4.2 Regional Groundwater Development Conditions in the Study Area

1) Groundwater Development Conditions in the Departomento of Chuquisaca

(1) Physiography, Geology, and Aquifers

The Departomento of Chuquisaca is located in the physiographical zones of "Cordillera Oriental", "Seranias Sub-Andinas" and "Llanura Chaco" (Main Report *afterhere written as MR*: MR Figure 4-1-1 and MR Figure 4-1-2).

In the Departomento of Chuquisaca, "Cordillera Oriental" reaches altitudes of 2,000 - 4,000 m and exhibits major distributions of Ordovician, Silurian and Devonian systems from the west to the east, in that order. These systems have been subjected to strong folding activities and the folding axis exihibit a south-north directivity. Part of the syncline axis areas, such as the area around Tarabuco, accompany Cretaceous and Tertiary systems of a small scale.

"Seranias Andinas" reaches altitudes of 1,000 -2,500 m and has distributions of Devonian, Carboniferous, Triassic, Cretaceous and Tertiary systems from the west to the east, in that order. These systems have been subjected to strong folding activities (MR Table 4-1-4 and MR Figure 4-1-5). The Devonian system is distributed on a small scale in only the northwestern part and a large part of the geology is occupied by the Tertiary system and then by the Carboniferous system. The Triassic and Cretaceous systems are found on a small scale between the Tertiary and Carboniferous systems. Parts of the Triassic system have layer-like gypsum sandwiched in between and the groundwater in such Triassic systems may be high in salinity.

"Llanura Chaco" corresponds to being the southern part of "Llanura Chaco-Beniana" and is a bush zone located at altitudes of 200 - 1,000 m. The geology immediately beneath the surface is a Tertiary system in the hills located at the western part of "Llanura Chaco" called the "costa" and is a Quaternary system in the eastern part of this plain called the "llano." From the conditions of the geology in the Departomento of Santa Cruz, it is considered that beds of Carboniferous to Cretaceous systems are distributed below the Quaternary system in the "llano."

The aquifers in "Cordillera Oriental" are of the Quaternary system that fills the valleys and of the Ordovician, Silurian and Devonian systems which comprise the bedrock.

The aquifers in "Seranias Sub-Andinas" are of the Quaternary system that fills the valleys and of the Devonian, Carboniferous, Permian, Cretaceous and Tertiary systems which comprise the bedrock. Among these, the major aquifers are of the Tertiary and Carboniferous systems.

The aquifers in the "costa" region of Llanura Chaco are of the Tertiary system while the major aquifers of the "llano" region are of the Tertiary and Cretaceous systems. Well No. JC-6 and No. JC-7, which were drilled in the present Study, were respectively drilled in the "costa" and "llano" regions.

The above-mentioned Ordovician system is comprised of quartzite, shale and mudstone, the Silurian system of conglomerate, mudstone (diamicitas), sandstone and shale, the Devonian system of sandstone, shale, mudstone, and limestone, the Carboniferous system of conglomerate mudstone, conglomerate, sandstone and shale, the Triassic system of sandstone, limestone and marl, the Cretaceous system of sandstone, conglomerate, siltstone (arcilitas), limestone and marl, the Tertiary system of sandstone, conglomerate, siltstone and gypsum, and the Quaternary system of alluvial sediment, lake-bottom colluvium, sand, mud and clay.

The water systems in the Departomento of Chuquisaca are mainly influenced by a north-south fold axis, such as that seen in "Cordillera Oriental" and "Seranias Sub-Andinas" and can be largely divided by the watersheds that cross this structure obliquely into the "Amazon River System" and the "La Plata River System" (MR Figure 4-1-4). These watersheds are lined in a row which crosses the Departomento of Chuquisaca in the northwest to southeast direction, running parallel to the Pilcomaya river from the north shore to the east shore between "Cordillera Oriental" and "Seranias Sub-Andinas" bending in the ENE direction at the eastern end of "Seranias Sub-Andinas" and then running parallel to the southern boundary of the Departomento of Santa Cruz. The row of watersheds then bends in the NNW direction to cross "Seranias Chiquitanas" and continues to the uppermost stream of the Itenez o Guapor River.

Only the uppermost streams of the "Amazon River System" are located in the Departomento of Chuquisaca and the "Amazon River System" is important as a water system only around Monteagudo ("Seranias Sub-Andinas"). The water systems here continue onto the Parapeti river which enters the Departomento of Santa Cruz from the eastern edge of "Seranias Sub-Andinas" and flow across "Llanura Chaco" in the NE direction.

The other parts of the "Amazon River System" in the Departomento of Chuquisaca continue onto the Rio Grande River and flow in NE direction across the Departomento of Santa Cruz from the eastern edge of "Seranias Sub-Andinas".

The water systems belonging to the "La Plata River System" are mainly influenced by the north-south folding structure and are all tributaries of the Pilcomayo River. The Pilcomayo River is a great river that crosses the Departomento of Chuquisaca from the northeast to the southeast and flows outside the Departomento of Chuqisaca at the eastern edge of "Cordillera Oriental" where it enters the Departomento of Tarija and flows in the southeast direction to "Seranias Sub-Andinas" and then to "Llanura Chaco."

Because of such river conditions, there are no major lakes and rivers in the "Llanura Chaco" region in the Departomento of Chuquisaca.

(2) Quantities of Groundwater Resouces

According to estimations of the water balance in the Departomento of Chuquisaca, the groundwater recharge is 74mm for a mean annual precipitation of 780 mm (MR Figure 4-1-8 and MR Table 4-1-5). This corresponds to a recharge of 3,835,000,000 m^3/yr for the entire Departomento of Chuquisaca and indicates that 8,450 m^3/yr of groundwater can be utilized sustainably per person.

Though the above recharge occurs at the river basins of the Rio Grande River, the Izozog River, the Pilcomayo River, and the Paraguay River, the groundwater recharge is negative at the Rio Grande and Paraguay river basins. On the other hand, the groundwater recharge is large and reaches 235 - 140 mm at the Izozog and Pilcomayo river basins.

(3) Types of Groundwater

In "Cordillera Oriental," "stratum water" exists in the Quaternary system which fills the valleys of the valley areas and "fissure water" exists in the Ordovician, Silurian and Devonian systems which comprise the bedrock.

In "Seranias Sub-Andinas," "stratum water" exists in the Quaternary system which fills the valleys of the valley areas and "fissure water" exists in the Devonian, Carboniferous, Cretaceous and Tertiary systems. Up until now, groundwater development has been mainly carried out on the "stratum water" in the Quaternary system and on the groundwater in the weathered belt of the bedrock.

In the "costa" region of "Llanura Chaco", it is thought that "fissure water" exists in the Tertiary system while in the "llano" region, it is thought that "fissure water" exists in the Tertiary and Cretaceous systems. However, existing data indicate that the majority of wells in these areas have yields of approximately 10 m^3/hr, implying that "stratum water" may also exist in the Tertiary and Cretaceous systems.

Groundwater cannot be expected from the Quaternary system in "Llanura Chaco".

(4) Past Groundwater Development

Past groundwater development activities in the "Cordillera Oriental" zone in the Departomento of Chuquisaca have been concentrated in districts between the Departomento capital of Sucre and Padilla, which corresponds to being the northern part of this Departomento (MR Figure 4-2-1). These districts are lined along the "watersheds" between the "Amazon River System" and the "La Plata River System" and cannot be considered to be favorable for well construction in terms of both drilling depth and groundwater recharge system. This is also apparent from the analytical drawings in the well database (MR Figure 4-2-3).

Besides the above, groundwater development has been carried out in the past in Sud Cinti province located at the boundary between the Departomentos of Chuquisaca and Tarija.

These areas are included in the "belt-like region with a width of 150km in the east-west direction from 'Seranias Sub-Andinas' to 'Llanura Chaco-Beniano' and extending in the north-south direction", where the groundwater development activities in Bolivia have been concentrated. This belt-like region continues from the Departomento of Santa Cruz and extends to "Cordillera Oriental" in the Departomento of Chuquisaca. However, there are no records of groundwater development for the central part of "Cordillera Oriental" located between the abovementioned "watersheds" and Sud Cinti province.

With regard to the "Seranias Sub-Andinas" zone in the Departomento of Chuquisaca, records of groundwater development are extremely few and exist only for Ivo and Santa Rosa in Luis Calvo province. However, this area is part of the "belt-like region with a width of 150km in the east-west direction from 'Seranias Sub-Andinas' to 'Llanura Chaco-Beniano' and extending in the north-south direction".

"Llanuro Chaco" occupies the central and eastern parts of Carandayti in Luis Calvo province. Since there are no major lakes or rivers in this region, as was indicated in the "Physiography, Geology and Aquifers" section, artificial ponds, called "atajado" have served as the water source for humans and livestock. However, when oil prospecting was carried out in this region, it was confirmed that aquifers exists 250-450 m underground and groundwater development plans have been proposed since then.

Due to the capacities of drilling equipment and past economic conditions, the construction of existing wells were generally carried out at a depth range of 20 - 180 m. However, since the major communities of the Departomento of Chuquisaca exist along the "watersheds" of the "Amazon River System" and "La Plata River System", the depths of such wells were inadequate and, as a result, the water levels of wells accompanied seasonal variations and the supply of water tended to be in shortage due to low well yields. Due to such reasons, it is difficult to even formulate well development plans for the Departomento of Chuquisaca and therefore, river water, rain water collected during the rainy season, and water in the atajodos have been used despite sanitation problems in the various regions in the Departomento of Chuquisaca.

(5) Current Problems in Terms of Groundwater Development

The regions which require groundwater development most urgently in the Departomento of Chuquisaca are the communities located along the abovementioned "watersheds" and those located in "Llanura Chaco". However, deep wells with depths of 120-180 m have begun to be constructed in such regions in "Cordillera Oriental" and "Seranias Sub-Andinas". Although the number of such wells is very few, it has been shown that the well yields can be improved by constructing deep wells. It has also been shown from the drilling of deep wells for petroleum development in "Llanura Chaco" that aquifers exist at depths of 250-450 m.

However, as shown below, the drilling equipment owned by the Departomento of Chuquisaca are 1974-1978 models and lack adequate capacities even for the construction of wells of the level of the existing wells. Accessory equipment are also lacking. Furthermore, there are no private well constructors in the Departomento of Chuquisaca and there are problems presently with the private well constructors of the Departomento of Santa Cruz as well.

Although the following drilling equipment exist in the Departomento of Chuquisaca, none of these are operating presently.

Depart.	Name of Organization	Instit. Pub.(A) Priv.(B) Coop.(C)	Number of Equipment	Model of Equipment	TradeMark of Equipment	Type of Drill. (D):rotary (E):percu.	Capacity for Drilling (m)	Efficiency & Diameter of the Depth		Note
								Depth (m)	Diameter	
Chuquisaca	CORDECH	A	1	1974	Failing - 1250	D(1)	200	200	2-7/8" *5	*5: ?
	Dir. Saneam. Ambiental	A	1	1976	Porta Drill	(D)1	200	200	2-7/8"	
Total	-	-	2	-	-	-	-	-	-	

Since the construction cost will be high for deep wells, geophysical prospecting techniques must be exploited to carefully select the well position and to raise the rate of success of wells. Logging must be performed after drilling the well and screens must be set accurately to thereby increase the well yields.

(6) Results of Geophysical Prospecting

The geological structures presumed from the electrical sounding and electromagnetic sounding carried out at Campo Leon and Simbolar in the Departomento of Chuquisaca are consistent with the structures obtained from the construction and logging results of wells constructed in the same districts (JC-6 and JC-7: Figures 4-2-1, 4-2-2).

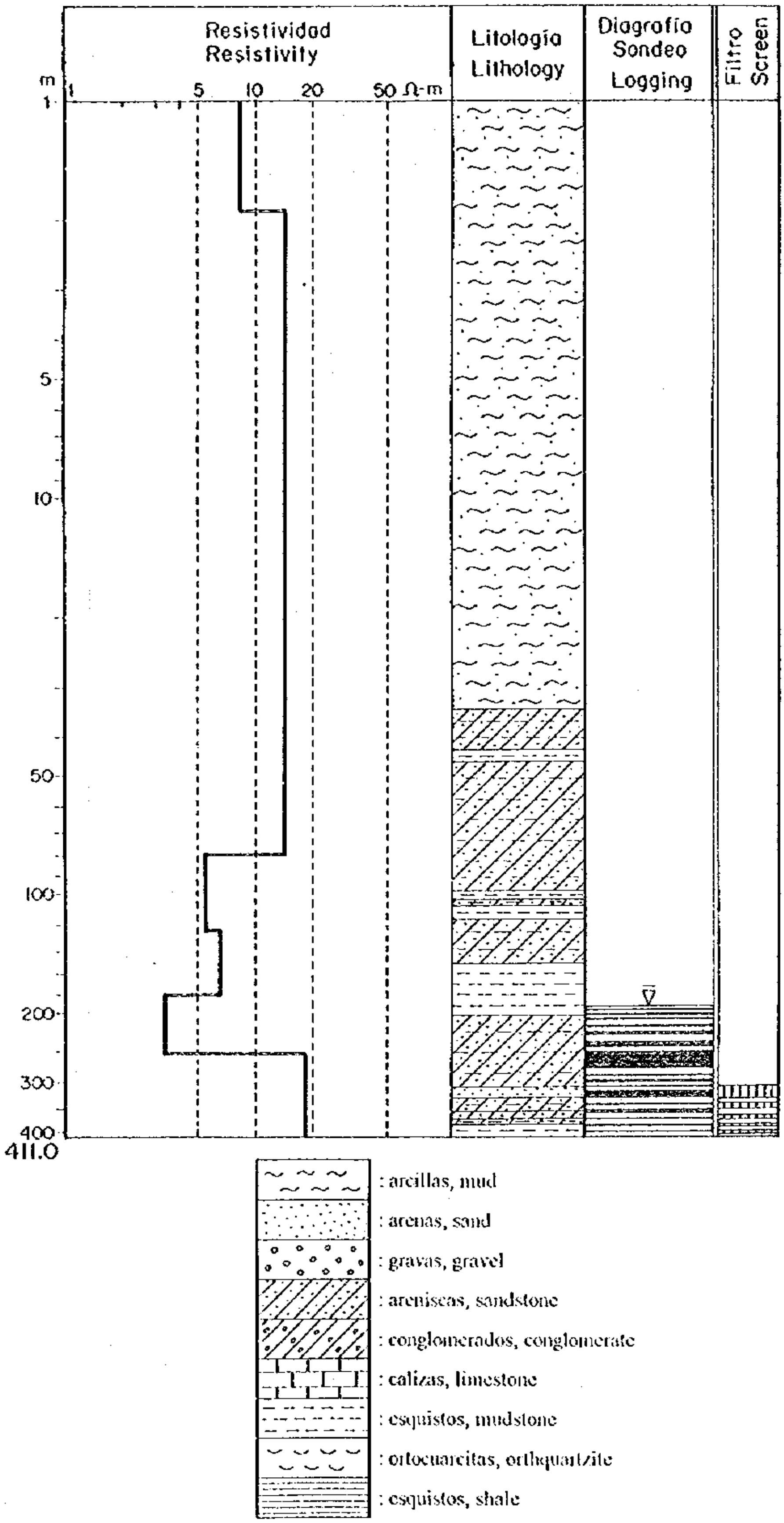


Figura 4-2-1 Relation de Resultados entre Prospeccion Geoficica, Perforacion y Sondeo sobre JC-6

Figure 4-2-1 Relation of Results among Geophysical Prospecting, Drilling and Logging on JC-6

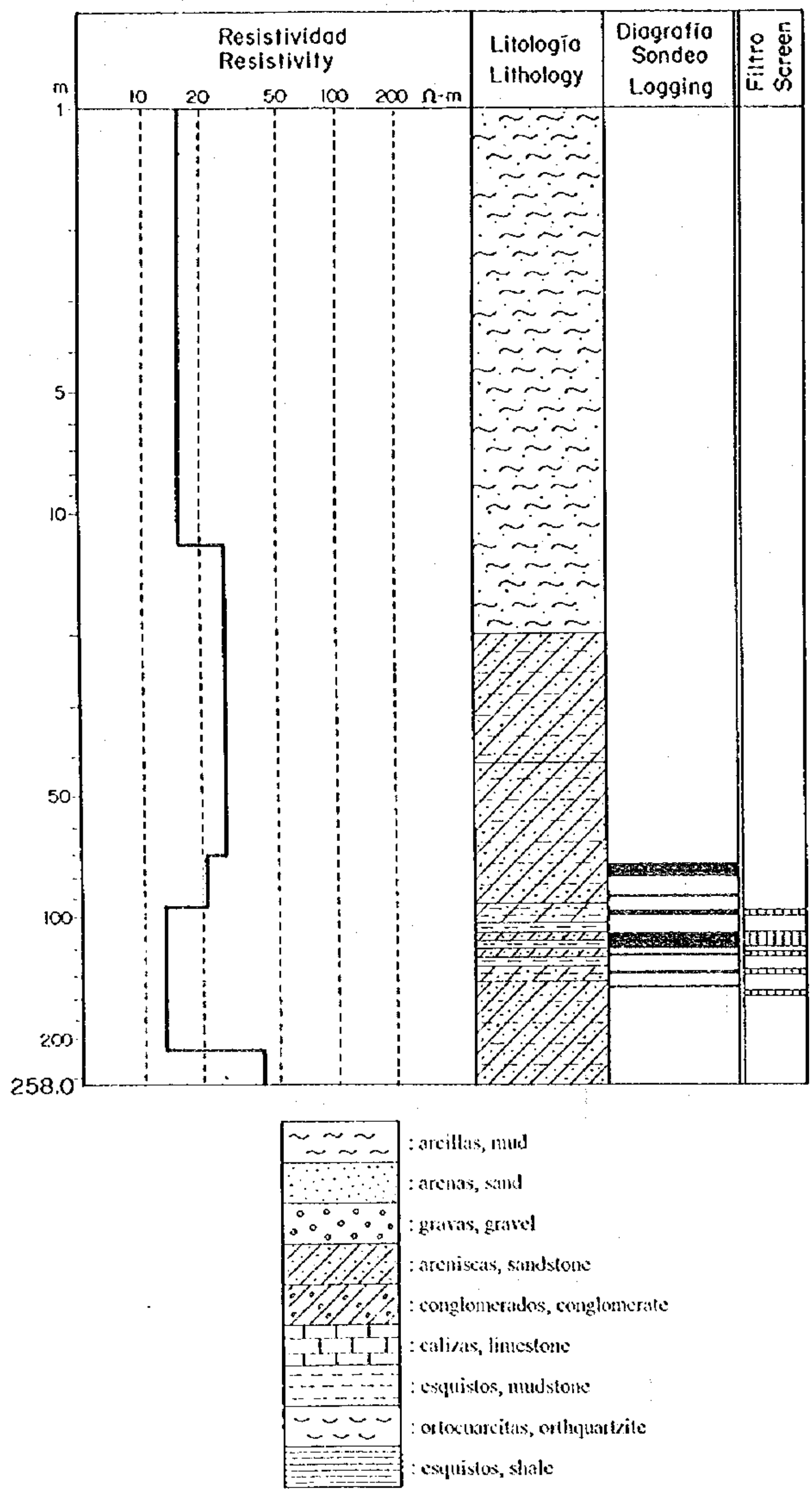


Figura 4-2-2 Relation de Resultados entre Prospeccion Geoficica, Perforacion y Sondeo sobre JC-7

Figure 4-2-2 Relation of Results among Geophysical Prospecting, Drilling and Logging on JC-7

(7) Results of Test Wells

In the Departomento of Chuquisaca, well No. JC-6 was drilled in Campo Leon and well No. JC-7 was drilled in Simbolar (MR Figure 4-1-25).

Campo Leon, where well No. JC-6 was drilled, is located on a hilly mountain range with an altitude of approximately 800 m in the "costa" of "Llanura Chaco." This mountain range is comprised of a Tertiary system that extends in the north-south direction.

The geology at this well is as follows:

0.0 m - 34.0 m:	Quaternary system	: clay, sand with mud
34.0 m - 97.0 m:	Tertiary system	: mudstone with sandstone
97.0 m -103.0 m:	Tertiary system	: sandstone with mudstone
103.0 m -108.0 m:	Tertiary system	: mudstone with sandstone
108.0 m -114.0 m:	Tertiary system	: sandstone with mudstone
114.0 m -190.0 m:	Tertiary system	: mudstone with sandstone
190.0 m -297.0 m:	Tertiary system	: mudstone with sandstone
297.0 m -306.0 m:	Tertiary system	: sandstone with mudstone
306.0 m -328.0 m:	Tertiary system	: **Aquifer** ; mudstone intercalated with sand
328.0 m -340.0 m:	Tertiary system	: mudstone with sandstone
340.0 m -352.0 m:	Tertiary system	: mudstone with sandstone
352.0 m -368.0 m:	Tertiary system	: **Aquifer** ; mudstone intercalated with sand
368.0 m -382.0 m:	Tertiary system	: mudstone with sandstone
382.0 m -386.0 m:	Tertiary system	: **Aquifer** ; mudstone intercalated with sand
386.0 m -394.0 m:	Tertiary system	: mudstone with sandstone
394.0 m -398.0 m:	Tertiary system	: **Aquifer** ; mudstone intercalated with sand
398.0 m -411.0 m:	Tertiary system	: mudstone with sandstone

Simbolar, where well No. JC-7 was drilled, is located east of Campo Leon in the "llano" of "Llanura Chaco". The topography is flat and the altitude is about 570 m. Although the geology of the surface is a Quaternary system, a Cretaceous system is developed below the Quaternary system.

The geology at this well is as follows:

0.0 m - 21.0 m :	Quaternary system	: clay, sand with mud
21.0 m -142.0 m :	Cretaceous system	: alternation of mudstone with sandstone
142.0 m -155.0 m :	Cretaceous system	: **Aquifer** ; mudstone intercalated with sand
155.0 m -258.0 m :	Cretaceous system	: mudstone with sandstone

The conditions of these wells are as follows:

	Block #	a: Diameter of dril. (m)	b: Dep. of Drill (m)	k: Static W.L. (m)	l:Yield (m3/hr)	n:Draw down (m)sw	p:Specific Cap. (m3/day)	q: Transmisivity <T>	r: Hydraulic Cond. <K>	s: Strativity <S>
JC-6	110030309	311.2	411.0	190.0	8.1	92.9	0.09	0.104x10-3 m2/sec.	0.0027x10-3 m/sec.	-
JC-7	110030307	311.2	258.0	139.0	-	-	-	-	-	-

For well No. JC-6, the well depth is 411.0 m, the static water level is 190.0 m, the yield is 8.1 m^3/hr, and the drawdown after 24 hours was 92.9 m. The dynamic water level at this time was 282.9 m, with about 23 m left to the head part of the uppermost screen among the screens that were set at 5 locations.

From the well structure, it is estimated that the pump discharge of well No. JC-6 is limited to about 10 m3/day (3 m^3/hr). The transmissivity was calculated using Jacob's non-equilibrium formula to be 0.104×10^{-3} m^2/sec.

The logging results for well No. JC-7 show a clear geological boundary at a depth of around 155.0 m and an aquifer-like structure above this boundary.

The water level at the time of logging was about 15m and since there was no loss of water upon spreading the well subsequently, screens were set as indicated below with a casing for an extension of 12m being set below the lowermost screen. The bottom of this casing is plugged.

99m - 102m
112m - 121m
125m - 128m
138m - 141m
156m - 159m

However, since the water level dropped thereafter and the static water level stabilized at 139.0 m, the screens were only 5m below the water surface and continuous pumping tests could not be carried out.

Although the geophysical prospecting results and logging results show an "aquifer-like structure" in the Cretaceous system at depths of between 21.0 m - 155.0 m, since the geology is an unsaturated (aerated) zone until a depth of 139m, the above "aquifer-like structure" does not accompany groundwater down to this depth.

The logging results do not show an aquifer structure between depths of 155.0-250.0 m and the logging record patterns show an uniform, lutite pattern and indicate that the geology at these depths comprise an impermeable formation. From the results of geophysical prospecting, it is estimated that this impermeable formation continues to a depth of approximately 310 m. The results also show what can be considered to be an aquifer below the impermeable formation.

(8) Feasibility of Groundwater Development

Within the "belt-like region with a width of 150km in the east-west direction from 'Seranias Sub-Andinas' to 'Llanura Chaco-Beniano' and extending in the north-south direction" in the Departmento of Chuquisaca, groundwater development can be carried out feasibly in the regions along the "watersheds" of the "Amazon River System" and the "La Plata River System" to provide wells with depths similar to those of existing wells and with yields of 1-10 m^3/hr or an average yield of 5 m^3/hr. The yield may be increased to about 15 m3/hr by increasing the well depth. In the central southern part of "Cordillera Oriental," there is a possibility for groundwater development for providing yields of 10 m^3/hr or more with wells of depths similar to those of existing wells.

In the "costa" of Llanura Chaco, the static water level of groundwater is 130.0 - 250.0 m and the yield per well is about 8.0 - 15.0 m^3/hr. However, the yield is considered to be only about 5.0 m^3/hr in general.

Meanwhile in the "llano," although an aquifer-like structure can be seen between depths of 21.0 - 155.0 m, since the zones down to depths of 139 m are unsaturated zones (aerated zones) where groundwater does not exist, drilling depths of 300 - 350 m will be necessary for groundwater development. The static water level of groundwater is predicted to be 130.0 - 140.0 m. From the existing data, it is considered that the yield per well is similar to that in the "costa."

(9) Policy for Future Groundwater Development

MR Figure 4-2-7 shows the provincia-wise criteria for the Departomento of Chuquisaca as considered from a hydrogeological viewpoint. These can be summarized in a general manner as follows.

In terms of well yield and the rate of success, the "belt-like region with a width of 150km in the east-west direction from 'Seranias Sub-Andinas' to 'Llanura Chaco-Beniano' and extending in the north-south direction" is a promising candidate region for groundwater development in the Departomento of Chuquisaca. Within this range, the region from the central part to the southern part of the Departomento is particularly promising. In this region, development must be targeted at the "stratum water" existing near the boundary between the bottom of the Quaternary system and the base rock below it or at the "fissure water" existing in the base rock further below. Drilling depths of about 100 - 150 m will be required.

Due to the hydrogeological structure, wells with depths of about 200 - 250 m are required to secure a yield of 10 m3/hr in groundwater development at regions along the "watersheds" between the "Amazon River System" and the "La Plata River System" at the northern part of this Departomento.

Deep wells with depths of about 450 m and 350 m are basically required for groundwater development in the "costa" and "llano," respectively, of "Llanura Chaco." However, since the geology is rich in muddy matter, the well construction period must be minimized as much as possible to prevent the collapsing of well walls and washing must be performed adequately after the completion of the well. Since the static water level is extremely low, the washing with an air compressor after the completion of the well must be performed while repeatedly injecting water.

From the above, it is concluded that 100 - 450 m class wells must be constructed in the Departomento of Chuquisaca.

The well diameter at the well bottom during drilling should be in the range 10 5/8" - 12 1/4", the diameters of screens and casings should be 6" - 8 5/8", and the ratio of the length of the screen to the drilling length should be 15%-30%. In order to obtain a high well yield, the screens or casings must be inserted to the bottom of the well.

In regions where the groundwater at shallow underground locations are high in salinity, the filling from the depth of the aquifer accompanying groundwater of high salinity to the surface should be performed not with gravel but with a clayish substance or cement, etc. to prevent the intake of groundwater of high salinity at the upper levels. Salt-resistant cement will be required in such a case and this requirement also applies to the bentonite to be used for well drilling. Furthermore, the conductivity of the circulating water during well drilling should be measured or so-called "well-logging" should be performed to determine the depth at which clayish substance/cement filling is to be performed.

In order to raise the rate of success of future wells, the investigation records before and after well construction should be incorporated into the database successively and arranged and classified in diagrams designated for the purpose to nurture personnel and techniques for utilizing such data.

(10) Requirements for Future Groundwater Development

For the groundwater development in the Departomento of Chuquisaca, geological structure analysis and geophysical prospecting must be carried out to grasp the geological structure of the area around a well before constructing the well in order to raise the rate of success of wells. For this purpose, the necessary personnel must be secured. Office equipment for arranging various data, aerial photographs, geophysical prospecting equipment, and a station wagon, pickup truck, etc. for providing mobility for the prospecting team are also needed.

In groundwater development, electrical sounding methods are generally used to grasp the aquifer structure at 200 - 250 m below the surface. On the other hand, electromagnetic sounding or gravity prospecting methods are effective for grasping base structures below 250 m.

While trees must be cleared to provide a long traverse line for measurements in the case of electromagnetic sounding, such clearing is hardly required in the case of gravity prospecting. Gravity prospecting is therefore preferred over electromagnetic sounding in the "chaco" regions where the vegetation is dense and in mountainous areas with steep landforms. Gravity prospecting is also more preferable in cases where shallow underground locations accompany groundwater of high salinity.

The drilling of wells require personnel for drilling and drilling equipment that can tolerate the drilling of 100 - 450 m class wells. 500 - 600 m class drilling equipment will thus be necessary to provide leeway in the capacity of the equipment.

For drilling equipment, models with functions for the reverse circulation method must be selected to cope with riverbed sediments comprised of unconsolidated or semi-consolidated boulders and boulder gravel. The drilling equipment must also enable rotary and down-the-hole methods for development targeting the "stratum water" in the Quaternary system and the "fissure water" in the hard base rock. A tank lorry for drilling water, an air compressor with adequately high pressure and air volume, and bits of various sizes for rotary and down-the-hole methods will thus be required.

A small tank lorry for fuel, a support truck with crane, a small truck, a station wagon for engineers, workshop vehicles for equipment repairs, etc. are also needed. Communication equipment are also necessary for communication between the well construction site and the office for schedule management.

Each of the above equipment require spare parts. Since the station wagon for engineers will be driven out of necessity at relatively high speeds and over long distances, the wearing of tires and various types of spring systems will be severe. The replenishment of such spare parts will thus be essential.

Logging must be performed to increase the yield of the well. This will require functions for electrical resistivity logging, self-potential logging as well as gamma ray logging, which is effective for detection of parts besides the aquifer. Electronic recording methods are preferred as recording methods. Logging equipment should be operated and maintained by the geophysical prospecting team.

Although steel pipes should be adequate for the casings for final construction of the well, screens must be made of stainless steel as steel screens are weak against corrosion.

Pumping tests must be carried out on completed wells in order to determine the well yields for water supply facility designs and to grasp the hydrogeological characteristics of the aquifer for planning future groundwater development and environmental conservation.

In the pumping test, the pump discharge, the dynamic water level, variations in water quality during pumping (especially the pH and conductivity), etc. should be recorded and water quality analysis should be performed as a final step after the completion of the pumping test. A submerged pump, a generator, instruments for measuring the water level, pH, and conductivity, a water quality analysis set, etc. are needed for this purpose. The capacities of the submerged pump and generator for pumping tests should preferably be adequate for a pump head of 80 - 300 m and a pump discharge of 5 - 40 m^3/hr.

Pumps for production wells will require a submerged pump with a capacity adequate for a pump head of 80 - 300 m and a pump discharge of 5 - 15 m^3/hr.

Safe storage locations of adequate area must be secured and appropriate storage and management methods must be established for the storage of the above-mentioned equipment and materials.

The securing of personnel for operating and managing the above-mentioned equipment and materials is a most important requirement. Personnel for operating the equipment should be secured to enable 24-hour drilling work.

It is preferable to construct a facility that provides the functions of a "machine shop (repair shop)," a "spare parts repository," and a "training center" at the central agency of the Departomento and to gather engineers in the regional areas every few years to such a facility to provide training by engineers of the central agency on the disassembly, repair, etc. of generators, pumps, water supply equipment, etc. and to collect records for groundwater management at each regional area in order to examine matters pertaining to maintenance and management.

2) Groundwater Development Conditions in the Southern Part of the Department of La Paz

(1) Physiography, Geology, and Aquifers

The southern part of the Department of La Paz is situated in the physiographical zones of "Cordillera Occidental," and "Altiplano" (MR Figure 4-1-1 and MR Figure 4-1-2).

"Cordillera Occidental" reaches altitudes of 4,000 - 5,600 m and exhibits distributions of Cretaceous, Tertiary and Quaternary systems and intrusive rocks. The Cretaceous system forms the ridgeline of "Cordillera Occidental". The Tertiary system is distributed at the flanks of "Cordillera Occidental" and the Quaternary system is distributed at the foot of mountains and the topographical lowlands in the mountainous landforms. Intrusive rocks penetrate the Cretaceous and Tertiary systems (MR Table 4-1-4 and MR Figure 4-1-5).

The Altiplano is a plain with a gentle relief at altitudes of about 4,000 m. A small mountain range, which is a few hundred meters in relative height difference, extends in the north-south direction in the eastern part of the Altiplano. A similar mountain range also exists at the central part of the plain. The geology is comprised of Silurian, Tertiary, and Quaternary systems.

The Silurian system forms the "Cordillera Oriental" to the east of the southern part of La Paz as well as the small mountain range in the eastern part of the Altiplano within the southern part of La Paz. The Tertiary system forms the hills in the central part of the Altiplano while the Quaternary system is distributed in the topographical lowlands that occupy the area between these hills.

The aquifers in the "Cordillera Occidental" zones in the southern part of La Paz are of the Quaternary system, which fills the valleys, and of the Cretaceous and Tertiary systems. which comprise the bedrock.

The aquifers in the "Altiplano" zone in the southern part of La Paz are of the Silurian, Tertiary, and Quaternary systems.

The above-mentioned Silurian system is comprised of diamictite (diamicitas), sandstone, limestone, slate, mudstone (limolitas), etc., the Cretaceous system of sandstone, conglomerate, siltstone (arcilitas), limestone and marl, the Tertiary system of sandstone, conglomerate, siltstone and gypsum, and the Quaternary system of alluvial sediment, colluvial, sand, mud and clay. The intrusive rocks are granitic rocks of the Tertiary system.

The river systems in the southern part of La Paz are comprised by the Desuaguadero River, which flows south from Lake Titicaca, and the tributaries of said river which originate in the slopes of "Cordillera Occidental" and "Cordillera Oriental." These river systems are closed river systems having Lake Popoo in the Department of Oruro as the low position and the river waters evaporate upon reaching Lake Popoo.

(2) Quantities of Groundwater Resouces

According to estimations of the water balance in the southern part of the Department of La Paz, the groundwater recharge is -59 mm for a mean annual precipitation of 353 mm. This result is due to the use of a formula arranged from a formula that was originally intended for estimating the quantity of "surface water" as the resource quantity. The estimation result was therefore uninfluenced by the formula term relevant to groundwater flow and strongly influenced by the severe evapotranspiration at the surface and shallow underground locations. Although the presently available data do not enable estimation of the quantity of groundwater resources in which even the groundwater flow is considered, the above groundwater recharge will be more favorable if the spring water ("fissure water") in the "vertientes", which are distributed in several locations of the Altiplano, are taken into consideration as groundwater flow.

The scale of the quantity of spring water from such "vertientes" can be estimated from the "vertiente" in the "Isle of the Sun," located in the middle of Lake Titicaca. This "vertiente" is located 50 - 60 m above the lake surface and the yield thereof is said to be 1,000,000 m^3/yr. This yield indicates that 8 m^3/yr of groundwater can be utilized per person sustainably in the entire southern part of the Department of La Paz.

(3) Types of Groundwater

In the southern part of the Department of La Paz, "stratum water" exists in the Quaternary system and "fissure water" exists in the bedrock below the Quaternary system.

The silt, sand, gravel, etc., that comprise the Quaternary system in the southern part of La Paz, consist of glacial drifts, river bottom sediments, etc. Due to such characteristics of the facies of the Quaternary system and due to this formation being stratified, the Quaternary system tends to receive the groundwater recharge from the rivers. The Quaternary system thus comprises aquifers of "stratum water" type groundwater at the shores of rivers with abundant freshwater at the foot of mountains.

Welded tuff, tuff and lava are intercalated in the Tertiary system in the southern part of La Paz. In general, "tuff" of low consolidation tends to be intercalated in the welded tuff and such "tuff" tends to accompany "stratum water" type groundwater. Welded tuff are mainly distributed in "Cordillera Occidental."

Also, even in formations accompanying "fissure water" type tgroundwater, the groundwater flows in a "stratum water"-like manner at parts where open "fissures" develop in a network-like manner at the weathered parts and the shallow underground locations of such formations.

Of the Silurian system distributed in the southern part of La Paz, the limestone parts accompany springs at the slopes of mountains called "verientes." These are springs from which "fissure water" type groundwater springs forth.

Furthermore, "fissures," which accompany "fissure water" type groundwater are developed generally in the welded parts of the welded tuff of the Tertiary system.

Although "stratum water" and "fissure water" do exist in the southern part of La Paz as described above, in the plain regions of the Altiplano, the "stratum water" at shallow underground locations of the Quaternary system is generally high in salinity due to the low mean annual precipitation and the severe evapotranspiration. Also, the river water of the Desuaguadero River, which flows in the plain regions of the Altiplano, tend to be high in salinity from the source onwards. The stratum water in the Quaternary system at the shores of the Desuaguadero River also tends to be high in salinity. Therefore, in carrying out groundwater development aiming at the Quaternary system of the Altiplano, care must be taken to avoid groundwater development of shallow underground locations and aquifers should be secured at levels higher than the water level of the Desuagudero River at the shores of this river.

(4) Past Groundwater Development

Due to the capacities of drilling equipment and past economic conditions, the groundwater developments that were carried out in the past in the southern part of the Department of La Paz were carried out to depth ranges of 5 - 70 m in the eastern parts and the "Cordillera Occidental" zone of the southern part of this Department. Hand-dug wells are especially numerous in Gualberto Villarroel province. These wells are extremely shallow in static water level and the groundwater is polluted with organic matter.

At the above-mentioned wells, "stratum water" or "stratum water" type groundwater fre obtained from the weathered parts of the Quaternary system in the eastern parts of the southern part of La Paz and from the weathered parts of the Silurian system in the "Cordillera Occidental" zone.

(5) Current Problems in Terms of Groundwater Development

The majority of wells that have been constructed in the past in the southern part of the Department of La Paz are 50 m or less in depth though a few wells of the 60 - 70 m class have been constructed recently. The yields of existing wells are therefore low and the construction of 100 - 250 m class wells, which reach the "fissure water" existing the below the Quaternary system, is desired.

However, as shown below, the drilling equipment owned by the Department of La Paz are old and lack adequate capacities even for the construction of wells of the same level as the existing wells. Accessory equipment are also lacking. Furthermore, there are no private well constructors in the Department of La Paz and there are problems presently with the GEOBOL of the Department of Cochabamba and the private well constructors of the Department of Santa Cruz as well.

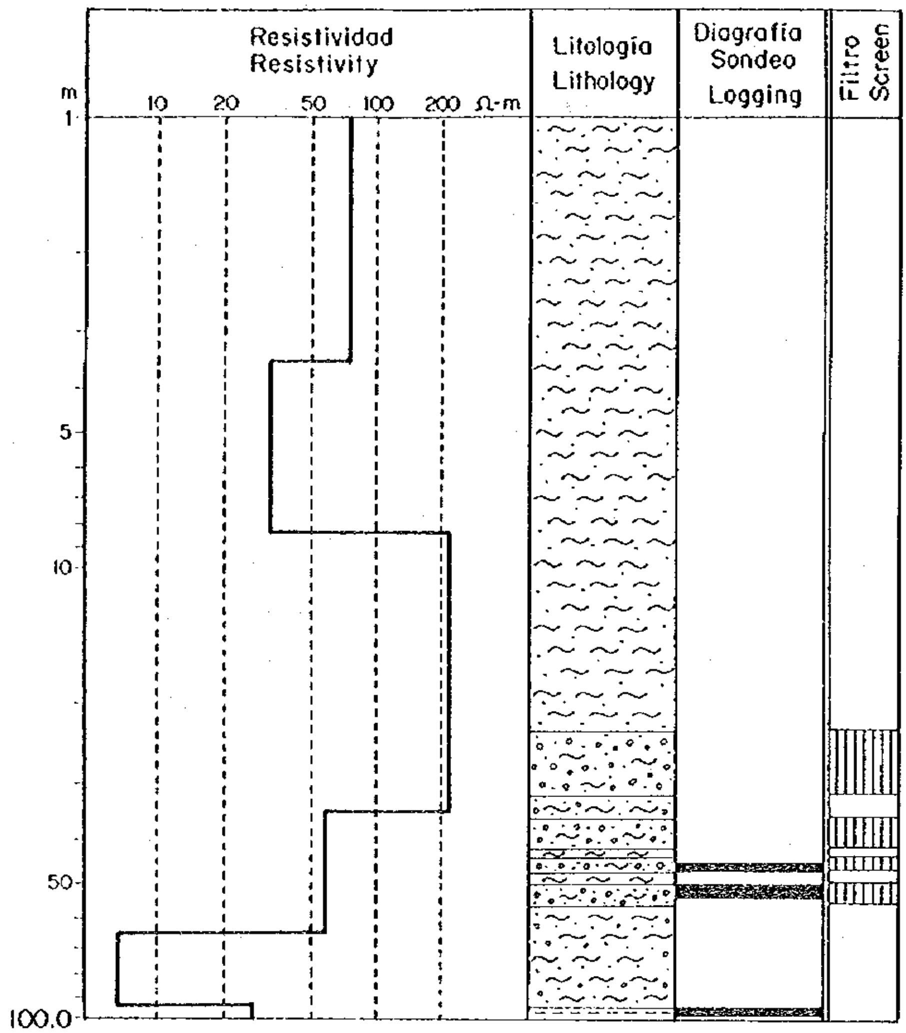
Although the following drilling equipment exist in the Department of Chuquisaca, 20 - 40 years have passed since these were manufactured.

Since the construction cost will be high for deep wells, geophysical prospecting techniques must be exploited to carefully select the well position and to raise the rate of success of wells. Logging must be performed after drilling the well and the setting positions of screens must be determined accurately in order to increase the well yields.

(6) Results of Geophysical Prospecting

The aquifer structure presumed from the analysis of the results of electrical sounding carried out at Patacamaya in the southern part of the Department of La Paz is consistent with the structure determined from the construction and logging results of a test well (JC-1) (Figure 4-2-3).

However, the structure determined from the results of electrical sounding carried out by local geophysical prospectors prior to the present Study differ from the structure determined from the construction and logging results of well No. JC-1. It is thus considered that there is room for improvement in the dry-condition measurement and analysis techniques used by the geophysical prospectors of Bolivia.



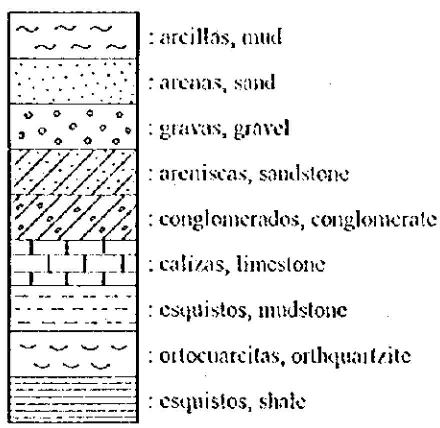


Figura 4-2-3 Relation de Resultados entre Prospeccion Geoficica, Perforacion y Sondeo sobre JC-1

Figure 4-2-3 Relation of Results among Geophysical Prospecting, Drilling and Logging on JC-1

(7) Results of Test Wells

In the southern part of the Department of La Paz, well No. JC-1 was drilled in Patacamaya, which is located in the eastern part of this study area (MR Figure 4-1-25).

Patacamaya, where well No. JC-1 was drilled, is located at the eastern rim of the Altiplano and is a town that is built on the fan or glacial drift comprised of Quaternary gravel supplied from "Cordillera Oriental." The altitude here is 3,800 m.

The geology at this well is as follows:

0.0 m - 23.0 m: Quaternary system	: clay, sand with mud
23.0 m - 53.0 m: Quaternary system	: Aquifer ; mud and sand with gravel
53.0 m - 63.0 m: Quaternary system	: clay, mud, sand
63.0 m - 70.0 m: Quaternary system	: clay and mud with sand and gravel
70.0 m - 77.0 m: Quaternary system	: clay and mud with sand
77.0 m - 79.0 m: Quaternary system	: clay and mud with sand and gravel
79.0 m - 85.0 m: Quaternary system	: clay and mud with sand
85.0 m - 86.0 m: Quaternary system	: clay and mud with sand and gravel
86.0 m - 95.0 m: Quaternary system	: clay and mud with sand
95.0 m -100.0 m: Silrian system	: mudstone with sandstone

The conditions of this well are as follows:

Table 4.2.1 Hydraulic Constants

	Block No.	a: Diameter of dril. (m)	b: Dep. of Drill (m)	k: Static W.L. (m)	l:Yield (m3/hr)	n:Draw down (m)sw	p:Specific Cap. (m3/day)	q: Transmisivity <T>	r: Hydraulic Cond. <K>	s: Strativity <S>
JC-1	213003401	216.0	100.0	13.7	14.4	13.8	1.0	0.463×10^{-3} m^2/sec.	0.0027×10^{-3} m/sec.	$\times 10^{-2}$

For well No. JC-1, the drawdown after 48 hours was approximately 13.8 m for a well depth of 100 m, a static water level of 13.4 m, and a pump discharge of 14.4 m^3/hr. The dynamic water level at this time was 28.2 m and was about 5 m below the head part of the uppermost screen among the screens that were set at 4 locations. From these conditions and the well structure, it is estimated that the pump discharge of well No. JC-1 is limited to about 330 m^3/day (14 m^3/hr).

The transmissivity was calculated using Jacob's non-equilibrium formula to be 0.463 x 10^{-3} m^2/sec.

(8) Feasibility of Groundwater Development

Although the groundwater in the Quaternary system distributed in the plain regions of the Altiplano generally tends to be high in salinity, the "stratum water" in the Quaternary system is low in salinity at the small mountain range in the eastern part of the Altiplano and at the foot of mountains of "Cordillera Occidental." Groundwater development aimed at such "stratum water" is highly feasible.

Furthermore, in the above-mentioned regions, "fissure water" type groundwater exists in the Silurian system distributed below the Quaternary system (small mountain range in the eastern part of the Altiplano) and in the Tertiary system distributed below the Quaternary system (Cordillera Occidental).

The test well (JC-1) for the southern part of the Department of La Paz was drilled for the purpose of checking the groundwater development feasibility in such regions and it has thereby been confirmed that groundwater development for providing yields of 13 - 14 m^3/hour is possible at the foot of mountains of the small mountain range in the eastern part of the Altiplano.

(9) Policy for Future Groundwater Development

MR Figure 4-2-7 shows the provincia-wise criteria for the southern part of the Department of La Paz as considered from a hydrogeological viewpoint. These can be summarized in a general manner as follows.

For the groundwater development in the southern part of the Department of La Paz, priority should be placed on aiming at the "stratum water" in the Quaternary system distributed in the foot of mountains of the small mountain range at the eastern part of the Altiplano and in the foot of mountains of "Cordillera Occidental." Among these regions, the foot of the mountains in the small mountain range in the eastern part of the Altiplano should be given top priority in view of the access to the groundwater development site and the groundwater recharge system. The well database analysis results also indicate that the above region should be given top priority (MR Figure 4-2-7).

The foot of hills, located centrally in the east-west direction in the Altiplano and comprised of the Tertiary system, can be considered as a region similar to the foot of mountains of the small mountain range in the eastern part of the Altiplano and of "Cordillera Occidental." "Stratum water" of good water quality exists at the bottom of the Quaternary layer in this region since it is separated from the Desuaguadero river basin and because of the groundwater recharge system in this region.

In general, the wells constructed in the Quaternary system of the Altiplano tend to receive seasonal effects and have unstable yields. Thus, in carrying out groundwater development in the Altiplano, wells that penetrate through the Quatenary system and reach the Silurian or Tertiary system must be constructed to obtain not only the "stratum water" in the Quaternary system but also the "fissure water" in the bedrock at the same time.

In the plain regions of the Altiplano, the "fissure water" in the bedrock must be obtained not only in terms of the well yield but also in terms of water quality. For example, although the "stratum water" at shallow underground locations in the Quaternary system of the plain regions of the Altiplano is high in salinity, "fissure water" of good water quality has been obtained from the Tertiary system below the Quaternary system as shown by the results of well No. JC-1.

From the above, it is concluded that 100 - 250 m class wells must be constructed in the southern part of the Department of La Paz.

The well diameter at the well bottom during drilling should be in the range 10 5/8" - 12 1/4", the diameters of screens and casings should be 6" - 8 5/8", and the ratio of the length of the screen to the drilling length should be approximately 15% - 30%. In order to obtain a high well yield, the screens or casings must be inserted dwon to the bottom of the well.

In the flat regions located centrally in the east-west direction in the Altiplano, the filling from the depth of the aquifer accompanying groundwater of high salinity to the surface should be performed not with gravel but with a clayish substance or cement, etc. in order to prevent the intake of groundwater of high salinity in the Quaternary system. Since the filled parts accompany groundwater of high salinity, salt-resistant cement will be required. This requirement also applies to the bentonite to be used during well drilling. Furthermore, the conductivity of the circulating water during well drilling should be measured or so-called "well-logging" should be performed to determine the depth at which clayish substance/cement filling is to be performed.

(10) Requirements for Future Groundwater Development

For the groundwater development in the southern part of the Department of La Paz, geological structure analysis and geophysical prospecting must be carried out to grasp the geological structure of the surrounding area before constructing a well in order to raise the rate of success of the well. For this purpose, the necessary personnel must be secured. Office equipment for arranging various data, aerial photographs, geophysical prospecting equipment, and a station wagon, pickup truck, etc. for providing mobility for the prospecting team will also be needed.

In groundwater development, electrical sounding methods are generally used to grasp the aquifer structure at 200 - 250 m below the surface. On the other hand, electromagnetic sounding or gravity prospecting methods are effective for grasping base structures below 250 m.

While trees must be cleared to provide a long traverse line for measurements in the case of electromagnetic sounding, such clearing is hardly required in the case of gravity prospecting. Gravity prospecting is therefore preferred over electromagnetic sounding in regions where the vegetation is dense and in mountainous areas with steep landforms. Gravity prospecting is also more preferable in cases where shallow underground locations accompany groundwater of high salinity.

The drilling of wells require personnel for drilling and drilling equipment that can tolerate the drilling of 100 - 250 m class wells. 350 - 400 m class drilling equipment will thus be necessary to provide leeway in the capacity of the equipment.

For the drilling equipment, models with functions for the reverse circulation method must be selected to cope with riverbed sediments comprised of unconsolidated or semi-consolidated boulders and boulder gravel. The drilling equipment must also enable rotary and down-the-hole methods for development targeting the "stratum water" in the Quaternary system and the "fissure water" in the hard bedrock. A tank lorry for drilling water, an air compressor with adequately high pressure and air volume, and bits of various sizes for rotary and down-the-hole methods will thus be required.

A small tank lorry for fuel, a support truck with crane, a small truck, a station wagon for engineers, workshop vehicles for equipment repairs, etc. are also needed. Communication equipment are also necessary for communication between the well construction site and the office for schedule management.

Each of the above equipment require spare parts. Since the station wagon for engineers will be driven out of necessity at relatively high speeds and over long distances, the wearing of tires and various types of spring systems will be severe. The replenishment of such spare parts will thus be essential.

Logging must be performed to increase the yield of the well. This will require functions for electrical resistivity logging, self-potential logging as well as gamma ray logging, which is effective for detection of parts besides the aquifer. Electronic recording methods are preferred as recording methods. Logging equipment should be operated and maintained by the geophysical prospecting team.

Although steel pipes should be adequate for the casings for final construction of the well, screens must be made of stainless steel as steel screens are weak against corrosion.

Pumping tests must be carried out on completed wells in order to determine the well yields for water supply facility designs and to grasp the hydrogeological characteristics of the aquifer for planning future groundwater development and environmental conservation.

In the pumping test, the pump discharge, the dynamic water level, variations in water quality during pumping (especially the pH and conductivity), etc. should be recorded and water quality analysis should be performed as a final step after the completion of the pumping test. A submerged pump, a generator, instruments for measuring the water level, pH, and conductivity, a water quality analysis set, etc. are needed for this purpose. The capacities of the submerged pump and generator for pumping tests should preferably be adequate for a pump head of 80 - 200 m and a pump discharge of 5 - 40 m^3/hr.

Pumps for production wells will require a submerged pump with a capacity adequate for a pump head of 80 - 200 m and a pump discharge of 5 - 15 m^3/hr.

Safe storage locations of adequate area must be secured and appropriate storage and management methods must be established for the storage of the above-mentioned equipment and materials.

The securing of personnel for operating and managing the above-mentioned equipment and materials is a most important requirement. Personnel for operating the equipment should be secured to enable 24-hour drilling work.

It is preferable to construct a facility that provides the functions of a "machine shop (repair shop)," a "spare parts repository," and a "training center" at the central agency of the Department and to gather engineers in the regional areas every few years to such a facility to provide training by engineers of the central agency on the disassembly, repair, etc. of generators, pumps, water supply equipment, etc. and to collect records for groundwater management at each regional area in order to examine matters pertaining to maintenance and management.

3) Groundwater Development Conditions in the Department of Oruro

(1) Physiography, Geology, and Aquifers

The Department of Oruro lies adjacently south of the southern part of the Department of La Paz and is situated in the physiographical zones of "Cordillera Occidental," and "Altiplano" (MR Figure 4-1-1 and MR Figure 4-1-2). Both the topography and climate are similar to those of the southern part of the Department of La Paz.

In the Department of Oruro, "Cordillera Occidental" reaches altitudes of 4,000 - 4,900 m and exhibits distributions of Tertiary and Quaternary systems. The Tertiary system of "Cordillera Occidental" comprise the mountain masses aligned in the north-south direction while the Quaternary system is distributed in topographical lowlands at the foot of mountains of these mountain masses and between these mountain masses (MR Table 4-1-4 amd MR Figure 4-1-5).

In the Department of Oruro, the Altiplano has the topography of an extensive plain at altitudes of about 4,000 m. A small mountain range, which is a few hundred meters in relative height difference, extends in the north-south direction at the eastern part of Altiplano. A similar mountain range also exists at the central part of the plain.

The geology of the Altiplano is comprised of Silurian, Cretaceous, Tertiary, and Quaternary systems and intrusive rocks. The Silurian system forms the "Cordillera Oriental" to the east of the Department of Oruro and a small mountain range that extends parallel to "Cordillera Oriental" within the Department of Oruro. The Cretaceous system is exposed on a small scale as small mountain masses in the extensive plain of the Altiplano and the Tertiary system forms the hills in the central part of the Altiplano. The Quaternary system is distributed in the vast topographical lowlands that occupy the areas between these mountain masses and hills.

The intrusive rocks are covered by the Quaternary system and dot the areas west of Lake Popoo.

The aquifers in the "Cordillera Occidental" zone of the Department of Oruro are of the Quaternary system that fills the valleys and of the Tertiary system which comprises the bedrock.

The aquifers in the "Altiplano" zone of the Department of Oruro are of the Silurian, Tertiary, and Quaternary systems.

The above-mentioned Silurian system is comprised of diamictite(diamicitas), sandstone, limestone, slate, mudstone (limolitas), etc., the Cretaceous system of sandstone, conglomerate, siltstone (arcilitas), limestone, and marl, the Tertiary system of sandstone, conglomerate, siltstone, and gypsum, and the Quaternary system of alluvial sediment, colluvial, sand, mud, and clay. The intrusive rocks are granitic rocks of the Tertiary system.

The river systems in the Department of Oruro are comprised by the Desuaguadero River, which flows south from Lake Titicaca, and the tributaries of said river which originate in the slopes of "Cordillera Occidental" and "Cordillera Oriental." These river systems are closed river systems having Lake Popoo as the low position and the river waters evaporate upon reaching Lake Popoo.

(2) Quantities of Groundwater Resouces

According to estimations of the water balance in the Department of Oruro, the groundwater recharge is -94 mm for a mean annual precipitation of 212 mm. This result is due to the use of a formula arranged from a formula that was originally intended for estimating the quantity of "surface water" as the resource quantity. The estimation result was therefore uninfluenced by the formula term relevant to groundwater flow and strongly influenced by the severe evapotranspiration at the surface and shallow underground locations. Although the presently available data do not enable the estimation of the quantity of groundwater resources in which even the groundwater flow is considered, the above groundwater recharge will be more favorable if the spring water ("fissure water") in the "vertientes", distributed in several locations of the Altiplano, are taken into consideration as groundwater flow.

The importance of the spring water from such "vertientes" can be estimated from scale of the "vertiente" in the "Isle of the Sun" in Lake Titicaca as well as from the "vertiente" located east of Oruro City, which has supplied 25 l/sec of spring water continuously and invariably since its construction in 1927. The yield of this "vertiente" located east of Oruro City reaches 788,400 m3/yr and indicates that 5 m^3/yr of groundwater can be utilized per person sustainably in the entire Department of Oruro.

(3) Types of Groundwater

In the Department of Oruro, "stratum water" exists in the Quaternary system and "fissure water" exists in the bedrock below the Quaternary system.

The silt, sand, gravel, etc., that comprise the Quaternary system in the Department of Oruro, consist of glacial drifts, river bottom sediments, etc. Due to such characteristics of the facies of the Quaternary system and due to this formation being stratified, the Quaternary system tends to receive the groundwater recharge from the rivers. The Quaternary system thus comprises aquifers of "stratum water" type groundwater at the shores of the rivers with abundant freshwater at the foot of mountains.

Also, even in the case of formations accompanying "fissure water" type tgroundwater, the groundwater flows in a "stratum water"-like manner at parts where open "fissures" develop in a network-like manner at the weathered parts and the shallow underground locations of such formations. The water of the test well (JC-2) in Corque springs forth from such parts.

Of the Silurian system distributed in the Department of Oruro, the limestone parts accompany springs at the slopes of mountains called "verientes." These are springs from which "fissure water" type groundwater springs forth. "Verientes" are also developed in the Tertiary system in the plain regions of the Altiplano.

Although "stratum water" and "fissure water" do exist in the Department of Oruro as described above, in the plain regions of the Altiplano, the groundwater at shallow underground locations of the Quaternary system is generally high in salinity due to the low mean annual precipitation and the severe evapotranspiration. Also, the river water of the Desuaguadero River, which flows in the plain regions of the Altiplano, tend to be high in salinity from the source onwards. The the stratum water in the Quaternary system at the shores of the Desuaguadero River thus also tends to be high in salinity. Therefore, in carrying out groundwater development aiming at the Quaternary system of the Altiplano, care must be taken to avoid groundwater development of shallow underground locations and aquifers should be secured at levels higher than the water level of the Desuagudero River at the shores of this river.

(4) Past Groundwater Development

Due to the capacities of drilling equipment and past economic conditions, the groundwater developments that were carried out in the past in the Department of Oruro were carried out to depth ranges of 10 - 80 m in the eastern parts of this Department.

Although the majority of these wells target the "stratum water" in the Quaternary system that covers the foot of mountains of the small mountain range in the eastern part of the Altiplano, seasonal variations in the yield are seen with these wells.

Also in Popoqueli, which is located in the plain region of the Altiplano, "stratum water" in the Quaternary system is obtained from a dug well with a depth of approximately 2.2 m. Seasonal variations in the yield are also seen with this well.

Furthermore, although made is use of the spring water of "verientes" in the eastern parts and the "Cordillera Occidental" zone in the Department Oruro, the current yields of the "verientes" tend to be inadequate for the demand.

(5) Current Problems in Terms of Groundwater Development

The majority of wells with yields of 10 m3/hr or more in the Department of Oruro are wells with depths of 50 m or more which were constructed at the foot of mountains of the small mountain range in the eastern part of the Altiplano. In contrast, hardly any wells have been constructed in the plain region in the Altiplano and the areas near "Cordillera Occidental" and there are no data on formations below the Quaternary layer for the plain region even though there is a need to obtain groundwater from formations below the Quaternary layer.

The dug well in Popoqueli and the small-scale "verientes" seen in numerous parts along the rivers in the plain region of the Altiplano provide groundwater arising from the interflow immediately after rains and which is not of true groundwater flow. When the water level decreases with the approach of the dry season, such groundwater decrease in yield and the permeation of river water from rivers cause the groundwater to become salinized.

In order to solve such problems of groundwater development in the Department of Oruro, the construction of wells of a 100 m class or more, which reach the "fissure water" in the Silurian system, is desired for the eastern part of the Altiplano while the construction of wells which reach the Tertiary system below the Quaternary system is desired for the plain region of the Altiplano. Since the old landform of the Tertiary system is predicted to be steep from the conditions of the surrounding landforms, the construction of wells of a 300 m class will be necessary in the plain region of the Altiplano.

However, as shown below, the drilling equipment owned by the Department of Oruro are ???? - ???? models and lack adequate capacities even for the construction of wells of the same level as the existing wells. Accessory equipment are also lacking. Furthermore, there are no private well constructors in the Department of Oruro and there are problems presently with the GEOBOL of the Department of Cochabamba and the private well constructors of the Department of Santa Cruz as well.

Although the following drilling equipment exist in the Department of Chuquisaca, these only have the capacity for construction of wells of the 20 - 50 m class.

Since the construction cost will be high for deep wells, geophysical prospecting techniques must be exploited to carefully select the well position and to raise the rate of success of wells. Logging must be performed after drilling the well and the setting positions of screens must be determined accurately in order to increase the well yields.

(6) Results of Geophysical Prospecting

The aquifer structures presumed from the analysis of the results of electrical sounding carried out at Corque and Penas in the Department of Oruro are consistent with the structures determined from the construction and logging results of test wells (JC-2 and JC-3) which were constructed in these districts (JC-2 and JC-3 : Figure 4-2-4 and Figure 4-2-5).

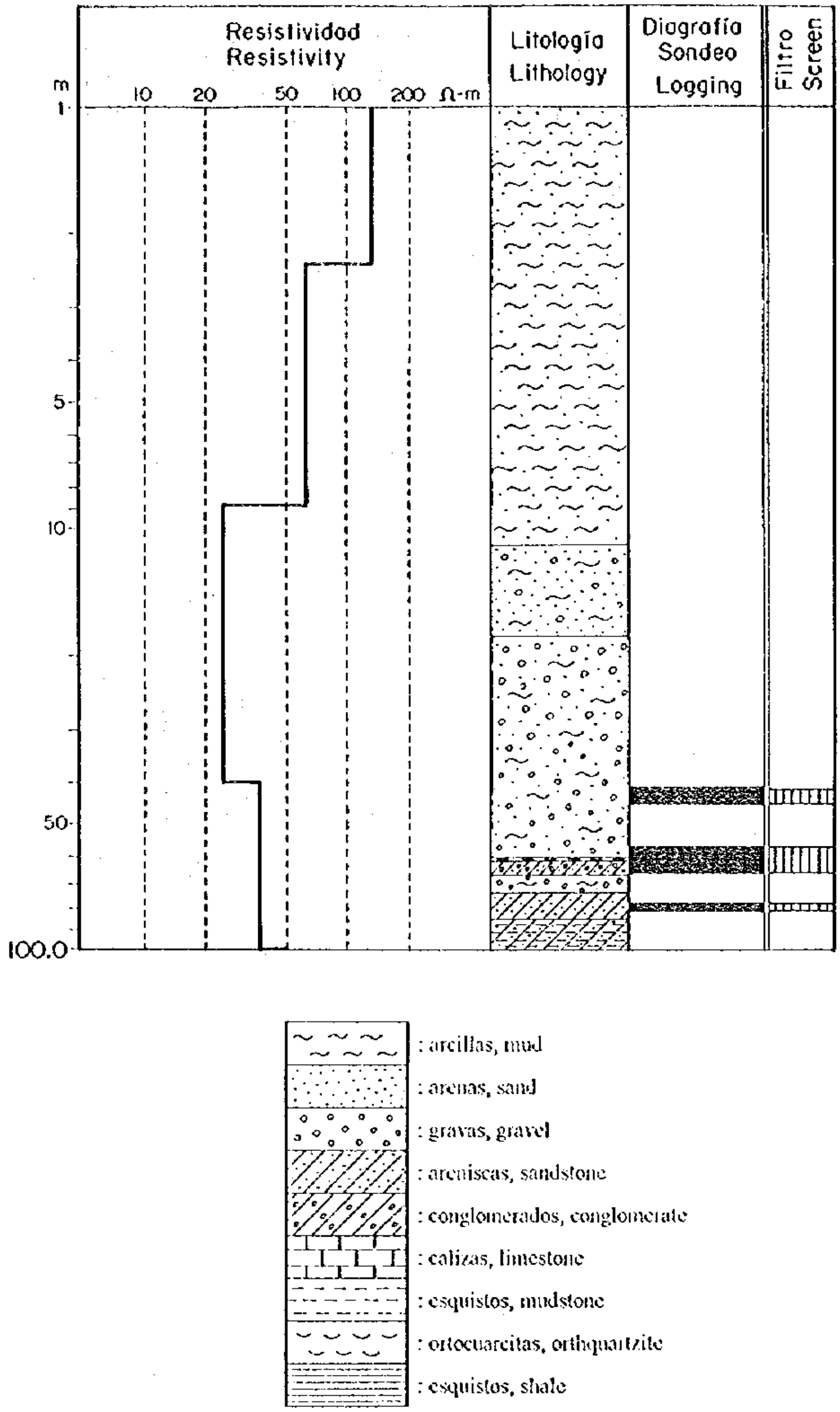
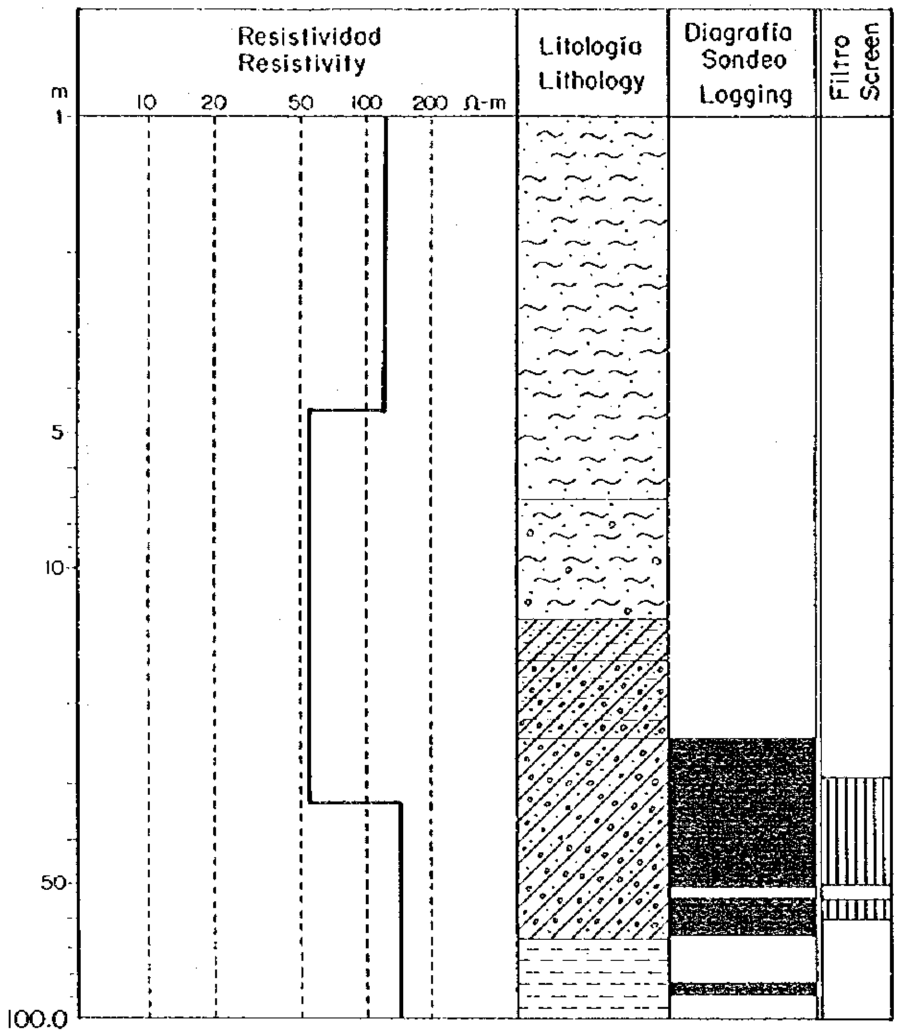


Figura 4-2-4 Relation de Resultados entre Prospeccion Geoficica, Perforacion y Sondeo sobre JC-2

Figure 4-2-4 Relation of Results among Geophysical Prospecting, Drilling and Logging on JC-2



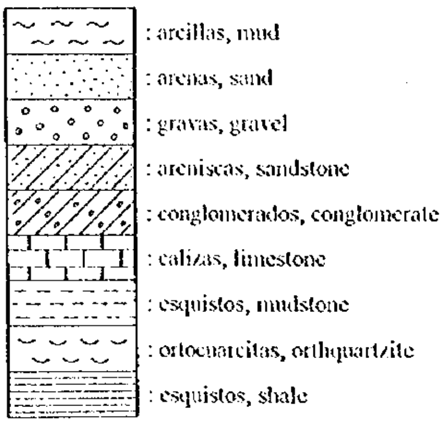


Figura 4-2-5 Relation de Resultados entre Prospeccion Geoficica, Perforacion y Sondeo sobre JC-3

Figure 4-2-5 Relation of Results among Geophysical Prospecting, Drilling and Logging on JC-3

(7) Results of Test Wells

In the Department of Oruro, well No. JC-2 was drilled in Corque and well No. 3 was drilled in Penas (MR Figure 4-1-25).

Corque, where well No. JC-2 was drilled, is located at an altitude of 3,730 m between the two mountain ranges which exist independently in the plain area of the Altiplano. These mountain ranges are comprised of the Tertiary system and extend in the north-south direction. A Quaternary sand formation is deposited in a flat manner between these mountain ranges. The groundwater at the shallow underground locations of this Quaternary sand formation is high in salinity.

Well No. JC-2 was constructed on a flat surface of this sand formation between the mountain ranges and 1 km to the north of a well which was found to yield the above-mentioned groundwater of high salinity. The purpose of the construction of this well was to study the conditions of groundwater in the Quaternary sand formation as well as to grasp the conditions of groundwater in the Tertiary system.

The geology at this well is as follows:

0.0 m - 11.0 m: Quaternary system	: clay and sand with mud
11.0 m - 18.0 m: Quaternary system	: sand with clay and gravel
18.0 m - 32.0 m: Quaternary system	: clay, mud and sand
32.0 m - 39.0 m: Quaternary system	: gravel with clay, mud and sand
39.0 m - 47.0 m: Quaternary system	: **Aquifer** ; sand with clay and mud intercalated with gravel
47.0 m - 55.0 m: Quaternary system	: clay, mud and gravel with sand
55.0 m - 66.0 m: Quaternary system	: **Aquifer** ; clay with mud and sand intercalated with gravel
66.0 m - 73.0 m: Tertiary system	: mudstone with conglomerate
73.0 m - 84.0 m: Tertiary system	: sandstone
84.0 m - 89.0 m: Tertiary system	: **Aquifer** ; mudstone intercalated with gravel
89.0 m - 93.0 m: Tertiary system	: **Aquifer** ; sandstone and mudstone
93.0 m - 95.0 m: Tertiary system	: **Aquifer** ; mudstone intercalated with sand and gravel
95.0 m - 98.0 m: Tertiary system	: **Aquifer** ; sandstone and mudstone
98.0 m -100.0 m:Tertiary system	: **Aquifer** ; mudstone intercalated with sand and gravel

Penas, where well No. JC-3 was drilled, is located at an altitude of 3,790 m between the small mountain ranges at the eastern part of the Altiplano. These mountain ranges are comprised of the Silurian system and extend in the north-south direction. Silt and gravel of the Quaternary system form terraces between the above-mentioned mountain ranges.

The geology at this well is as follows:

0.0 m - 6.0 m: Quaternary system	: clay and sand with mud
6.0 m - 13.0 m: Quaternary system	: Aquifer ; sand with clay and mud
13.0 m - 16.0 m: Quaternary system	: clay, mud and sand
16.0 m - 22.0 m: Quaternary system	: Aquifer ; sandstone and mudstone
22.0 m - 50.0 m: Silurian system	: sandstone and conglomerate
50.0 m - 54.0 m: Silurian system	: Aquifer ; fissured sandstone and conglomerate
54.0 m - 66.0 m: Silurian system	: sandstone and conglomerate
66.0 m - 70.0 m: Silurian system	: Aquifer ; fissured mudstone
70.0 m - 74.0 m: Silurian system	: mudstone
74.0 m - 77.0 m: Silurian system	: Aquifer ; fissured mudstone
77.0 m - 81.0 m: Silurian system	: mudstone
81.0 m - 83.0 m: Silurian system	: Aquifer ; fissured mudstone
83.0 m -100.0 m: Silurian system	: mudstone

The conditions of the above wells are as follows:

Table 4.2.2 Hydraulic Constants

	Block No.	a: Diameter of dril. (m)	b: Dep. of Drill (m)	k: Static W.L. (m)	l:Yield (m3/hr)	n:Draw down (m)sw	p:Specific Cap. (m3/day)	q: Transmisivity <T>	r: Hydraulic Cond. <K>	s: Strativity <S>
JC-2	403000101	218.0	100.0	6.5	7.2	19.0	0.4	0.521×10^{-3} m²/sec.	0.043×10^{-3} m/sec.	0.000×10^{-2}
JC-3	406000101	216.0	100.0	7.2	7.2	21.8	0.2	0.086×10^{-3} m²/sec.	0.003×10^{-3} m/sec.	0.000×10^{-2}

For well No. JC-2, the drawdown after 48 hours was approximately 19.6 m. for a well depth of 100 m, a static water level of 6.5 m, and a pump discharge of 7.2 m^3/hr. The dynamic water level at this time was 26.1 m, with about 16 m left to the head part of the uppermost screen among the screens that were set at 2 locations.

The transmissivity was calculated using Jacob's non-equilibrium formula to be 0.521×10^{-3} m^2/sec.

The relationship between the drawdown, s, and the pump discharge, Q, for well No. JC-2, is given by the following formula:

$Q < 2$ l/sec (7.2 m^3/hr, 172.8 m^3/day)

$$s = 0.0743Q + 2.532 \times 10^{-5} \cdot Q2 \quad \cdots\cdots\cdots \quad (4.2.3 - 1)$$

$Q \geqq 2$ l/sec (7.2 m^3/hr, 172.8 m^3/day)

$$s = 0.0655Q + 8.33 \times 10^{-5} \cdot Q2 \quad \cdots\cdots\cdots \quad (4.2.3 - 2)$$

Here, the unit of Q is m^3/day.

From this formula and from the well structure, it is estimated that the pump discharge of well No. JC-2 is limited to about 160 m^3/day (7 m^3/hr).

For well No. JC-3, the drawdown after 48 hours was approximately 21.8 m for a pump discharge is 7.2 m^3/hr. The dynamic water level at this time was 29.0 m and reached the the uppermost screen among the screens that were set at 2 locations.

From this condition and from the well structure, it is estimated that the pump discharge of well No. JC-3 is limited to about 160 m^3/day (7 m^3/hr).

(8) Feasibility of Groundwater Development

Although the groundwater generally tends to be high in salinity in the Quaternary system distributed in the plain regions of the Altiplano, the "stratum water" in the Quaternary system is low in salinity at the small mountain ranges in the eastern part of the Altiplano at the foot of mountains in the independent mountain ranges in the plain region of the Altiplano, and at the foot of mountains of "Cordillera Occidental." Groundwater development aimed at such "stratum water" is thus highly feasible.

Furthermore, in the above-mentioned regions, "fissure water" type groundwater exists in the Silurian system distributed below the Quaternary system (small mountain ranges in the eastern part of the Altiplano) and in the Tertiary system distributed below the Quaternary system (Cordillera Occidental).

The test well (JC-2) for the Department of Oruro was drilled for the purpose of checking the groundwater development feasibility in such regions and it has thereby been confirmed that groundwater development for providing yields of approximately 7 m^3/hour is possible in the mountain ranges existing independently in the plain region of the Altiplano.

It was also confirmed from test well No. JC-3, which was drilled in an area in the small mountain range in the eastern part of the Altiplano, that groundwater development for providing yields of approximately 7 m^3/hour is possible.

However, the construction location of well No. JC-3 was not one that was deemed to be optimal by geophysical prospecting but was selected after negotiations with the landowner of the initial candidate location. The hydrogeological structure and the geophysical prospecting results show that the region further north of well No. JC-3 is more suitable for groundwater development than the location of well No. JC-3 and it is considered that yields of approximately 15 m3/hr per well is possible in this region.

(9) Policy for Future Groundwater Development

MR Figure 4-2-7 shows the provincia-wise criteria for the Department of Oruro as considered from a hydrogeological viewpoint. These can be summarized in a general manner as follows.

For the groundwater development in the Department of Oruro, priority should be placed on aiming at the "stratum water" in the Quaternary system distributed at the foot of mountains of the small mountain ranges at the eastern part of the Altiplano and at the foot of mountains of "Cordillera Occidental." Among these regions, the foot of mountains in the small mountain ranges in the eastern part of the Altiplano should be given top priority in view of the access to the groundwater development site and the groundwater recharge system. The well database analysis results also indicate that the above region should be given top priority (MR Figure 4-2-7).

The regions in the mountain ridges, which run parallel to each other in the north-south direction at the central part of the Altiplano in the east-west direction and which are comprised of the Tertiary system, can be considered as regions similar to the foot of mountains of the small mountain range in the eastern part of the Altiplano and of "Cordillera Occidental." "Stratum water" of good water quality exists at the bottom of the Quaternary layer deposited between the above-mentioned mountain ridges since this region is separated from the Desuaguadero river basin and because of the groundwater recharge system in this region.

In general, the wells constructed in the Quaternary system of the Altiplano tend to receive seasonal effects and have unstable yields. Thus, in carrying out groundwater development in the Altiplano, wells that penetrate through the Quatenary system and reach the Silurian or Tertiary system must be constructed to obtain not only the "stratum water" in the Quaternary system but also the "fissure water" in the bedrock at the same time.

In the plain regions of the Altiplano, the "fissure water" in the bedrock must be obtained not only in terms of the well yield but also in terms of water quality. For example, in Corque, although the "stratum water" at shallow underground locations in the Quaternary system is high in salinity, "fissure water" of good water quality has been obtained from the Tertiary system below the Quaternary system as shown by the results of well No. JC-2.

From the above, it is concluded that 100 - 300 m class wells must be constructed in the Department of Oruro.

The well diameter at the well bottom during drilling should be in the range 10 5/8" - 12 1/4", the diameters of screens and casings should be 6" - 8 5/8", and the ratio of the length of the screen to the drilling length should be approximately 15% - 30%. In order to obtain a high well yield, the screens or casings must be inserted down to the bottom of the well.

In the flat regions located centrally in the east-west direction in the Altiplano, the filling from the depth of the aquifer accompanying groundwater of high salinity to the surface should be performed not with gravel but with a clayish substance or cement, etc. in order to prevent the intake of groundwater of high salinity in the Quaternary system. Since the filled parts accompany groundwater of high salinity, salt-resistant cement will be required. This requirement also applies to the bentonite to be used during well drilling. Furthermore, the conductivity of the circulating water during well drilling should be measured or so-called "well-logging" should be performed to determine the depth at which clayish substance/cement filling is to be performed.

(10) Requirements for Future Groundwater Development

For the groundwater development in the Department of Oruro, geological structure analysis and geophysical prospecting must be carried out to grasp the geological structure of the surrounding area before constructing a well in order to raise the rate of success of the well. For this purpose, the necessary personnel must be secured. Office equipment for arranging various data, aerial photographs, geophysical prospecting equipment, and a station wagon, pickup truck, etc. for providing mobility for the prospecting team will also be needed.

In groundwater development, electrical sounding methods are generally used to grasp the aquifer structure at 200 - 250 m below the surface. On the other hand, electromagnetic sounding or gravity prospecting methods are effective for grasping base structures below 250 m.

While trees must be cleared to provide a long traverse line for measurements in the case of electromagnetic sounding, such clearing is hardly required in the case of gravity prospecting. Gravity prospecting is therefore preferred over electromagnetic sounding in regions where the vegetation is dense and in mountainous areas with steep landforms. Gravity prospecting is also more preferable in cases where shallow underground locations accompany groundwater of high salinity.

The drilling of wells require personnel for drilling and drilling equipment that can tolerate the drilling of 100 - 300 m class wells. 350 - 400 m class drilling equipment will thus be necessary to provide leeway in the capacity of the equipment.

For the drilling equipment, models with functions for the reverse circulation method must be selected to cope with riverbed sediments comprised of unconsolidated or semi-consolidated boulders and boulder gravel. The drilling equipment must also enable rotary and down-the-hole methods for development targeting the "stratum water" in the Quaternary system and the "fissure water" in the hard bedrock. A tank lorry for drilling water, an air compressor with adequately high pressure and air volume, and bits of various sizes for rotary and down-the-hole methods will thus be required.

A small tank lorry for fuel, a support truck with crane, a small truck, a station wagon for engineers, workshop vehicles for equipment repairs, etc. are also needed. Communication equipment are also necessary for communication between the well construction site and the office for schedule management.

Each of the above equipment require spare parts. Since the station wagon for engineers will be driven out of necessity at relatively high speeds and over long distances, the wearing of tires and various types of spring systems will be severe. The replenishment of such spare parts will thus be essential.

Logging must be performed to increase the yield of the well. This will require functions for electrical resistivity logging, self-potential logging as well as gamma ray logging, which is effective for detection of parts besides the aquifer. Electronic recording methods are preferred as recording methods. Logging equipment should be operated and maintained by the geophysical prospecting team.

Although steel pipes should be adequate for the casings for final construction of the well, screens must be made of stainless steel as steel screens are weak against corrosion.

Pumping tests must be carried out on completed wells in order to determine the well yields for water supply facility designs and to grasp the hydrogeological characteristics of the aquifer for planning future groundwater development and environmental conservation.

In the pumping test, the pump discharge, the dynamic water level, variations in water quality during pumping (especially the pH and conductivity), etc. should be recorded and water quality analysis should be performed as a final step after the completion of the pumping test. A submerged pump, a generator, instruments for measuring the water level, pH, and conductivity, a water quality analysis set, etc. are needed for this purpose. The capacities of the submerged pump and generator for pumping tests should preferably be adequate for a pump head of 80 - 200 m and a pump discharge of 5 - 40 m^3/hr.

Pumps for production wells will require a submerged pump with a capacity adequate for a pump head of 80 - 200 m and a pump discharge of 5 - 15 m^3/hr.

Safe storage locations of adequate area must be secured and appropriate storage and management methods must be established for the storage of the above-mentioned equipment and materials.

The securing of personnel for operating and managing the above-mentioned equipment and materials is a most important requirement. Personnel for operating the equipment should be secured to enable 24-hour drilling work.

It is preferable to construct a facility that provides the functions of a "machine shop (repair shop)," a "spare parts repository," and a "training center" at the central agency of the Department and to gather engineers in the regional areas every few years to such a facility to provide training by engineers of the central agency on the disassembly, repair, etc. of generators, pumps, water supply equipment, etc. and to collect records for groundwater management at each regional area in order to examine matters pertaining to maintenance and management.

4) Groundwater Development Conditions in the Department of Tarija

(1) Physiography, Geology, and Aquifers

The Department of Tarija is situated in the physiographical zones of "Cordillera Oriental," "Seranias Sub-Andinas," and "Llanura Chaco" (MR Figure 4-1-1 and MR Figure 4-1-2).

In the Department of Tarija, "Cordillera Oriental" reaches altitudes of 1,600 - 4,000 m and exhibits major distributions of Ordovician, Silurian, and Devonian systems from the west to the east, in that order. These systems have been subjected to strong folding activities and the folding axis exhibit a south-north directivity. Part of the syncline axis areas, such as the area north of Tarija City, accompany Tertiary systems of a small scale (MR Table 4-1-4 and MR Figure 4-1-5).

"Seranias Sub-Andinas" reaches altitudes of 1,200 -2,500 m and has distributions of Carboniferous, Triassic, Cretaceous, and Tertiary systems. These systems have been subjected to strong folding activities. These systems exhibit a south-north directivity and are arranged repeatedly in a belt-like manner. The Tertiary system, which is distributed at the syncline axis parts, exhibits the widest belt among these systems.

"Llanura Chaco" is a bush zone located at altitudes of 200 - 1,000 m. The geology of the surface is a Tertiary system at the hills located at the western part of "Llanura Chaco" called the "costa" and is a Quaternary system in the eastern part of this plain called the "llano." From the conditions of the geology in the Department of Santa Cruz and the Department of Chuquisaca, it is considered that beds of Carboniferous to Cretaceous systems are distributed below the Quaternary system in the "llano" in the Department of Tarija.

The aquifers in "Cordillera Oriental" are of the Quaternary system that fills the valleys and of the Ordovician, Silurian, and Devonian systems which comprise the bedrock.

The aquifers in "Seranias Sub-Andinas" are of the Quaternary system that fills the valleys and of the Carboniferous, Triassic, Cretaceous, and Tertiary systems which comprise the bedrock. Among these, the major aquifers are of the Tertiary and Carboniferous systems.

The aquifers in the "costa" region of Llanura Chaco are of the Tertiary system while the major aquifers of the "llano" region are of the Tertiary and Cretaceous systems.

The above-mentioned Ordovician system is comprised of quartzite, sandstone, shale and mudstone, the Silurian system of diamictite (diamicitas), sandstone, limistone, slate and mudstone (limolitas), the Devonian system of sandstone, shale, mudstone and limestone, the Carboniferous system of diamictite, conglomerate, sandstone and shale, the Triassic system of sandstone, limestone and marl, the Cretaceous system of sandstone, conglomerate, siltstone (arcilitas), limestone and marl, the Tertiary system of sandstone, conglomerate, siltstone and gypsum, and the Quaternary system of alluvial sediment, colluvial, sand, mud and clay.

Although the river systems in the Department of Tarija are mainly influenced by a north-south fold axis, such as that seen in "Cordillera Oriental" and "Seranias Sub-Andinas", they all belong to the "La Plata River System".

(2) Quantities of Groundwater Resouces

According to estimations of the water balance in the Department of Tarija, the groundwater recharge is 46 mm for a mean annual precipitation of 800 mm. This corresponds to a recharge of 1,716,000,000 m^3/yr for the entire Department of Tarija and indicates that 5,890 m^3/yr of groundwater can be utilized sustainably per person.

Though the above recharge occurs at the river basins of the Pilcomayo River, the Paraguay River, and the Bermejo river, the groundwater recharge is negative at the Paraguay river basin. On the other hand, the groundwater recharge is large and reaches 66 - 50 mm at the Pilcomayo and Bermejo river basins.

(3) Types of Groundwater

In "Cordillera Oriental," "stratum water" exists in the Quaternary system which fills the valleys of the valley areas and "fissure water" exists in the Ordovician, Silurian, and Devonian systems which comprise the bedrock.

In "Seranias Sub-Andinas," "stratum water" exists in the Quaternary system which fills the valleys of the valley areas and "fissure water" exists in the Carboniferous, Triassic, Cretaceous, and Tertiary systems. Up until now, groundwater development has been mainly carried out on the "stratum water" in the Quaternary system and on the groundwater in the weathered belt of the bedrock.

In the "costa" region of "Llanura Chaco," "fissure water" exists in the Tertiary system while in the "llano" region, "fissure water" exists in the Tertiary and Cretaceous systems.

(4) Past Groundwater Development

In the Department of Tarija, groundwater development has been carried out in the past in the southern extensions of the "belt-like region with a width of 150km in the east-west direction from 'Seranias Sub-Andinas' to 'Llanura Chaco-Beniano' and extending in the north-south direction", where the groundwater development activities in Bolivia have been concentrated. This belt-like region continues into the Department of Tarija from the Department of Santa Cruz and through the Department of Chuquisaqa. From the Department of Tarija and further south, the belt-like region in which groundwater development has been concentrated extends to "Cordillera Oriental". The records of past groundwater development in the Department of Tarija are few for the "Seranias Sub-Andinas" zone and numerous fro the "Cordillera Oriental" and "Llanura Chaco" zones.

Although the past groundwater developments in the Department of Tarija have been carried out mainly around Tarija City, which is located in the "Cordillera Oriental" zone, the number of wells is few and only a few of the records are complete. However, the number of wells in the areas near the boundary of the "Seranias Sub-Andinas" and "Llanura Chaco" zones is beginning to increase, particulary in such areas in the "Llanura Chaco" zone. This is the result of the large-scale hydrogeological study carried out in the "Llanura Chaco" in 1992 - 1995 by the Republic of Germany and the primary (1992 - 1994) and secondary (currently being continued) well construction based on the results of the above-mentioned study and carried out with loans from China. Although the records for these well construction projects have not yet been arranged in a systematic manner, the drilling depths in "Llanura Chaco" have reached 150 - 250 m. As in the "Llanura Chaco" zone in the the Department of Chuquisaca, the drilling depths tend to be deep in the "costa" region and shallow in the "llano" region.

In "Cordillera Oriental," yields of 10 m^3/hr - 28 m^3/hr are being obtained from recently constructed wells with depths of approximately 100 - 200 m and a comparison of old and new wells shows that yields are definitely greater at the recently constructed deep wells than the old shallow wells with depths of 100 m or less.

In "Seranias Sub-Andinas," groundwater developments have been carried out in the eastern parts, that is, in the region corresponding to the western part of Gran Chaco province. The wells there are approximately 100 - 200 m in depth and provide yields of 10 - 70 m^3/hr.

In "Llanura Chaco," records exist only for 1 well in the eastern part of Gran Chaco, ie. that in Ibibobo, which is located in the "llano." This well has a depth of approximately 70 m and provides a yield of approximately 10 m^3/hr.

(5) Current Problems in Terms of Groundwater Development

Numerous basins are formed in the "Cordillera Oriental" zone in the Department of Tarija. Although there are deposits of the Quaternary system in such basins, groundwater development in the basins is not necessarily easy since the Quaternary system is comprised of clay-like matter at parts besides the lower parts. Also, even in cases where groundwater can be obtained from within the Quaternary system at shallow underground locations, the yields are minute and the groundwater is high in salinity and unfit for cooking and drinking. Hand-well dugs are thus hardly dug in the Quaternary system and are not used for cooking and drinking water even when they are dug.

Since a negative correlation is seen between the well yield and salinity in such regions, deep wells, which reach the base gravel of the Quaternary system or the bedrock below it, must be constructed. Well No. JC-8, which was drilled in the present Study, was constructed for this purpose in a district where there are dug wells in the vicinity that yield water of high salinity. Favorable results were obtained at this test well in terms of water quality, water quantity and level of confinement (artesian).

Since "Seranias Sub-Andinas" exhibits an extremely steep landform, the communities in this region are not formed on the slopes of mountains but are aligned along the shores of the Bermejo River or along the watersheds of the Bermejo River System and the Pilcomayo River System.

Due to the extremely steep landform, all of the degradation matter from the mountain mass fall to the river bottom and large-scale talus cones do not tend to form at the slopes. Thus along the shores of the Bermejo River, although water of the minute "verientes" (springs) formed at the small-scale talus cone parts and the turbid water of the Bermejo River are used, wells are not constructed due to the hard bedrocks. The triangular region between the Bermejo River and the Rio Grande River is the only flat area of a large scale in the "Seranias Sub-Anidnas" zone. Although dug wells have been constructed here, it is difficult to drill deeper wells since boulders and boulder gravel are reached and groundwater springs forth at depths of only a few meters. Water pollution due to the shallowness of the wells is becoming a problem in this region.

In the communities along the watersheds of the Bermejo River System and the Pilcomayo River System, the groundwater of shallow wells is high in salinity. Although deep wells must be constructed to resolve this problem, they have not been dug because of the hard bedrock.

In the past, the Pilcomayo River has repeatedly changed its flow path upon reaching "Llanura Chaco" from "Seranias Sub-Andinas". The conditions of groundwater accompaniment in "Llanura Chaco" has therefore been heavily influenced by the flow paths in the past. Since a negative correlation is seen between the well yield and salinity in "Llanura Chaco", it is important to grasp the flow paths of the past for groundwater development in this zone.

The groundwater in "Llanura Chaco" tends to be similar in static water level to the groundwater in the "Llanura Chaco" zone of the Department of Chuqisaca and since the static water level is deep (100 - 200 m) in the regions ("costa") from "Seranias Sub-Andinas" to "Llanura Chaco", the construction of deep wells is needed here. There is also the possibility that wells of a 300 m class may be needed near the Department border with the Department of Chuquisaca.

Due to the above conditions, wells of the 100 - 300 m class must be constructed in the Department of Tarija and drilling equipment with drilling capacities for 150 - 450 m class wells are required for this purpose.

However, as shown below, the drilling machines owned by the Department of Tarija are 1973-1975 models and and if the high salinity of the groundwater at shallow underground locations is considered, the capacities of the existing drilling machines are inadequate even for groundwater development targeting the Quaternary system. Accessory equipment are also lacking. Furthermore, there are no private well constructors in the Department of Tarija and there are problems presently with the private well constructors of the Department of Santa Cruz as well.

Although the following drilling equipment exist in the Department of Tarija, none of these are operating presently.

Depart.	Name of Organization	Instit. Pub.(A) Priv.(B) Coop.(C)	Number of Equipment	Model of Equipment	TradeMark of Equipment	Type of Drill. (D):rotary (E):percu.	Capacity for Drilling (m)	Efficiency & Diameter of the Depth		Note
								Depth (m)	Diameter	
Tarija	CODETAR	A	1	1978	EnginSoil	D(1)	120 =0	120	12"	=G: Solamente
	Dir. Sancam. Ambiental	A	1	1975	Failling	(D)1	120 =0	120	12"	Nominal
Total	-	-	2	-	-	-	-	-	-	

Since the construction cost will be high for deep wells, geophysical prospecting techniques must be exploited to grasp the bedrock structure, the old flow paths of the Pilcomayo River, etc., to carefully select the well position, and to raise the rate of success of wells. Also, after drilling the well, the setting positions of screens must be determined accurately in order to increase the well yields.

(6) Results of Geophysical Prospecting

The geological structures presumed from the electrical sounding and electromagnetic sounding carried out at La Choza and Naranjos in the Department of Tarija are consistent with the structures determined from the construction and logging results of wells constructed in the same districts (JC-8 and JC-9 : Figures 4-2-6, 4-2-7).

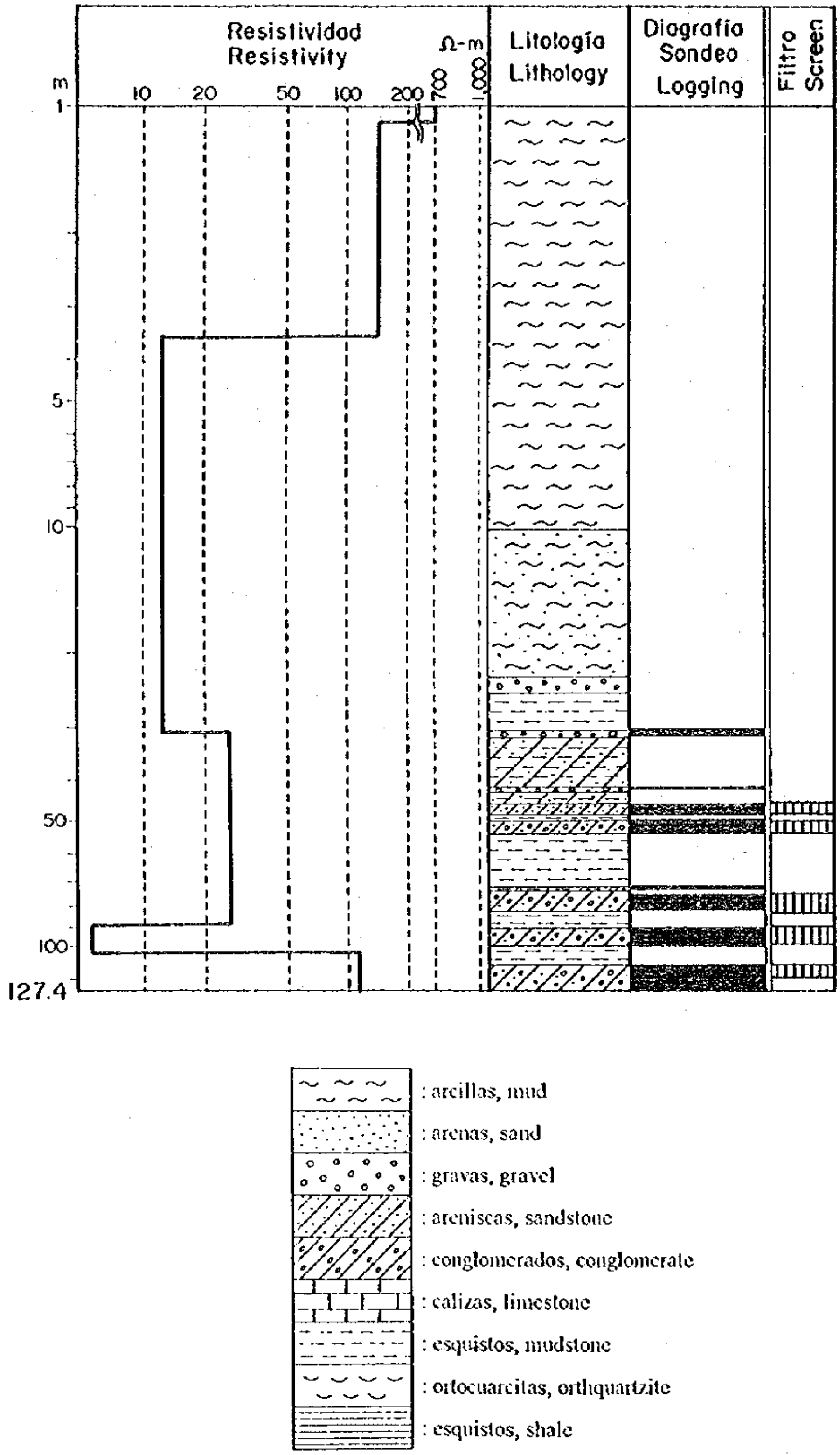
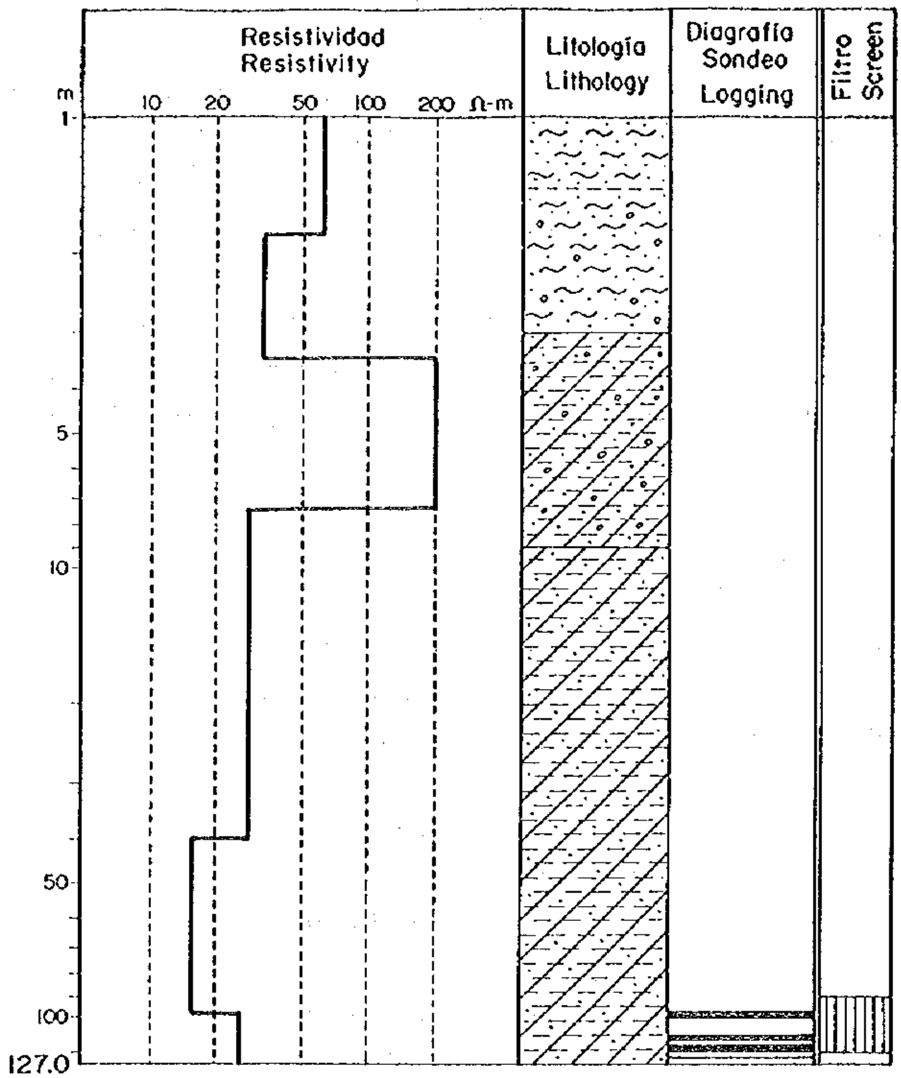


Figura 4-2-6 Relation de Resultados entre Prospeccion Geoficica, Perforacion y Sondeo sobre JC-8

Figure 4-2-6 Relation of Results among Geophysical Prospecting, Drilling and Logging on JC-8



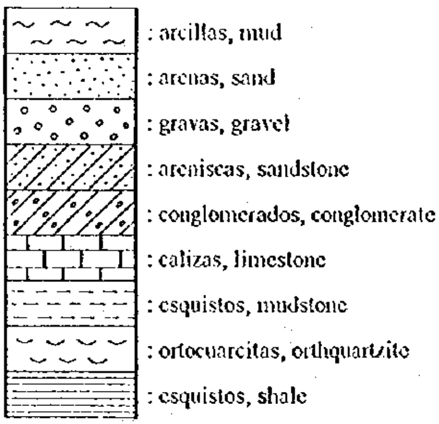


Figura 4-2-7 Relation de Resultados entre Prospeccion Geoficica, Perforacion y Sondeo sobre JC-9

Figure 4-2-7 Relation of Results among Geophysical Prospecting, Drilling and Logging on JC-9

(7) Results of Test Wells

In the Department of Tarija, well No. JC-8 was drilled in La Choza and well No. JC-9 was drilled in Naranjos. The locations of these test wells are within the "belt-like region with a width of 150km in the east-west direction from 'Seranias Sub-Andinas' to 'Llanura Chaco-Beniano' and extending in the north-south direction", which continues on from the Department of Santa Cruz.

La Choza, where well No. JC-8 was drilled, is located in a basin at an altitude of approximately 1,685 m in "Cordillera Oriental." Although the geology of the surface is comprised of the Quaternary system, that at depths of 25 m or more is comprised of the Devonian system.

The geology at this well is as follows:

0.0 m - 10.0 m: Quaternary system	: clay and mud
10.0 m - 23.0 m: Quaternary system	: clay and sand with mud
23.0 m - 25.0 m: Quaternary system	: **Aquifer** ; sand and gravel
25.0 m - 31.0 m: Devonian system	: mudstone
31.0 m - 42.0 m: Devonian system	: **Aquifer** ; fissured sandstone and conglomerate
42.0 m - 46.0 m: Devonian system	: mudstone and sandstone
46.0 m - 49.0 m: Devonian system	: **Aquifer** ; fissured sandstone and conglomerate
49.0 m - 51.0 m: Devonian system	: mudstone
51.0 m - 54.0 m: Devonian system	: **Aquifer** ; fissured sandstone and conglomerate
54.0 m - 71.0 m: Devonian system	: mudstone
71.0 m - 72.0 m: Devonian system	: **Aquifer** ; fissured mudstone
72.0 m - 76.0 m: Devonian system	: mudstone
76.0 m - 83.0 m: Devonian system	: **Aquifer** ; fissured sandstone and conglomerate
83.0 m - 91.0 m: Devonian system	: mudstone
91.0 m -100.0 m: Devonian system	: **Aquifer** ; fissured sandstone and conglomerate
100.0 m -117.0 m: Devonian system	: sandstone and conglomerate
117.0 m -127.0 m: Devonian system	: **Aquifer** ; fissured sandstone and conglomerate

Naranjos, where well No. JC-9 was drilled, is located at the central part of the "Seranias Sub-Andinas," slightly into the Bermejo River System from the watershed between the Bermejo River System and the Pilcomayo River System. The altitude of this location is 1,250 m.

The geology at this well is as follows:

0.0 m - 0.5 m: Quaternary system	: clay and sand

0.5 m - 3.0 m:	Quaternary system	: clay and sand with gravel
3.0 m - 9.0 m:	Tertiary system	: mudstone and sandstone intercalated with conglomerate
9.0 m -127.0 m:	Tertiary system	: mudstone and sandstone

The conditions of these wells are as follows:

Table 4.2.3 Hydraulic Constants

	Block No.	a: Diameter of dril. (m)	b: Dep. of Drill (m)	k: Static W.L. (m)	l:Yield (m3/hr)	n:Draw down (m)sw	p:Specific Cap. (m3/day)	q: Transmisivity <T>	r: Hydraulic Cond. <K>	s: Strativity <S>
JC-8	601010707	215.0	127.1	-6.0	-	-	-	-	-	-
JC-9	606011702	[illegible]	127.0	0.0	0	0.0	-	-	-	-

The groundwater at well No. JC-8 is confined with a water head 6 meters above ground level and the artesian discharge reaches 14 - 18 m^3/hr. Though a pumping test was attempted in order to check the yield of this well, the test was not carried out since the water pressure prevented the insertion of the pump. The relationship between the drawdown, s, and the pump discharge, Q, the transmissivity, etc. therefore could not be determined.

There is a dug well with a depth of approximately 17 m at a location approximately 100m west of and -30 m in height difference with respect to well No. JC-8. The static water level of the groundwater here was 8.6 m and the salinity was 1,999 micro-s/cm.

Well No. JC-8 was drilled at a location that is +30 m in relative height from the mouth of the above-mentioned dug well and the bottom of well No. JC-8 was drilled to a level that is approximately 80 m deeper than the bottom of the above-mentioned dug well. That the water level was + 6 m, the artesian discharge 14 - 18 m^3/hr, and the salinity 500 micro-s/cm for the groundwater of well No. JC-8 under the above conditions indicates that both water quantity and quality are improved and groundwater development can be carried out favorably by making the well depth deeper. Similarly significant results were also obtained for well No. JC-4 (San Carlos) in the Department of Santa Cruz and also in Corque in the Department of Oruro.

Well No. JC-9 had no success because the well was dry.

(8) Feasibility of Groundwater Development

Although the district with a basin-like structure in "Cordillera Oriental" in the Department of Tarija is considered to be the bottom of an ancient lake, the Quaternary system that has deposited here is comprised of clay-like matter except at the base part and is low in tranmissivity and high in groundwater salinity. Even in such regions, the base parts of the Quaternary system and the Devonian system below the Quaternary system accompany gravel at several depths. It has thus become clear that groundwater development for providing yields of approximately 15 m^3/hr is possible by appropriate selection of the locations and depths of wells in consideration of the groundwater flow structure.

Within "Seranias Sub-Andinas," the triangular region between the Bermejo River and the Rio Grande River comprises a region suited for groundwater development. This is due to the distribution of boulder and boulder gravel formations with thicknesses of approximately 40 m from shallow underground locations onwards. The static water levels are expected to be approximately 5 m and the well yields are expected to be 15.0 - 30.0 m^3/hr for wells in this region.

In the "costa" region of "Llanura Chaco," though the static water level of groundwater ranges from 30 - 150m and the yield per well is about 15.0 m^3/hr, it is considered that groundwater development can be carried out to provide yields of 30.0 $m^3/hour$ by selecting locations in the old flow paths of the Pilcomayo River as well locations through geological structure analysis.

On the other hand, the static water level of groundwater is predicted to be approximately 30 - 100 m in the "llano" region. From the existing data, the yield per well is considered to be similar to those in the "costa" region.

(9) Policy for Future Groundwater Development

MR Figure 4-2-7 shows the provincia-wise criteria for the Department of Tarija as considered from a hydrogeological viewpoint. These can be summarized in a general manner as follows.

In terms of well yield and the rate of success, the region, which includes "Corillera Oriental" along with the "belt-like region with a width of 150km in the east-west direction from 'Seranias Sub-Andinas' to 'Llanura Chaco-Beniano' and extending in the north-south direction," is a promising candidate region for groundwater development in the Department of Tarija. Within this range and among the districts with basin-like structure distributed in "Cordillera Oriental," the triangular zone between the Bermejo River and Rio Grande River and belonging to the "Seranias Sub-Andinas" zone, and the region extending from the shores of the Bermejo River and the eastern part of "Seranias Sub-Andinas" to the western part of "Llanura Chaco," groundwater development should be carried out with priority in the regions in "Llanura Chaco" that correspond to the old flow paths of the Pilcomayo River.

Wells of the 100 - 450 m class must be constructed in the Department of Tarija.

The well diameter at the well bottom during drilling should be in the range 10 5/8" - 12 1/4", the diameters of screens and casings should be 6" - 8 5/8", and the ratio of the length of the screen to the drilling length should be 15% - 30%. In order to obtain a high well yield, the screens or casings must be inserted down to the bottom of the well.

In regions where the groundwater at shallow underground locations are high in salinity, the filling from the depth of the aquifer accompanying groundwater of high salinity to the surface should be performed not with gravel but with a clayish substance or cement, etc. to prevent the intake of groundwater of high salinity at the upper levels. Since the filled parts accompany groundwater of high salinity, salt-resistant cement will be required. This requirement also applies to the bentonite to be used for well drilling. Furthermore, the conductivity of the circulating water during well drilling should be measured or so-called "well-logging" should be performed to determine the depth at which clayish substance/cement filling is to be performed.

In order to raise the rate of success of future wells, the investigation records before and after well construction should be incorporated into the database successively and arranged and classified in diagrams designated for the purpose to nurture personnel and techniques for utilizing such data.

(10) Requirements for Future Groundwater Development

For the groundwater development in the Department of Tarija, geological structure analysis and geophysical prospecting must be carried out to grasp the geological structure of the surrounding area before constructing a well in order to raise the rate of success of the well. For this purpose, the necessary personnel must be secured. Office equipment for arranging various data, aerial photographs, geophysical prospecting equipment, and a station wagon, pickup truck, etc. for providing mobility for the prospecting team will also be needed.

In groundwater development, electrical sounding methods are generally used to grasp the aquifer structure at 200 - 250 m below the surface. On the other hand, electromagnetic sounding or gravity prospecting methods are effective for grasping base structures below 250 m.

While trees must be cleared to provide a long traverse line for measurements in the case of electromagnetic sounding, such clearing is hardly required in the case of gravity prospecting. Gravity prospecting is therefore preferred over electromagnetic sounding in regions where the vegetation is dense and in mountainous areas with steep landforms. Gravity prospecting is also more preferable in cases where shallow underground locations accompany groundwater of high salinity.

The drilling of wells require personnel for drilling and drilling equipment that can tolerate the drilling of 100 - 300 m class wells. 200 - 450 m class drilling equipment will thus be necessary to provide leeway in the capacity of the equipment.

For the drilling equipment, models with functions for the reverse circulation method must be selected to cope with riverbed sediments comprised of unconsolidated or semi-consolidated boulders and boulder gravel. The drilling equipment must also enable rotary and down-the-hole methods for development targeting the "stratum water" in the Quaternary system and the "fissure water" in the hard bedrock. A tank lorry for drilling water, an air compressor with adequately high pressure and air volume, and bits of various sizes for rotary and down-the-hole methods will thus be required.

A small tank lorry for fuel, a support truck with crane, a small truck, a station wagon for engineers, workshop vehicles for equipment repairs, etc. are also needed. Communication equipment are also necessary for communication between the well construction site and the office for schedule management.

Each of the above equipment require spare parts. Since the station wagon for engineers will be driven out of necessity at relatively high speeds and over long distances, the wearing of tires and various types of spring systems will be severe. The replenishment of such spare parts will thus be essential.

Logging must be performed to increase the yield of the well. This will require functions for electrical resistivity logging, self-potential logging as well as gamma ray logging, which is effective for detection of parts besides the aquifer. Electronic recording methods are preferred as recording methods. Logging equipment should be operated and maintained by the geophysical prospecting team.

Although steel pipes should be adequate for the casings for final construction of the well, screens must be made of stainless steel as steel screens are weak against corrosion.

Pumping tests must be carried out on completed wells in order to determine the well yields for water supply facility designs and to grasp the hydrogeological characteristics of the aquifer for planning future groundwater development and environmental conservation.

In the pumping test, the pump discharge, the dynamic water level, variations in water quality during pumping (especially the pH and conductivity), etc. should be recorded and water quality analysis should be performed as a final step after the completion of the pumping test. A submerged pump, a generator, instruments for measuring the water level, pH, and conductivity, a water quality analysis set, etc. are needed for this purpose.

The capacities of the submerged pump and generator for pumping tests should preferably be adequate for a pump head of 80 - 150 m and a pump discharge of 5 - 50 m^3/hr.

Pumps for production wells will require a submerged pump with a capacity adequate for a pump head of 80 - 150 m and a pump discharge of 5 - 30 m^3/hr.

Safe storage locations of adequate area must be secured and appropriate storage and management methods must be established for the storage of the above-mentioned equipment and materials.

The securing of personnel for operating and managing the above-mentioned equipment and materials is a most important requirement. Personnel for operating the equipment should be secured to enable 24-hour drilling work.

It is preferable to construct a facility that provides the functions of a "machine shop (repair shop)," a "spare parts repository," and a "training center" at the central agency of the Department and to gather engineers in the regional areas every few years to such a facility to provide training by engineers of the central agency on the disassembly, repair, etc. of generators, pumps, water supply equipment, etc. and to collect records for groundwater management at each regional area in order to examine matters pertaining to maintenance and management.

5) Groundwater Development Conditions in the Department of Santa Cruz

(1) Physiography, Geology, and Aquifers

The Department of Santa Cruz is situated in the physiographical zones of "Seranias Sub-Andinas," and "Llanura Chaco-Beniana," "Seranias Chiquitanas," and "Escudo Central" (MR Figure 4-1-1 and MR Figure 4-1-2).

In the Department of Santa Cruz, "Seranias Sub-Andinas" reaches altitudes of 1,000 - 2,500 m and exhibits major distributions of Devonian, Carboniferous, Cretaceous, and Tertiary systems the west to the east, in that order. The Cretaceous system is distributed on a small scale at the flanks of the fold axis and the Tertiary system is seen in the southern part of "Seranias Sub-Andinas" and in regions where "Seranias Sub-Andinas" changes to "Llanura Chaco-Beniana" (MR Table 4-1-4 and MR Figure 4-1-5). Among these, the Tertiary system distributed in the southern part of "Seranias Sub-Andinas" has parts that with gypsum interleaved in a stratum-like manner. The groundwater in such parts is high in salinity.

"Llanura Chaco-Beniana" is situated at altitudesof 200 - 1,000m. A Pre-Cambrian system is distributed below the Quaternary system at the northern part of this Department and a Tertiary system is distrubuted below the "Llanura Beniana" zone further south. A Devonian, Carboniferous, or Cretaceous system is distributed below the Quaternary system in the "Llanura Chaco" zone from Santa Cruz City and further south.

Stratum water can be obtained from the weathered belt at the top parts of these rocks covered by the Quaternary system and fissure water can be obtained from the fissure parts of these rocks.

"Seranias Chiquitanas" is a mountain mass that protrudes into the Quaternary system south of San Jose de Chiquitos and has altitudes of 450 - 500 m. "Seranias Chiquitanas" is comprised of Pre-Cambrian, Ordovician, Devonian, Silurian, and Cretaceous systems and the groundwater of verientes which spring forth from the "fissures" in the Pre-Cambrian system is used in San Jose de Chiquitos as clean water.

"Escudo Central," which is located at the eastern edge of the Department of Santa Cruz, is situated at altitudes of 200 - 500 m and is mainly comprised of a Pre-Cambrian system. Although the geology here is basically impermeable, the weathered belts accompany stratum water as favorable aquifers and the parts where fissures have developed accompany fissure water. It is recorded in the well database that wells with pump discharges reaching 24 - 45 m^3/hr exist in such parts.

The above-mentioned Pre-Cambrian system is comprised of limestone, sandstone, conglomerate and dolerite, the Ordovician system of sandstone, quartzite, shale, mudstone, conglomerate and chert, the Devonian system of sandstone, shale, mudstone and limestone, the Carboniferous system of diamictite (diamicitas), conglomerate, sandstone and shale, the Cretaceous system of sandstone, conglomerate, siltstone (arcilitas), limestone and marl, the Tertiary system of sandstone, conglomerate, siltstone and gypsum, and the Quaternary system of alluvial sediment, lake-bottom colluvium, sand, mud, and clay.

Although the major aquifers which were targeted in past groundwater developments are of the Quaternary system, a part of such aquifers have groundwater with odor or high salinity or have yields that vary seasonally. Well No. JC-4, which was drilled in the present Study, was drilled aiming at the boundary between the Quaternary and Tertiary system in such a district and provided favorable results in terms of both water quality and water quantity. On the other hand, the groundwater in the Quaternary system is said to be high in salinity at the "central parts of the Department of Santa Cruz" from Pailon, located to the east of Santa Cruz City, to Cantera Vieja further east.

(2) Quantities of Groundwater Resouces

According to estimations of the water balance in the Department of Santa Cruz, the groundwater recharge is 91 mm for a mean annual precipitation of 1,284 mm. This corresponds to a recharge of 33,591,000,000 m^3/yr for the entire Department of Santa Cruz and indicates that 24,620 m^3/yr of groundwater can be utilized sustainably per person.

Though the above recharge occurs at the river basins of the Itenez River, the Mamore River, the Isozog River, and the Paraguay River, the groundwater recharge is negative at the Itenez and Isozog river basins. On the other hand, the groundwater recharge is large and reaches 326 - 202 mm at the Mamore and Paraguay river basins.

(3) Types of Groundwater

In "Escudo Central," the weathered belts of the Pre-Cambrian system serve as favorable aquifers which accompany stratum water and parts of the Pre-Cambrian system where fissures have developed accompany fissure water.

In "Cordillera Oriental," "stratum water" exists in the Quaternary system which fills the valleys of the valley region and "fissure water" exists in the Devonian, Carboniferous, Cretaceous, and Tertiary systems which comprise the bedrock. Although the stratum water in the Quaternary system has been mainly targeted for development in the past, development targeting the fissure water in the bedrock is beginning to be carried out recently due to improvements in the capacities of drilling equipment and in drilling techniques.

In "Llanura Chaco-Beniana," stratum water exists in the Quaternary system. The boundary between Quaternary system and the Tertiary system below the Quaternary system also serves as a good aquifer for stratum water.

(4) Past Groundwater Development

In the Department of Santa Cruz, groundwater development has been carried out in high concentrations in the past in the "belt-like region with a width of 150km in the east-west direction from 'Seranias Sub-Andinas' to 'Llanura Chaco-Beniano' and extending in the north-south direction." Groundwater development has also been carried in a dispersed manner in "Escudo Central." Besides the above regions, well construction has been carried out only sparsely in the central part (called the "chaco") and northern part of the Department of Santa Cruz and in the eastern parts of "Escudo Central."

Until recently, the construction of wells in the above-mentioned regions were carried out generally to a depth range of 5 - 200 m due to the capacities of driling machines and past economic conditions. As a result, in cases where the groundwater had odors or was high in salinity and in cases where the well yield varied seasonally, the problems were left unsolved and rainwater collected during the rainy season and water in the "atajados" were used despite sanitation problems.

However, as deep underground locations have come to be drilled in relation to recent oil development activities, it has become clear that excellent aquifers exist at deep locations. Wells of the 300 - 400 m class have thus gradually begun to be drilled and the above-mentioned problems are beginning to be solved.

(5) Current Problems in Terms of Groundwater Development

One of the reasons why wells have been constructed only sparsely in the central part of the Department of Santa Cruz is that the groundwater at shallow underground locations is high in salinity. Although it is good news that this problem is gradually beginning to be solved in the Department of Santa Cruz through the planning of groundwater development aimed at deep underground locations, since the private well constructors of Bolivia are reusing old drilling machines for oil development as machines for drilling deep locations, all of the equipment and materials, including the accessory equipment, are unnecessarily large. thus, not only is time required for transport and demobilization but all types of costs, such as operation costs and repair costs, are also becoming expensive (MR Table 4-3-7).

Furthermore, since most of the existing drilling equipment for well construction are old models and since developments targeting the stratum water in the Quaternary system have been carried out with such drilling equipment, the drilling machines lack the capacity to drill the bedrock further below or lack the equipment and materials necessary. Thus drilling machines fail frequently and it is difficult to set drilling costs and schedules.

Depart.	Name of Organization	Instit. Pub.(A) Priv.(B) Coop.(C)	Number of Equipment	Model of Equipment	TradeMark of Equipment	Type of Drill. (D):rotary (E):percu.	Capacity for Drilling (m)	Effici. & Dia. of the Depth Depth (m)	Diameter	Note
Santa Cruz	AQUATEC	B	5	1975*2	-	D(5)	100-600	500	24"	*2 to 1990
	HIDROSUR	B	3	1985*3	-	D(3)	100-600	600	30"	*3 to 1990
	EMPRESA ORIENTE	B	5	1975*1	-	D(5)	100-300	300	30"	*1 to 1986
	CAPTAGUA	B	3	1980*4	-	D(3)	300	300	20"	*4 TO1986
	ABELPO	B	1	1980	-	D(1)	100-200	200	17"	
	INCOTEC	B	1	1982	-	D(1)	100-200	200	17"	
	HNOS.WUANG	B	1	1975	-	D(1)	100-150	150	12"	
	BASO FERRY	B	31	1985	-	D(1)	100-120	120	12"	
Total	-	-	20	-	-	-	-	-	-	

Since the construction cost will be high for deep wells, geophysical prospecting techniques must be exploited in order to carefully select the well position, and to raise the rate of success of wells. Also, after drilling the well, the setting positions of screens must be determined accurately to thereby increase the well yields.

(6) Results of Geophysical Prospecting

The geological structures presumed from the electrical sounding and electromagnetic sounding carried out at San Carlos and Quituquina in the Department of Santa Cruz are consistent with the structures determined from the construction and logging results of wells constructed in the same districts (JC-4 and JC-5 : Figures 4-2-8, 4-2-9).

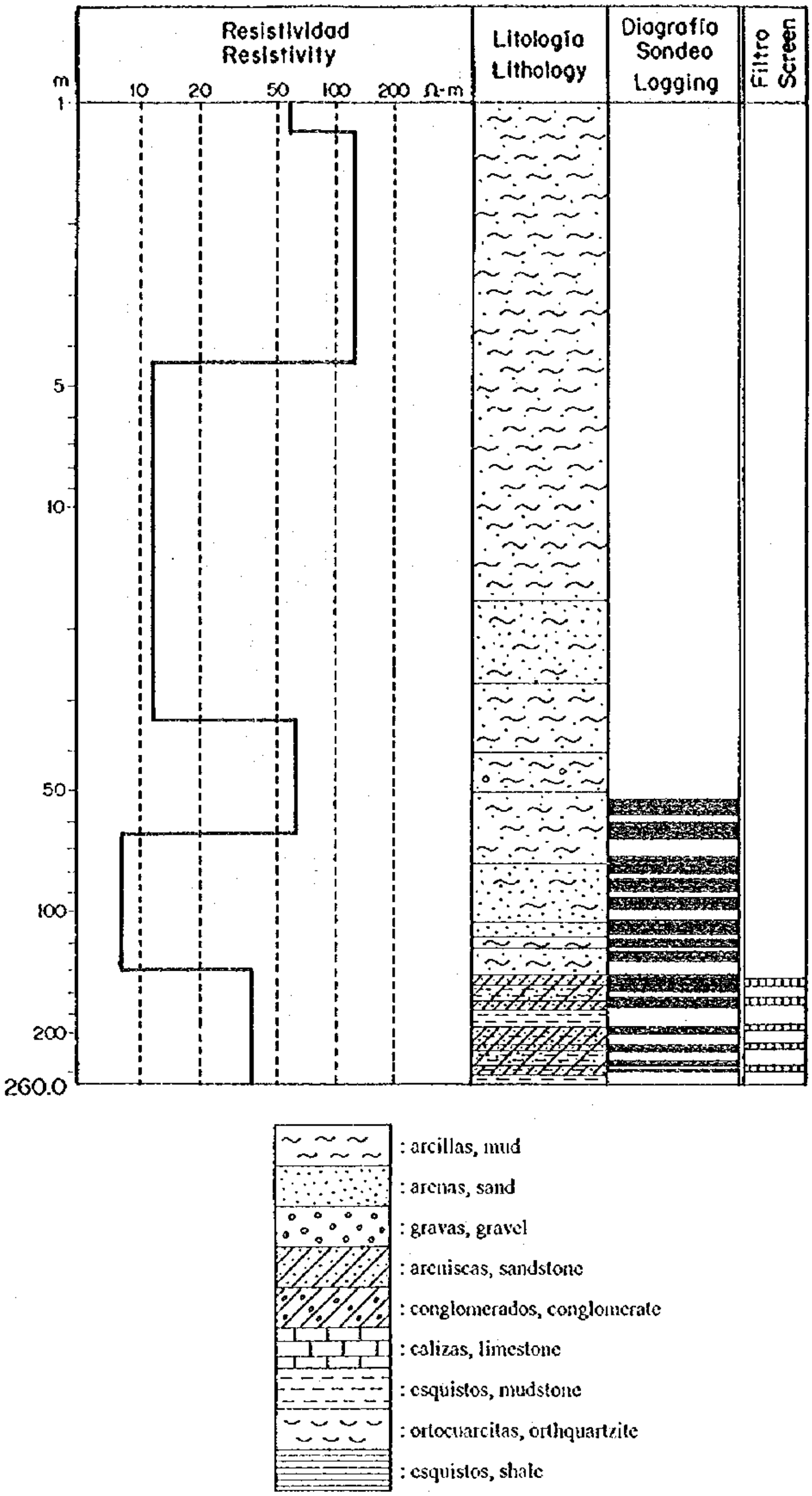


Figura 4-2-8 Relation de Resultados entre Prospeccion Geoficica, Perforacion y Sondeo sobre JC-4

Figure 4-2-8 Relation of Results among Geophysical Prospecting, Drilling and Logging on JC-4

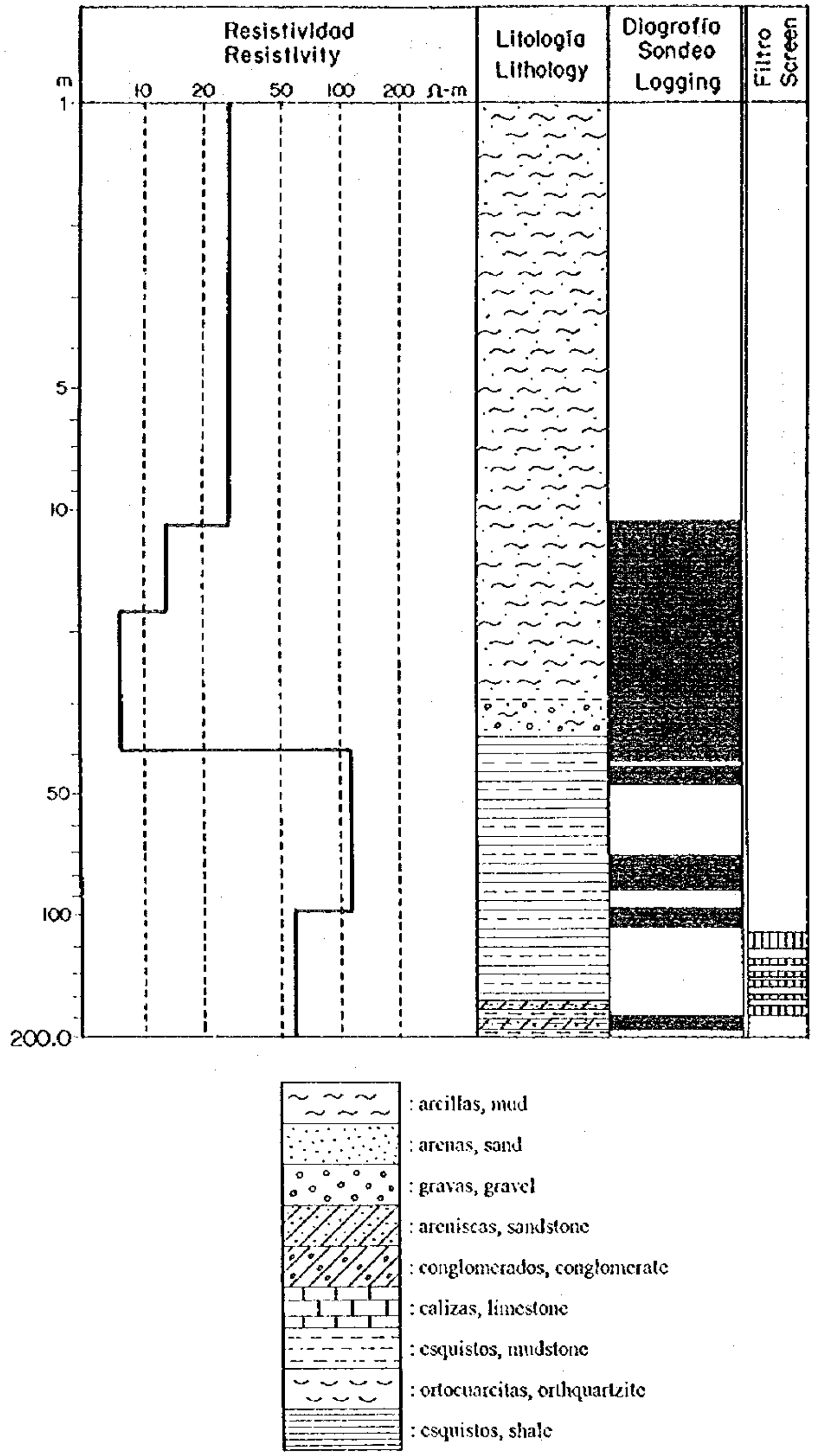


Figura 4-2-9 Relation de Resultados entre Prospeccion Geoficica, Perforacion y Sondeo sobre JC-5

Figure 4-2-9 Relation of Results among Geophysical Prospecting, Drilling and Logging on JC-5

(7) Results of Test Wells

In the Department of Santa Cruz, well No. JC-4 was drilled in San Carlos and well No. JC-5 was drilled in Quituquina.

San Carlos, where well No. JC-4 was drilled, is located at an altitude of 555 m in the western part of "Llanura Chaco-beniana." Although there is a well which has been drilled to a depth of 130 m in the Quaternary system in this region, groundwater does not exist in this well and the groundwater of the shallow wells in the vicinity accompany odors.

The geology at this test well is as follows:

0.0 m - 5.0 m: Quaternary system	: clay with sand
5.0 m - 10.0 m: Quaternary system	: sand with mud
10.0 m - 19.0 m: Quaternary system	: mud with sand
19.0 m - 29.0 m: Quaternary system	: sand with mud
29.0 m - 37.0 m: Quaternary system	: mud with sand
37.0 m - 47.0 m: Quaternary system	: mud and sand with gravel
47.0 m - 80.0 m: Quaternary system	: mud with sand
80.0 m -136.0 m: Quaternary system	: sand with mud
136.0 m -154.0 m: Tertiary system	: **Aquifer** ; sand and mud
154.0 m -159.0 m: Tertiary system	: sandstone, mudstone and conglomerate
159.0 m -165.0 m: Tertiary system	: sandstone and mudstone
165.0 m -173.0 m: Tertiary system	: **Aquifer** ; fissured sandstone
173.0 m -190.0 m: Tertiary system	: **Aquifer** : alternation of sandstone, mudstone and conglomerate
190.0 m -260.0 m: Tertiary system	: **Aquifer** ; alternation of sandstone, mudstone

Quituquina, where well No. JC-5 was drilled, is located at the eastern edge of "Llanura Chaco-Beniana" and is a village at an altitude of 290 m between "Escudo Central" and "Seranias Chiquitanas."

The geology at this well is as follows:

0.0 m - 9.0 m: Quaternary system	: clay and mud
9.0 m - 25.0 m: Quaternary system	: sand and clay
25.0 m - 30.0 m: Quaternary system	: sand and clay with gravel
30.0 m - 38.0 m: Quaternary system	: shale
38.0 m -200.0 m: Precambrian system	: partly **Aquifer** : alternation of

shale and mudstone

The conditions of these wells are as follows:

Table 4.2.4 Hydraulic Constants

	Block #	a: Diameter of dril. (m)	b: Dep. of Drill (m)	k: Static W.L. (m)	l:Yield (m3/hr)	n:Draw down (m)sw	p:Specific Cap. (m3/day)	q: Transmisivity <T>	r: Hydraulic Cond. <K>	s: Strativity <S>
JC-4	701020130	218.0	100.0	6.5	7.2	19.0	0.4	0.521×10^{-3} m²/sec.	0.043×10^{-3} m/sec.	0.000×10^{-2}
JC-5	705010104	216.0	100.0	7.2	7.2	21.8	0.2	0.086×10^{-3} m²/sec.	0.003×10^{-3} m/sec.	0.000×10^{-2}

For well No. JC-4, the drawdown after 24 hours was 35.5 m for a well depth of 260 m, static water level of 57.5 m, and a pump discharge of 36.0 m^3/hr. The dynamic water level at this time was 92.96 m, with about 53 m left to the head part of the uppermost screen among the screens that were set at 5 locations.

From this condition and from the well structure, it is estimated that the pump discharge of well No. JC-4 is limited to about 1,200 m^3/day (50 m^3/hr). The transmissivity calculated with Jacob's non-equilibrium formula was 0.613 x 10-3 m^2/sec.

The abovementioned empty well with a depth of 130 m is located 250 m east of well No. JC-4 and a shallow well with groundwater with odor exists 1,500 m to the southwest of well No. JC-4. That the conditions of well No. JC-4 are as indicated above despite the conditions of these other wells indicates that both water quantity and quality are improved and groundwater development can be carried out favorably by making the well depth deeper. Similarly significant results were also obtained for well No. JC-8 (La Choza) in the Department of Tarija and also in Corque in the Department of Oruro.

For well No. JC-5, the drawdown after 15 hours was 90.0 m for a depth of 200 m, a static water level of 32.5 m and a pump discharge of 2.5 m3/hr. The dynamic water level at this time was 122.5 m, and reaches the uppermost screen among the screens that were set at 6 locations. However, the dynamic water level rose thereafter and recovered to 88.5 m 24 hours after the start of pumping.

From this condition and from the well structure, it is estimated that the pump discharge of well No. JC-4 is limited to about 43 m^3/day (1.8 m^3/hr).

Due to the capacity of the pump and the yield and head of the well, the data necessary for deriving the formula for the relationship between the drawdown, s, and the pump discharge, Q, could not be determined for well No. JC-5.

The transmissivity calculated with Jacob's non-equilibrium formula was 0.002×10^{-3} m^2/sec.

(8) Feasibility of Groundwater Development

Although it has become clear from the results of well No. JC-4 and from the well database that yields of 15 - 50 m^3/hr can be anticipated from the boundary between the Tertiary and Quaternary systems at the western part of "Llanura Chaco-Beniana," it has also become clear from well No. JC-5 that yields of only 2 - 3 m^3/hr can be expected at regions sandwiched between "Escudo Central" and "Seranias Chiquitanas."

With regard to the above results, although the yields expected in the western part of "Llanura Chaco-Beniana" are consistent with the well yields that can be determined from the well database, the yields expected for the region between "Escudo Central" and "Seranias Chiquitanas" are extremely low in comparison to the well yields that can be determined from the database (MR Figure 4-2-3). This is because the number of existing wells is extremely few in this region between "Escudo Central" and "Seranias Chiquitanas" and the records of wells with unusually high yields, which were coincidentally obtained from this region, were strongly reflected in the analysis diagram prepared from the database. From the geological conditions of the surrounding area, the results of well No. 5 is considered to be close to the characteristics of a typical well with a depth of approximately 200 m in the region between "Escudo Central" and "Seranias Chiquitanas."

As can be seen from the results of well No. JC-5, although the groundwater in the region between "Escudo Central" and "Seranias Chiquitanas" has a tendency to be extremely high in salinity, since there is a negative correlation between well yield and salinity in Bolivia, groundwater of good quality could be obtained if an aquifer of high transmissivity is secured by setting a deep drilling depth in a region where the bedrock of the Pre-Cambrian system rises to a depth of 200 - 300 m.

(9) Policy for Future Groundwater Development

MR Figure 4-2-7 shows the provincia-wise criteria for the Department of Santa Cruz as considered from a hydrogeological viewpoint. These can be summarized in a general manner as follows:

In terms of well yield and the rate of success, the "belt-like region with a width of 150km in the east-west direction from 'Seranias Sub-Andinas' to 'Llanura Chaco-Beniano' and extending in the north-south direction" is a promising candidate region for groundwater development in the Department of Santa Cruz. Within this range, groundwater development should be targeted at the "stratum water" existing at the boundary between the bottom of the Quaternary system and the bedrock below it and at the "fissure water" in the bedrock further below.

Since the groundwater in the Quaternary system is high in salinity at the central part of the Department of Santa Cruz, there is a necessity for securing the "fissure water" in the bedrock below the Quaternary system and from past experience, it is considered that well depths of 250 - 450 m will be required. In such regions, the filling from the depth of the aquifer accompanying groundwater of high salinity to the surface should be performed not with gravel but with a clayish substance or cement, etc. to prevent the intake of groundwater of high salinity at the upper levels. Since the filled parts accompany groundwater of high salinity, salt-resistant cement will be required. This requirement also applies to the bentonite to be used for well drilling. Furthermore, the conductivity of the circulating water during well drilling should be measured or so-called "well-logging" should be performed to determine the depth at which clayish substance/cement filling is to be performed.

There are parts with gypsum interleaved in a stratum-like manner in the Tertiary system distributed in the southern part of "Seranias Sub-Andinas" and considerations similar to those necesary for the central part of the Department of Santa Cruz are required for such parts. It is also predicted from the well database that wells with depths of approximately 400 m must be constructed at locations adjacent to the above-mentioned parts and near the Department boundary with the Department of Chuquisaca.

In the "Escudo Central" zone, which is comprised of the Pre-Cambrian system, wells targeted at the "stratum water" in the weathered belt in the bedrock or the "fissure water" in fissures should be constructed to depths of approximately 100 m for the time being. Although there is a possibility that the groundwater in the region between "Escudo Central" and "Seranias Chiquitanas" is extremely high in salinity, since this trend is predicted to be in negative correlation with the well yield, the lineament structure of the surroundings should be analyzed and regions with favorable groundwater flow conditions should be selected as well construction districts.

From the above, wells of the 100 - 450 m class must be constructed in the Department of Santa Cruz.

The well diameter at the well bottom during drilling should be in the range 10 5/8" - 12 1/4", the diameters of screens and casings should be 6" - 8 5/8", and the ratio of the length of the screen to the drilling length should be 15% - 30%. In order to obtain a high well yield, the screens or casings must be inserted down to the bottom of the well.

In regions where the groundwater at shallow underground locations are high in salinity, such as the central part of the Department of Santa Cruz, the filling from the depth of the aquifer accompanying groundwater of high salinity to the surface should be performed not with gravel but with a clayish substance or cement, etc. to prevent the intake of groundwater of high salinity at the upper levels. Since the filled parts accompany groundwater of high salinity, salt-resistant cement will be required. This requirement also applies to the bentonite to be used for well drilling. Furthermore, the conductivity of the circulating water during well drilling should be measured or so-called "well-logging" should be performed to determine the depth at which clayish substance/cement filling is to be performed.

10) Requirements for Future Groundwater Development

For the groundwater development in the Department of Santa Cruz, geological structure analysis and geophysical prospecting must be carried out to grasp the geological structure of the area around a well before constructing the well in order to raise the rate of success of wells. For this purpose, the necessary personnel must be secured. Office equipment for arranging various data, aerial photographs, geophysical prospecting equipment, and a station wagon, pickup truck, etc. for providing mobility for the prospecting team are also needed.

In groundwater development, electrical sounding methods are generally used to grasp the aquifer structure at 200 - 250 m below the surface. On the other hand, electromagnetic sounding or gravity prospecting methods are effective for grasping base structures below 250 m.

While trees must be cleared to provide a long traverse line for measurements in the case of electromagnetic sounding, such clearing is hardly required in the case of gravity prospecting. Gravity prospecting is therefore preferred over electromagnetic sounding in regions where the vegetation is dense and in mountainous areas with steep landforms. Gravity prospecting is also more preferable in cases where shallow underground locations accompany groundwater of high salinity.

The drilling of wells require personnel for drilling and drilling equipment that can tolerate the drilling of 100 - 450 m class wells. 500 - 600 m class drilling equipment will thus be necessary to provide leeway in the capacity of the equipment.

For the drilling equipment, models with functions for the reverse circulation method must be selected to cope with riverbed sediments comprised of unconsolidated or semi-consolidated boulders and boulder gravel. The drilling equipment must also enable rotary and down-the-hole methods for development targeting the "stratum water" in the Quaternary system and the "fissure water" in the hard bedrock. A tank lorry for drilling water, an air compressor with adequately high pressure and air volume, and bits of various sizes for rotary and down-the-hole methods will thus be required.

A small tank lorry for fuel, a support truck with crane, a small truck, a station wagon for engineers, workshop vehicles for equipment repairs, etc. are also needed. Communication equipment are also necessary for communication between the well construction site and the office for schedule management.

Each of the above equipment require spare parts. Since the station wagon for engineers will be driven out of necessity at relatively high speeds and over long distances, the wearing of tires and various types of spring systems will be severe. The replenishment of such spare parts will thus be essential.

Logging must be performed to increase the yield of the well. This will require functions for electrical resistivity logging, self-potential logging as well as gamma ray logging, which is effective for detection of parts besides the aquifer. Electronic recording methods are preferred as recording methods. Logging equipment should be operated and maintained by the geophysical prospecting team.

Although steel pipes should be adequate for the casings for final construction of the well, screens must be made of stainless steel as steel screens are weak against corrosion.

Pumping tests must be carried out on completed wells in order to determine the well yields for water supply facility designs and to grasp the hydrogeological characteristics of the aquifer for planning future groundwater development and environmental conservation.

In the pumping test, the pump discharge, the dynamic water level, variations in water quality during pumping (especially the pH and conductivity), etc. should be recorded and water quality analysis should be performed as a final step after the completion of the pumping test. A submerged pump, a generator, instruments for measuring the water level, pH, and conductivity, a water quality analysis set, etc. are needed for this purpose.

The capacities of the submerged pump and generator for pumping tests should preferably be adequate for a pump head of 80 - 350 m and a pump discharge of 5 - 50 m3/hr.

Pumps for production wells will require a submerged pump with a capacity adequate for a pump head of 80 - 350 m and a pump discharge of 5 - 30 m3/hr.

Safe storage locations of adequate area must be secured and appropriate storage and management methods must be established for the storage of the above-mentioned equipment and materials.

The securing of personnel for operating and managing the above-mentioned equipment and materials is a most important requirement. Personnel for operating the equipment should be secured to enable 24-hour drilling work.

It is preferable to construct a facility that provides the functions of a "machine shop (repair shop)," a "spare parts repository," and a "training center" at the central agency of the Department and to gather engineers in the regional areas every few years to such a facility to provide training by engineers of the central agency on the disassembly, repair, etc. of generators, pumps, water supply equipment, etc. and to collect records for groundwater management at each regional area in order to examine matters pertaining to maintenance and management.

D. REGIONAL GROUNDWATER DEVELOPMENT PLAN

1. Procedure to Estimate Future Capacity of Existing Water Supply Systems
2. List of Candidate Water Blocks for Development Plan
3. Unit Cost for Construction of Water Supply Facility
4. Investment Plan up to 2000 Year

D. REGIONAL GROUNDWATER DEVELOPMENT PLAN

1. Procedure to Estimate Future Capacity of Existing Water Supply Systems
2. List of Candidate Water Blocks for Development Plan
3. Unit Cost for Construction of Water Supply Facility
4. Investment Plan up to 2000 Year

[illegible]

[illegible]

[illegible]

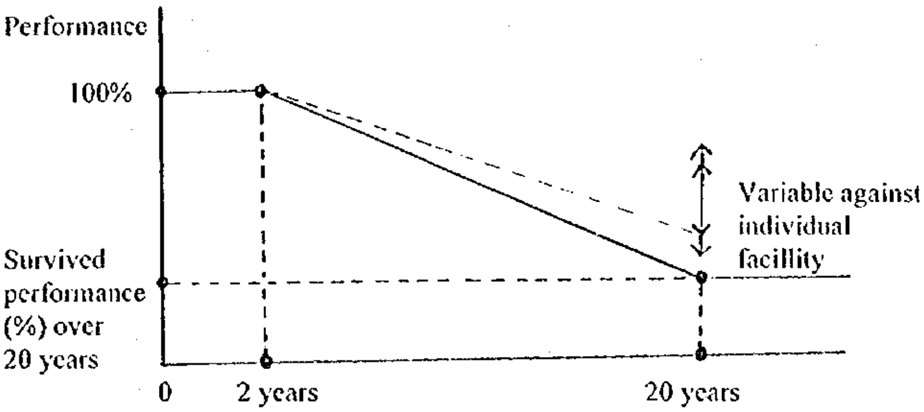
[illegible]

[illegible]

AN ESTIMATION PROCEDURE OF THE EXISTING WATER SUPPLY CAPACITY MAINTANAIBLE BY 2,000 YEAR

(1) Pattern of Performance Decrease

A water supply facility can usually for a few tens years but its performance decreases with age cannot be avoidable. A typical pattern of the performance decrease shall be as follow.



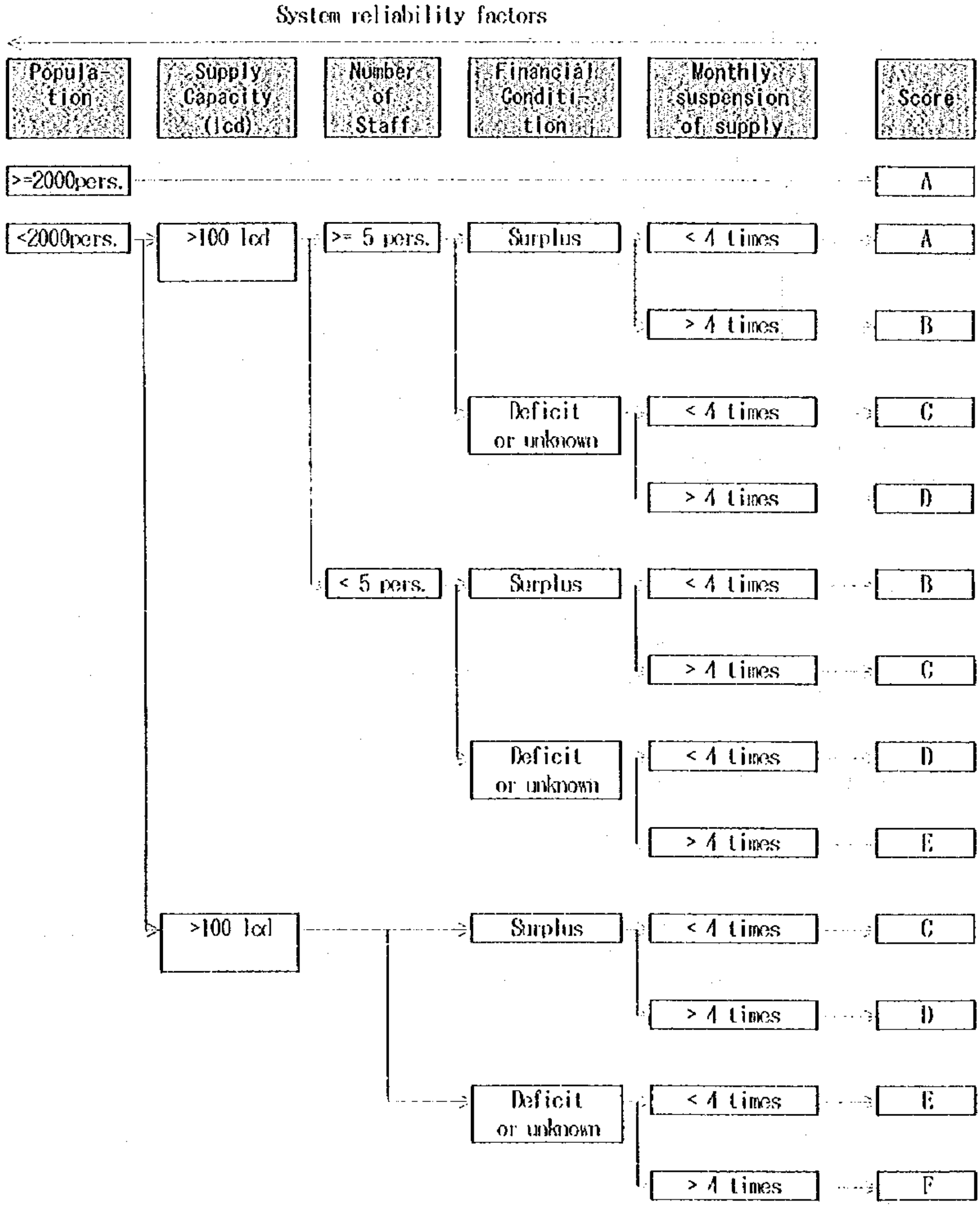
Period-1, 0 to 2 years: almost no performance decrease as facility is still quitte new.
Period-2, 2 to 20 years: performance will be on the decline as the practiceof maintenance is not sufficintly gained by rural persons in charge.
Period-3, 20 to more years: persons in charge make a good use of learning effect in maintenance, so the decline of performance become stop.

(2) Estimating Procedure of System Performance in the Future

The capacity of the existing water supply facility at 2000 yeqr shall be estimated by a following procedure.

(a) At first the sustainability of the existing facility is indirectly quessed by an appraisal of System Reliablity Factors, for which special score is given.
Refer to Figure of System Reliability and Score.

System Reliability and Score



Against above score, the system capacit over 2000 year is assumed as following Table.

Table Survived System Performance (%) over 20 years.

Score	Performance (%) able to survive over 20 years
A	100%
B	80%
C	60%
D	50%
E	40%
F	30%
G	20%
H	10%

(3) The Servived Performance Hold by Existing Facility at 2000 year

(a) For the existing facility that shall pass overe 20 working age in 2000 year.

i) At first, decide maintainable performance (%) over 20 years by use of the figure and Table.

ii) Next, as in this case, the facility is standing in the period-3 in 2000 year, same above 20 year's performance (%).

(b) For the existing facility that shall be within 19 working age in 2000 year.

i) At first, decide maintainable performance (%) 20 year's by use of the evaluation figure and table.

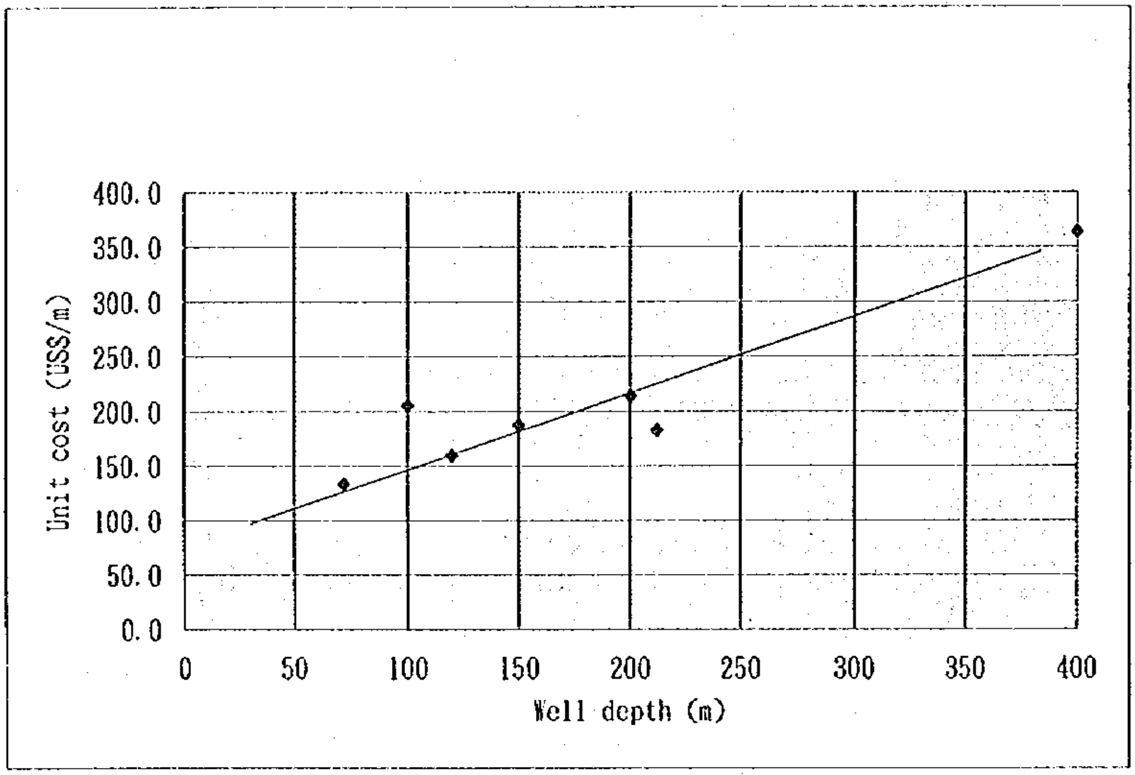
ii) Draw a performance decrerasing curve, connecting the point of 100% performance to the point of performance (%) a 20 year.

iii) On the decreasing curve, find maintainable performance (%) in 2000 year (or at actual facility age).

Unit cost for well construction

(Including well casing, screen, and gravel packing)

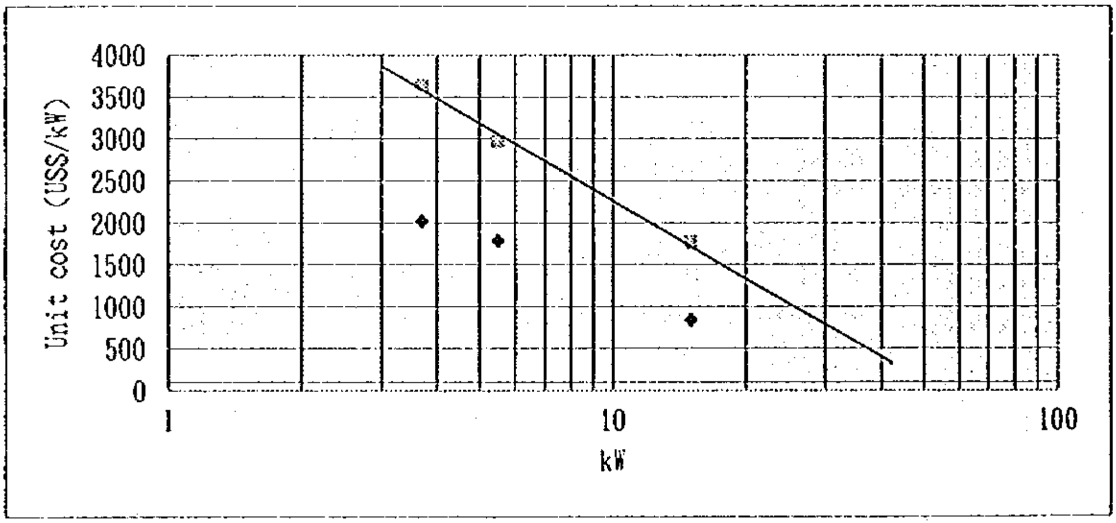
Well depth (m)	400	212	200	150	120	100	72
Unit cost (US$/m)	363.3	183.0	214.0	187.6	160.0	205.2	134.0



Submersible motor pump

(Resume cost)

kW	3.7	5.5	15
US$/kW	2021.6	1785.5	836.0
US$/kW (include pannel)	3634.0	2967.0	1761.0



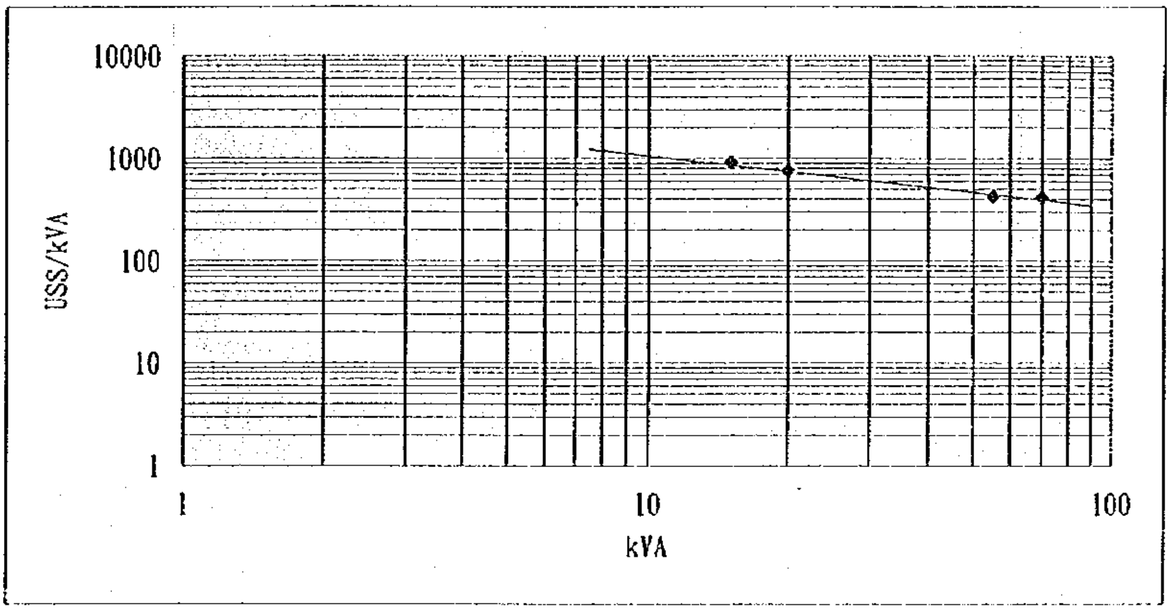
Hand pump

(Including construction and transport)

Yacu	238 US$

Engine generator unit cost resume

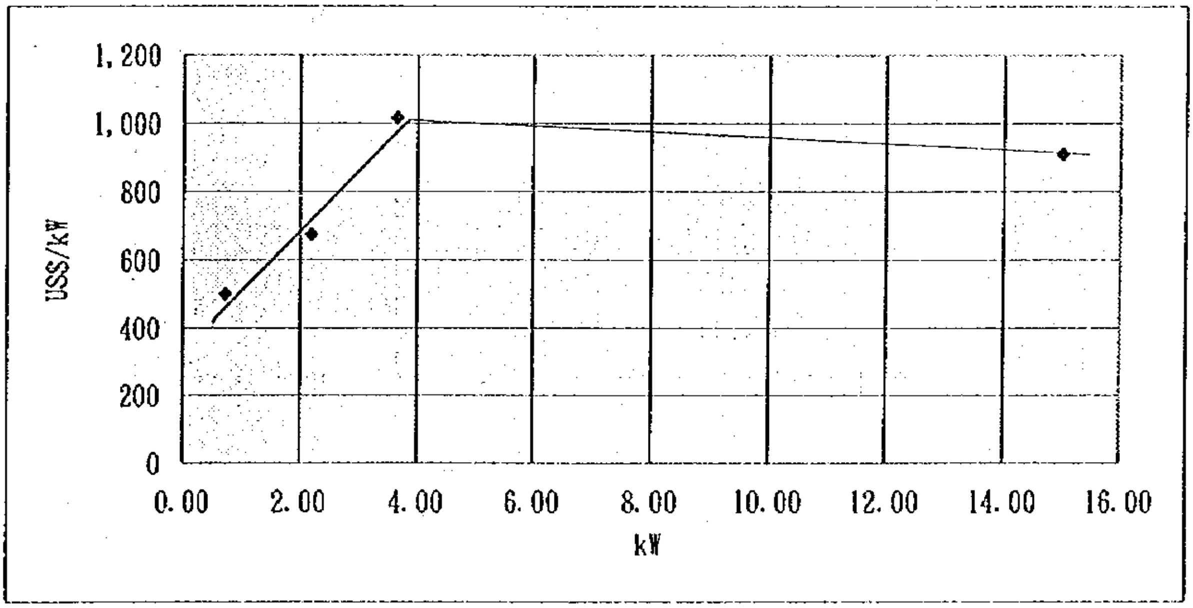
kVA	15	20	55	70
US$/kVA	922.7	762.5	423.2	416.7



Booster pump

(Include control pannel, construction, and transport)

kW	0.73	2.19	3.65	15.00
US$/kW	500	675	1,015	910



Pipe PVC

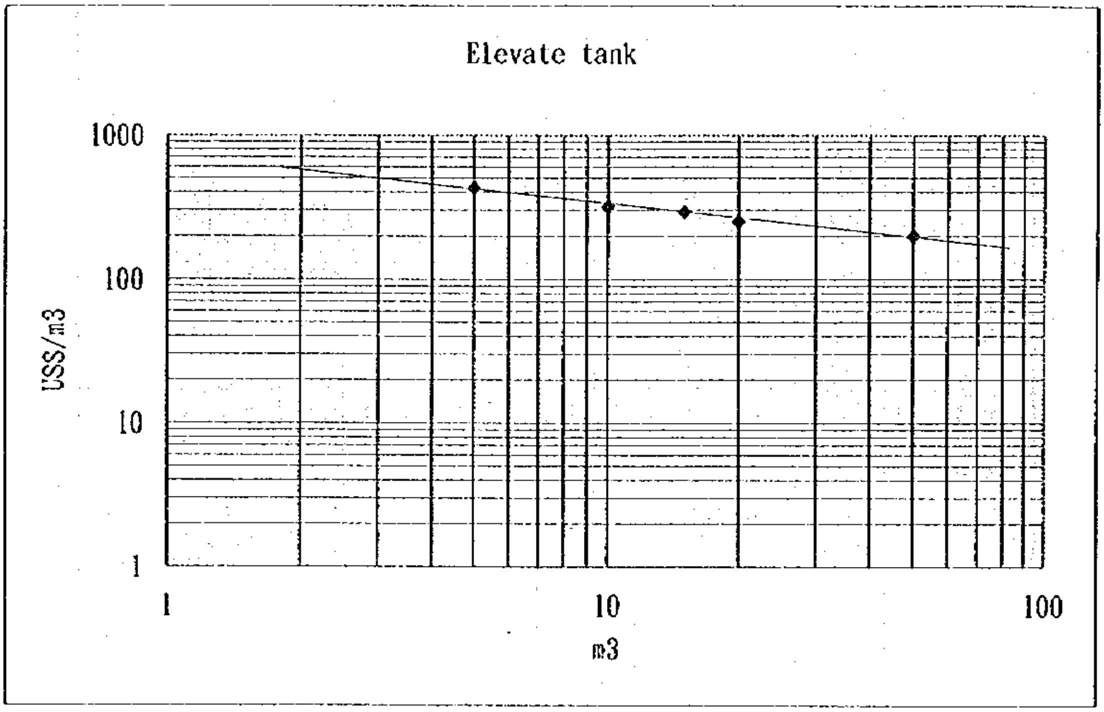
Diameter (Inch)	Cost 1 (US$/m)	Cost 2 (US$/m) (Including pipe fittings, installations and transportation)
3/4"	1.15	1.72
1"	1.70	2.55
1½"	2.73	4.10
2"	3.85	5.77
3"	6.02	9.03
4"	12.67	19.00
6"	22.34	33.51
8"	33.63	50.45
10"	42.32	63.48

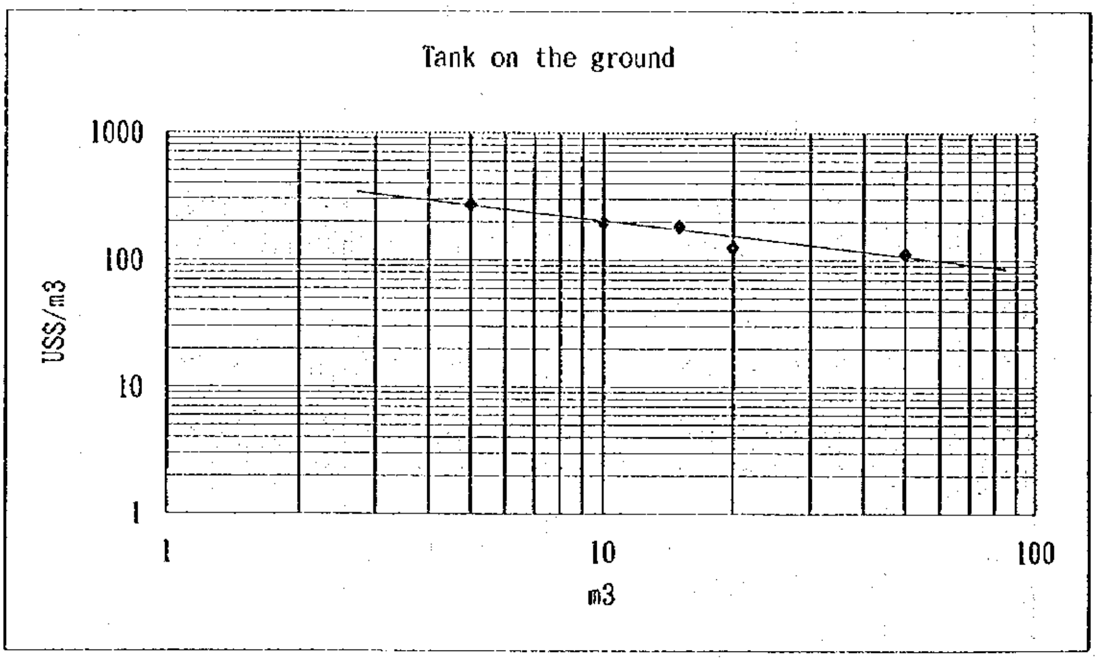
Diameter (inch)	L (m)	Type	Price in	Cost (US$)	Cost/m (US$)
6"	6	Camdana E40	La Paz	134.00	22.34
6"	6	Camdana E40	La Paz	201.00	33.50
6"	6	Clase 9	La Paz	123.83	20.64
6"		C9 US	Santa Cruz		15.51
6"		C12 US	Santa Cruz		5.71
6"		Clase S.E.L	Santa Cruz		4.73
					22.34
8"	6	Camdana E40	La Paz	201.81	33.64
8"	6	Clase 9	La Paz	191.17	31.86
8"		C9 US	Santa Cruz		23.91
8"		C12 US	Santa Cruz		22.94
					33.63
10"	6	Camdana E40	La Paz	286.08	47.68
10"		C 15 (NBR5647)	Santa Cruz		42.32
10"		C 9	Santa Cruz		38.67
10"		C12	Santa Cruz		38.67
					42.32

Diameter (inch)	L (m)	Type	Price in	Cost (US$)	Cost/m (US$)
3/4"	5	Rosca	La Paz	5.70	1.14
3/4"	5	Rosca	Santa Cruz	4.25	0.85
3/4"	6	Camdana E40	La Paz	6.87	1.15
					1.15
1"	5	Rosca	La Paz	8.47	1.69
1"	5	Rosca	Santa Cruz	7.02	1.40
1"	6	Camdana E40	La Paz	10.08	1.68
					1.70
$1^{1/2}$"	5	Rosca	La Paz	13.63	2.73
$1^{1/2}$"	5	Rosca	Santa Cruz	11.70	2.34
$1^{1/2}$"	6	Camdana E40	La Paz	16.36	2.73
$1^{1/2}$"	6	Camdana E40	Santa Cruz	12.76	2.13
					2.73
2"	5	Rosca	La Paz	13.64	2.73
2"	6	Camdana E40	La Paz	23.13	3.85
2"	6	Camdana E40	Santa Cruz	17.02	2.84
2"		C12 US	Santa Cruz	-	2.30
2"		2CI5	Santa Cruz	-	3.29
2"	6	Camdana E40	La Paz	35.36	5.89
					3.85
3"	4	Rosca	La Paz	8.17	2.04
3"	6	Camdana E40	La Paz	53.40	8.90
3"	6	Camdana E40	Santa Cruz	36.17	6.02
3"	6	Camdana E40	La Paz	72.23	12.04
3"	6	Clase 9	La Paz	34.82	5.80
3"	6	Clase 9	Santa Cruz		4.36
3"		C12 US	Santa Cruz		2.30
3"		Clase S.E.L	Santa Cruz		1.27
		Duraplast			
					6.02
4"	4			11.93	2.98
4"	6	Camdana E40	La Paz	76.04	12.67
4"	6	Camdana E40	Santa Cruz	53.19	8.87
4"	6	Camdana E40	La Paz	86.34	14.39
4"	6	Clase 9	La Paz	57.53	9.59
4"	6	Clase 9	Santa Cruz		7.19
4"		CL I2 US	Santa Cruz		8.47
4"		C-I5	Santa Cruz		8.17
4"		CL I2	Santa Cruz		57.57
4"		Clase S.E.L	Santa Cruz		1.81
		Duraplast			
					12.67

Tank (resume cost)

Elevate tank					
Capacity (m^3)	5	10	15	20	50
Unit cost (US$/$m^3$)	430	315	291	250	200
Tank on the ground					
Capacity (m^3)	5	10	15	20	50
Unit cost (US$/$m^3$)	271	197	183	125	112





Infiltration gallery

Description	Vol	Unit	Unit P. (US$)	Partial P. (US$)
Pipe hormigon 48"	5.0	Ml	90.0	4.0
Pipe hormigon 10"	49.0	Ml	7.7	377.3
Colocado tubo 10"	49.0	Ml	5.7	279.3
Colocado tubo 48"	6.0	Ml	10.0	60.0
Excavation h=1.5m	29.4	m^3	2.7	79.4
Excavation h=5m	5.0	m^3	4.0	20.0
Relleno	29.4	m^3	1.7	48.9
Total price				868.9

Spring Box

Description	Vol	Unit	Unit P. (US$)	Partial P. (US$)
Excavation	6.0	m^3	2.7	16.2
H. Ciclopeo	12.8	m^3	31.6	404.5
Material selection	1.6	m^3	13.8	22.1
Tapa Ho Ao	0.9		115.7	106.2
Accesorios		GLB		20.0
Total price				569.0

Operation house

Description	Unit	Unit C. (US$)	3 x 3 type		3 x 9 type	
			Quant.	(US$)	Quant.	(US$)
Replanteo	m2	0.18	17.60	3.17	42.00	7.56
Excavacion manual	m3	2.60	2.80	7.28	7.68	19.97
Cimiento HoC	m3	31.70	2.90	91.93	5.80	183.86
Sobrecimiento Hoc	m3	51.80	0.70	36.26	1.38	71.48
Alslamiento Plastico	ml	0.42	2.60	1.09	5.20	2.18
Muro ladrillo 6h	m2	9.60	30.30	290.88	62.70	601.92
Encadenado HoAo	m3	178.60	0.48	85.73	0.96	171.46
Cubierta duralit C/sepcha	m2	12.00	13.60	163.20	37.60	451.20
Empedrado y contradiso	m2	7.00	17.60	123.20	42.00	294.00
Quincalleria				32.70		32.70
Puerta	GL	83.00	1.00	83.00	1.00	83.00
Ueutana	Gl	14.20	1.00	14.20	2.00	28.40
Revoque de Co		6.30	30.30	190.89	62.70	395.01
Pintura a la Cal.		0.98	30.30	29.69	62.70	61.45
Pintura barniz copal		1.03	30.30	31.21	62.70	64.58
Limpieza	Gl			10.00		10.00
Total (US$)				1194.43		2478.77
Area (m2)			9		27	
Unit Cost (US$/m2)				132.7146		91.80626

Operation house unit cost = 92US$/m2

Transformator

	10kVA	
	20kVA	
Alta tension = 6000	400	(industrial)
Trans. para bomba de 5HP		
	para 30 HP	110 kVA

House connection = 25 US$/Pt.

Unit Cost for the Calculation of Project Costs in the Case Studies

1) Procurement of Drilling Equipment

(1) A-type Rig (Drilling depth: 100~150m)	174,600,000¥
(2) B-type Rig (Drilling depth: 200~300m)	230,200,000¥
(3) C-type Rig (Drilling depth: 200~500m)	287,100,000¥
(4) Additional equipment	186,000,000¥
[a] Supporting truck	72,500,000¥
[b] Logging test equipment	30,600,000¥
[c] Prospecting equipment	48,200,000¥
[d] Radio Communication equipment	4,800,000¥
[e] Workshop car	29,900,000¥

Method of calculation:

- In case of procurement only 1 rig of A-type: (1)+(4)+[d] ≒	450,000,000¥
- In case of procurement only 1 rig of B-type: (2)+(4)+[d] ≒	510,000,000¥
- In case of procurement only 1 rig of C-type: (3)+(4)+[d] ≒	570,000,000¥
- In case of procurement 2 rig of A-type and B-type: (1)+(2)+(4)+(4) ≒	850,000,000¥
- In case of procurement 2 rig of A-type and C-type: (1)+(3)+(4)+(4) ≒	920,000,000¥
- In case of procurement 2 rig of B-type and B-type: (2)+(2)+(4)+(4) ≒	920,000,000¥
- In case of procurement 2 rig of B-type and C-type: (2)+(3)+(4)+(4) ≒	980,000,000¥
- In case of procurement 3 rig: (1)+(2)+(3)+(4)+[a]+[d] ≒	1,260,000,000¥

2) Drilling work

(1) By commissioned Bolivian private company	US$300/1m drilled depth
(2) By Japanese team using Japanese rig	US$800/1 m drilled depth
(3) By Bolivian team using Japanese rig	US$200/1 m drilled depth

3) Other equipments and construction of water supply facility

(1) Pump and generator	1,000,000¥/set
(2) Casing	6,888¥/m
(3) Screening	38,500¥/m
(4) Construction of water supply facility	US$50,000/location + US$60/person

Investment Plan of Groundwater Development (1996-2000)
Department of CHUQUISACA

Target:

Population 57,295 persons

Number of Blocks (Wells) 98 (98)

Cost:

(Unit: Million US Dollars)

	1996		1997	1998	1999	2000	Total
	External	Internal	Internal	Internal	Internal	External	
Rig Purchase	7,800						7,800
Drilling Expenses	930		140	140	140	183	1,533
Water Supply Facilities	400		685	685	685	685	3,140
Water Supply Construction			716	716	716	717	2,865
Personnel Expenses		70	140	140	140	140	630
Total	9,130	70	1,681	1,681	1,681	1,725	15,968

Financing

	1996		1997	1998	1999	2000	Total
	External	Internal	External	External	External	External	
Direct Foreign Aid	9,130						9,130
Indirect Foreign Aid			500	500	500	505	2,005
Central Government			300	300	300	300	1,200
Department			526	526	526	565	2,143
Municipalities		70	355	355	355	355	1,490
Total	9,130	70	1,681	1,681	1,681	1,725	15,968

Review

	Investment on Basic Sanitation Average ('92-'94) (A)	Expected Ceiling on G.Water (B)(=A/2)	Ceiling for 5 year on G.Water (C)(=Bx5)	Plan 1996-2000 (D)	Plan compared with ceiling % (D/C)	Viability of Plan
Direct Foreign Aid	--	--	--	9,130	--	
Indirect Foreign Aid	3,225	1,612	8,060	2,004	24.86%	ok
Central Government	493	247	1,235	1,200	97.17%	ok
Department	1,350	675	3,375	2,144	63.53%	ok
Municipalities	--			1,490	26.01%	ok
		$100/p	$100/p	($26.01/p)		

Investment Plan of Groundwater Development (1996-2000)
Southern Part of La Paz

Target:
Population 19,957 persons
Number of Blocks (Wells) 46 (46)

Cost:

(Unit: Million US Dollars)

	1996		1997	1998	1999	2000	Total
	External	Internal	Internal	Internal	Internal	External	
Rig Purchase	4,160						4,160
Drilling Expenses	1,110		54	54	54	54	1,326
Water Supply Facilities	400		295	295	295	295	1,580
Water Supply Construction			245	245	245	263	998
Personnel Expenses		40	80	80	80	80	360
Total	5,670	40	674	674	674	692	8,424

Financing

	1996		1997	1998	1999	2000	Total
	External	Internal	External	External	External	External	
Direct Foreign Aid	5,670						5,670
Indirect Foreign Aid			175	175	175	175	700
Central Government			225	225	225	225	900
Department			124	124	124	124	496
Municipalities		40	150	150	150	168	658
Total	5,670	40	674	674	674	692	8,424

Review

	Investment on Basic Sanitation Average ('92-'94) (A)	Expected Ceiling on G.Water (B)(=A/2)	Ceiling for 5 year on G.Water (C)(=Bx5)	Plan 1996-2000 (D)	Plan compared with ceiling % (D/C)	Viability of Plan
Direct Foreign Aid	--	--	--	5,670	--	
Indirect Foreign Aid	3,709	1,855	9,275	700	7.55%	ok
Central Government	834	417	2,085	900	43.17%	ok
Department	1,500	750	3,750	496	13.23%	ok
Municipalities	--			658	32.97%	ok
		$100/p	$100/p	($32.97/p)		

Investment Plan of Groundwater Development (1996-2000)
Department of ORURO

Target:
- Population: 31,009 persons
- Number of Blocks (Wells): 72 (73)

Cost:

(Unit: Million US Dollars)

	1996		1997	1998	1999	2000	Total
	External	Internal	Internal	Internal	Internal	External	
Rig Purchase	4,160						4,160
Drilling Expenses	1,650		100	100	100	108	2,058
Water Supply Facilities	400		500	500	500	490	2,390
Water Supply Construction			350	350	350	500	1,550
Personnel Expenses		40	80	80	80	80	360
Total	6,210	40	1,030	1,030	1,030	1,178	10,518

Financing

	1996		1997	1998	1999	2000	Total
	External	Internal	External	External	External	External	
Direct Foreign Aid	6,210						6,210
Indirect Foreign Aid			245	245	245	350	1,085
Central Government			400	400	400	400	1,600
Department			200	200	200	198	798
Municipalities		40	185	185	185	230	825
Total	6,210	40	1,030	1,030	1,030	1,178	10,518

Review

	Investment on Basic Sanitation Average ('92-'94) (A)	Expected Ceiling on G.Water (B)(=A/2)	Ceiling for 5 year on G.Water (C)(=Bx5)	Plan 1996-2000 (D)	Plan compared with ceiling % (D/C)	Viability of Plan
Direct Foreign Aid	--	--	--	6,210	--	
Indirect Foreign Aid	3,480	1,740	8,700	1,085	12.47%	ok
Central Government	646	323	1,615	1,600	99.07%	ok
Department	375	187	935	798	85.35%	ok
Municipalities	--			825	26.61%	ok
		$100/p	$100/p	($26.61/p)		

Investment Plan of Groundwater Development (1996-2000)
Department of TARIJA

Target:

Population 35,128 persons

Number of Blocks (Wells) 85 (85)

Cost:

(Unit: Million US Dollars)

	1996		1997	1998	1999	2000	Total
	External	Internal	Internal	Internal	Internal	External	
Rig Purchase	7,800						7,800
Drilling Expenses	1,620		135	135	135	129	2,154
Water Supply Facilities	400		590	590	590	580	2,750
Water Supply Construction			435	435	435	451	1,756
Personnel Expenses		70	140	140	140	140	630
Total	9,820	70	1,300	1,300	1,300	1,300	15,090

Financing

	1996		1997	1998	1999	2000	Total
	External	Internal	External	External	External	External	
Direct Foreign Aid	9,820						9,820
Indirect Foreign Aid			305	305	305	314	1,229
Central Government			190	190	190	180	750
Department			535	535	535	529	2,134
Municipalities		70	270	270	270	277	1,157
Total	9,820	70	1,300	1,300	1,300	1,300	15,090

Review

	Investment on Basic Sanitation Average ('92-'94) (A)	Expected Ceiling on G.Water (B)(=A/2)	Ceiling for 5 year on G.Water (C)(=Bx5)	Plan 1996-2000 (D)	Plan compared with ceiling % (D/C)	Viability of Plan
Direct Foreign Aid	--	--	--	9,820	--	
Indirect Foreign Aid	482	241	1,205	1,229	101.99%	ok
Central Government	188	94	470	750	159.57%	ok
Department	1,725	863	4,315	2,134	49.46%	ok
Municipalities	--			1,157	32.94%	ok
		$100/p	$100/p	($32.94/p)		

Investment Plan of Groundwater Development (1996-2000)
Department of SANTA CRUZ

Target:

Population 112,396 persons

Number of Blocks (Wells) 155 (158)

Cost:

(Unit: Million US Dollars)

	1996		1997	1998	1999	2000	Total
	External	Internal	Internal	Internal	Internal	External	
Rig Purchase	9,600						9,600
Drilling Expenses	1,620		250	250	250	327	2,697
Water Supply Facilities	400		1,150	1,150	1,150	1,090	4,940
Water Supply Construction			1,400	1,400	1,400	1,420	5,620
Personnel Expenses		100	200	200	200	200	900
Total	11,620	100	3,000	3,000	3,000	3,037	23,757

Financing

	1996		1997	1998	1999	2000	Total
	External	Internal	External	External	External	External	
Direct Foreign Aid	11,620						11,620
Indirect Foreign Aid			980	980	980	994	3,934
Central Government			425	425	425	425	1,700
Department			973	973	973	998	3,917
Municipalities		100	622	622	622	620	2,586
Total	11,620	100	3,000	3,000	3,000	3,037	23,757

Review

	Investment on Basic Sanitation Average ('92-'94) (A)	Expected Ceiling on G.Water (B)(=A/2)	Ceiling for 5 year on G.Water (C)(=Bx5)	Plan 1996-2000 (D)	Plan compared with ceiling % (D/C)	Viability of Plan
Direct Foreign Aid	--	--	--	11,620	--	
Indirect Foreign Aid	2,940	1,470	7,350	3,934	53.52%	ok
Central Government	346	173	865	1,700	196.53%	ok
Department	2,850	1,425	7,125	3,917	54.98%	ok
Municipalities	--			2,586	23.01%	ok
		$100/p	$100/p	($23.01/p)		