot of neighboring mountains and near areas where the bedrock is exposed. Although in areas which were islands during the time when the Altiplano was a lake, the aquifer can be expected to be located at depths of about 10m within a limited range from such islands, it is also presumed that a stratum which contains groundwater of high salinity lies below the aquifer. Further away from such areas, the thickness of the aquifer decreases rapidly due to the mechanism of the sedimentation process and the upper depth of the salt water layer rises accordingly.

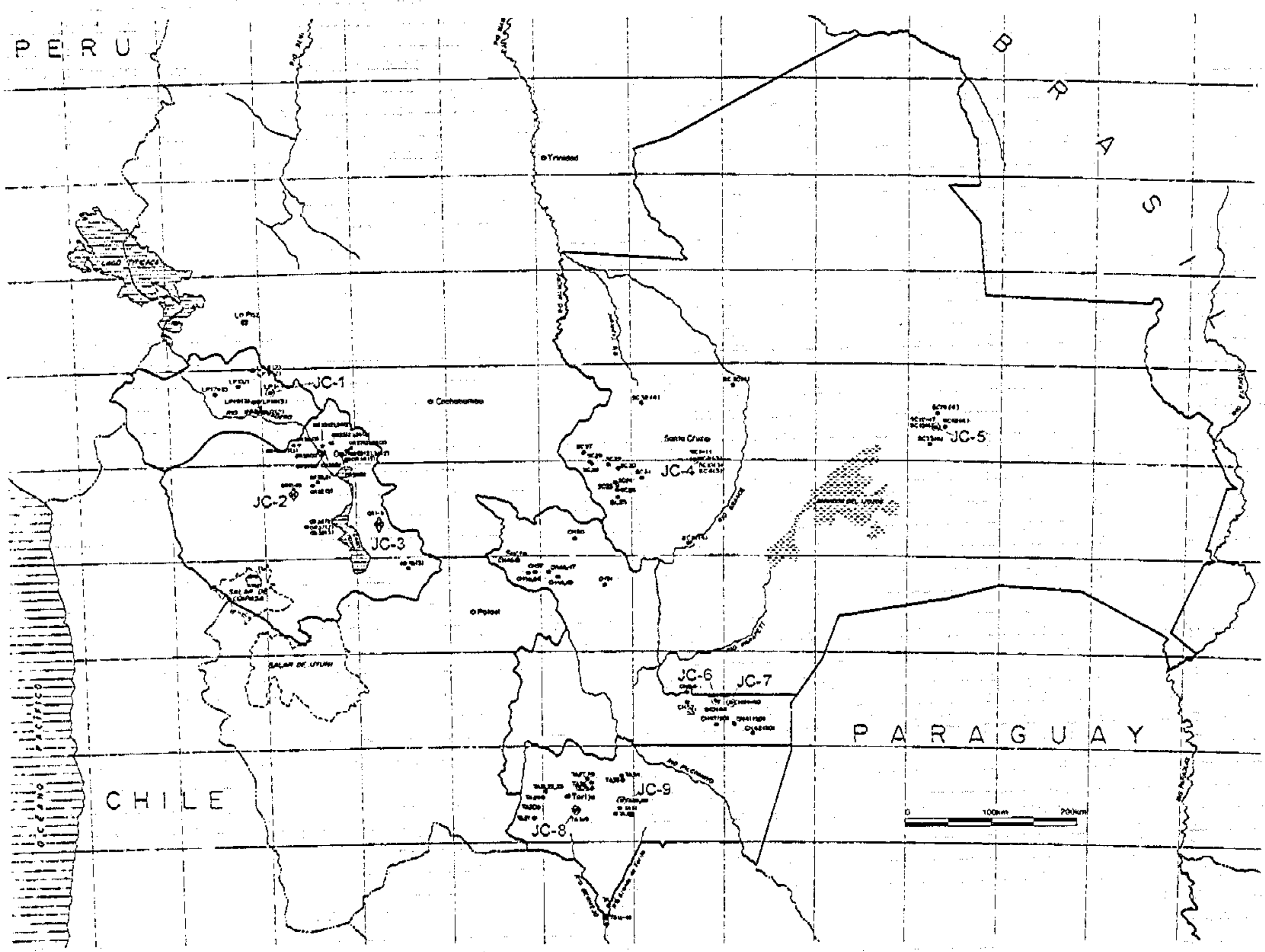


Figure 4-2-1 Geophysical Prospecting Points and Test Well Boring Points

Although the valley zone extends in the north-south direction over the three Departments of Chuquisaca, Tarija, and Santa Cruz, the aquifer conditions of each Department differ according to the differences in the topography and geology of each region. In Chuquisaca, the aquifer depth is generally shallow in the western part and tends to become gradually deeper in the eastward direction. In the vast Quaternary deposit basin located in the western part of Santa Cruz, the aquifer depth is deepest near the central part of the basin and gradually becomes shallower at the peripheral parts. As in Chuquisaca, the aquifer depth is also shallow in the western part and deep in the eastern part in Tarija. For the northeastern part of Entre Rios, it was presumed that groundwater of high salinity exist in the strata and that aquifers accompanying groundwater suited for drinking could not be found at depths of up to 200m.

In the plain zone, it was seen that the aquifer depth tended to be relatively deep near the boundary between the valley zone and the plain zone and to become shallower eastward towards the flat parts of the zone.

The aquifer depth in the Chaco region is considerably deeper than that of other regions and there are parts in the Luis Carbo province of Chuquisaca where there are no aquifers up to depths of 400m or more.

4.2.2 Test Well Drilling

1) Outline of the Survey

In order to check the geological structure and groundwater properties in the Study Areas, test boring surveys were carried out at the 9 locations shown in Figure 4-2-1. Table 4-2-1 shows the survey points and an outline of the drilling work. The surveys were carried out by commissioning the work to local drilling firms. After drilling the pilot hole, electrical logging was performed to determine the screen insertion positions. The main hole was then drilled, screens and casings were inserted, and gravel was filled between the casings and the well wall of the borehole. Thereafter, washing of the borehole, stepwise pumping tests, continuous pumping tests, and recovery tests were performed and hydraulic constants were calculated.

Although Campo Grande was initially planned for JC-9, the point was moved to Naranjos because of difficulties in drilling due to the abundance of cobble. Also, although drilling to 150m was scheduled for JC-8 and JC-9, drilling was interrupted at 127m at both sites, the reason being the spontaneous flowing out of groundwater in the case of JC-8 and the accidental collapsing of the bit in the case of JC-9.

Table 4-2-1 Outline of the Test Boring Surveys

Point No.	Department	Community	Term of Drilling	Drilling Firm	Rig Model
JC-1	S. La Paz	Patacamaya	08.11.95~23.11.95	GEOBOL	TH-60 USA
JC-2	Oruro	Corque	21.09.95~03.11.95	GEOBOL	R-36 USA
JC-3	Oruro	Penas	25.11.95~20.12.95	GEOBOL	TH-60 USA
JC-4	Santa Cruz	San Carlos	23.08.95~01.10.95	HIDROSUR	LEE MOORE USA85
JC-5	Santa Cruz	Quituquina	18.10.95~17.12.95	HIDROSUR	LEE MOORE USA85
JC-6	Chuquisaca	Campo Leon	24.08.95~26.10.95	HIDROSUR	WILSON USA 79
JC-7	Chuquisaca	Simbolar	03.11.95~24.11.95	HIDROSUR	WILSON USA 79
JC-8	Tarija	La Chosa	15.09.95~12.10.95	HIDROSUR	FAILING USA75
JC-9	Tarija	Naranjos	12.12.95~04.02.96	HIDROSUR	FAILING USA75

2) Results of the Survey

The survey results are shown in Table 4-2-2. Whereas the per-second-yield obtained was 4.0 liters for JC-1, 2.0 liters for JC-2, 2.0 liters for JC-3, 10 liters for JC-4, 0.7 liters for JC-5, 2.25 liters for JC-6, and 7.55 liters for JC-8. Water was not obtained from JC-7 and JC-9. The geology at JC-5 was mudstone and a satisfactory aquifer could not be found up to the drilling depth. The hydraulic constants calculated from the results of the pumping tests are as shown in Table 4-2-3.

The surveys required a term of 16 to 65 days from the arrival of equipment at the site to completion, and the drilling rate per month was 70 to 200m (overall average: 123 m).

The geology and the aquifer depths which were clarified by the test boring surveys were highly consistent with the results of geophysical prospecting, thus demonstrating the effectiveness of geophysical prospecting.

Table 4-2-2 Results of Test Well Drilling

No.	Community	Drilling Diameter (inch)	Drilling Depth (GL-m)	Casing Diameter (inch)	Casing Length (m)	Screen Position (GL-m)	Geology of the Aquifer	Static Level (GL-m)	Yield (l/s)	Dynamic Level (GL-m)	Draw-down (m)
JC-1	Patacamaya	12-1/4	100	6	62	23-32 36-42 44-47 50-56	clay, silt	13.4	4.0	27.2	13.8
JC-2	Corque	12-1/4	100	6	87	42-45 58-67 78-81	clay, silt	6.5	2.0	26.1	19.6
JC-3	Penas	12-1/4	100	6	66	29-50 54-60	gravel, sand	7.2	2.0	29.0	21.8
JC-4	San Carlos	17-1/2	260	8	254	146-152 164-170 191-197 213-219 242-248	lulite	57.5	10.0	93.0	35.5
JC-5	Quituquina	17-1/2	200	8	197	117-123 132-135 142-145 149-155 162-165 173-182	sand, clay	32.5	0.71	122.5	90.0
JC-6	Campo Leon	17-1/2	411	8	405	306-312 319-328 338-344 352-361 366-369 383-386 393-399	sand, clay	190.0	2.25	282.9	92.9
JC-7	Simbolar	12-1/4	258	8	171	99-102 112-121 125-128 138-141 156-159	sand, clay	139.0	-	-	-
JC-8	La Choza	12-1/4	127	6	127	46-49 51-54 75-84 91-100 113-119	gravel	artesian (+6.9)	7.55	-	-
JC-9	Naranjos	12-1/4	127	8	127	91-121	clay, silt, sand	-	-	-	-

Table 4-2-3 Hydraulic Constants

Point No.	Safe Yield (l/sec)	Drawdown (m)	Specific Capacity (m^2/day)	Transmissivity (m^2/sec)	Coefficient of Permeability (m/sec)
JC-1	4.0	13.8	25.0	4.63×10^{-4}	1.93×10^{-5}
JC-2	2.0	19.6	8.82	5.21×10^{-4}	4.34×10^{-5}
JC-3	2.0	21.8	7.93	6.94×10^{-5}	2.57×10^{-6}
JC-4	10.0	35.5	24.3	6.13×10^{-4}	2.08×10^{-5}
JC-5	0.71	90.0	0.67	2.31×10^{-6}	7.72×10^{-8}
JC-6	2.25	92.9	2.09	1.04×10^{-4}	2.66×10^{-6}
JC-8	7.55	-	-	-	-

3) Groundwater Quality

The water quality test results for the groundwater obtained at the test boring survey points are shown in Table 4-2-4. The groundwater at JC-5 was high in turbidity and concentration of soluble matter and was thus unsuitable as drinking water. Although the groundwater at JC-1 and JC-2 were somewhat high in iron concentration, the water quality items satisfied the drinking water quality standards of the Republic of Bolivia. The water quality of groundwater from other survey points also satisfied the drinking water quality standards and were low in turbidity and organic pollutants. Also, the concentrations of soluble matter were not particularly high in comparison to water from shallow wells. With the exception of JC-5, the conductivity was in the range, 380~830 $\mu\Omega$/cm, and the total hardness was in the range, 139~237 mg/l.

Table 4-2-4 Quality of Groundwater from the Test Boring Survey Points

項　目	JC-1 Patacamaya	JC-2 Corque	JC-3 Penas	JC-4 San Carlos	JC-5 Quituquina	JC-6 Campo Leon	JC-8 La Choza
Water temperature (°C)	16.00	–	13.00	27.7	24.9	30.3	20.5
pH	6.75	8.10	8.35	6.96	7.62	7.44	8.0
Color	–	–	–	3.0	98.0	12.0	5.0
Turbidity	clear	crystalline	clear	1.0	11.0	5.0	0.40
Total hardness (mg/l-$CaCO_3$)	138.4	236.17	119.18	363	217	137	271.4
Conductivity (μ Ω/cm)	386.2	831.81	415.9	733	5,350	719	500
Soluble matter (mg/l)	–	–	–	513	3,745	503	–
Alkalinity (mg/l-$CaCO_3$)	113.30	177.54	121.47	425	722	160	376
E. coli colonies (MNP/100ml)	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Ca (mg/ℓ)	32.4	63.44	30.75	105.0	43.4	46.0	–
Mg (mg/ℓ)	13.93	18.85	10.26	24.5	26.4	5.3	–
K+Na (mg/ℓ)	54.2	60.9	111.7	–	–	–	–
Fe (mg/ℓ)	3.19	2.30	0.32	0.04	2.85	0.08	ND
Mn (mg/ℓ)	–	–	–	0.00	0.00	0.00	–
Cl (mg/ℓ)	17.3	63.45	32.69	8.5	50.50	78.0	31.1
SO_4 (mg/ℓ)	51.08	63.27	44.82	13.9	1,524.2	124.0	175.0
HCO_3 (mg/ℓ)	113.30	177.54	102.79	88.3	34.2	11.5	412.0
NO_3 (mg/ℓ)	–	–	–	4.5	0.0	22.3	–
NO_2 (mg/ℓ)	ND	–	ND	0.01	0.00	0.17	ND

4.3 Potential for Groundwater Development

4.3.1 Past Groundwater Development

1) Distribution Conditions of Wells

According to the 1992 INE Census, 46.9% of all households in the Study Areas that are not receiving water supply service depend on well water. The population using well water is especially large in the southern part of La Paz, Oruro, and the northern part of Santa Cruz and it is presumed that the majority of the wells are shallow, hand-dug wells.

The number of wells determined from the well data in the Water Supply Database are tabulated in Table 4-3-1, and the locations of these wells are shown in Figure 4-3-1. Although the data are skewed towards regions of high population since relatively newly developed wells were targeted, the following trends can be seen.

① The regions in which groundwater development has been carried out actively include the vicinity of Santa Cruz City, the vicinity of Tarija City, the western region of Santa Cruz, which forms the boundary between Las Seranias Sub-Andinas and Llanura Chaco-Beniana and extends in a band-like manner in the north-south direction, the eastern Altiplano region, etc.

② The newer the well, the deeper the well depth.

③ In general, the well depths are approximately 50~100m in the Altiplano and approximately 100~300m in the western Santa Cruz region. There are wells that are 200 to 400m deep or even deeper in the Chaco region.

④ The yields vary widely from 1.5 to 10 liters per second in the Altiplano. The yields are approximately 4 to 10 liters per second in the western Santa Cruz region and approximately 1.5 to 3 liters per second in the Chaco region.

⑤ The static water levels are 20~25m in the Altiplano, 20~50m in the western Santa Cruz region, and may be 100 to 200m or even deeper in the Chaco region.

Table 4-3-1 Number of Wells according to Well Depth (based on the Water Supply Database)

Depth (m)	0~10	11~29	30~49	50~99	100~199	>=200	Total
Chuquisaca	0	7	4	22	7	11	59
S. of La Paz	17	3	6	3	0	0	29
Oruro	16	12	19	29	3	0	79
Tarija	22	7	2	24	37	0	92
Santa Cruz	2	33	81	277	153	11	557
Total	57	62	112	355	200	22	808

Figure 4-3-2 to 4-3-4 show the distributions of the well drilling depths, the well productivities (yields), and static water levels based on the well data in the Water Supply Database.

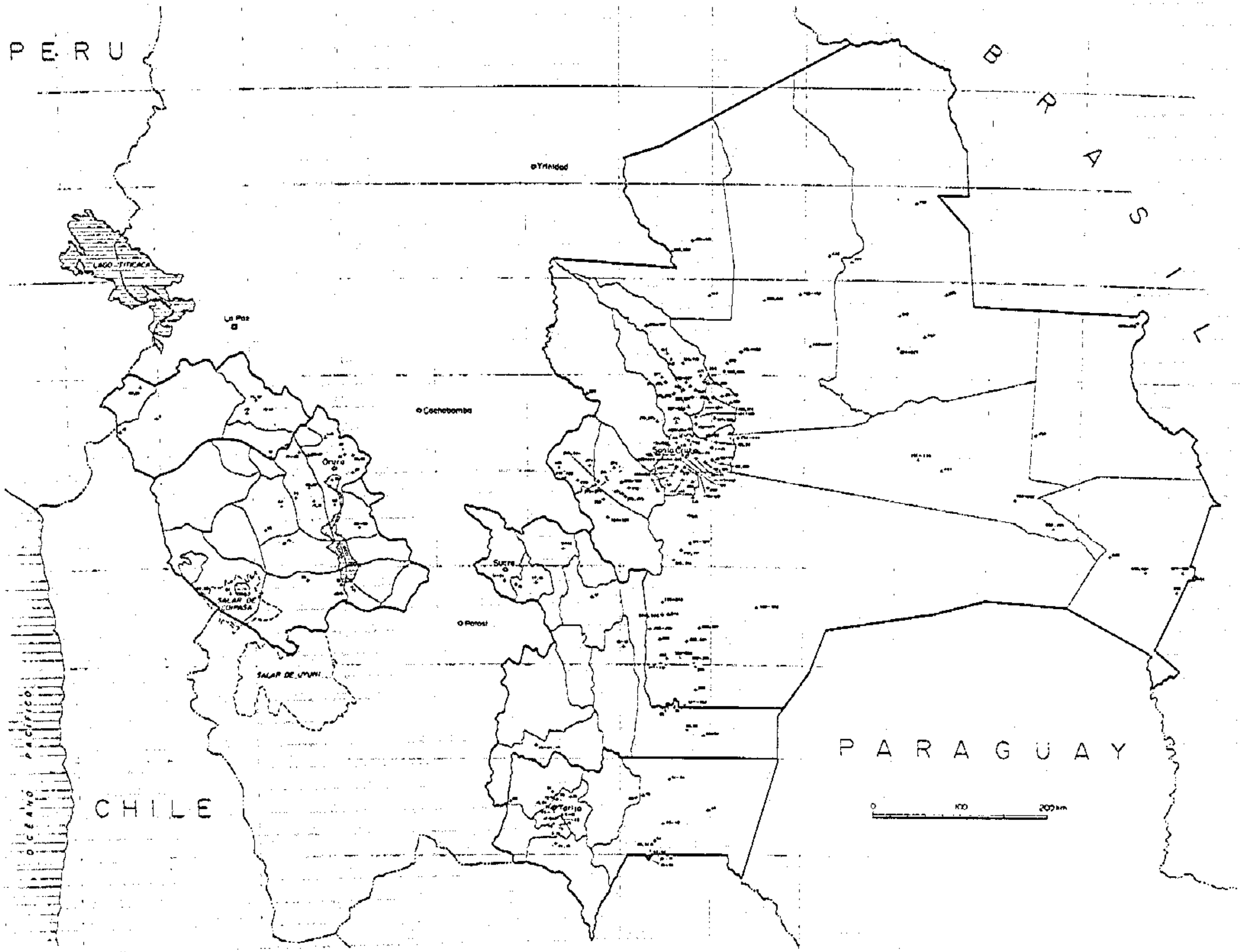


Figure 4-3-1 Locations of the Wells (from Water Supply Database)

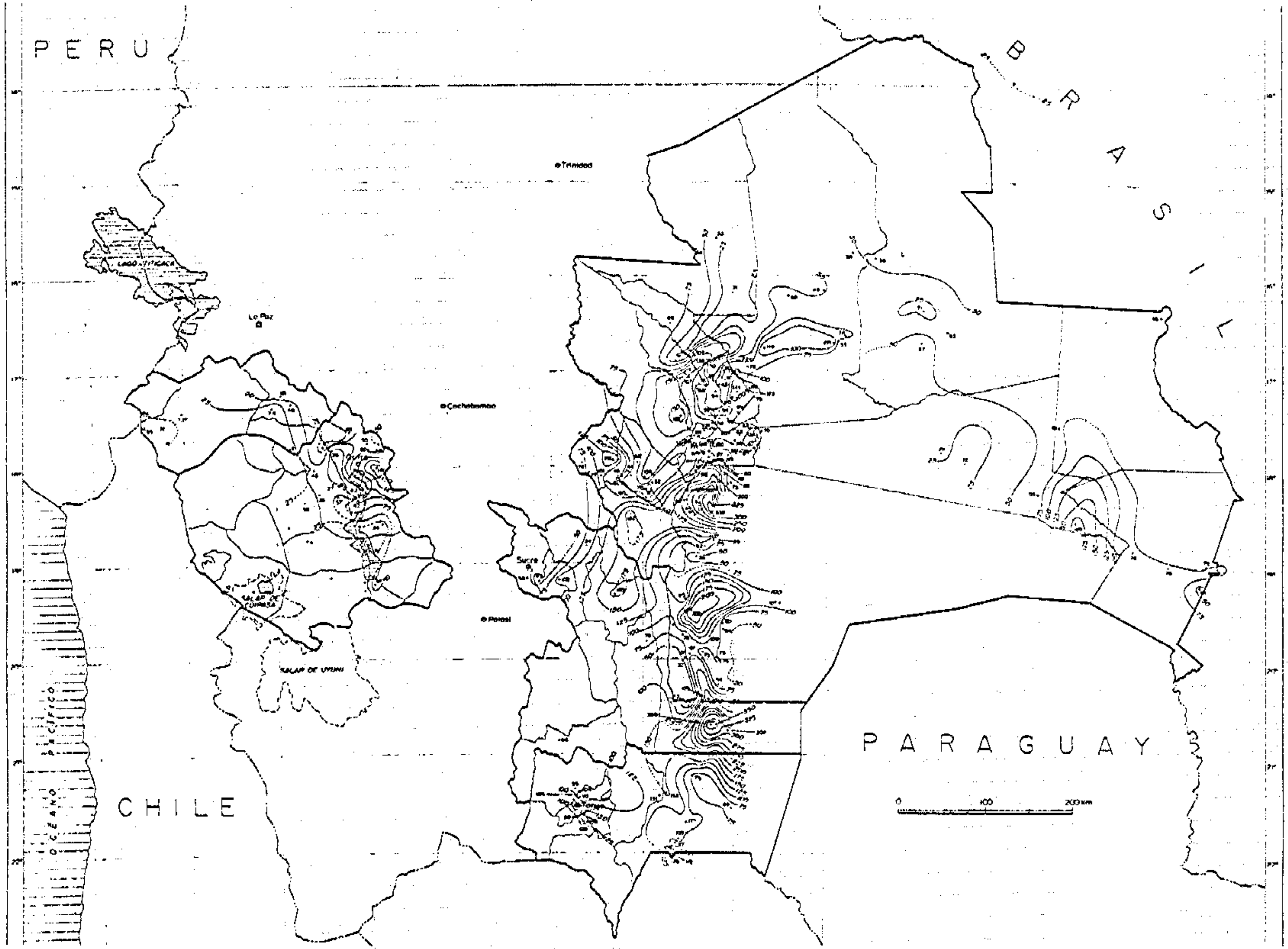


Figure 4-3-2 Distribution of the Well Depths (from Water Supply Database)

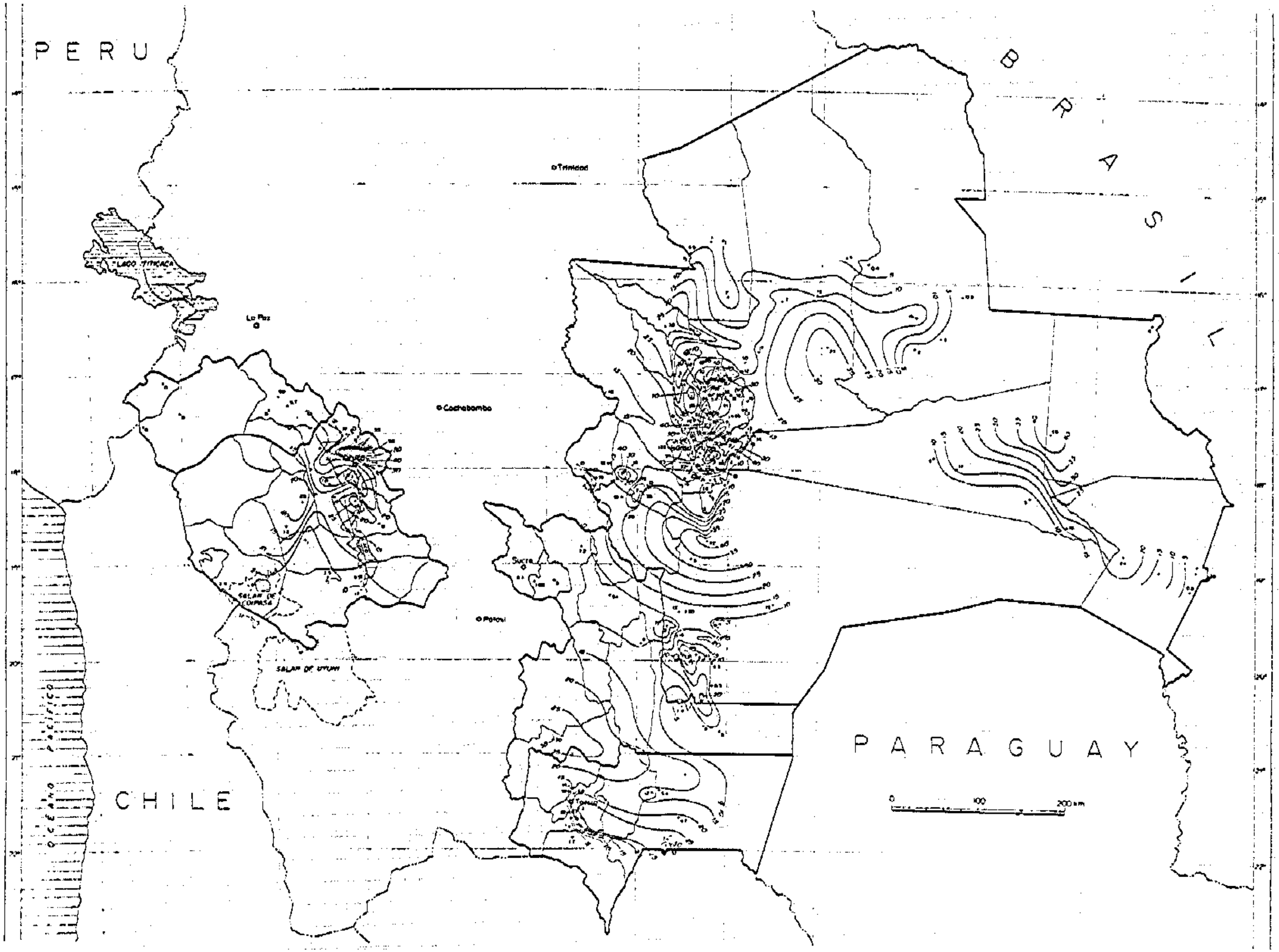


Figure 4-3-3 Distribution of the Well Yields (from Water Supply Database)

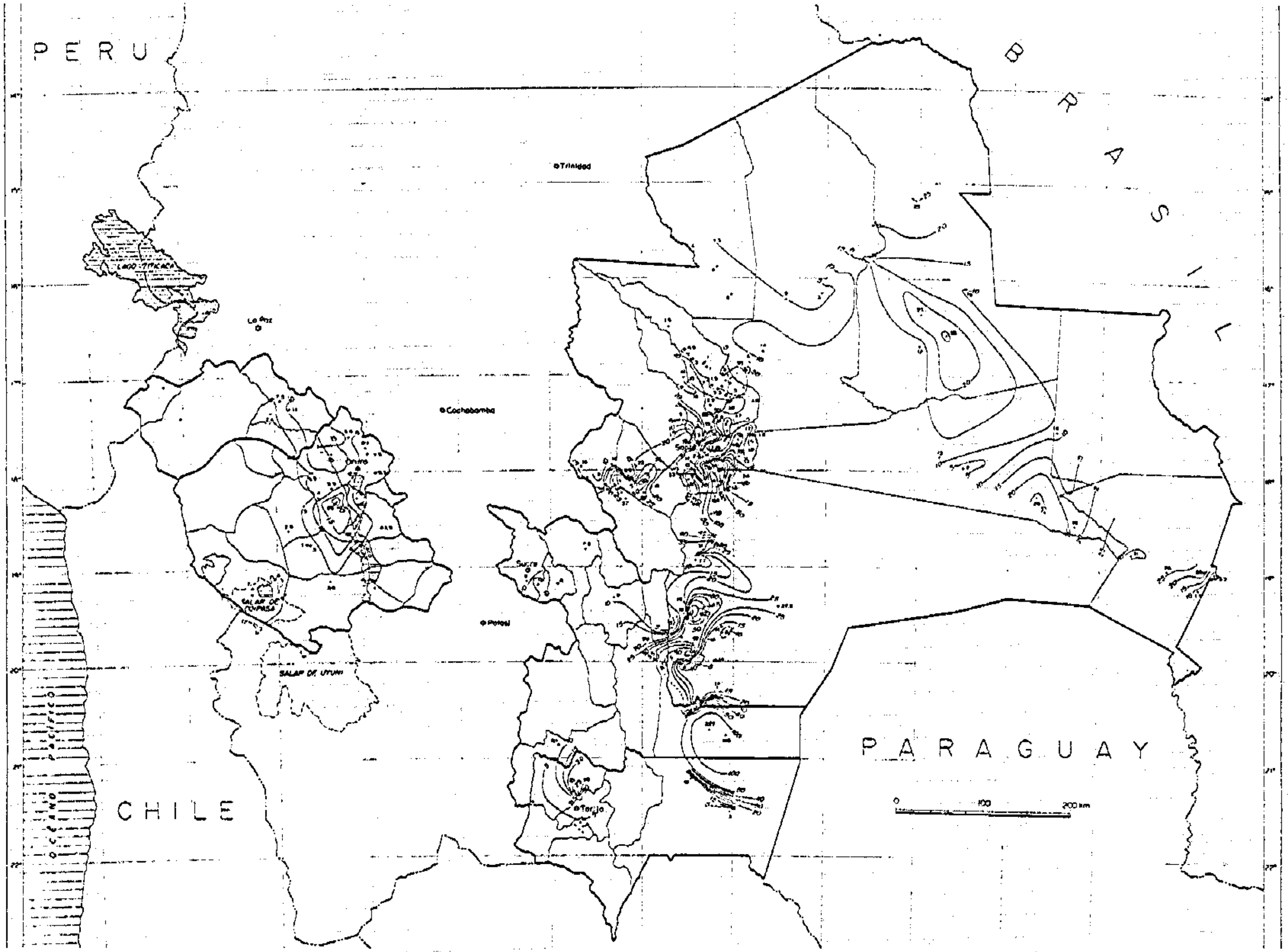


Figure 4-3-4 Distribution of the Well Static Water Level (from Water Supply Database)

2) Status of Drilling Equipment Ownership and Well Drillers

Among the Study Areas, the two Departments of Chuquisaca and Oruro respectively own well drilling equipment. However, the equipment are obsolete, 1974 or '75 model equipment with low capacity and drilling work is carried out only at one or two sites a year. The other three Departments do not own drilling equipment and have to commission groundwater development to private well drillers. Although several private well drillers exist in the Departments of La Paz and Santa Cruz, most are small to medium enterprises that own only obsolete well drilling equipment for shallow wells and are low in management ability. There are only 3 to 5 well drillers who have the capacity for drilling deep wells.

Besides the above, the Drinking Water and Sewer Corporation of Cochabamba owns relatively new Japanese drilling equipment and the YPFB owns large-scale petroleum prospecting equipment.

Although steel casings and general-purpose lift pumps, etc. can be obtained domestically, stainless steel screens, submerged motor pumps, special spare parts, etc. must be imported.

Although there are many persons who are experienced in drilling work and the well drilling technology of Bolivia has reached a considerable level, there is a shortage of information on groundwater prospecting methods and the newest drilling techniques and the number of engineers with hydrogeological know-how is low.

4.3.2 Assessment of Groundwater Development Potential

1) Hydrogeological Features

The hydrogeological map of Figure 4-3-5 and the hydrogeological cross section map of Figure 4-3-6 were prepared in order to assess the groundwater development potential of the Study Area. These maps are based on topographical and geological maps and reflect the well distribution and the results of geophysical prospecting, test boring surveys, etc. The geology, predicted aquifer depths, groundwater levels, yields, etc. are summarized according to Department and Provincia in Table 4-3-2.

With regard to the general groundwater development potential, the Study Area can be considered in terms of the following five hydrogeological zones.

(1) La Cuenca Endorreca del Altiplano Andino (Southern Part of La Paz, Oruro)

Groundwater basins, in which Quaternary deposits have accumulated, have formed in this zone and the permeability is relatively good. Although the rainfall is low, the existing groundwater quantity is high for the water zone as a whole. The Study Area which are located in the Altiplano are low in altitude and receive inflow of groundwater from the mountainous parts and northern regions. It is considered that in general, the deeper the depth, the greater the quantity of groundwater. Whereas good groundwater can be obtained from springs and from relatively shallow depths at the foot of mountains, it is difficult to obtain groundwater at locations other than deep locations at the central part of this zone.

The groundwater is salinized in part of the region and cavity water or fissure water in deep layers must be developed in such areas. Past groundwater development have been targeted at groundwater at relatively shallow locations and it is considered that the development potential for deep groundwater is high.

(2) Valley Zone (Chuquisaca, Western Tarija, Western Santa Cruz)

Although Paleozoic strata form the bedrock in the valley zone, erosion has progressed considerably and many small valley parts have been formed. The precipitation is 500~700 mm in parts of the "Cordillera Andina" zone at altitudes of 2,000m or more and 600 ~ 1,000 mm at the foot of the "Cordillera Andina" zone below altitudes of 2,000m. Although river water and spring water have been used frequently from the past and groundwater development has not been carried out often, a significant amount of groundwater flow can be anticipated at the valley parts and the potential for groundwater development is high. However, there are communities for which access by transportation is difficult and there are regions where well drilling is made difficult by the hard geology.

(3) Amazon River Basin (Central Santa Cruz)

The humid zone in the northern part has a high precipitation of 1,000~2,000 mm and groundwater can be obtained from relatively shallow locations. The dry zone in the southern part has a low precipitation of 500~1,000 mm and the aquifer depth is deep. Although the river basin area is vast and the groundwater development potential is high, there may be groundwater pollution due to floods in the northern region.

(4) El Escudo Central (Northeastern Santa Cruz)

This zone has an annual precipitation of 1,200~1,600 mm and belongs to the Itenez river system. Although the bedrock is formed from Pre-Cambrian strata, erosion is well progressed. The groundwater flow is considerably high and it is considered that the potential for groundwater development is high.

(5) Chaco Region (Chuquisaca, Eastern Tarija, Southern Santa Cruz)

Although the strata consist of Quaternary deposits and the permeability is good, because the precipitation is low, being only 500~700 mm, and because this zone is located at the watershed between the Amazon and La Plata river systems, the existing groundwater quantity is low. However, since surface water is hard to obtain and adequate water quantities cannot be obtained with shallow wells either, there is a need to carry out active development of deep groundwater. The aquifer depth is about 400m or more for the groundwater basin at the central part of Luis Carbo province of Chuquisaca. Well drilling is being performed with international cooperation from China in the Grand Chaco province of Tarija.

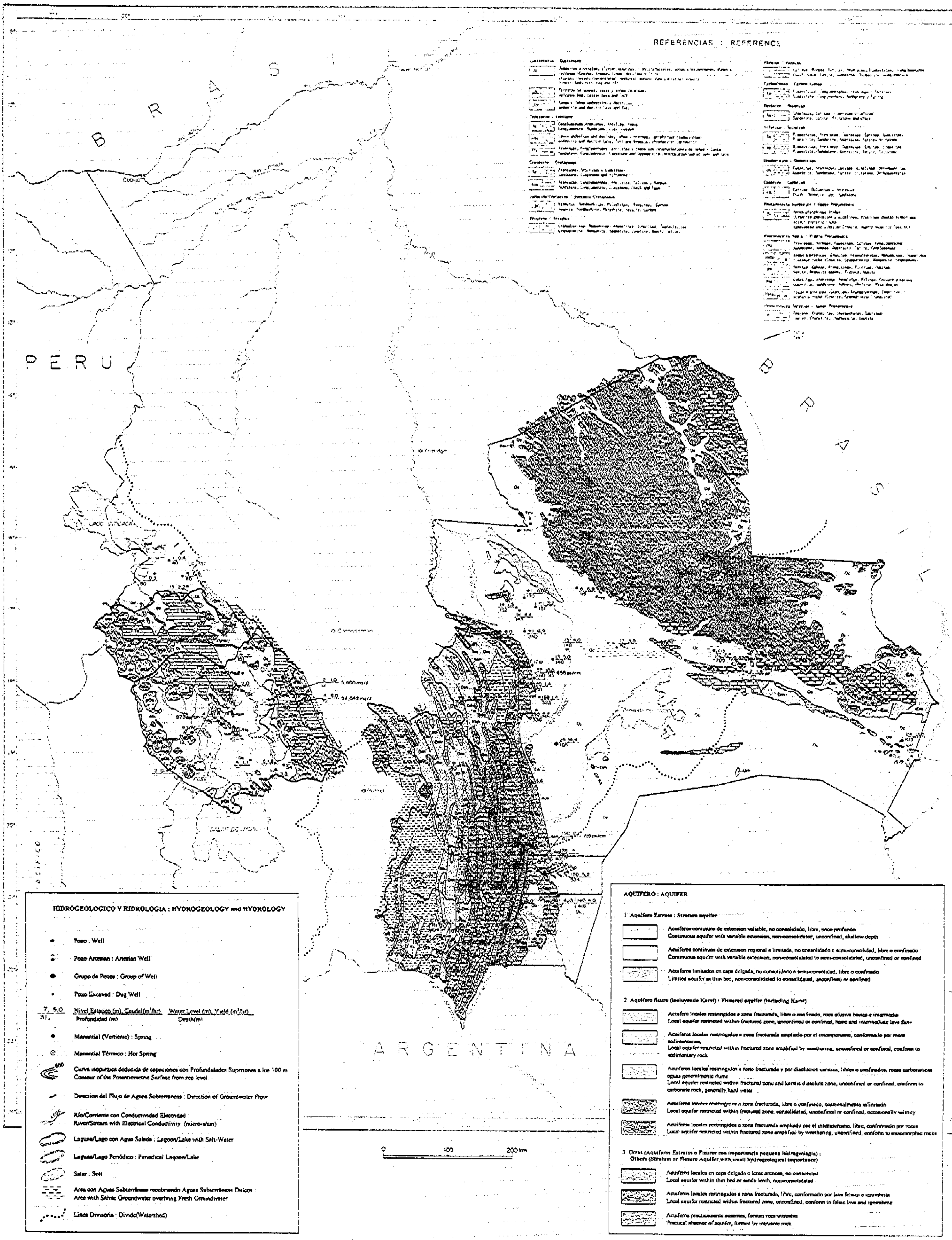


Figure 4-3-5 Hydrogeological Map of the Study Area

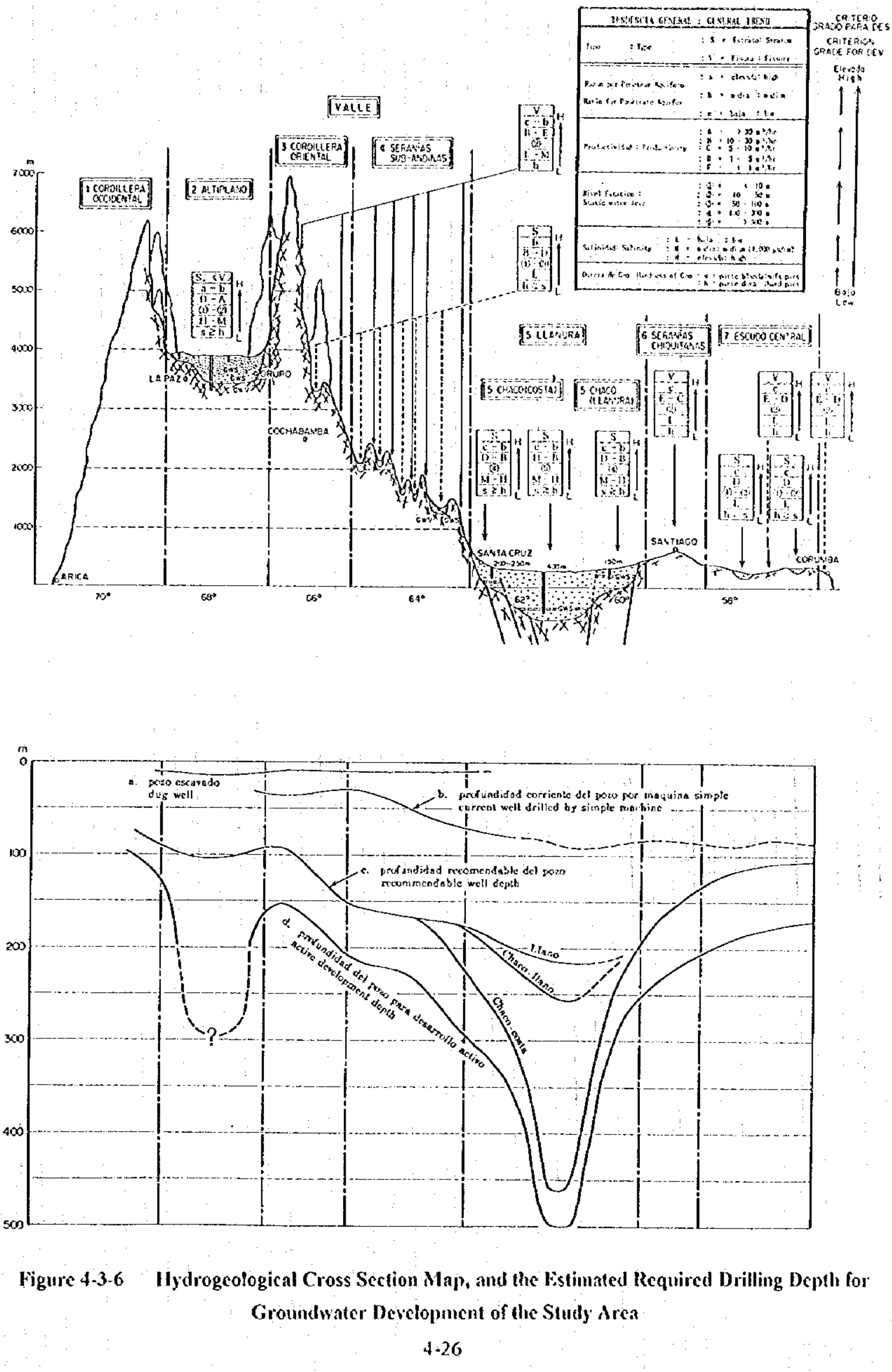


Figure 4-3-6 Hydrogeological Cross Section Map, and the Estimated Required Drilling Depth for Groundwater Development of the Study Area

2) Groundwater Targeted for Development and Estimations of Depths and Yields

The groundwater of the Study Areas can be classified into the five types of ① unconfined groundwater that can be collected using shallow wells, ② confined groundwater existing as deep stratum water, ③ unconfined groundwater in the weathered parts of the bedrock, ④ fissure water in the bedrock, and ⑤ unconfined groundwater which exists as river infiltration water or as groundwater streams in the valley part.

Among the above, ① has been used most frequently for water conventionally in the Altiplano and the plains of Beni and Santa Cruz. However, the water is unsuitable as drinking water due to the salinity, turbidity, etc. and often dry up during the dry season. In the Chaco region, such groundwater can hardly be anticipated in terms of quantity as well.

Although groundwater of type ② has not been developed often in the past, it presents the highest development potential in terms of quantity and quality.

Groundwater of type ③ has been used in El Escudo Central from the past and is high in development potential. Depending on the region, such groundwater can be anticipated from the hill zone also.

Although groundwater of type ④ presents an adequate potential for development, it is difficult to locate. It should however be a development target since it may provide good water quality in cases where the stratum water is salinized and the water sources are lacking, such as in the Altiplano.

Water of type ⑤ are used widely as the water source for the existing water supply system in rural areas, and are collected by erecting water intake tanks and dams at the valley parts. Even in parts of the hill zone where there are no water supply system, there are many residents who collect water that remain at the bottom parts of dried rivers and valleys. There are many regions where the collection of water can be made possible by the construction of a shallow well or infiltration gallery at locations with groundwater flow. However, such sources may dry up during the dry season in the case of regions of small water collection area and water pollution and countermeasures against disaster must be taken into consideration in regions of large water collection area.

The present plan is targeted at the supplying of domestic water to regional residents. Deep groundwater, which are low in quantity variations in the rainy and dry seasons and have good water quality, are suited as water sources for such domestic water in the Study Area and are thus assessed to be high in development potential.

Figure 4-3-7 shows the aquifer depth distribution of the groundwater to be targeted in the plan as estimated based on the results of hydrogeological investigation, the Water Supply Database, etc. The estimated aquifer depths, potential yields, and groundwater levels are summarized for each Department and Provincia in Table 4-3-2.

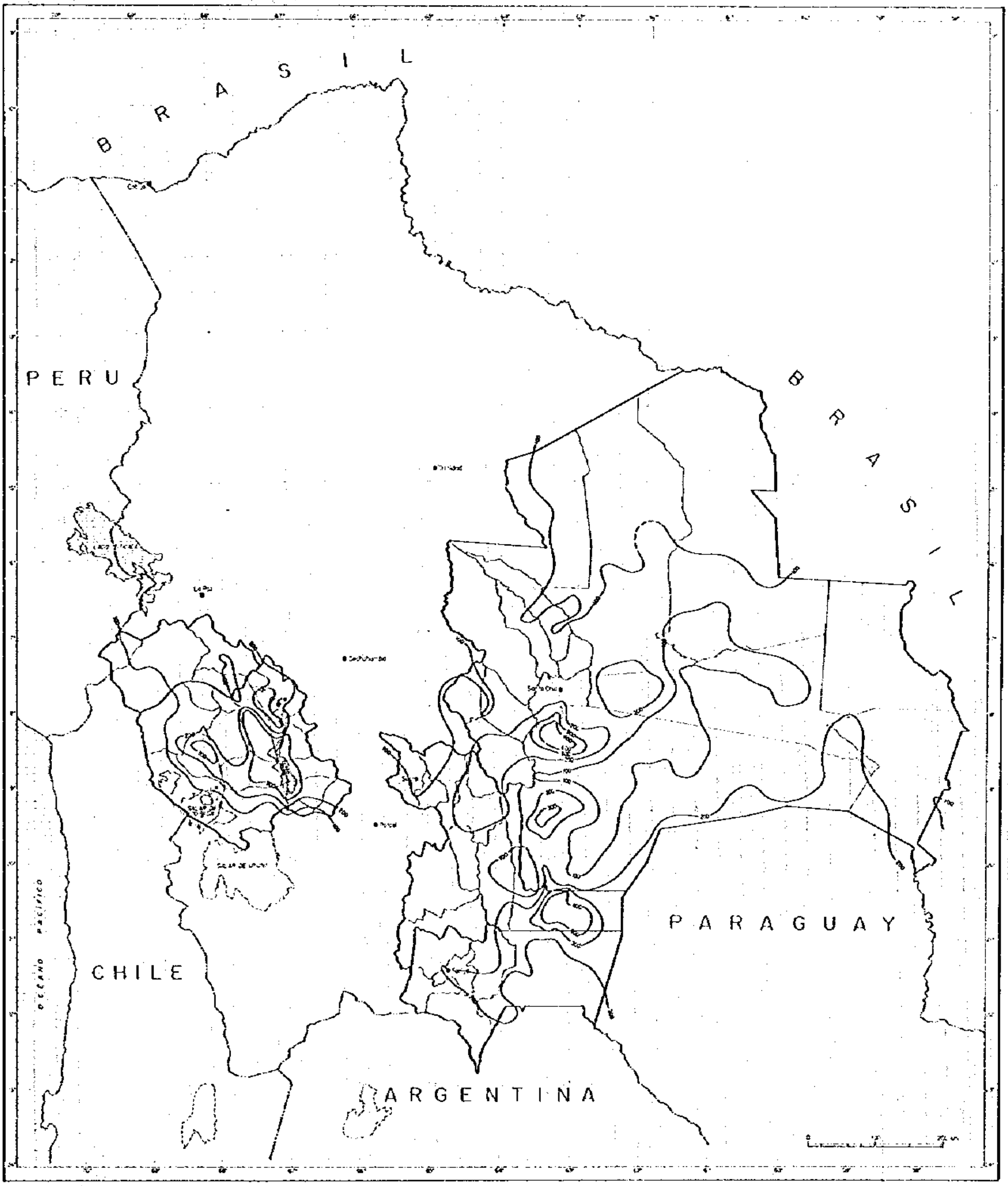


Figure 4-3-7 Estimated Depths of the Aquifer of the Study Area

Table 4-3-2 Groundwater Development Potential of the Study Area

Dept.	Province	Depth of Aquifer (m)	Static Water Level (m)	Potential Water yield (m3/hr)	Dynamic Water Level (m)	Specific Capacity (m3/day/m)
1. CHUQUI SACA	01. Oropeza	50~200	5~ 24	5~ 10	50	~ 0.3
	02. Azurduy	100~200	5~100	10~ 20	50	~ 0.8
	03. Zudanes	50~200	5~ 20	5~ 10	30	~ 0.3
	04. Tomina	200~300	5~ 30	5~ 10	50	~ 0.3
	05. H. Siles	100~200	15~ 90	5~ 20	50	~ 0.8
	06. Yamparaez	100~200	5~ 30	3~ 10	50	~ 0.3
	07. Nor Cinti	100~200	5~ 60	15~ 30	30	~ 1.0
	08. B. Boeto	200~300	5~ 30	10~ 20	50	~ 0.8
	09. Sud Cinti	100~200	5~ 30	20~ 30	30	~ 1.0
	10. Luis Calvo	100~450	5~270	3~ 15	92.9	0.08~ 0.5
2. SUR DE LA PAZ	03. Pacajes	50~200	5~150	3~ 15	50	~ 0.5
	13. Aroma	50~200	5~ 30	3~ 10	13.8	0.3 ~ 1.04
	18. G. Villarroel	50~200	5~ 20	5~ 15	30	~ 0.5
	19. G.J.M. Pando	50~200	5~100	5~ 10	50	~ 0.3
4. ORURO	01. Cercado	50~300	5~ 20	3~ 55	30	~ 0.8
	02. Challapata o Avaroa	200~350	5~100	10~ 20	30	~ 0.8
	03. Carangas	100~200	5~ 20	10~ 25	19.6	0.37~ 0.8
	04. Sajama	50~200	5~100	5~ 10	50	~ 0.3
	05. Litoral	200~350	5~100	10~ 15	50	~ 0.5
	06. Poopo	200~350	5~ 20	15~ 25	21.8	0.33~ 0.8
	07. P. Dalence	200~300	5~ 20	10~ 20	30	~ 0.8
	08. L. Cabera	50~300	5~100	3~ 10	50	~ 0.3
	09. Atahuallpa	50~200	5~160	5~ 10	50	~ 0.3
	10. Saucari	100~350	5~ 50	3~ 20	50	~ 0.8
	11. Tomas Barron	100~200	10~ 30	5~ 15	30	~ 0.5
	12. Sud carangas	200~350	5~ 30	3~ 10	50	~ 0.3
	13. San Pedro de Totora	100~200	5~ 40	3~ 10	30	~ 0.3
	14. S. Pagador	100~300	5~ 20	10~ 15	30	~ 0.5
	15. Mejillones	50~100	5~100	3~ 10	50	~ 0.3
	16. Nor Carangas	100~200	5~ 20	15~ 20	30	~ 0.8

Table 4-3-2 Groundwater Development Potential of the Study Area (continue)

Dept.	Province	Depth of Aquifer (m)	Static Water Level (m)	Potential Water yield (m3/hr)	Dynamic Water Level (m)	Specific Capacity (m3/day/m)
6. TARIJA	01. Cercado	100~300	5~ 20	15~ 30	20	~ 1.0
	02. Arce	100~200	5~150	3~ 30	20	~ 1.0
	03. Gran Chaco	100~400	3~100	5~ 30	90	~ 1.0
	04. Aviles	100~200	5~ 20	3~ 25	30	~ 0.8
	05. Mendez	100~200	5~ 60	15~ 20	30	~ 0.8
	06. Burnet O'connor	100~300	5~150	15~ 30	50	~ 1.0
7. SANTA CRUZ	01. Andes Ibanez	100~300	5~120	10~ 40	35.5	1.02~ 1.2
	02. Warnes	100~200	5~ 30	15~ 40	30	~ 1.2
	03. Velasco	50~100	10~ 50	3~ 20	50	~ 0.8
	04. Ichilo	100~200	5~ 50	10~ 25	30	~ 0.8
	05. Chuquitos	50~300	5~ 50	3~ 45	90	0.03~ 1.5
	06. Sarah	100~200	5~ 30	3~ 20	50	~ 0.8
	07. Cordillera	50~350	5~150	3~ 40	90	~ 1.2
	08. Valle Grande	100~300	5~ 70	15~ 30	50	~ 1.0
	09. Florida	100~300	5~ 70	10~ 40	50	~ 1.2
	10. O. Antiesteban	50~200	5~ 30	5~ 30	50	~ 1.0
	11. Nuflo de Chaves	50~200	5~ 30	5~ 30	90	~ 1.0
	12. Angel Sandoval	100~200	5~ 40	3~ 45	50	~ 1.5
	13. Manuel Ceballero	100~200	5~ 60	15~ 30	50	~ 1.0
	14. German Bushu	100~200	5~ 60	3~ 25	30	~ 0.8
	15. Guarayos	50~200	5~ 20	3~ 25	30	~ 0.8

4.3.3 Conditions for Groundwater Development

The technical conditions and themes for promoting groundwater development in Bolivia in the future can be summarized as follows.

1) Procurement of Well Drilling Equipment

Due to the low amount of equipment owned by public agencies, the well drilling in Bolivia have been carried out through hand digging and commissioned work using equipment owned by private enterprises. However, due to the well drilling by private enterprises being high in cost and because of the obsolescence and poor performance of publicly-owned equipment, groundwater development has been delayed.

Drilling equipment capable of deep drilling and with excellent performance are necessary in order to promote groundwater development in the future. The drilling equipment must be able to accommodate for the various geological features of the Study Areas and must be excellent in terms of mobility.

2) Improvement of Well Drilling Skills

Although well drilling has been mainly carried out by the private sector, much of it is dependent solely on experience and there are many enterprises which lack the fundamental know-how of drilling techniques and are low in management ability. Education of engineers is also inadequate and the spreading of the newest drilling technologies is delayed.

Experience in deep well drilling is lacking in particular and guidance and training of engineers on the operation methods of well drilling equipment, methods of formulating drilling work plans, equipment repairing skills, work management skills, logging, pumping test, and water quality test methods, etc. are needed. In order to acquire drilling skills, it is desirable to carry out cooperative work with engineers of advanced nations.

3) Spreading of Groundwater Prospecting Techniques

Data on the hydrogeological structures and groundwater flow conditions in Bolivia have not been accumulated adequately. In order to improve the rate of success of well drilling, preparatory studies by hydrogeological investigation, geophysical prospecting, etc. must be carried out in detail and it is important to spread groundwater prospecting techniques.

4) Spreading of Groundwater Conservation Measures

Groundwater is a valuable resource and in order to enable sustained groundwater utilization, residents must be encouraged and educated to prevent groundwater pollution and wasteful pumping, and measures, such as the furnishing of systems for monitoring the yields, water level, and water quality and the regulation of non-systematic groundwater development, must be taken.

CHAPTER 5 REGIONAL GROUNDWATER DEVELOPMENT STRATEGIES

5.1 Objectives and Basic Concepts

5.1.1 Objectives

The objectives of the groundwater development project are to develop new water resources for providing inhabitants of rural communities in five Departments of the Study Area with stable supplies of safe and sanitary drinking water at appropriate prices and to thereby improve and expand the current status of water supply services. The development strategies are aimed at arranging the conditions for early realization of the project and for formulating the basic policies.

These development strategies shall be formulated as plans of highest priority which are anticipated to be carried out as soon as possible in order to resolve the shortage of water in the rural areas of Bolivia.

5.1.2 Basic Concepts

The development strategies are formulated on the basis of the following basic concepts.

1) Stable Supply of Domestic Water to Rural Areas

A large difference in the supply of domestic water exists between urban areas and rural areas in the Bolivia. In the regional rural areas, the water supply coverage is extremely low and there is a serious shortage of water. An overwhelming number of communities completely lack water supply systems and the furnishing of water supply services is an urgent theme.

While the water demand in rural areas mainly consist of domestic water and agricultural water, at least drinking water and domestic water must be supplied in a stable manner to all inhabitants of the communities, and water supply system should be furnished with top priority.

2) Promotion of Groundwater Development

The greatest cause of the delay in water supply services in Bolivia is the difficulty of water source development. Although development of water sources based on surface water and shallow wells have been carried out from the past, adequate water quantities cannot be obtained and there are also many problems in terms of water quality. Furthermore, even in areas with an existing water supply system, the water source dries up in the dry season in many cases.

Water sources can largely be divided into surface water, such as river and lake water, and groundwater such as well water and spring water. As can be seen from the comparison of groundwater, river water, and lake water shown in Table 5-1-1, groundwater is generally stable in temperature and quality is good relatively. Furthermore, groundwater is suited as a water source for small-scale water supply systems since groundwater can be pumped up near the points of demand. Especially, deep groundwater is suited as a water source since it is stable in terms of quantity and presents a high development potential even in dry regions, such as the Study Area, where precipitation is low and water source is scarce.

Despite being high in development potential, the development of deep groundwater in the Study Area is delayed due to the lack of equipment, resources, and skills. The groundwater development should therefore be promoted actively as sources of domestic water.

3) Early Realization of the Project

There is an urgent need to furnish water supply services for rural communities and short-term, concentrated investments should be made to enable early execution of the groundwater development project, upon making adjustments among relevant domestic agencies, international cooperation, and NGO's. Effective and well-organized international cooperation should be promoted for the procurement of equipment, technology, and funds that are lacking in Bolivia to ensure the effectiveness of the project. Also, fortification of the project implementing organization and system, as well as technical improvement should be carried forth to promote the continuation of the project.

In executing the project, priority should be placed on impoverished regions with a high degree of necessity while taking into consideration the potential for groundwater development, investment efficiency, and sustainability of operation and maintenance.

4) Sustainability of Water Supply Systems

The operation and maintenance of water supply systems shall basically be carried out through self-management by beneficiary communities. In many cases in medium and small communities, the water supply systems are not provided with adequate maintenance and are abandoned even after a short time of operation. Therefore, operation and maintenance education and sanitation education, as well as guidance for the establishment of a self-management organization, should be provided to enhance the self-help abilities of the beneficiary communities. Efforts should also be made towards establishing a support system.

Also, in the construction of water supply systems, the adoption of appropriate technologies that match the operation and maintenance capabilities of communities and the participation of inhabitants should be promoted.

5) Conservation and Optimal Utilization of Groundwater Resources

In view of the conservation of groundwater resources, groundwater development shall be performed in a manner which will not destroy the water balance of groundwater basins and which will enable stable and long-term groundwater development.

Table 5-1-1 Comparison of Various Water Sources for Water Systems

	Groundwater	River Water	Lake Water
Water quantity	Nearly constant. Generally difficult to increase artificially in a short time.	Varies greatly with the seasons. Some level of artificial adjustment is possible through water source recharging forests, dam construction, etc.	Relatively stable. The amount of discharge (intake) can be adjusted in the case of dam lakes. Recharging of water sources in the collection area is essential.
Water temperature	Constant all year round.	Varies in accompaniment with the air temperature.	Varies in accompaniment with the air temperature at the surface layer. Differs at the lower layer.
Turbidity	Extremely low.	High. Exhibits large, temporary variations due to rainfall, etc.	High during flooding. Some turbidity is caused by living organisms.
Dissolved salts	Generally high in quantity. Tends to be hard water.	Relatively low.	Relatively low.
Influence of pollution	Usually tends to be unaffected with the exception of some substances. However, recovery is extremely difficult once the water is polluted.	Tends to be polluted easily. Both polluting substances and pollution levels may vary widely and an advanced ability to counteract is necessary.	Tends to receive pollution due to eutrophication. Recovery is extremely difficult once eutrophication occurs.
Others	Excessive drawing of water may lead to land subsidence and entry of salt water.	Drying up of spring water and loss of self-purification capacity due to river modification, etc. Intake of water discharged upstream at the downstream side through repeated use of river water.	Problems caused by living organisms tend to occur. Dilemma between the development of tourism and the conservation of water quality in the region.

5.2 Targets

5.2.1 Target Year

The target year for the development strategies shall be set to the year 2000. The term of the project has been set to five years, from 1996 to 2000.

5.2.2 Target Water Supply Coverage

The target water supply coverages for the year 2000 have been set for the urban area and rural area of each Department as shown in Table 5-2-1. These target coverages were established after examined the feasible scale of the project of well drilling and construction works for five years, as described in Section 5.3.2. It was supposed that in urban area and in cities whose present water supply coverage is over 60%, the present water supply coverages will maintain in the same level continuously to the target year.

Table 5-2-1 Target Water Supply Coverage (%)

Department	Present Water Supply Coverage			Target Water Supply Coverage		
	Urban Area	Rural Area	Total	Urban Area	Rural Area	Total
Chuquisaca	88.5	16.4	19.6	90	30	33
South of La Paz	26.0	16.4	17.0	80	30	34
Oruro	63.3	21.3	33.0	80	40	51
Tarija	88.8	36.8	54.8	90	50	65
Santa Cruz	83.8	26.4	51.5	90	40	62
Study Area	81.7	23.3	40.5	89	38	54

5.2.3 Water Supply Service Targets

All households in the water supply districts shall receive water supply service over eight hours a day throughout the year, regardless of the rainy and dry seasons, or be accessible to such water supply points with a distance within 250 meters approximately.

The levels of water supply service are classified into three levels; namely Level 1 (point source), Level 2 (public faucet), and Level 3 (house-to-house connection). As a rule, house-to-house water supplies shall be furnished in concentrated-population type communities and public faucets shall be furnished in dispersed-population type communities. While this strategy focuses on the planning of water supply facilities up to the main distribution pipe, other facilities should be constructed in accordance with the actual conditions of the communities.

5.2.4 Water Quality Targets

The water quality for domestic use should be accorded with the following conditions.

① Not contain organisms or substances contaminated by pathogenic organisms.

② Not contain hazardous substances which may affect the protection of human health.

③ Not contain more than allowable amounts of hazardous substances that may cause problems for domestic water use.

④ Not exhibit unusual acidity or alkalinity.

⑤ Not have any unusual odors or taste.

⑥ Be substantially colorless and transparent in appearance.

The quality of the water to be targeted in the development should comply with the Drinking Water Quality Standards in Bolivia. Disinfecting and filtration equipment shall be provided in cases where the standards are not complied with and the water containing hazardous substances that may affect human health shall not be used as a water source for drinking water.

5.3 Approaches to the Strategies

5.3.1 Building up of the Water Supply Database

The groundwater development plan must be planned upon performing field studies on the current status of water demand and supply, groundwater development potential, existence of alternative water sources, topography, geology, meteorology, etc. to ascertain the actual conditions in each water supply block. However, since the Study Area is vast and contains 4,265 water supply blocks, a water supply database was built up to compile these data, and the groundwater development strategies was formulated on the basis of this water supply database.

5.3.2 Classification of Water Supply Blocks

1) Objectives and Concepts

In order to determine the targets, the development priorities, and to formulate the development strategies, it needs to estimate the quantity of facility and equipment, and calculate the project cost required to achieve the targets.

In the strategy formulation process, the water supply blocks were classified using the water supply database, and the project cost was estimated upon determining the standard specifications of water supply facilities and equipments for each classified package. Case studies on the planning targets and development priorities were then performed to examine the appropriate project scale, project strategy, project form, etc.

In the implementation stage for the groundwater development project, field studies must be carried out in advance to check the actual circumstances of each water supply block.

Since the database is utilized for classification, the items and classes of classification can be changed freely according to the purpose of use once the reliability of the data has been confirmed. The classification may be simplified using a small number of indices in order to grasp the overall trends in outline or items may be added and the classification be made finer in cases where more detailed examination is necessary.

2) Indices of Classification

The following indices, which are the basic data that indicate the characteristics of water supply blocks in terms of the urgency and potential of groundwater development and which are considered to be high in reliability among the data in the database, were set as the classification indices.

① Scale of the water supply block (present population)

② Circumstances of the water supply system (existence of water supply facility and present coverage)

③ Groundwater development potential (existence of aquifer and its estimated depth)

④ Site conditions of the water supply block (topography, geology)

The results of performing classification according to each Department using the above indices are shown in Tables 5-3-1 ~ 5-3-4.

Table 5-3-1 Number of Blocks by Population Scale

Population (persons)	>=2000	1000~ 1999	500~ 999	300~ 499	50~ 299	Total
Chuquisaca	4	11	54	190	964	1,223
South of La Paz	2	7	15	43	695	762
Oruro	8	10	15	50	461	544
Tarija	5	7	28	93	378	511
Santa Cruz	41	34	90	267	793	1,225
Total	60	69	202	643	3,291	4,265

Table 5-3-2 Number of Blocks by Existing System and Present Coverage

Present Coverage	No existing facilities	With existing facilities			Total
	-	1~29%	30~59%	60~100%	
Chuquisaca	959	64	71	129	1,223
South of La Paz	676	24	19	43	762
Oruro	396	57	47	44	544
Tarija	248	38	67	158	511
Santa Cruz	810	129	65	221	1,255
Total	3,089	312	269	595	4,265