References

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

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

<3: Estudio del Origen y Proceso de Salinización de las Aguas del Río San José, I Región, Chile, November 1991 for DGA by Peña, Pollastri, Salazar y Gutiérrez.

<4: Estudio Análisis de los Recursos de Agua de la Primera Región de Tarapacá, June 1991 for DGA by Ingeniería y Geotecnía Ltda.

Table B-I, 3.1 Dynamic Water Level (Azapa Valley)

<Nivel Dinámico (Valle de Azapa)>

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

NOTE: COMPILED FROM WELL INVENTORY

Table B-I, 3.2 (1) Variation of Groundwater Table (Azapa Valley)

< Variación de Nivel Estatico (Valle de Azapa)>

WELL	226-0	133-7	126-4	214-7	108-K	164-7	110-8	111-6	108-6	109-4	122-1	129-9	115-9	112-4	113-2
	1880 7910	1880 7910	1880 7910	1880 7910	1880 7910	1880 7910	1880 7910	1880 7910	1880 7910	1880 7910	1880 7910	1880 7000	1880 7000	1830 7000	1830 7000
DATE	AD-13	CC-15	CC-16	CC-21	CD-12	CD-13	CD-24	CD-25	CD-31	CD-32	DC-5	AA-1	AA-2	AA-3	AA-4
82/1															
2															
3															
4															
5												25.30			
6												25.35			
7												25.14			
8															
9												24.61			
10												24.32			
11												24.12			
12												24.08			
83/1												24.10			
2												23.81			
3												23.74			
4												22.55			
5												19.83			
6												19.81			
7												18.30			
8												17.45			
9												18.20			
10												15.22			
11												14.97			
12												15.40			
84/1															
2												15.88			
3												15.80			
4												15.74			
5												16.05			
6												16.34			
7												16.05			
8												15.94			
9															
10												16.08			
11												16.70			
12												17.21			
85/1												17.58			
2												15.25			
3															
4												15.75			
5												17.72			
6												17.80			
7												17.97			
8															
9															
10															
11												18.69			
12															
86/1															
2															
3												19.70			
4															
5															
6												20.36			
7												20.44			
8												20.47			
9												20.63			
10															
11												20.95			
12												21.20			
87/1															
2															
3															
4												22.00			
5															
6															
7															
8															
9															
10												20.84			
11															
12															
88/1															
2															
3															
4															
5															
6															
7												17.50			
8															
9															
10												18.50			
11															
12															
89/1												20.58			
2															
3															
4															
5															

Table B-I, 3.2 (2) Variation of Groundwater Table (Azapa Valley)

< Variación de Nivel Estatico (Valle de Azapa)>

WELL / DATE	226-0 1820 7010 AD-13	133-7 1820 7010 CC-15	126-4 1820 7010 CC-16	214-7 1820 7010 CC-21	106-K 1820 7010 CD-12	164-7 1820 7010 CD-13	110-8 1820 7010 CD-24	111-6 1820 7010 CD-25	108-6 1820 7010 CD-31	109-4 1820 7010 CD-32	122-1 1820 7010 DC-5	129-9 1830 7000 AA-1	115-9 1830 7000 AA-2	112-4 1830 7000 AA-3	113-2 1830 7000 AA-4
6															
7															
8															
9															
10															
11															
12															
70/1															
2															
3															
4															
5															
6															
7															
8															
9															
10															
11															
12												25.27			
71/1												25.38			
2												21.88			
3															
4															
5															
6															
7												20.98			
8															
9															
10															
11												20.95			
12															
72/1												21.78			
2												20.75			
3												19.20			
4															
5												17.84			
6															
7															
8												16.83			
9															
10												16.93			
11															
12															
73/1												17.78			
2															
3												14.15			
4															
5												13.79			
6												15.45			
7															
8															
9															
10												13.20			
11		24.20										13.20			
12												13.80			
74/1															
2		23.60										13.40			
3		23.60													
4															
5		23.60													
6		23.00													
7		22.50													
8		22.69										12.09			
9		22.97													
10		23.00										12.89			
11		23.10													
12		22.98										13.70			
75/1		22.51													
2		22.32													
3		22.76										12.93			
4		22.59										12.43			
5															
6															
7															
8															
9															
10															
11															
12					16.51		16.86		32.30	13.13		4.93			
76/1					16.44		16.70		31.33	13.14		4.93			
2					15.77		16.11		31.92	12.39		4.76			
3												4.34			
4		25.86			13.48		14.00			9.98	17.20	4.40			
5												4.40			
6		17.82			12.12		12.75		28.42	8.72		4.52			
7		18.92			12.87		12.07		25.96	9.62		4.55			
8		18.58			12.85		11.71		24.93	3.20		4.47			
9		18.57			12.02		11.34		24.71	8.50		4.58			
10		18.38			12.45		11.45		24.35	8.81		4.52			

Table B-I, 3.2 (3) Variation of Groundwater Table (Azapa Valley)

< Variación de Nivel Estatico (Valle de Azapa)>

WELL / DATE	228-0	133-7	128-4	214-7	108-K	184-7	110-8	111-8	108-6	109-4	122-1	129-9	115-9	112-4	113-2
	1989 7010	1989 7010	1989 7010	1989 7010	1989 7010	1989 7010	1989 7010	1989 7010	1989 7010	1989 7010	1989 7010	1989 7000	1989 7000	1989 7000	1989 7000
	AD-13	CC-15	CC-18	CC-21	CD-12	CD-13	CD-24	CD-25	CD-31	CD-32	DC-5	AA-1	AA-2	AA-3	AA-4
11												4.52			
12					15.29		12.30		23.87	10.90		4.51			
77/1		15.34			16.07		12.69			11.65	15.73	4.86			
2		14.77			15.48		13.29		24.30	12.02	14.99	4.58			
3		14.30			15.84		12.55			10.70	16.00	4.64			
4		14.02			14.28		13.50		21.96	11.09	16.10	4.20			
5		13.80			13.52		11.38		21.50	15.99	12.89	4.20			
6		13.03			12.55		10.34		20.75	9.35	12.80	4.24			
7		12.48			12.60		10.90		19.85	8.84	12.37	4.38			
8		12.40			11.75		10.79		19.47	8.56	12.75				
9		12.08					10.81		19.87	8.77	13.32	4.30			
10		11.85					10.97		20.00	9.27	13.93				
11		11.77					11.00		20.19	9.87	14.29	2.09			
12															
78/1															
2		10.58					12.02			11.58	15.38				
3															
4		11.52							21.15	12.22	16.00				
5		11.53							21.76	12.06	15.78				
6		11.88					12.00		21.73	12.00	16.00				
7		10.68					12.00		21.63	11.84	15.87				
8		10.80					12.30		21.53	11.80	16.00				
9		11.50					12.53		21.51	11.97	16.23				
10		11.86							10.96	13.10	16.20				
11		12.00							10.90	13.20	16.30				
12		11.67					13.90		22.30	14.34	16.13				
79/1											16.96				
2		11.72					14.57		22.66	15.08					
3		11.85					15.13		23.33	15.59	17.23				
4		11.70					15.52		23.40	15.65	17.49				
5		12.00					15.50		23.35	15.65	17.52				
6		21.77					15.61		22.37	15.67	17.50				
7		22.00					15.74		24.05	15.70	17.50				
8		12.00					16.00		24.11	15.85	17.60				
9															
10															
11		12.16					17.00		24.30	16.65	18.00				
12		12.05					17.12		24.35	16.75	18.00				
80/1		11.98					17.22		23.90	16.83	18.10				
2		12.41					17.30		25.67	16.83	18.35				
3		12.64					17.25		25.80	16.70	18.42				
4		12.67					19.19		26.40	17.78	18.79				
5		12.80					19.30		27.17	18.02	18.94				
6		12.70					19.20		27.25	18.00	18.90				
7		12.75					20.20		28.45	18.50	19.48				
8		12.75					20.15		28.40	18.95	20.38				
9		12.60					20.01		28.55	18.80	19.21				
10		12.00					23.34		28.72		19.02				
11		12.15					23.14		28.85		19.22				
12		12.20					22.64		28.02		21.02				
81/1									23.90						
2							22.91		28.51		21.83				
3									28.42		21.12				
4									25.52		21.07				
5									25.82		20.69				
6									25.92		20.82				
7							25.55		29.60		21.12				
8							25.79		29.97		20.26				
9							25.79		30.24		20.72				
10															
11															
12															
82/1							20.15		26.92		21.73				
2							20.04		27.14		21.73				
3							20.09		26.92		22.02				
4							20.15		26.61		22.14				
5							22.74		28.67						
6							28.86		33.90						
7							26.43		33.52	27.28					
8							28.52		33.72	27.24					
9							28.88		33.85	27.53					
10															
11															
12															
83/1															
2					31.41		30.45		35.09						
3					31.70		31.49		36.48						
4							31.11		31.30						
5					32.45		31.31		37.17						
6					32.51		31.55		36.44						
7					32.53		31.58		37.20						
8					32.53		32.20		37.33						
9					33.70		32.38		38.19			23.73			
10					32.67		32.40		38.02			23.95			
11					32.75		32.58		38.12			22.05			
12					33.35		33.21					23.93			
84/1					34.63		33.63		38.29			21.60			
2					33.60		33.76		38.32			21.71			
3							33.90		37.78			19.28			

Table B-I, 3.2 (4) Variation of Groundwater Table (Azapa Valley)

< Variación de Nivel Estatico (Valle de Azapa)>

WELL	226-0	133-7	126-4	214-7	108-K	184-7	110-8	111-6	108-6	108-4	122-1	129-9	115-9	112-4	113-2
	1880 7010	1880 7010	1880 7010	1880 7010	1880 7010	1880 7010	1880 7010	1880 7010	1880 7010	1880 7010	1880 7010	1830 7000	1830 7000	1830 7000	1830 7000
DATE	AD-13	CC-15	CC-16	CC-21	CD-12	CD-13	CD-24	CD-25	CD-31	CD-32	DC-5	AA-1	AA-2	AA-3	AA-4
4					34.70		34.05		37.88			18.66			
5					33.25		34.29		38.42			18.61			
6							34.41		38.64			18.81			
7							34.44		38.92	29.42		18.24			
8							34.78		39.06	29.37		18.20			
9							35.00		39.30	29.42		18.40			
10							35.05		39.39	29.43		18.67			
11							35.22		39.66	29.52		18.51			
12							35.31		39.81	29.53		18.55			
85/1							35.56		40.00	29.66		18.61			
2							35.50		40.02	29.71		18.26			
3							35.73		40.11	29.69		18.08			
4												18.08			
5															
6															
7							35.51		40.71	29.16		13.46			
8										29.16		13.23			
9							35.34			28.80					
10							35.20			28.83					
11															
12							35.33			28.84					
86/1							35.42			28.72					
2							35.70			28.99					
3							35.64			28.66					
4							35.58			28.17					
5															
6							35.25			27.69					
7															
8							36.12			32.25					
9															
10							34.45			32.18					
11															
12							34.45			27.45					
87/1															
2							34.39	21.30		27.45				9.35	16.68
3															
4							34.48	21.01		27.19				9.04	16.59
5			25.62				34.40	20.70		27.01			8.80		16.59
6			25.48				34.33	20.04		26.71			8.77		16.66
7			25.37				34.00	20.11		26.35			8.69		16.69
8			25.38				33.77	19.46		26.18			9.05		16.67
9															
10			25.25				33.73	20.15		25.95			9.38		16.81
11			25.04				33.37	21.44		25.61			9.75		
12							33.26			25.44					
88/1			25.03				33.25	21.55		25.38			10.11		17.15
2			25.12				33.22	21.48		25.28			10.43		17.09
3			25.07				33.11	21.52		25.20			10.75		17.20
4			25.04				32.72	21.46		25.19			10.50		17.13
5															
6			25.04				32.40	20.86		25.41			11.35		17.38
7							32.30			25.38			11.53		17.40
8			24.70				31.99	19.12		25.57			11.88		17.43
9							31.88			25.71			11.99		17.56
10										25.97			12.15		17.58
11															
12			24.43				31.99	20.87		26.79			12.10		17.70
89/1							32.28			27.18			13.17		17.77
2							32.37			27.39			12.95		17.80
3															
4							32.70			27.90			13.34		18.15
5															
6	17.99		22.65	20.67			32.85	20.78		28.69			8.16		
7															
8															
9	17.94		22.70	20.37			32.69	20.45		29.20			8.40		
10															
11	18.05		22.73	19.77			33.28	20.09		29.63			9.27		
12															
90/1															
2															
3	18.23			20.43			34.96	21.09		30.49			10.50		
4															
5	18.37						36.00			31.03			11.37		
6															
7	18.45						36.53						11.94		
8															
9	18.49						36.96			31.62			11.78		
10															
11	18.57						37.69			32.72					
12															
91/1	18.89						38.22			31.42			7.57		
2	18.86									34.09			7.71		
3	19.12									34.40			7.67		
4						29.71	39.20	20.73		33.86			7.54	17.92	18.94
5						30.77	39.35	20.65		33.87				18.09	18.89
6															
7						29.69	39.48			34.50				18.65	19.13
8						28.78	39.57	20.61		34.03				18.70	19.08

Table B-I, 3.2 (5) Variation of Groundwater Table (Azapa Valley)

< Variación de Nivel Estatico (Valle de Azapa)>

WELL / DATE	220-0	133-7	120-4	214-7	109-K	164-7	110-8	111-6	108-8	109-4	122-1	120-8	115-8	112-4	113-2
	1820 7010	1820 7010	1820 7010	1820 7010	1820 7010	1820 7010	1820 7010	1820 7010	1820 7010	1820 7010	1820 7010	1820 7000	1820 7000	1820 7000	1820 7000
	AD-13	CC-15	CC-18	CC-21	CD-12	CD-13	CD-24	CD-25	CD-31	CD-32	DC-5	AA-1	AA-2	AA-3	AA-4
9															
10															
11															
12							41.08			35.50					
92/1	19.67					40.42	41.48	21.91		35.34					
2	19.16					43.93	41.62	20.94		35.28					
3	19.19					43.97	41.42	21.06		35.50					
4	19.30							20.83							
5	19.34														
6															
7						45.90	43.12	20.77		35.81					19.49
8															
9	19.48					46.50	43.58	20.92		35.95					
10															
11															
12															
93/1															
2						47.90	45.00	20.93		37.45					
3	19.64					46.10	45.83	21.18		37.85					
4															
5															
6															
7															
8	19.82					46.97	46.76	22.00		39.97					
9															
10	20.22					48.00	47.14	20.19		40.60					
11	20.22					48.15	47.54	20.20		40.93					
12	19.95					48.48	47.93	20.13		41.08					

Table B-I, 3.2 (6) Variation of Groundwater Table (Azapa Valley)

< Variación de Nivel Estatico (Valle de Azapa)>

WELL	101-6	225-	100-0	116-7	117-5	224-4	104-3	103-5	220-1	196-5	125-6	199-K	134-5	102-7	114-0
	1830 7000	1830 7000	1830 7000	1830 7000	1830 7000	1830 7010	1830 7010	1830 7010	1830 7010	1830 7010	1830 7010	1830 7010	1830 7010	1830 7010	1830 7010
DATE	AA-5	AC-2	AD-3	AD-4	AD-5	AB-10	BA-10	BA-2	BA-20	BA-3	BA-6	BA-9	BB-2	BB-6	BB-8
62/1															
2															
3															
4														29.74	
5														29.65	
6	14.42													28.96	
7														28.87	
8	13.06													27.94	
9	12.94													28.18	
10	13.20													28.72	
11														29.43	
12														29.80	
63/1	13.66													19.55	
2	13.28													27.62	
3	10.28													29.49	
4	8.70													23.50	
5	6.74													23.50	
6	5.79													25.90	
7	4.18													27.70	
8	3.35													22.06	
9	2.70													21.44	
10	2.38													20.20	
11	2.44													13.90	
12															
64/1	2.51													18.62	
2	2.39													18.40	
3	2.35													19.15	
4	2.48													18.64	
5	2.69													18.47	
6	2.60													18.08	
7	2.55													17.86	
8															
9														17.75	
10	3.00													16.08	
11	3.32													18.38	
12	3.56													18.20	
65/1	3.69													18.00	
2															
3	3.67													19.00	
4	3.97													19.73	
5	4.25													19.60	
6	6.77													19.15	
7															
8															
9															
10														19.44	
11															
12															
66/1															
2														21.50	
3															
4															
5														21.60	
6	6.77														
7	6.87													20.80	
8	7.18													20.76	
9															
10														21.13	
11														22.43	
12															
67/1															
2															
3	8.92													24.74	
4	8.88													23.73	
5	8.78													23.90	
6	7.83													20.98	
7															
8	7.70													20.02	
9	7.38													19.93	
10	7.56													21.20	
11															
12														21.15	
68/1	8.88													20.00	
2	7.22													21.08	
3	5.45													18.72	
4															
5	3.17													17.08	
6	2.98													16.83	
7															
8	2.78													17.88	
9	2.20													17.57	
10	2.18													18.00	
11	2.74													17.57	
12	2.78													17.83	
69/1	2.85													17.91	
2	3.01													17.58	
3	2.84													17.02	
4	3.80													16.78	
5	3.89													16.56	

Table B-I, 3.2 (7) Variation of Groundwater Table (Azapa Valley)

< Variación de Nivel Estatico (Valle de Azapa)>

WELL / DATE	101-9	225-	100-0	116-7	117-5	224-4	104-3	103-5	220-1	198-5	125-6	190-K	134-5	102-7	114-0
	1920 7909	1920 7909	1920 7909	1920 7909	1920 7909	1920 7910	1920 7910	1920 7910	1920 7910	1920 7910	1920 7910	1920 7910	1920 7910	1920 7910	1920 7910
	AA-5	AC-2	AD-3	AD-4	AD-5	AB-10	BA-10	BA-2	BA-20	BA-3	BA-6	BA-8	BB-2	BB-6	BB-8
6	3.38													18.40	
7	3.45													18.61	
8	3.39													18.41	
9	3.41													18.54	
10	3.54													18.35	
11	3.48													18.30	
12	3.72													18.41	
70/1	4.10													18.40	
2	3.98													18.41	
3	4.20													19.10	
4	4.09													18.48	
5	4.03													18.45	
6														18.42	
7															
8	4.18													18.46	
9	4.10													18.40	
10	4.08													18.78	
11	6.58													19.77	
12	6.37													21.42	
71/1	6.66													19.88	
2															
3															
4	5.14													18.45	
5	5.17													17.28	
6	5.19													17.82	
7	5.21													17.54	
8														17.47	
9	5.40													17.58	
10	5.56													17.82	
11															
12	6.58													17.90	
72/1	5.61													19.00	
2															
3	3.72													18.65	
4	3.43													16.40	
5	3.15													18.95	
6														17.18	
7	2.75														
8															
9	2.53													17.40	
10	2.60													17.36	
11														18.91	
12	2.93													18.58	
73/1															
2	1.92													18.75	
3															
4	1.43													18.52	
5	1.05													15.44	
6															
7															
8															
9															
10	0.81														
11	0.99														
12															
74/1	0.86														
2															
3	1.15														
4															
5	0.92														
6	0.82														
7	0.89														
8	1.02														
9	1.00														
10	1.50														
11	1.20														
12	1.10														
75/1	1.01														
2	1.00														
3	1.04														
4															
5															
6															
7															
8															
9															
10	1.95														
11	1.55							5.06					18.61	15.00	8.20
12	1.44			26.23	26.39								18.54		
76/1				26.17	26.22			4.99					18.57	15.70	
2	1.36			25.55	25.71			3.36					18.25	14.07	8.39
3															
4	1.46							2.81					18.23	12.66	
5															
6	1.46													14.24	
7	1.43													18.69	
8	1.63													14.92	
9	1.46							2.40					18.16	15.02	
10	1.47													15.00	

Table B-I, 3.2 (8) Variation of Groundwater Table (Azapa Valley)

< Variación de Nivel Estatico (Valle de Azapa)>

WELL / DATE	101-9	225-	190-0	118-7	117-5	224-4	104-3	103-5	220-1	196-5	125-6	199-K	134-5	102-7	114-0
	1830 7000	1830 7000	1830 7000	1830 7000	1830 7000	1830 7010	1830 7010	1830 7010	1830 7010	1830 7010	1830 7010	1830 7010	1830 7010	1830 7010	1830 7010
	AA-5	AC-2	AD-3	AD-4	AD-5	AB-10	BA-10	BA-2	BA-20	BA-3	BA-6	BA-9	BB-2	BB-6	BB-8
11														15.20	
12	1.42			25.90	26.15			4.00					19.16	14.70	8.10
77/1	1.45						17.21							14.51	
2	1.47			26.30	26.52		18.00	4.21					18.85	14.58	7.41
3	1.53						17.21							14.80	
4	0.48			24.37	24.35		17.20	2.74						12.44	5.47
5	1.50			24.32	24.20		15.78	2.51						13.10	6.23
6	1.51			24.24	24.19		15.61	2.40			16.40			13.84	6.96
7	1.52			24.17	25.89		15.47	2.46			17.46			14.12	7.30
8	0.56			24.15	24.13		15.63	2.56			16.40			14.67	7.80
9	1.48			23.48	23.39		15.35	2.56			17.77			13.23	7.80
10	0.57			23.98	24.06		16.39	2.28			17.77			13.94	7.45
11	1.37			23.80	24.15		17.28	2.35						13.70	7.22
12															
78/1															
2	1.62			24.70	25.20		18.31							13.20	7.04
3	1.80			25.00	25.10										
4	1.56			24.90	25.18		19.12	3.25						14.82	8.00
5	1.52			26.59	25.77		18.90	3.65							8.00
6	1.80			26.40	25.60		19.55	3.82						14.52	8.10
7	1.52			26.59	25.60		18.30	3.38							7.57
8	1.48			26.56	25.56			2.50						14.15	7.65
9	1.50			26.50	25.50		19.35	3.42							7.63
10	1.54			26.47	25.55		19.40	3.20						14.20	7.56
11				26.35	25.46		19.35	4.05						14.25	7.73
12				26.30	25.40		20.28	4.16						14.80	8.88
79/1															
2				27.82	27.66		20.32	4.47						15.42	8.85
3	1.79			28.22			20.58	5.21						17.11	10.11
4	1.52			23.87			20.84	4.28						16.68	10.18
5	1.53			23.84			20.79	4.28						16.74	10.00
6	1.44			23.82				5.14						15.55	10.02
7	1.42			23.96				5.07						15.45	10.10
8	1.42			23.90			21.23	5.00							9.01
9															
10	1.40			23.85			21.33	5.33						15.31	8.71
11	1.45				23.75		20.75	5.53						16.60	8.80
12	1.50						20.70	5.50						16.69	8.90
80/1	1.50						20.85	5.60						17.05	8.95
2	1.60						22.14	6.00						16.90	11.55
3	1.75						22.01	5.85							12.12
4	1.70						22.74	6.75						18.37	11.85
5	1.57						22.63	7.08						18.70	11.74
6	1.54						22.60	7.10						18.40	11.70
7							20.30	7.30						18.45	11.60
8							21.90	7.20						18.30	11.31
9							20.15	7.16						18.20	11.40
10								6.69						18.40	11.12
11								6.75						18.30	11.37
12	1.87							8.68			36.50			18.65	12.12
81/1															
2	1.94							8.72			36.82			18.80	12.54
3	1.55							8.58						18.55	12.33
4	1.62						24.20	9.55			25.79			18.40	12.92
5	1.55						23.90	9.68			25.80			18.40	13.02
6	1.74						24.90	9.73			25.82			18.12	12.94
7	2.42						25.20	9.23						20.35	
8							25.15	9.41						20.48	12.92
9							25.25	9.63							13.12
10															
11															
12															
82/1							25.10	9.71							
2							25.30	9.76							
3							25.30	9.74							
4							25.35	9.86						21.30	
5							29.10	10.15						24.00	
6							30.40	12.60						25.01	
7							30.29	12.64						25.04	
8							30.49	12.82			25.10			25.10	
9								12.88							
10															
11															
12															
83/1															
2	3.08						32.24	13.91						26.20	
3	3.37						33.74	14.26						24.79	
4	4.15						32.67	14.24						26.36	
5	4.47						32.80	15.09						26.75	
6	4.73						33.37	15.29						28.88	
7	5.21						33.39							26.72	
8	5.28						33.37							26.74	
9	5.93						33.07							27.31	
10	6.39													27.21	
11	6.75						34.01							27.55	
12	7.07						33.90							28.36	
84/1	7.28						34.84							28.45	
2	7.32						34.24							28.69	
3	5.10						33.10							27.73	

Table B-I, 3.2 (9) Variation of Groundwater Table (Azapa Valley)

< Variación de Nivel Estatico (Valle de Azapa)>

WELL	101-9	225-	100-9	118-7	117-5	224-4	104-3	103-5	220-1	196-5	125-6	199-K	134-5	102-7	114-0
	1830 7000	1830 7000	1830 7000	1830 7000	1830 7000	1830 7010	1830 7010	1830 7010	1830 7010	1830 7010	1830 7010	1830 7010	1830 7010	1830 7010	1830 7010
DATE	AA-5	AC-2	AD-3	AD-4	AD-5	AB-10	BA-10	BA-2	BA-20	BA-3	BA-6	BA-9	BB-2	BB-6	BB-8
4	4.95						33.23							27.74	
5	4.97						32.98	15.78						28.06	
6	4.88						32.98	15.82						29.12	
7	4.08						32.94							28.89	
8	4.09						33.28							27.45	
9	4.28						33.27							28.10	
10							33.93							28.41	
11	4.49						33.59							28.45	
12	4.81						33.55							28.88	
85/1	5.23						33.50							28.91	
2	5.38						33.98							28.23	
3	3.28						33.60	15.92						27.17	18.87
4															
5															
6	2.03							15.15						25.37	
7	2.03						32.85	15.17						25.45	18.04
8	1.84							15.14						25.44	18.34
9	1.57						32.14	14.93						25.24	18.02
10	1.88						32.42							25.00	
11	1.33						31.88							25.05	
12	1.38						31.92							25.12	
86/1															
2	1.13						31.88	14.09						24.90	
3	1.23							13.40						23.18	
4							31.13	12.81						22.09	
5															
6	1.30						31.10	11.41						22.08	
7															
8							32.52	10.48						22.80	
9															
10							30.50							22.37	
11															
12							31.15							22.20	
87/1															
2	1.03		6.08				30.38	9.83						22.31	15.35
3															
4	1.22		5.53				30.17	9.88						22.50	15.52
5	1.20		5.71				28.90	9.54						22.55	
6	1.14		6.04				28.53	9.45						22.75	
7	1.13		6.40				28.10	9.13						22.04	
8	1.13		6.88				28.00	9.18						22.17	14.78
9															
10	1.01		7.35				28.04	9.51						22.08	14.82
11	1.03		8.13				27.29	9.49						22.08	15.31
12															
88/1	0.99		8.63				27.83	9.66		27.71				22.05	
2	1.01		9.25				28.28	9.91		28.22				21.84	
3	1.06		9.65				28.54	9.88						21.80	
4	1.12		9.88				28.52	10.12		25.44				21.42	
5															
6	1.13		10.33				28.88	10.29							
7	1.14		10.52				28.79	10.11						21.38	
8	1.26		10.84				29.53	10.00		25.89				21.30	
9	1.17		10.98				29.58	9.86		25.71				21.22	
10	1.18		11.24				29.63	9.98						21.01	
11															
12	1.77		12.95				30.07	10.23						20.82	
89/1	1.35		12.59				29.56	10.29						20.76	
2	1.26		12.58				30.21	10.24		26.92				20.73	
3															
4	1.25		12.48				30.46	10.28		26.36				20.50	
5															
6	1.17	13.34					30.61	10.70		27.65					
7															
8															
9	1.34	13.84					31.19	10.97		27.62					
10															
11	1.13	14.44					32.02	11.07		26.63					
12															
90/1															
2															
3	2.04	15.73					32.32	11.64		28.65					
4															
5	2.27	16.41					33.25	12.16		28.90					
6															
7		17.00					32.91	12.52		28.22					
8															
9	0.97	17.87					33.51	12.78		30.05					
10															
11	3.15	18.43					33.73	13.30		33.14					
12															
91/1	3.48	19.04					34.25	13.54		33.85					
2	3.51	19.23					35.29	13.86		32.58					
3	3.45	19.84					32.54	13.99		29.84					
4	3.83						35.35	14.16	33.48	36.34					32.38
5	3.54						35.65	14.26	32.79	30.13					32.44
6															
7	3.40						34.87	14.39							32.44
8	3.39						34.94	14.48	32.74	31.06					32.84

Table B-I, 3.2 (10) Variation of Groundwater Table (Azapa Valley)

< Variación de Nivel Estatico (Valle de Azapa)>

WELL / DATE	101-9 1830 7000 AA-5	225- 1830 7000 AC-2	100-0 1830 7000 AD-3	116-7 1830 7000 AD-4	117-5 1830 7000 AD-5	224-4 1830 7010 AB-10	104-3 1830 7010 BA-10	103-5 1830 7010 BA-2	220-1 1830 7010 BA-20	196-5 1830 7010 BA-3	125-8 1830 7010 BA-6	199-K 1830 7010 BA-9	134-5 1830 7010 BB-2	102-7 1830 7010 BB-6	114-0 1830 7010 BB-8
9															
10															
11															
12								14.99							
92/1								15.74				35.52			
2	4.30							15.76		31.11		32.74			
3	4.48					33.42		15.91		30.92		36.30			
4	4.74					33.61				31.49		34.90			
5															
6															
7								15.75	36.83	33.88					33.90
8															
9						34.23		15.78		32.67					
10															
11															
12															
93/1															
2	6.44					35.97		16.30		34.04		36.55			
3	6.58					36.34		16.72		34.14		36.51			
4															
5															
6															
7															
8	6.38					37.51		18.60		35.62		37.40			
9															
10	6.38					37.53		19.20		36.15		37.84			
11	6.41					38.75		19.33		36.25		38.10			
12	6.41					39.10		19.33		36.32		38.15			

Source : Observation by DGA.

Table B-I, 3.3 (1) Groundwater Quality (Azapa Valley)

<Calidad de Agua (Valle de Azapa)>

ITEM / WELL	pH	TDS	EC	Ca	Mg	Na	K	SO4	Cl	CO3	HCO3	NO3	Si02	Li	B	Fe	Mn	As	Zn	Cu	F	Al
			m.mho/cm	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l
STANDARD	6.5-8.0	1000	-	-	125	200	-	250	250	-	-	10	-	-	1.00	0.30	0.10	0.05	5.00	1.00	1.50	0.20
136-1	7.1	1252	1500	195.8	12.8	158.8	21.1	300.0	214.9	0.0	349.0											
135-3	7.0	1453	1353	189.7	15.8	104.9	5.2	169.7	346.1	75.5	223.9	18.6	177.0	0.1	0.0			0.0				
139-6	7.4	873	1094	150.6	18.0	73.4	4.4	240.6	122.1	9.1	196.8		42.8	<0.2					0.0	<0.01		0.1
140-K	7.1	859	1200	135.5	18.5	89.7	8.0	240.3	190.9	0.0	215.4	2.1	41.7		1.4	0.0	0.0	0.0		0.0	0.5	
141-B	7.2	1073	1524	186.9	22.7	180.6	12.9	242.9	227.1	6.7	247.9	10.6	55.7	<0.2	1.2	0.3	0.4	<0.05	0.0	<0.01	1.5	
142-6	7.1	946	1575	171.8	17.1	72.6	4.2	222.8	173.2	0.0	178.5	10.0	38.0	<0.2	0.8	0.2	<0.1	<0.05	0.0	<0.01	0.3	0.1
143-4	7.2	1381	1779	223.8	23.4	92.1	4.4	230.7	288.7	6.4	194.2	23.1		<0.2	1.1	0.3	<0.1	<0.05	0.1	<0.01	0.2	0.1
145-0	7.3	948	1268	166.8	14.2	75.8	3.3	198.7	191.9	0.0	196.5	5.6	52.2	0.0	1.0	0.0	0.0	<0.05	0.0	0.0		
147-7	7.2	753	961	141.6	17.0	68.9	3.7	174.0	127.2	4.2	181.7	6.4	40.8	<0.2		<0.1	<0.1	<0.05	0.1	<0.01	0.3	<0.1
148-5	7.2	657	1092	113.7	14.7	49.0	6.0	199.0	95.0	0.0	198.0	4.6	45.0									
149-3	5.8	1929	2525	309.4	49.2	168.6	12.6	473.5	577.6	0.0	93.0	11.5	62.5									
150-7	7.2	2835	4113	496.6	44.8	205.6	10.9	861.3	532.4	0.0	211.0	113.1	94.2	0.2				0.0				
106-K	7.7	881	1090	133.7	8.9	97.5	13.8	225.9	158.0	0.0	225.2	0.0	110.3	0.0	0.5			0.0				
108-6	7.9	659	740	113.9	11.4	66.0	3.7	206.2	81.4	0.0	193.7				1.7							
128-0	7.2	658	1110	126.0	13.5	79.8	4.6	199.7	92.0	0.0	169.4	3.1	34.8	<0.2	0.9					<0.01		
130-2	7.2	717	884	130.7	16.5	73.2	15.3	208.8	118.0	8.3	183.8	20.0	49.0	<0.2	1.2	<0.1	<0.1	<0.05		<0.01	0.2	
137-K	8.3	950		115.3	36.6	80.0	3.8	214.8	85.1	72.0	206.4				1.1			0.0				
138-8	7.3	886	1135	201.4	20.3	85.0	1.5	244.1	147.4		204.4	5.0			1.3	<0.1	<0.1	<0.05			0.4	
154-K	7.3	1351	1520	271.3	29.2	84.5	16.3	483.5	220.8	0.0	251.1			<0.2								
155-8	7.1	1573	1695	299.8	32.7	140.5	6.4	525.3	251.7	0.0	255.9							0.0				
157-4	7.2	798	1080	145.3	15.5	68.0	3.6	214.0	123.4	17.3	190.5	2.6	40.0			<0.1	<0.1	<0.05	0.0	<0.01	0.3	<0.1
158-2	7.0	958	1469	183.6	17.4	72.3	4.5	265.3	150.1	21.3	209.2	5.7	38.4	<0.2		<0.1	<0.1	<0.05	0.0	<0.01	0.4	0.0
159-0	7.0	1089	1520	200.2	8.5	63.7	3.9	270.4	146.1	0.0	222.7											
160-4	7.2	897		171.0	18.7	101.0	6.0	273.8	144.5	0.0	290.7		45.3	<0.2						0.0		0.0
161-2	7.1	975	1173	184.4	19.3	96.7	3.2	279.6	153.2	0.0	209.5		42.7	<0.2						<0.01		
165-5	7.1	922	1172	176.8	22.7	77.9	3.5	243.2	147.0	4.4	177.3	4.8	41.4	<0.2		0.2	<0.1	<0.05	0.1	<0.01	0.5	<0.1
166-3	7.5	886	1131	164.0	15.5	92.1	4.6	250.2	151.6	0.0	219.7	4.2	49.9	<0.2		<0.1	<0.1	<0.05	0.0	<0.01	0.4	0.0
167-1	7.1	905	1240	170.2	19.1	86.0	17.0	266.0	151.5	0.0	266.0		45.5	<0.2					0.0	<0.01		0.0
168-K	7.3	5624	8100	566.0	21.1	305.8	214.3	1240.5	2149.4	0.0	209.4											
121-3	7.7	1219	1300	200.2	18.3	93.1	5.4	322.6	191.7	0.0	215.3				1.7			0.0				
112-4	7.2	949	1160	182.4	18.0	90.0	7.0	249.0	166.1	0.0	220.8		38.0	<0.2	1.6	0.1	<0.1	<0.05		<0.01	0.2	
113-2	7.4	843	960	153.6	17.3	70.0	3.8	296.3	108.5	0.0	212.1				1.8							
129-9	7.4	777	987	142.4	15.9	65.4	2.3	229.1	125.4	13.4	178.5	9.7	34.3	<0.2	1.6	0.1	<0.1	<0.05		<0.01	<0.2	
216-3	7.0	714		138.0	16.0	75.0	3.8	216.0	122.0	0.0	204.0		45.0			0.3	<0.1	<0.05				
100-0	7.0	779	1420	126.1	14.8	90.3	5.3	294.0	137.0	0.0	318.0	4.0	26.5	<0.1	1.8	0.4	<0.1	<0.05		<0.01	0.2	
117-5	8.1	776	860	88.2	9.4	40.0	2.5	166.3	79.8	34.0	133.8	0.0	299.7		1.3							
177-9	7.3	741	954	131.5	17.2	66.8	5.3	199.2	108.0	2.6	194.5							0.0				
183-3	7.3	636	870	119.3	12.7	62.0	5.0	213.8	82.6	4.1	198.0							0.0				
184-1	7.1	615		115.0	13.0	59.0	3.9	209.0	87.0	0.0	161.0											
186-8	6.9	989	1406	174.3	17.4	73.9	3.9	274.6	145.3	0.0	216.4	6.9	48.8	<0.2		<0.1	<0.1	<0.05	0.0	<0.01	0.3	0.0
187-6	7.2	1026	1527	194.0	20.4	98.3	5.4	304.3	161.6	0.0	304.3		49.0	<0.2						<0.01		0.0
188-4	7.2	790		128.0	17.0			230.0	126.0	0.0	229.0		120.0							0.0		
190-6	7.7	798	953	134.6	15.9	79.4	5.3	271.2	108.2	0.0	119.8											
103-5	7.3	670		104.0	12.0	87.0	5.4	212.0	104.0	0.0	184.0	0.0	46.0									

Table B-I, 3.3 (2) Groundwater Quality (Azapa Valley)

<Calidad de Agua (Valle de Azapa)>

ITEM / WELL	pH	TDS	EC	Ca	Mg	Na	K	SO4	Cl	CO3	HCO3	NO3	Si02	Li	B	Fe	Mn	As	Zn	Cu	F	Al
			m.mho/cm	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l
STANDARD	6.5-8.0	1000	-	-	125	200	-	250	250	-	-	10	-	-	1.00	0.30	0.10	0.05	5.00	1.00	1.50	0.20
104-3	7.4	626		114.0	14.0	58.0	5.5	187.5	81.0	0.0	208.0	5.6	50.5									
107-8	7.4	479	473	62.2	6.7	68.0	5.8	117.1	98.4	0.0	371.0	0.9	27.8		0.4							
123-K	7.5	828	1157	213.0	22.0	200.0		239.3	112.7	0.0	249.6	5.6			1.5			0.0				
125-6	7.1	750	1151	136.0	13.7	61.9	5.1	222.1	89.1	0.0	219.0	4.2	132.5									
195-7	7.3	778	1110	139.5	15.0	87.0	5.0	242.5	118.5	0.0	236.0	1.5	46.5	<0.2		<0.1	<0.1	<0.05		<0.01	0.3	
197-3	7.3	543	905	96.0	12.0	56.0	5.8	170.0	74.0	0.0	176.0	0.0	37.0									
202-3	7.3	519		93.5	8.7	54.7	4.4	151.0	71.3	0.0	166.5	9.5	40.3									
203-1	7.8	905	1100	181.3	21.9	88.0	4.5	286.4	126.1	0.0	255.3											
218-K	7.0	960		199.0	20.0	87.0	4.6	272.0	204.0	0.0	236.0	17.0	39.0	<0.2		0.1	0.3	<0.05		<0.01	0.2	
221-K	7.1	901		185.0	19.0	83.0	4.2	279.0	158.0	0.0	254.0	8.9	38.0	<0.2		<0.1	<0.1	<0.05		<0.01	0.2	
222-8	7.0	895	1150	172.0	18.3	77.2	4.1	240.5	141.0	0.0	222.5	8.6	37.5	<0.2		0.1	<0.1	<0.05	0.0	<0.01	0.3	0.1
223-6	6.9	763		155.0	16.0	69.0	3.0	244.0	111.0	0.0	242.0	6.7	38.0	<0.2		<0.1	<0.1	<0.05		0.1	0.2	
102-7	7.4	527	860	63.8	2.5	87.0	13.0	16.5	124.1	0.0	19.0	0.0	45.3		0.5							
134-5	7.5	562	744	104.2	12.4	54.2	3.1	175.8	75.5	2.7	223.6	4.2	30.5	<0.2	1.7		<0.1	<0.05		0.0	0.2	
206-6		929																				
300-	7.7	740	980	129.7	14.6	75.0	5.1	263.1	100.6	0.0	201.6				1.0			0.1				
301-	7.2	700	980	160.5	6.1	68.0	15.6	222.6	147.6	0.0	189.2				0.0							
Average(*)	7.27	913	1248.96	162.8	17.5	86.7	6.34	253.24	154.15	4.86	212	9.56	59	<0.2	1.13	<0.1	<0.1	<0.05	0.02	<0.01	0.36	<0.1

(*): except well No. 168-k.

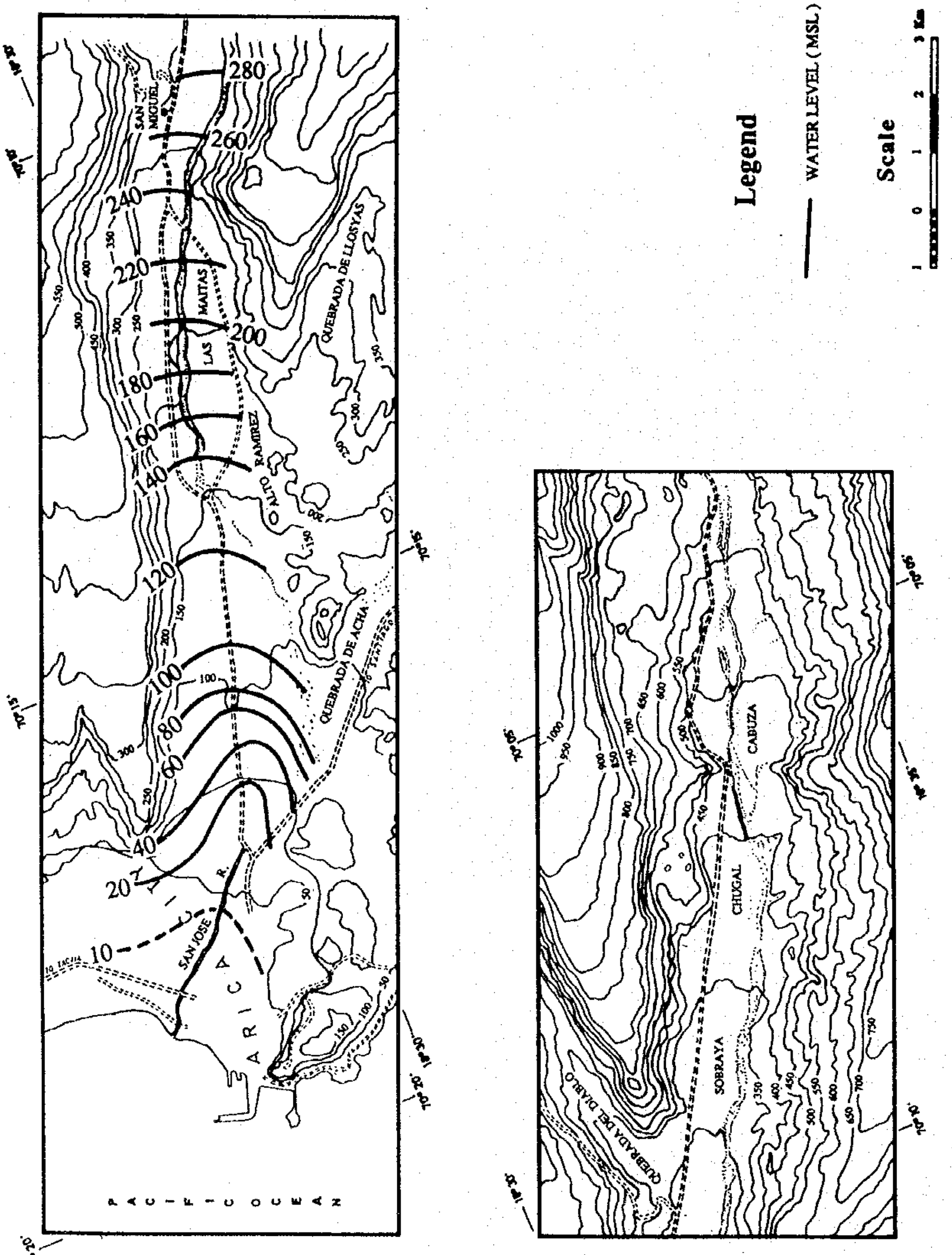


Fig. B-I. 3.1 Static Water Level (Azapa Valley) (Unit: mMSL)

< *Nivel Estático (Valle de Azapa)* >

Unit: m MSL

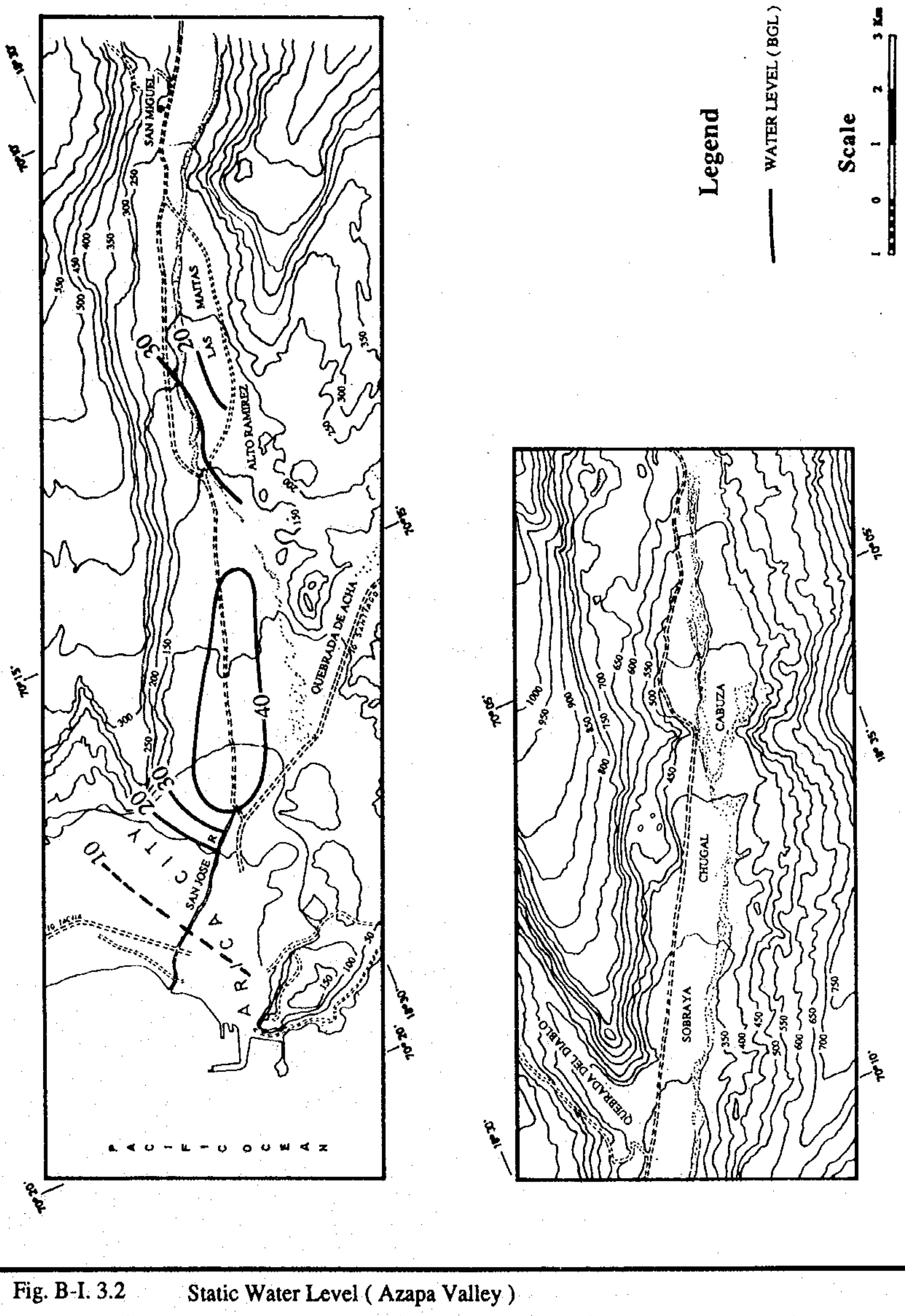


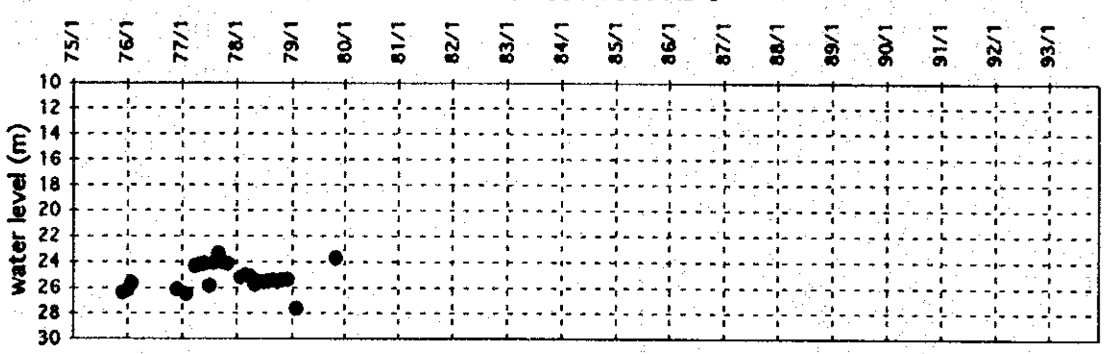
Fig. B-I. 3.2 Static Water Level (Azapa Valley)

< Nivel Estático (Valle de Azapa) >

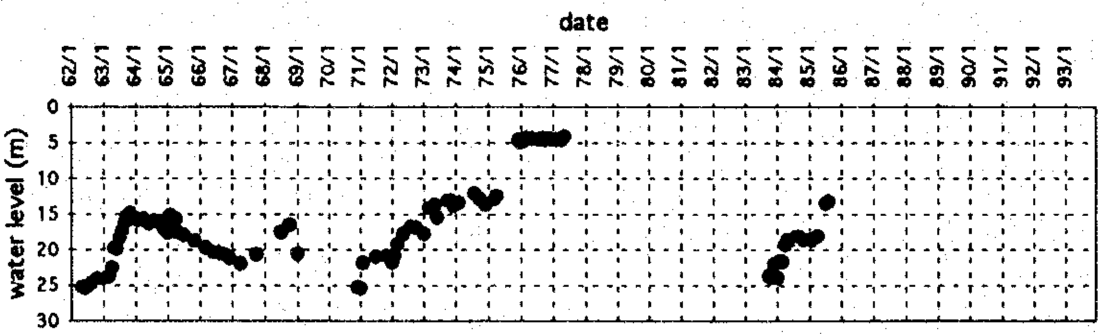
Unit: m BGL

Cabuza-Las Riveras

117-5 1830 7000 AD-5



129-9 1830 7000 AA-1



101-9 1830 7000 AA-5

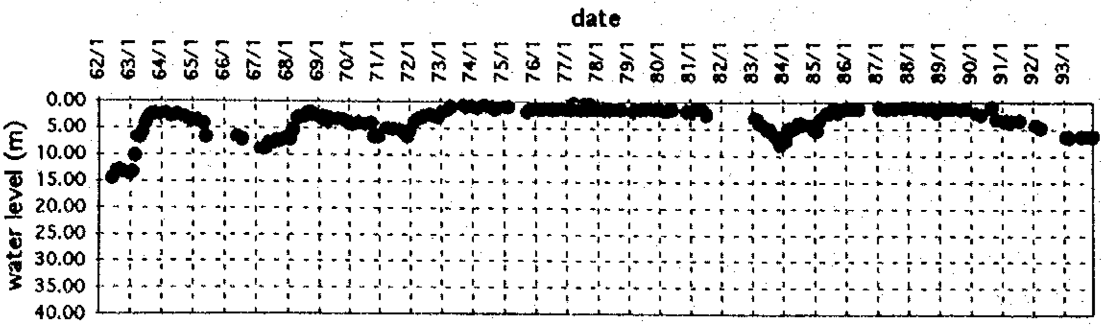
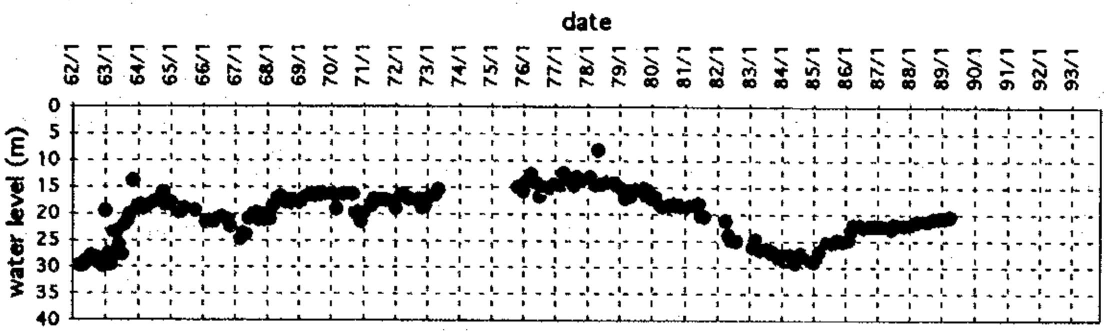


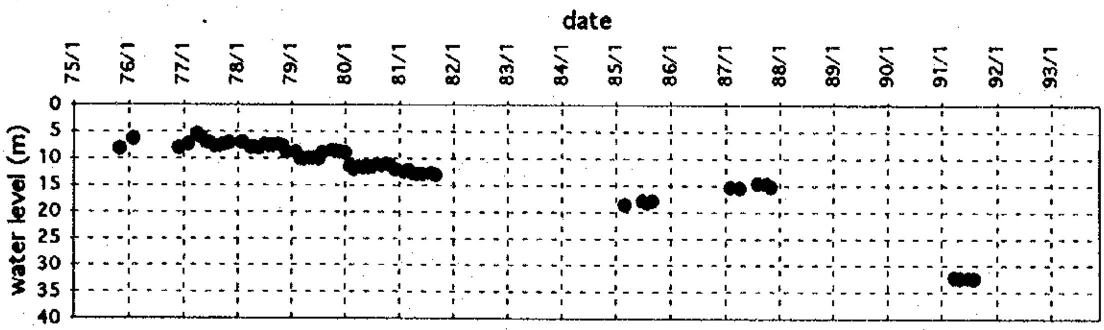
Fig. B-I. 3.3 (1) Variation of Groundwater Table (Azapa Valley)
< Variación de Nivel Estatico (Valle de Azapa)>

San Miguel

102-7 1830 7010 BB-6



114-0 (1830-7010 BB-8)



103-5 (1830 7010 BA-2)

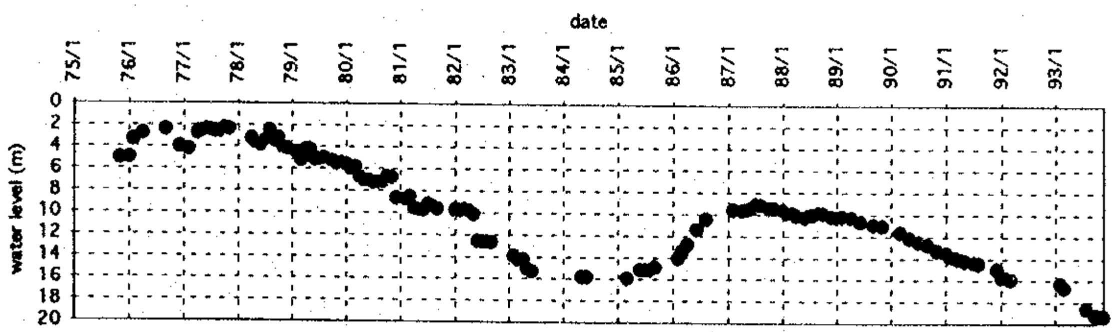


Fig. B-I. 3.3 (2) Variation of Groundwater Table (Azapa Valley)

< Variación de Nivel Estatico (Valle de Azapa)>

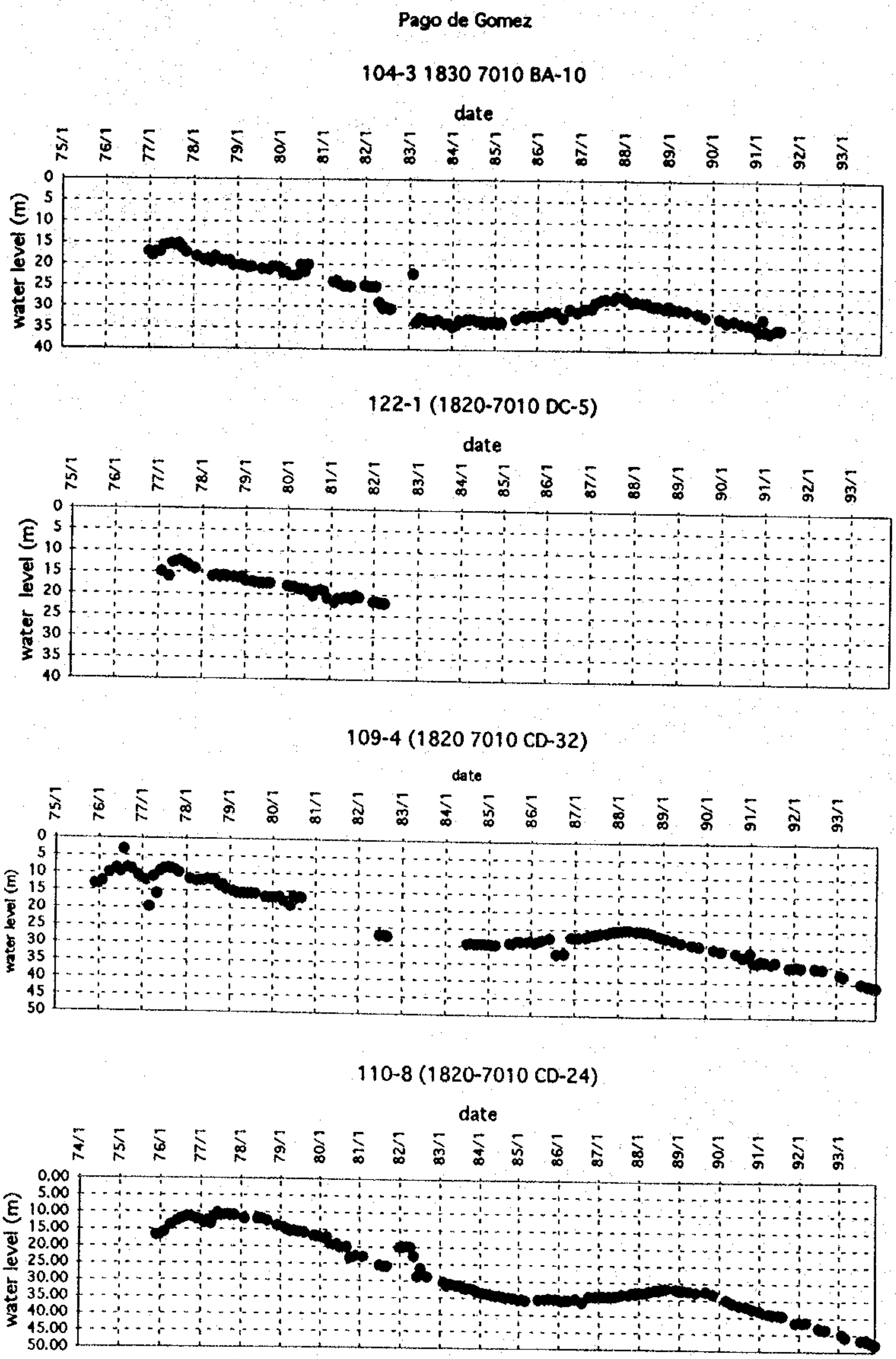
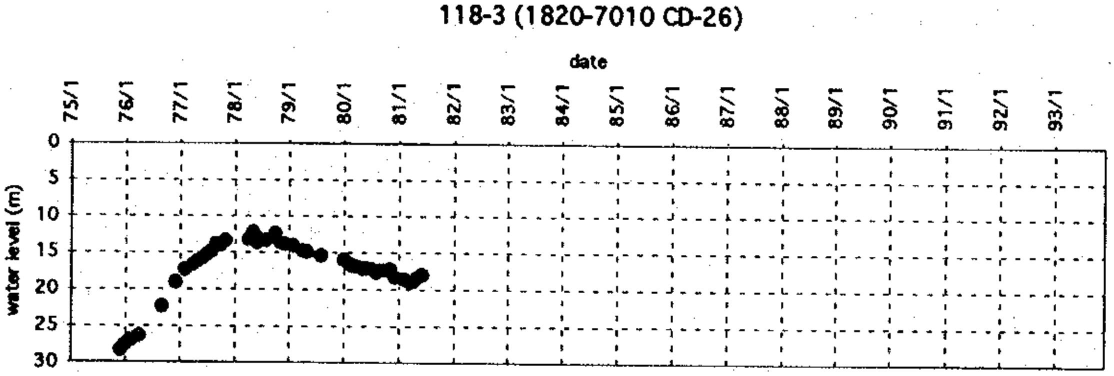


Fig. B-I. 3.3 (3) Variation of Groundwater Table (Azapa Valley)

< Variación de Nivel Estatico (Valle de Azapa)>

City Area of Arica



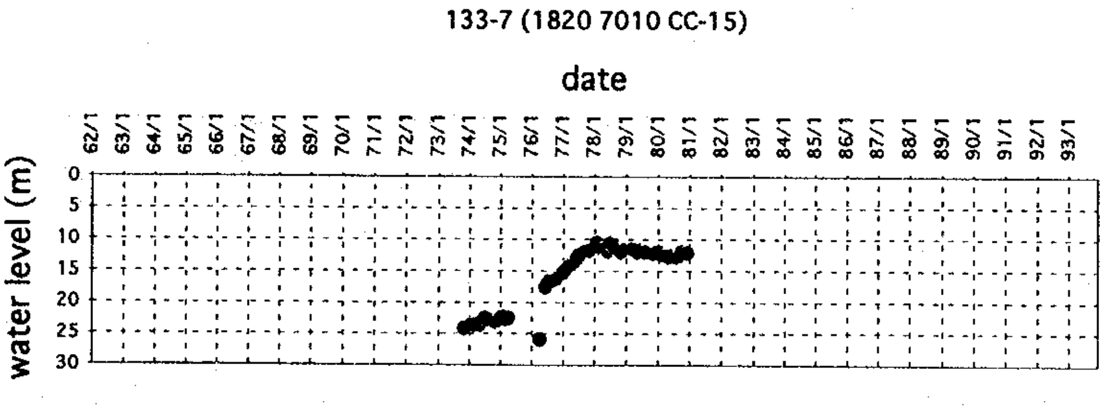
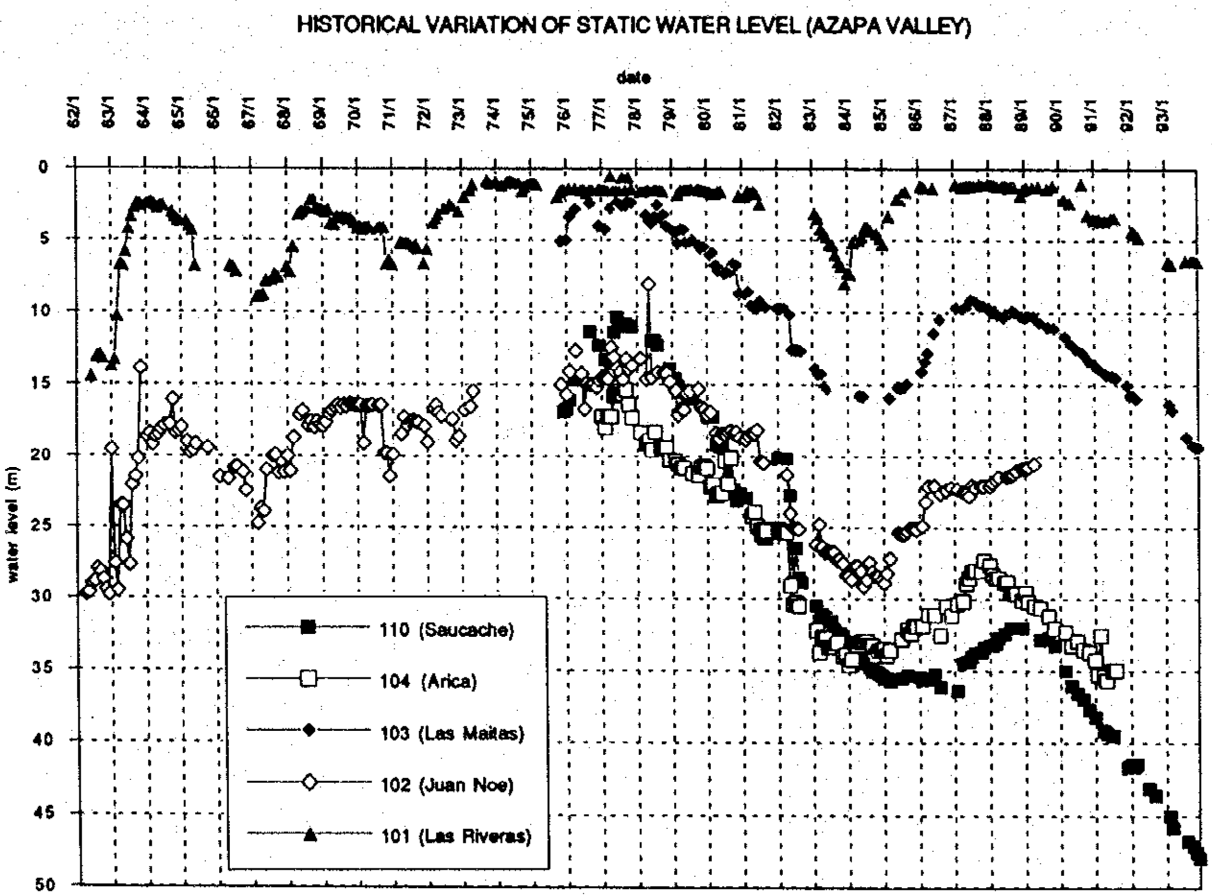


Fig. B-I. 3.3 (4) Variation of Groundwater Table (Azapa Valley)

< Variación de Nivel Estatico (Valle de Azapa)>



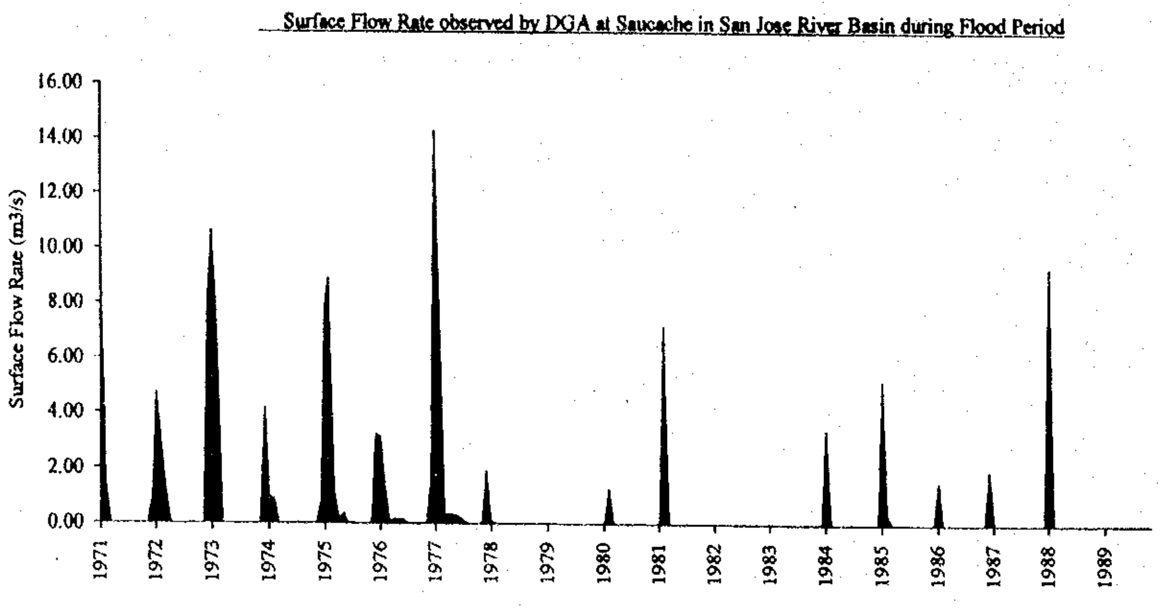


Fig. B-I. 3.4 Relation between Groundwater Level and Flood (Azapa Valley)

< Relación entre el Nivel Estático y Avenida (Valle de Azapa) >

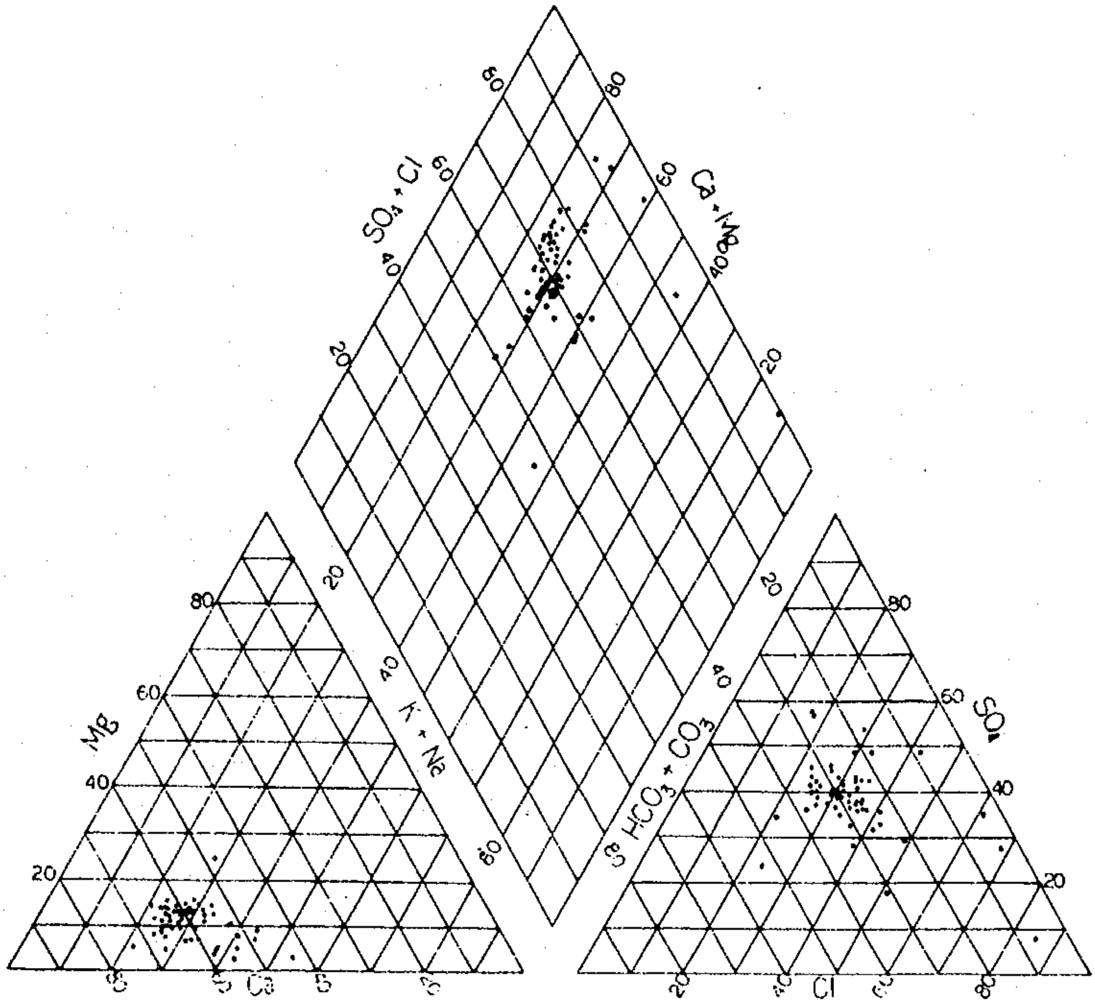


Fig. B-I. 3.5 Tri-linear Diagram of Major Ions (Azapa Valley)

< Diagrama Tri-Lineal de Iones Mayores (Valle de Azapa)>

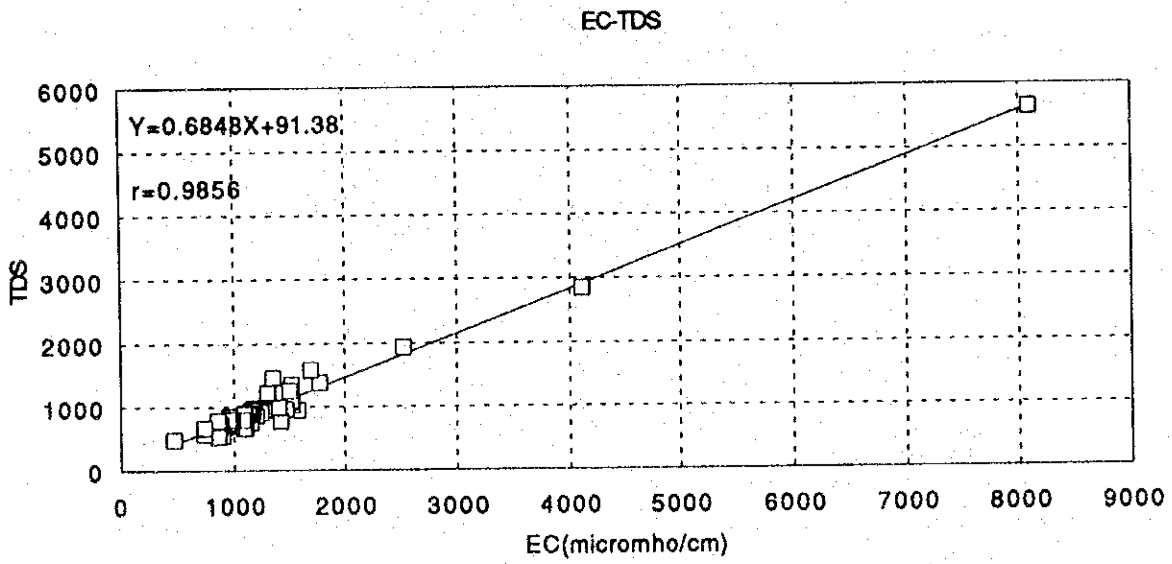


Fig. B-I. 3.6 Relation between TDS and EC (Azapa Valley)

< Relación entre TSD y CE (Valle de Azapa)>

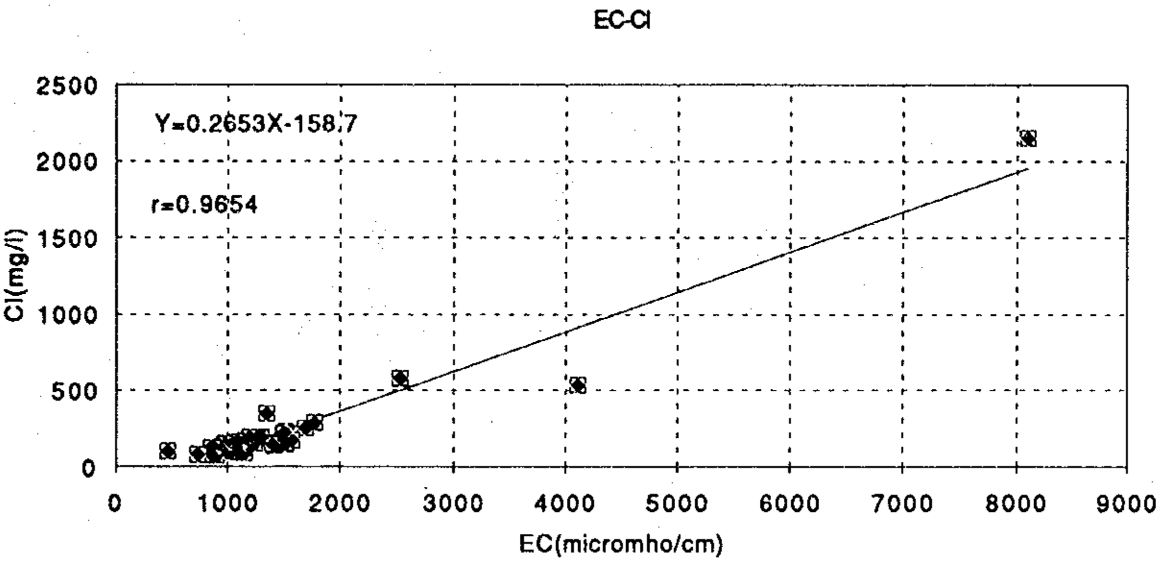


Fig. B-I. 3.7 Relation between Cl and EC (Azapa Valley)

< Relación entre Cl y CE (Valle de Azapa)>

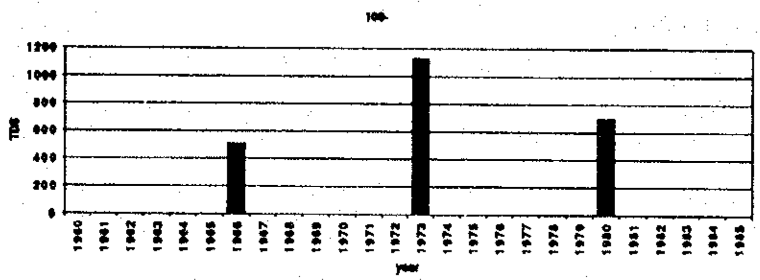


Fig. B-I. 3.8 (1) Variation of Salinity in Azapa Valley (Cabuza Area)

< Variación de Salinidad en Valle de Azapa (Zona Cabuza)>

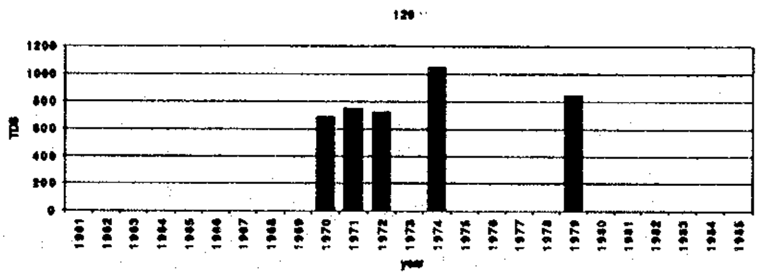


Fig. B-I. 3.8 (2) Variation of Salinity in Azapa Valley (Las Riveras Area)
< *Variación de Salinidad en Valle de Azapa (Zona Las* Riveras)>

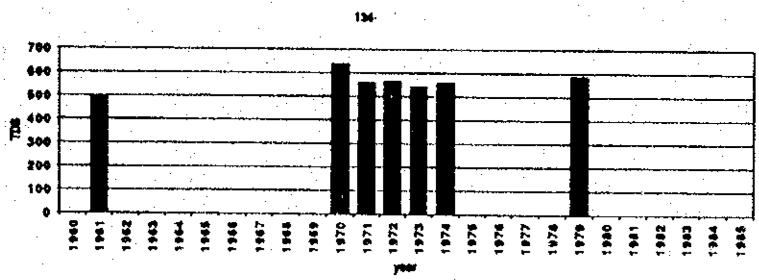


Fig. B-I. 3.8 (3) Variation of Salinity in Azapa Valley (San Miguel Area)

< Variación de Salinidad en Valle de Azapa (Zona San Miguel)>

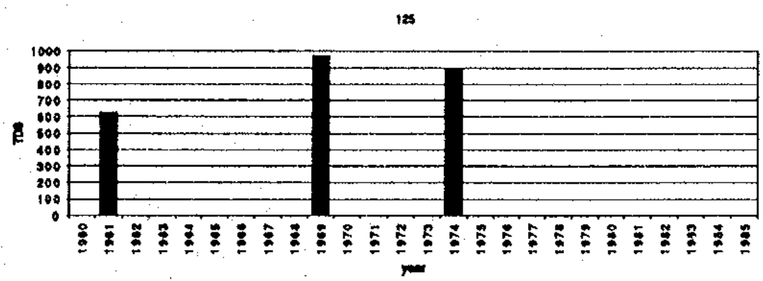


Fig. B-I. 3.8 (4) Variation of Salinity in Azapa Valley (Pago de Gomez Area)

< Variación de Salinidad en Valle de Azapa (Zona Pago de Gomez)>

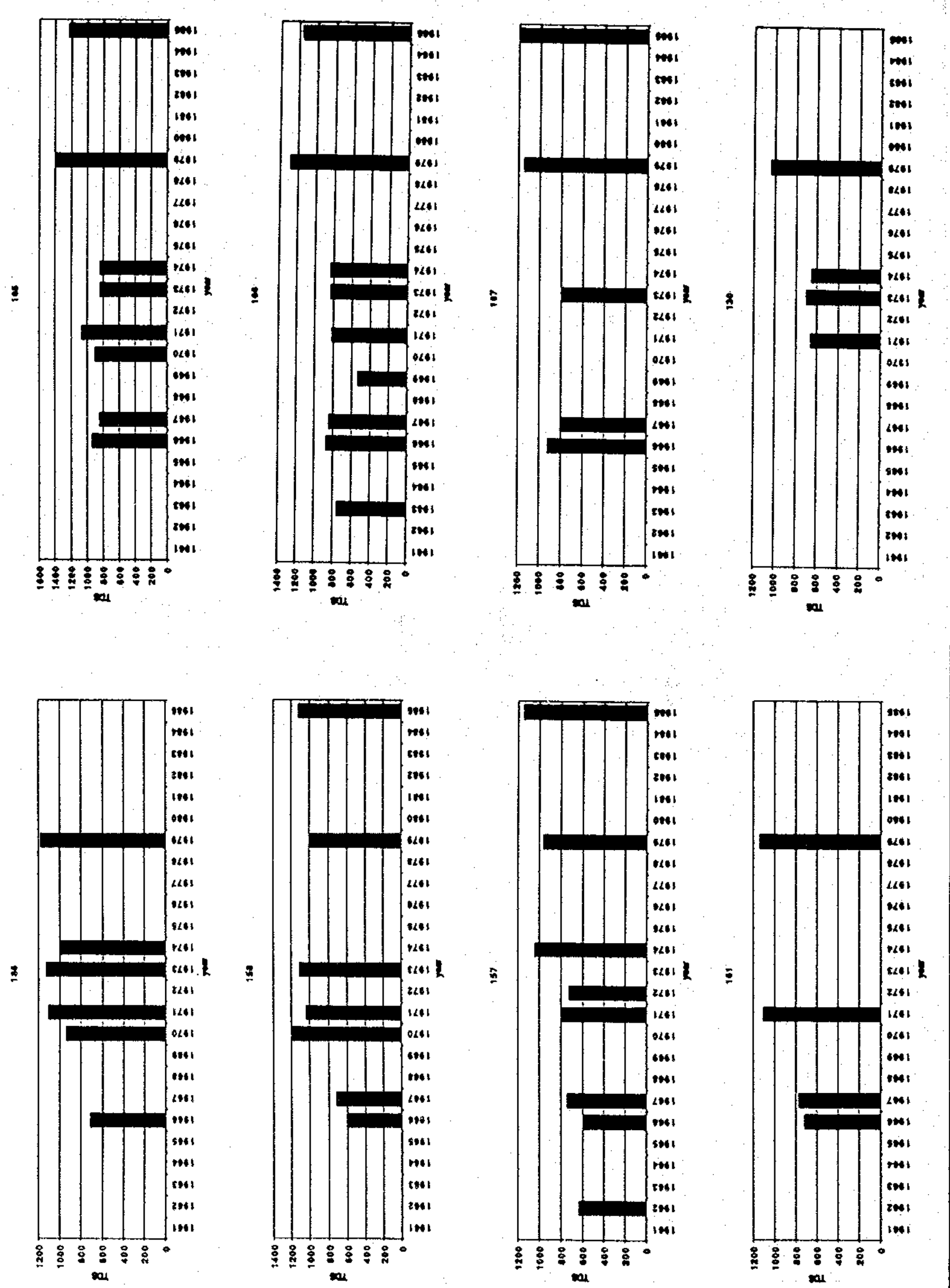
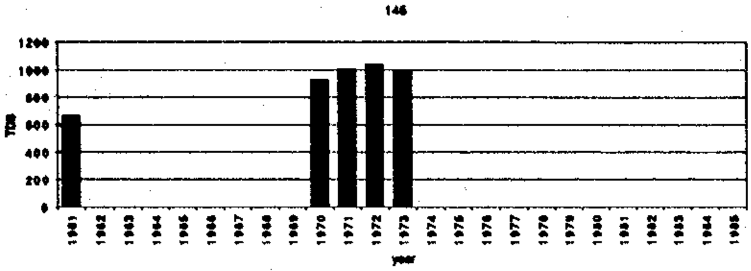
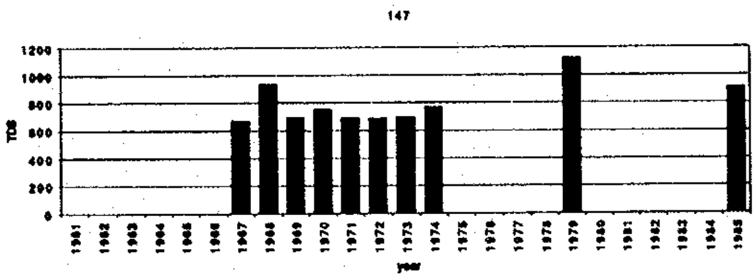
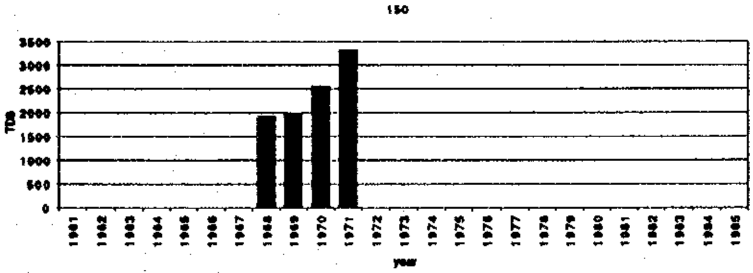


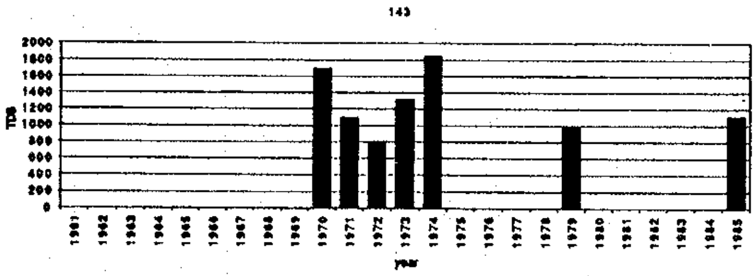
Fig. B-I. 3.8 (5) Variation of Salinity in Azapa Valley (Saucache Area)

< Variación de Salinidad en Valle de Azapa (Zona Saucache)>









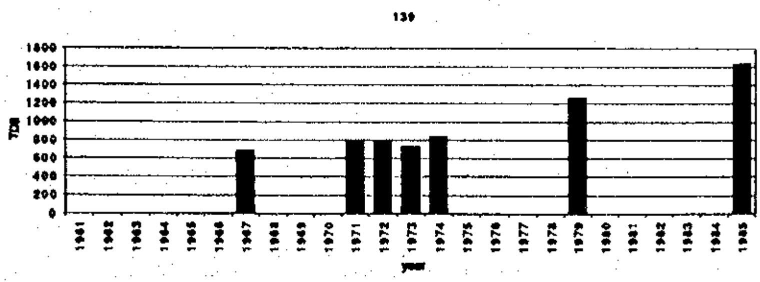


Fig. B-I. 3.8 (6) Variation of Salinity in Azapa Valley (City Area)
< Variación de Salinidad en Valle de Azapa (Zona Ciudad)>

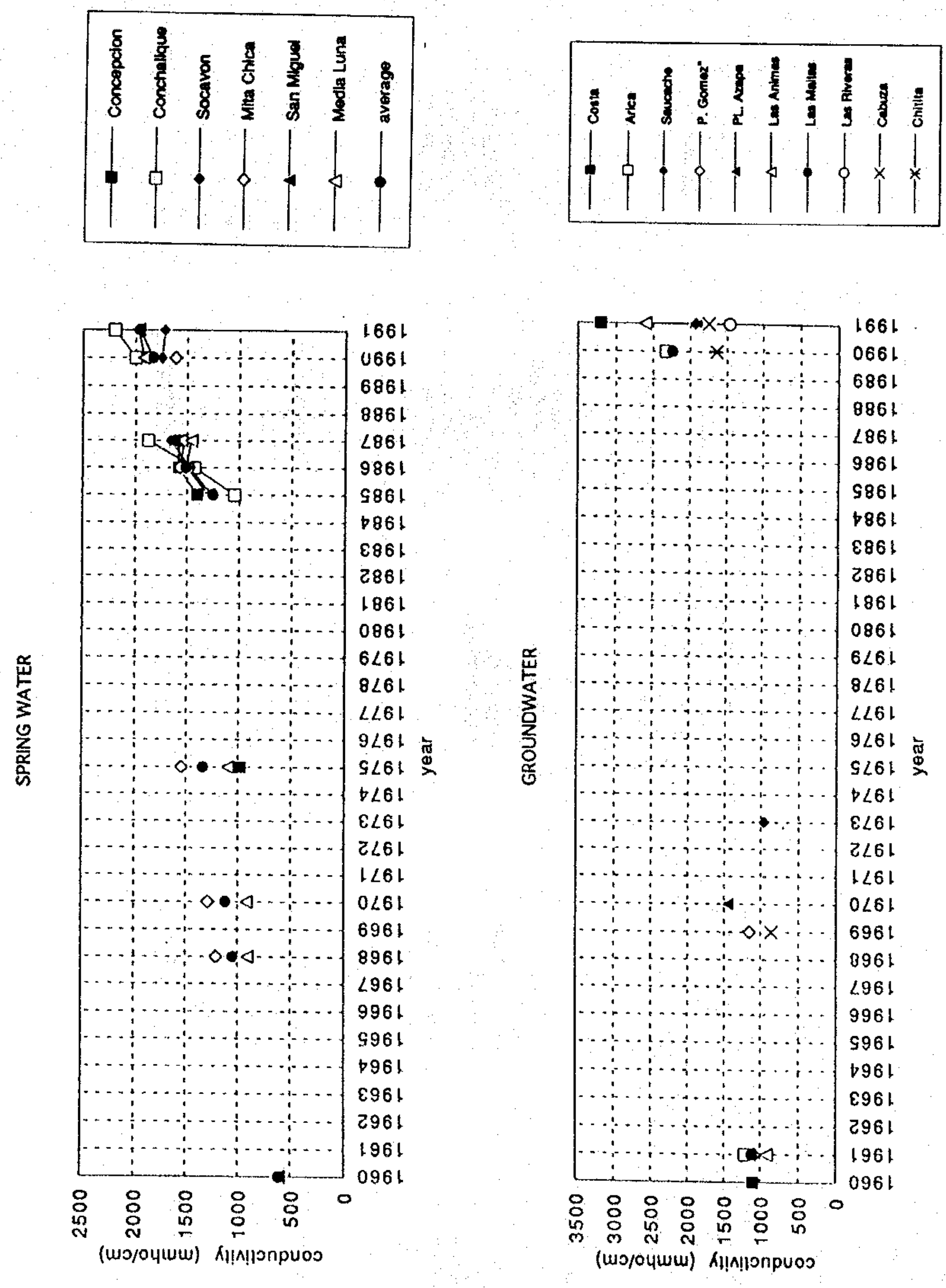


Fig. B-I. 3.9 Variation of Conductivity (Azapa Valley)

< Variación de Conductividad (Valle de Azapa)>

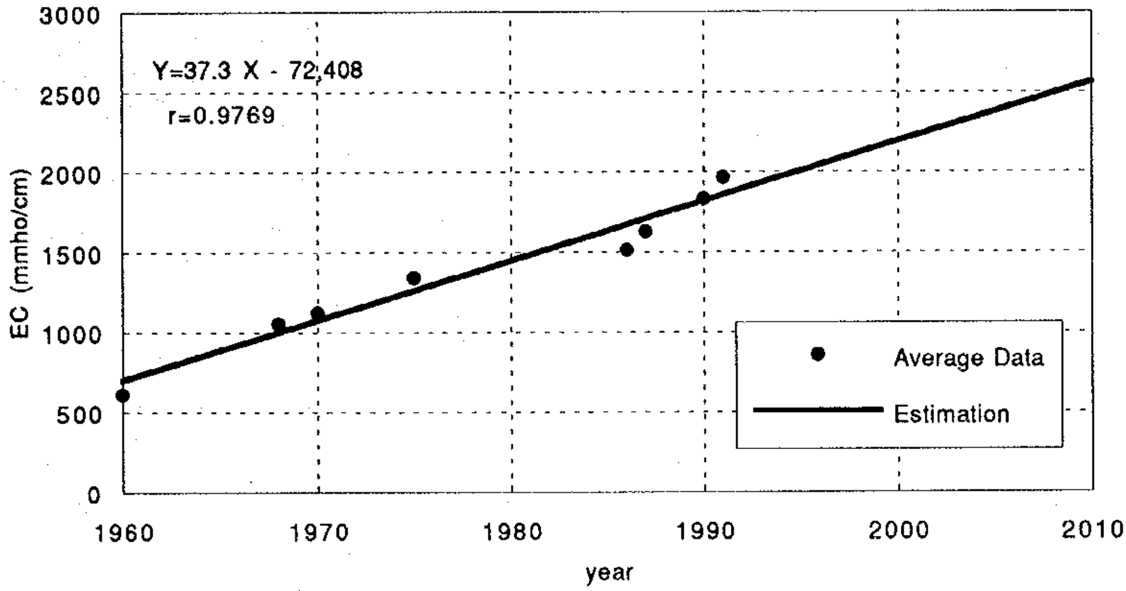


Fig. B-I. 3.10 Assumption of Salinity Increase (Azapa Valley)

< Hipótesis del Aumento de Salinidad (Valle de Azapa) >

Chapter IV GROUNDWATER MONITORING

Aquifers in the San José River Basin are distributed mainly in the Azapa Valley from Cabuza to Arica City area and are extensively used as water sources for potable water supply, irrigation water, industry water, etc. Amount of groundwater extraction reaches to 11,300,000 m^3/year. This amount is over the annual recharge. Static water level has been declined and salinity of groundwater is increased in the lower reaches and the city area. The life of aquifer is estimated about 30 years if present condition continues in future.

Under these circumstances, following groundwater monitoring plan is proposed for protection of water resources. Items of monitoring are water level and water quality. Proposed wells to be monitored are mentioned below. It is important to continue observation at the same wells and never to change monitoring wells.

Total number of 12 wells are selected for the observation as follows. For location, refer Fig. B-I, 2.1.

Well No.	Well Name	Interval of Observation	
		Water Level	Water Quality
-	any existing well in Cabuza	every 2 months	once a year
225 or 176	Facumoo Guiterrez or Chugal Santa Gena	every 2 months	once a year
115	Cerro Morbno	every 2 months	once a year
113	Las Riveras Madrid	every 2 months	once a year
114	Parcela 16	every 2 months	once a year
103	Las Maitas Violeta	every 2 months	once a year
196	Las Animas	every 2 months	once a year
199	Las Palomas	every 2 months	once a year
224	HDA. San Juan de Occurir	every 2 months	once a year
109	Algodnal	every 2 months	once a year
110	Saucache	every 2 months	once a year
142	AP Cancha Tucapel	every 2 months	once a year
133	AVDA. Tarapacá	every 2 months	once a year
126	AVDA. Azola	every 2 months	once a year
214	Hospital	every 2 months	once a year
147	Planta AP. San José	every 2 months	once a year

Wells to be observed are listed above. However, if it is impossible to observe at some wells, other wells should be selected in the adjacent areas.

Items of water quality to be analyzed are as follows;

Temperature, pH, TDS, Ca, Mg, K, Na, SO4, Cl, CO_3, HCO_3, NO_3, As, F, Cd, Cr, Pb, B, Fe, Mn, Zn, Cu, Al

B-II LLUTA RIVER BASIN

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B-II LLUTA RIVER BASIN

Chapter I. TOPOGRAPHY AND GEOLOGY

1.1. Topography

The Lluta River Basin shows the same topographic features as the San José River Basin and consists of a part of Altiplano, Precordillera and Intermediate Depression, as shown in Fig. B-I, 1.1. Drainage patterns of the basin extracted from LANDSAT images are shown in Fig. B-I, 1.2. This figure clearly shows that the catchment of the upper stream is extremely large and widely spread in the Altiplano characterized by abundant volcanoes.

1.2. Geology

1.2.1. Methodology of Geological Analysis

About details of the methodology, refer to the part of San José River Basin (B-I).

1) Interpretation of LANDSAT Images

As for the Lluta River Basin, the same four (4) images used for the San José River Basin were interpreted.

2) Interpretation of Aerial Photographs

Thirty four sheets of black and white aerial photographs taken in 1976 and 1977 were used for the interpretation.

1.2.2 General Geological Features of Basin

The results of the interpretation on the basin were compiled in Fig. B-I, 1.3. Since the lithological sequence distributed in the Lluta River Basin is almost the same as that of the San José River Basin, the details can be referred to the part of the San José River Basin (B-I, Chapter 1).

1) General Geology of Basin

The geological units mentioned in the part of San José River Basin (Ref. B-I, Chapter I) were also discriminated over the Lluta River Basin on the LANDSAT images and aerial photographs.

The characteristic feature for the basin in comparison with the geology of San José River Basin is that Quaternary volcanic rocks show a wider distribution at the upper part of the basin situated in the Altiplano.

The Concordia Formation outcropping around the mouth of the Lluta River, reported in Sonia Vogel and Tomas Vila (1980) and so on, is identified as clastic sediments constituting a marine terrace and showing interfinger relationship with fluvial deposits. It could not be discriminated from recent sediments on this interpretation.

Stratigraphy in the Lluta River Basin is summarized in the following table;

Age		Formation			Units
Quaternary	Recent	Recent Beach Deposits	Recent Fluvial Deposits	Detrital Deposits	Rb Rf Rd
	Pleistocene	Concordia Formation	Fluvial Deposits		Qc Qf (Qfu,Qfl)
Tertiary	Pliocene	El Diablo Formation			
	Miocene	Oxaya Formation			Tox
	Oligocene	Azapa Formation			Taz
Pre-Tertiary		Basement Rocks			B

2) General Geological Structure of Basin

Many faults and lineaments are identified in the area where the Oxaya and El Diablo Formations are cropping out, which consist of two systems in the NW-SE and E-W directions. NW-SE system is found in the lower stream. And E-W system can be seen throughout the basin; however, it is predominantly developed in the area of Precordillera.

At the lower stream, two systems are intersected in most cases, where the strata show a very complicated structure.

In addition to the above features, extremely dense minor fractures are detected on the aerial photographs around the Puquios railway station, on the ignimbrite of the Oxaya Formation. These show NW-SE directions.

1.2.3 Hydrogeology of Lluta Valley

A detailed geological map (Fig. B-II. 1.1), a geological profile (Fig. B-II. 1.2) and geological cross sections (Fig. B-II, 1.3) of the Lluta River Basin were compiled by the Study Team based on the geological field survey and review of existing geological maps (<1, <2, <3 and <4).

Geology of the Lluta River Basin is generally classified into Basement Rocks and Quaternary formations. Aquifers in the Lower Lluta Valley are occurred in the Quaternary formations, especially in the Fluvial Deposits. Although the Concordia Formation also seems to be a aquifer, it distributes very close to the sea. Therefore, only the Fluvial Deposits are considered to be prospective aquifer in the Lower Lluta Valley. The Lower Lluta Valley is occupied by the Fluvial Deposits. They are in a interfinger relation. The aquifers seem to be extended up to around Tocontasi.

The aquifers are accumulated in the coastal plain and the valley which was formed by eroding the impermeable Basement Rocks. Thus, the hydrogeological condition is same as that of the San José River Basin. Groundwater flows in the aquifer from the upstream to the downstream with neither leaking to the outside of the valley nor receiving water from the outside of the valley.

Although the river system is developed in the Lluta River Basin, no surface water is recognized in the quebradas in the middle to lower reaches except the main stream of the Lluta River. Therefore, the groundwater is recharged mainly by the surface water of the Lluta River. In addition to this, fissures developed in the Basement Rocks may supply a certain measure of water to the aquifers. Explanation of each formation is given below;

1) Basement Rocks

The Basement Rocks are composed of the Azapa Formation, the Oxaya Formation, the El Diablo Formation and their slid blocks in ascending order.

Fissures and joints are well developed near the surface of the rocks but less developed in the deep part. Thus, it is considered to be impermeable.
Described below is characteristic features of different formations.

(1) Azapa Formation

The Azapa Formation is composed of fine to middle grained sandstone, siltstone, mudstone, conglomerates, calcareous evaporitic sediments and tuffs. Each bed is consolidated and matrix of the conglomerates is rich in fine materials. Therefore, the Azapa Formation is considered to be impermeable to less permeable.

(2) Oxya Formation

The Oxya Formation is divided into three (3) members; the lower, the middle and the upper. The lower member consists of grey andesite intercalated with ignimbrites and volcanic ash. The middle member consists of breccia intercalated with tuffaceous sandstone and tuffite. The upper member consists mainly of ignimbrites variable in welding. Lithofacies of the Oxaya Formation show impermeable to less permeable.

(3) El Diablo Formation

The El Diablo Formation consists of conglomerates and sandstone with thick coarse sandstone and thin evaporitic intercalation. Thus this formation is considered to be permeable. However, it is distributed on the plateau, therefore, this has less relation with hydrogeological condition of the study area.

2) Quaternary Formations

Quaternary Formations consist of six (6) units; Fluvial Deposits, Concordia Formation, Detrital Deposits, Pumice Tuff, Recent Beach Deposits and Recent Fluvial Deposits.

Details of each unit are described below.

(1) Fluvial Deposits

The Lower Lluta Valley is occupied by the Fluvial Deposits. Drilling results of JICA wells revealed that total thickness of the formation is approximately 200 m and there appear tuff layers. The tuff layers are 7 m in thickness in J-B well, not clear in J-2 well, 3 m in J-A well and 11 m thick tuffaceous sandy gravel in J-1 well.

The deposits are stratigraphically divided into three (3) units, the lower, the middle and the upper, considering the boring results; the upper and lower units are composed mainly of gravel beds and the middle unit is composed of impermeable tuff beds, however, it is not necessarily distributed in the whole area of the Lower Lluta Valley. Lithofacies of the upper and the lower units are same; the deposits are formed mainly of rounded gravels having a diameter of 5 to 30 cm. Gravels are derived mainly from diorite, ignimbrite, andesite, basalt and hard sedimentary rocks. Matrix of the deposits are composed mainly of silt and very fine sand originated from volcanic ashes.

Judging from the lithofacies, both the upper and lower units are permeable. The middle unit, tuff to tuffaceous layers, is impermeable.

The aquifer appeared in the Fluvial Deposits is divided into two (2); the upper aquifer and the lower aquifer. The upper aquifer is mainly utilized at Villa Frontera; a total number of 10 wells were constructed.

The lower aquifer has not been developed; no well is extracting groundwater from this aquifer.

(2) Concordia Formation

The Concordia Formation is marine deposits, distributed in the Villa Frontera and Concordia area, the lower reaches of the Lluta Valley. It has a interfinguring relationship with the Fluvial Deposits in the Lower Lluta Valley (See, Fig. B-II, 1.2). It changes to the Fluvial Deposits near the Panamerican Highway. It has three (3) members, the lower, the middle and the upper. The lower and the upper members are composed mainly of unconsolidated sand. The middle member consists mainly of volcanic ashes. The total thickness reaches to 200 m. It seems that the formation is in a interfingering relation with other Quaternary Formations (<1 and <2). As for the thickness of the middle member, it is approximated to be 40 m (<3) or 120 m (<4).

Judging from the lithofacies, the lower and the upper members are permeable, and the middle member is impermeable.

As the Concordia Formation is distributed very close to the sea, it is less worth as the prospective aquifer in the area.

(3) Detrital Deposits

The Detrital Deposits consist of talus deposits, slope deposits and fan deposits. Talus and slope deposits are composed of different sizes of clastics. The surface of them is cemented in various degree by salts. Large blocks of Oxaya Formation are sometimes slid and overlaid the talus deposits. The fan deposits are composed of mainly silt and sand. The Detrital Deposits seem to be impermeable.

(4) Pumice Tuff

The Pumice Tuff consisting of pumice and volcanic ash is distributed in Gallinazos and Apacheta, the lower reaches of the Lluta River. Permeability of this deposits are considered to be small.

(5) Recent Beach Deposits

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

(6) Recent Fluvial Deposits

The Recent Fluvial Deposits are distributed along the river channel of the Lluta River. The unit is composed of sand, gravel and silt. The unit is less permeable because the matrix of this unit is rich in fine materials.

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

<4: Estudio Análisis de los Recursos de Agua de la Primera Región de Tarapacá, June 1991 for DGA by Ingenieria y Geotecnia Ltda.

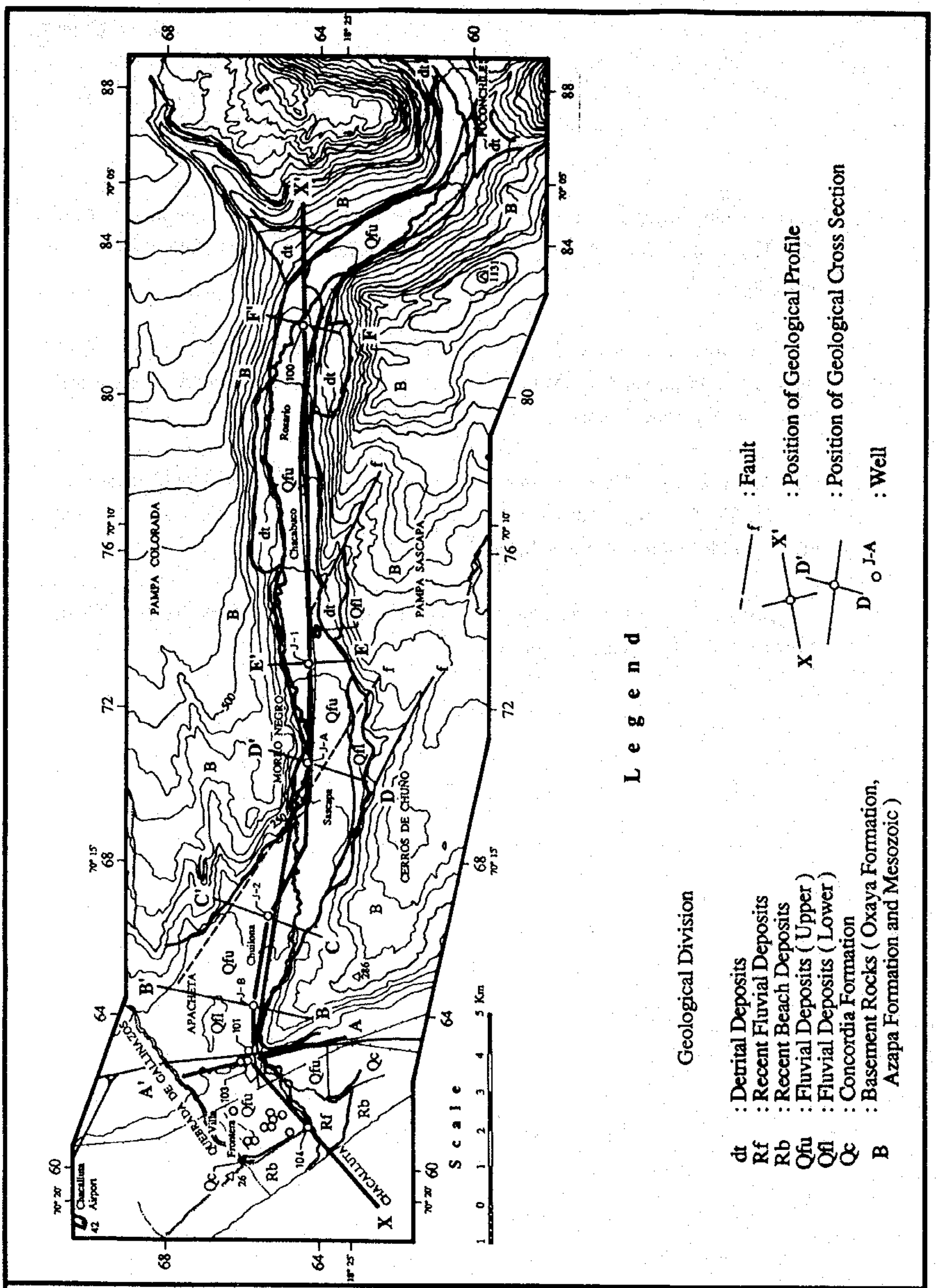

Fig. B-II, 1.1 Geological Map (Lluta Valley)

< Mapa Geológico (Valle de Lluta)>

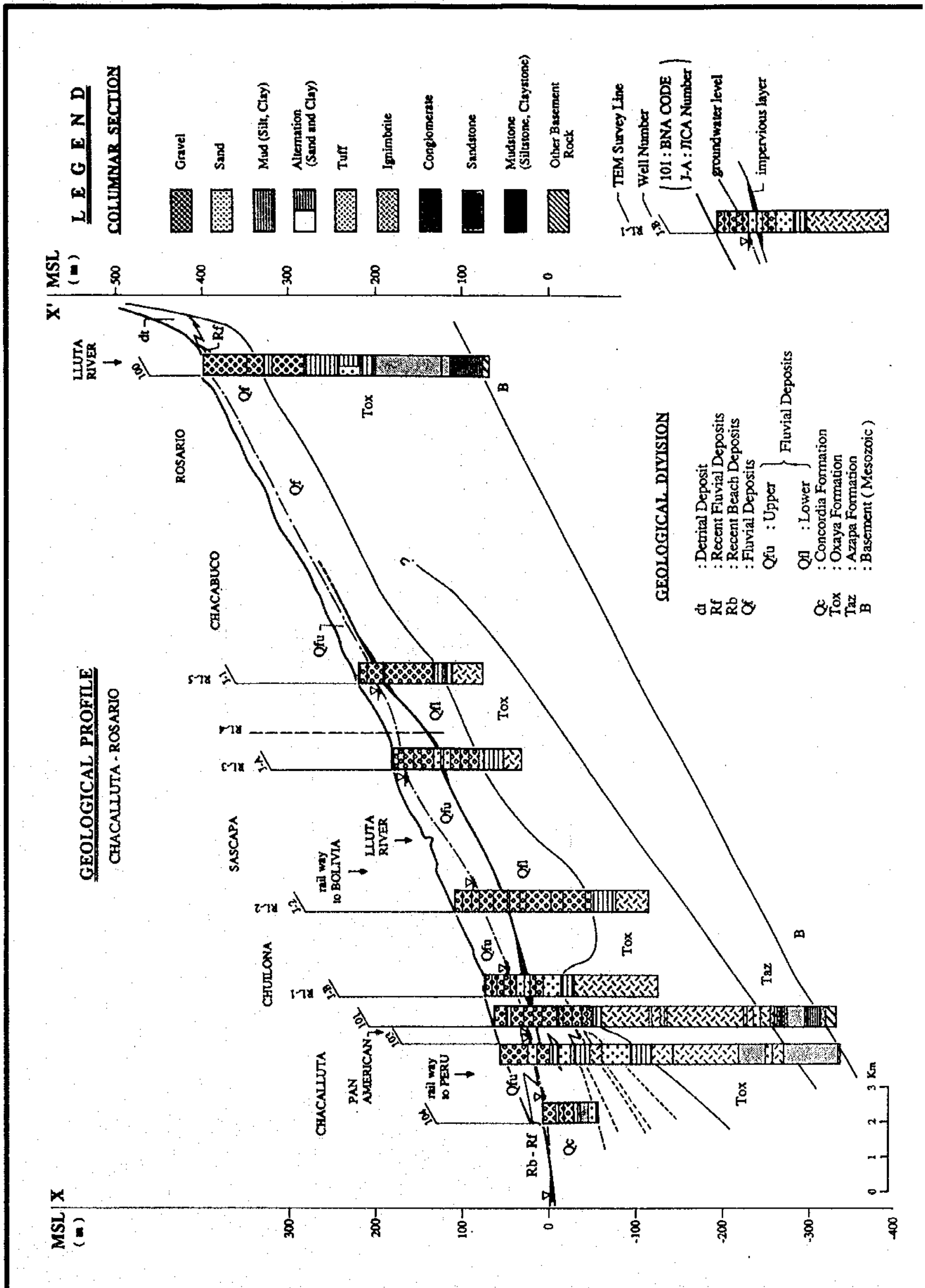

Fig. B-II, 1.2 Geological Profile (X-X')

< Perfil Geológico (X-X')>

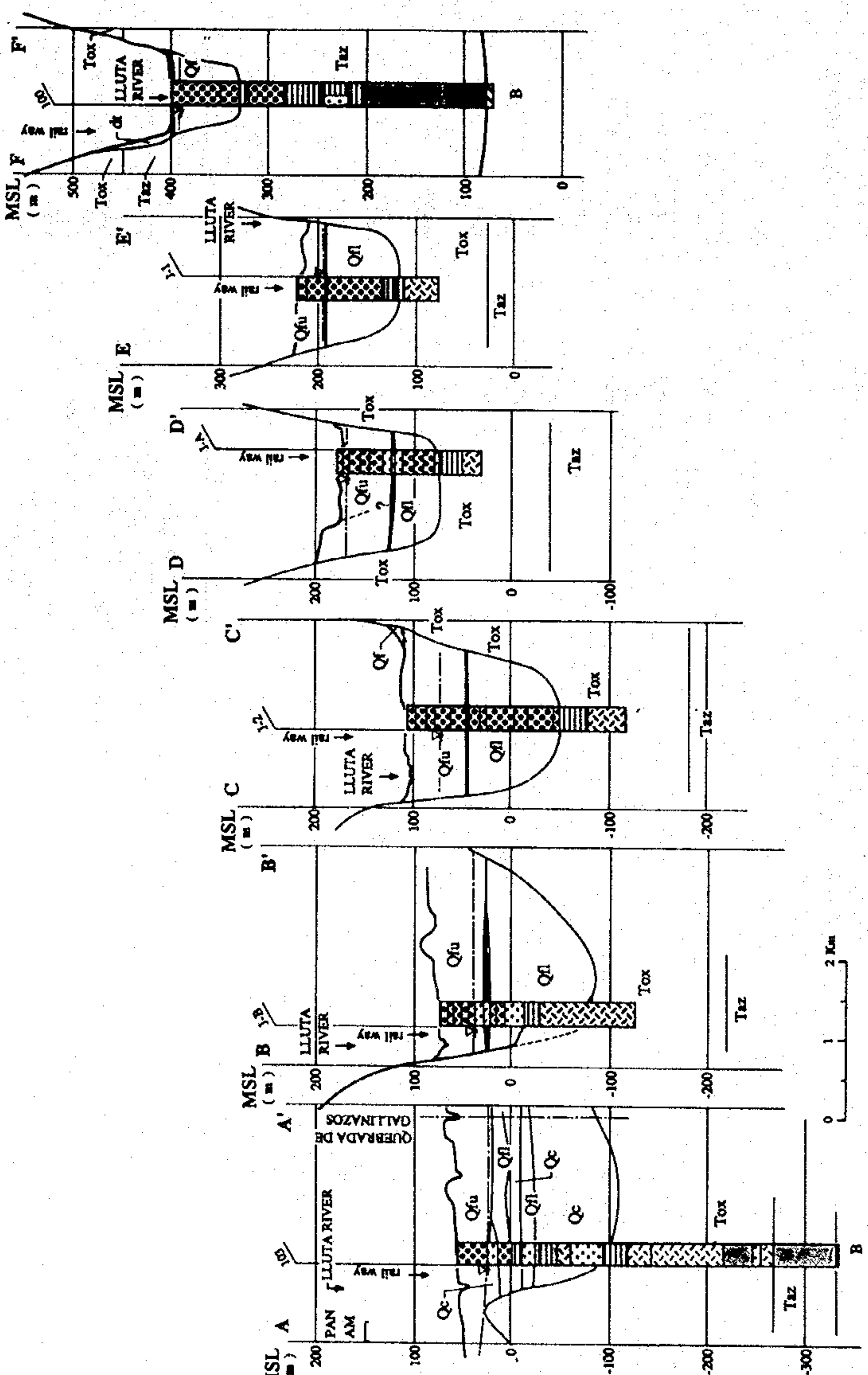

Fig. B-II, 1.3 Geological Cross Sections

<Seccion de es Cruce Geológico>

Chapter II. AQUIFER OF LLUTA VALLEY

2.1 Inventory of Existing Wells

The JICA Study Team established well inventory of existing wells, dug wells and springs by the same method as that of the Azapa Valley (refer to B-I, Chapter 2.1) based on the existing well inventories attached to following reports;

1) Análisis Crítico de la Red de Medición de Niveles de Agua Subterránea 1 Región, October 1987 for DGA by Alamos y Peralta Ingenieros Consultores Ltda.
2) Modelo de Simulación de las Aguas Subterráneas del Valle de Azapa, January 1989 for DGA by Ayala, Cabrera y Asociados Ltda. Ingenieros Consultores con la asesoris de IPLA Ltda.
3) Estudio Análisis de los Recursos de Agua de la Primera Región de Tarapacá, Informe Final de la Primera Etpa, June 1991, for DGA by Ingenieria y Geotecnica Ltda.

The CORFO code (1975) and the BNA code are applied to only deep wells (sondajes) in the area. Springs (vertientes) and dug wells (norias) had no number, therefore, the Study Team temporarily assigned the numbers to the wells: V-1 and 2 for springs and N-0 to 9 for dug wells. The DGA code has not been applied in the Lluta River Basin.

Total number of existing wells comes to 19, consisting seven (7) deep wells, 10 dug wells and two (2) springs in the valley. The Well List is shown in Table B-II, 2.1 including four (4) JICA wells. Well locations are shown in Fig. B-II, 2.1. The Well Inventory is attached as Data Book. Items included in the inventory are same as that of the Azapa Valley. None of the dug wells has any information, therefore, DGA and the JICA Study Team executed field survey on these dug wells. In the field survey, exact locations of dug wells were measured by GPS (Global Positioning System). The results of the measurement are also included in the Well List.

Most wells are located in the Villa Frontera. In this area there are five (5) deep wells and the rest are dug wells. Other two (2) deep wells are located in the middle stream of the Lluta River; one is at Bocanegra and the another is at Rosario. Among these, six (6) deep wells were constructed in 1960s. As for remaining one (1) deep well and all the dug wells, no data is available.

2.2 Existing Boring Data

2.2.1 Boring Logs

Available boring data are for following six (6) logs of deep wells;

100-7	Bocanegra
100-2	Rosario
101-0	Villa Frontera (near the Panamerican)
102-0	Villa Frontera (near the railway to Peru)
103-7	Villa Frontera (near the railway to Peru)
104-5	Playa Las Machas (near the coast)

Geostratigraphic columns of these wells are attached to the Well Inventory (see, Data Book).

2.2.2 Pumping Test

The Well List (Table B-II, 2.1) shows the results of the pumping test executed at the completion of well construction. Six (6) data are available in the basin. However, aquifer constants are not analyzed. Based on these data, specific yield (Sy) is calculated by the Study Team. Results are shown in Table B-II, 2.1.

2.3 Supplementary Geological Survey

The following geological surveys were executed by the JICA Study Team to supplement the existing geological data. The survey locations are shown in Fig. B-II, 2.2.

1) Electromagnetic Survey — 30 survey points (5 lines)

2) Boring Test
   - (1) Drilling
     - Test well drilling — 2 wells
     - Observation well drilling — 2 wells
   - (2) Pumping Test — 4 wells

3) Water Quality Analysis — 4 wells (JICA wells)

4) C-14 analysis — 1 well

2.3.1 Electromagnetic (TEM) Survey

1) Survey Area

The survey area is located along the Route 11 in the Lower Lluta Valley (Fig. B-II, 2.2). Five (5) TEM lines were set perpendicular to the main axis of the Lluta River. A total of 30 stations were set at an interval of 250m each as shown below ;

Quantity of TEM Survey

Profile	Stations	Station Interval
RL-1	6	250 m
RL-2	6	250 m
RL-3	6	250 m
RL-4	6	250 m
RL-5	6	250 m
Total	30	

2) Methodology of Survey

(1) Selected Method

The purpose of the electromagnetic exploration is to clarify the resistivity structure of layers and to select the promising boring locations.

The measurement of the electrical resistivity of layers has been a tool for groundwater exploration for many years. Traditionally, D.C. current methods (Wenner, Schlumberger, etc.) have been widely used for this purpose. However, often are problems encountered in typical areas such as desert and rocky surface where it is difficult to obtain sufficient current flow. Furthermore, a considerable effort is usually required to lay out the array, so that D.C. resistivity surveys tend to be expensive to perform. For these reasons, there is a growing interest in the use of non-contacting electromagnetic (EM) techniques to measure resistivity. The TEM method used here, is starting to be widely used for groundwater exploration with measuring depth from hundreds to thousands meters. For the above mentioned reasons, the TEM method was adopted for the project.

(2) Principal of TEM Method.

In the TEM method most commonly used, a square transmitter loop, of which side length is decided corresponding to the desired depth of exploration, is laid out on the ground and energized with an alternating current wave. This current wave form induces horizontal eddy current loops in the ground which expand in radius and diffuse to greater depths with passage of time. By measuring the decaying magnetic field from these eddy currents as a function of time, information is successively derived from greater depth. The value of magnitude of the decaying magnetic field is converted to an apparent resistivity as a function of time, from which a layered earth interpretation can be made using techniques analogous to those for conventional resistivity soundings.

3) Survey Results

Measured apparent resistivity curves in the area are shown in Fig. B-II, 2.3. Geoelectrical profiles are prepared from the apparent resistivity curve of each station. The geoelectrical profiles along Line RL-1 to RL-5 are shown in Fig. B-II, 2.4. According to the data from DGA, conductivities of groundwater in this area show high values of 2,600 (3.8 Ω-m) to 5,200 (1.9 Ω-m) mΩ/cm.

The resistivity structure in this area consists of 3 to 4 layers, with a stratiform structure, in general. Resistivities of the layers are relatively low, less than 200 Ω-m. The geophysical characteristics of each layer are summarized as follows.

(1) The first layer (5 m to 70 m thick) shows a resistivity range of 28 to 300 Ω-m. The resistivity of the layer other than profile RL-5, is relatively high (99 - 300 Ω-m). These layer is considered dry. On the other hand, in RL-5 it shows a relatively low resistivity (28 - 84 Ω-m) due to the wet land conditions by irrigation water.

(2) The second layer (50 m to 250 m thick) shows a resistivity range of 11 to 30 Ω-m. This layer is distributed in the whole area. It is considered as a expected aquifer because the resistivity value of prospective aquifer is usually in the order of ten (10) times of that of the groundwater in the area.

(3) The third layer (70 to 190 m thick) shows a resistivity range of 29 to 96 Ω-m. The layer exists only in stations 1 and 2 of RL-3, and in all stations of RL-4. The layer of RL-3 is considered as expected aquifer because of its low resistivity. On the other hand, the layer of RL-4 is considered dry or impermeable, judging from its high resistivity.

(4) The forth layer shows a resistivity value of less than 9.8 Ω-m. The layer is distributed in the whole area. The layer is presumed to have groundwater potential to some degree. However, its extremely low resistivity indicates that the layer is much contaminated by salty to brackish water.

Lateral discontinuities of resistivity exist between station No. 1 and No. 2 of profile RL-1 and between stations No. 2 and No. 3 of RL-3. These discontinuities may be coincident with geological boundaries, such as faults or fracture zones.

4) Interpretation with Boring Log

Geoelectric profiles, described in above section, are analyzed together with the boring logs (lithological description and geophysical logging data). Fig. B-II, 2.4 shows geoelectric profile and Figures B-II, 2.5 (1) to 2.5 (5) show analyzed resistivity profiles Results of interpretation are summarized as follows.

(1) Profile RL-1 (see, Fig. B-II, 2.5 (1))

The profile is analyzed as a three (3) layered model from resistivity curves. The results are shown in the table mentioned below.

The first layer is considered to be dry layer because of its relatively high resistivity range. It corresponds to surface deposits. Judging from the resistivity, the second layer is considered to be a aquifer. However, groundwater in the aquifer may contain a little quantity of salty contents because the resistivity of the aquifer is relatively low.

The third layer consists of Ignimbrite appearing at the depth of 40 m. Resistivity of the third layer is generally low, less than 9.8 Ω-m. This is probably due to the following geological characteristics.

- Joints are developed in the upper part of the rock by which the rock was broken into blocks. Then, groundwater saturated these joints and it made the resistivity of the rock low.

It is considered to be difficult to exploit the groundwater in this aquifer, because the groundwater is stored in the large spacing joints.

Layer	Depth (mBGL)	Resistivity Range(Ω-m)	Lithology	Interpretation
1 st	0 - 46	65 - 180	gravel, sandy to clayey	surface deposits
2 nd	46 - 150	13 - 26	gravel to sand in upper, clay to ignimbrite in lower	expected aquifer
3 rd	150 <	< 9.8	ignimbrite	ignimbrite with joints

(2) Profile RL-2 (see, Fig, B-II, 2.5 (2))

The profile was analyzed as a three (3) layered model and no discontinuity throughout the survey line. The results are summerized in the table mentioned below.

The first layer shows a resistivity range of 65-80 Ω-m and correspond to dry surface deposits. The second layer has a resistivity range of 17 to 30 Ω-m and considered as expected aquifer. The third layer is of low resistivity range, lower than 12 Ω-m, and is correlated to ignimbrite with joints as previously mentioned on the survey line RL-1.

The well No. J-2 is drilled on this survey line and lithology of each layer was confirmed as follows.

Layer	Depth (mBGL)	Resistivity Range(Ω-m)	Lithology	Interpretation
1 st	0 - 20	110 - 300	gravel	surface deposits
2 nd	20 - 158	17 - 30	gravel, sandy to clayey	expected aquifer
3 rd	158<	<12	clay and ignimbrite	ignimbrite with joints

(3) Profile RL-3 (see, Fig. B-II, 2.5 (3))

The profile was analyzed as a three (3) layered model. The results are summerized as the table mentioned below. The first layer has a relatively high and is correlated with the dry surface deposits. The second is considered as a expected aquiferjudging from the resistivity. The third layer shows a relatively low resistivity range, therefore, it is considered to be correspond to the jointed ignimbrite as described in (1).

A resistivity discontinuity was observed between the station No. 2 and No. 3; The profile was analyzed as four (4) layered model on the southern side (No. 1 and 2) and as three (3) layered model on the northern side (No. 3 to 5). However, the second layer and the third layer are basically same unit because there is not so large difference in the resistivity of the both layers. The second layer is a resistivity range of 13 to 14 Ω-m and the third layer is in a rang of 29 to 47 Ω-m. Then, the third layer was included in the second layer. This feature may be due to the difference of lithofacies of aquifer; The upper is more silty and the lower is more gravelly.

The well No. J-A was drilled on this survey line and the lithology of each layer is confirmed as following table.

Layer	Depth (mBGL)	Resistivity Range(Ω-m)	Lithology	Interpretation
1 st	0 - 30	120 - 160	gravel	surface deposits
2 nd	30 - 180	26 - 12	gravel, sandy to clayey	expected aquifer
3 rd	180<	<7.6	clay and ignimbrite	ignimbrite with joints

(4) Profile RL-4 (see, Fig. B-II, 2.5 (4))

A four (4) layered model was established and no discontinuity of resisitivity is observed. The results of interpretation is shown in the table mentioned below.

The first layer has a relatively high resistivity range, therfore, it is correlated with dry surface deposits. The secoend layer is considered as an expected aquifer from its resistivity. The second layer indicates a resistivity range of

13 to 26 Ω-m and considered as an expected aquifer. The third layer is of relatively low resistivity range. Then, it corresponds to the ignimbrite with joints as mentioned in (1).

No drilling was made on this survey line, therfore, lithology of each layer was confirmed.

Layer	Depth (mBGL)	Resistivity Range(Ω-m)	Lithology	Interpretation
1 st	0 - 40	100 - 140	not confirmed	surface deposits
2 nd	20 - 180	13 - 26	not confirmed	expected aquifer
3 rd	70-335	71 - 96	not confirmed	impermeable bed
4 rd	335<	4.2 - 6.8	not confirmed	ignimbrite with joints

(5) Profile RL-5 (see, Fig. B-II, 2.5 (5))

A three (3) layered model was established on the profile. The results are summerized as the table mentioned below.

The first layer is correlated with dry surface deposits since it shows relatively high resistivity. The second layer has a resistivity range of 11 to 23 Ω-m and is considered to be an expected aquifer. The third layer shows a low resistivity range, therfore, it corresponds to the ignimbrite with joints. The boundary of the 2nd and 3rd layers is unclear at station 4.

The well No. J-1 was located on this survey line.

Layer	Depth (mBGL)	Resistivity Range(Ω-m)	Lithology	Interpretation
1 st	0 - 12	28 - 84	clayey gravel	surface deposits
2nd	12 - 230?	11 - 23	gravel, sandy to clayey and ignimbrite (?)	expected aquifer
3rd	230<	<5.8	not confirmed	ignimbrite with joints

2.3.2 Boring Test

1) Location and Depth of Well

Two (2) test wells (J-A, J-B) and two (2) observation wells (J-1, J-2) are placed along the line of the TEM survey (see Fig. B-II, 2.2). Location, drilling depth and casing size of each well are summarized as follows.

Well No.	Location	Latitude	Longitude	Elevation (mMSL)	Casing (inch)	Depth (mBGL)
J-A	Lluta	18° 23' 08.95"	70° 13' 58.16"	178.510	8-5/8"	150.0
J-B	Panamericana	18° 24' 03.85"	70° 17' 19.04"	74.301	8-5/8"	200.4
J-1	Chacabuco	18° 25' 42.54"	70° 13' 03.31"	219.539	5-1/2"	145.0
J-2	Lluta	18° 23' 40.05"	70° 16' 06.17"	107.769	5-1/2"	225.0

2) Methodology of Well Construction

(1) Drilling Method and Procedure

Both test and observation wells were drilled by the rotary drilling method with a direct mud circulation system. The reason is why this drilling method is much suitable for taking cutting samples and well logging than other method such as percussion type drilling method. It is indispensable to take samples and well logging for the evaluation of hydrogeological evaluation. Furthermore, the construction period can be much reduced by rotary drilling method.

Typical well designs are shown in Fig. B-II, 2.10 for test well and Fig. B-II, 2.11 for observation well. The procedure of the drilling is described below. However, drilling depth, packing depth and test interval were altered by the Drilling Experts of the Study Team to meet the hydrogeological conditions of the site.

i) Test Well

The well was designed as a 8-5/8" cased well, therefore, following procedure and bit size (borehole size) are specified.

Step No.	Work Procedure	Specification
1	Drill a conductor borehole to a depth of 5.5m to 8.0m.	Hole size: 17-1/2" (444.5 mm)
2	Install a conductor pipe to the drilled depth.	Pipe size: 14" (355.6 mm)
3	Seal the annular space between the borehole and the conductor pipe by cementing.	Maximum 8m depth
4	Resume drilling of the borehole to the required depth.	Bit size: 13-1/4" (336.5 mm)
5	Perform well logging through the drilled borehole.	Resistivity, SP, Temperature, Gamma Ray,
6	Determine the position(s) of well screen.	Designed by Drilling Expert of JICA Study Team
7	Install casing and screen pipes as determined.	Casing size: 8-5/8" (219.1 mm) Screen size: 8-5/8" (219.1 mm)
8	Make gravel-packing for the annular space between the borehole and pipes.	Grain size: 3 - 5 mm
9	Make clay-packing for the annular space between the borehole and casing pipes.	At least 3m thickness.
10	Cementation for the annular space above the clay-packing.	Up to ground surface.
11	Perform the development of the well by air-lifting and/or surging.	At least 1 hour for each piece of screen
12	Carry out the pumping test by submersible pump.	Step draw down test, constant discharge test and recovery test.

ii) Observation well

The well was designed as a 5-1/2" cased well, therfore the following procedure and bit size (borehole size) are specified.

Step No.	Work Procedure	Specification
1	Drill a conductor borehole to a depth of 5m to 8m.	Hole size: 17-1/2" (444.5 mm)
2	Install a conductor pipe to the conductor borehole.	Pipe size: 12" (323.9 mm)
3	Seal the annular space between the borehole and the conductor pipe by cementing.	Maximum 8m depth.
4	Resume drilling of the borehole to the required depth.	Bit size: 10-5/8" (269.9 mm)
5	Perform Well logging through the drilled borehole.	Resistivity, SP, Temperature, Gamma Ray,
6	Determine the position(s) of well screen.	Designed by Drilling Expert of JICA Study Team.
7	Install casing and screen pipes as determined.	Casing size: 5-1/2" (141.3 mm) Screen size: 5-1/2" (138.8 mm)
8	Make gravel-packing for the annular space between the borehole and pipe.	Grain size: 3 - 5 mm
9	Make clay-packing for the annular space between the borehole and casing.	At least 3m thickness.
10	Cement the annular space above the clay-packing.	Up to the ground surface
11	Perform the development of a well by air-lifting and/or surging.	At least 1 hour for each piece of screen
12	Carry out the pumping test by submersible pump.	Step draw down test, constant discharge test and recovery test.

(2) Structural Design of Well

i) Test Well

The structure of borehole was determined considering the size of the permanent casing and screen pipes, and planned drilling depth. The standard design is shown in Fig. B-II, 2.6. The borehole size was designed as 13-1/4" in order to keep enough space for gravel packing in an annular space between 8-5/8" pipes and borehole wall. Maximum depth was planned as 250m.

For future pumping use and periodical water level measurement, the well head was constructed as shown in Fig. B-II 2.8. Internal and external well caps were installed on the well head as shown in Fig. B-II, 2.9. The fence was built up around the well head as shown in Fig. B-II, 2.10.

ii) Observation Well

Considering the same purpose of the test well, the borehole size was designed as 10-5/8". The standard design of the observation well is shown in Fig. B-II, 2.7. Maximum depth was planned as 300m.

A water level recorder donated by JICA was installed on the well head as shown in Fig. B-II, 2.11 for successive measurement by DGA. The same fence as the test well was built up around each well.

(3) Materials Used

Particular materials were selected for test and observation wells. The specifications of major materials are described hereunder.

i) Pipes

(i) Conductor Pipe

Standard : ASTM A-106 Grade B schedule 40

Outside Diameter	Wall Thickness	Type of Well
355.6 mm (14")	12 mm	Test Well
323.9 mm (12")	12 mm	Observation Well

(ii) Casing Pipe

Standard : ASTM A-106 Grade B schedule 40

Outside Diameter	Wall Thickness	Type of Well
a) 8-5/8" (219.10mm)	11.2 mm	Test Well
b) 5-1/2" (141.30mm)	13.1 mm	Observation Well

(iii) Screen Pipe

Johnson type was selected as the screen pipe. The detailed specifications are as follows:

a) For Test Well

Nominal size (inch)	:	ASTM 8-5/8"
Screen outside diameter (mm)	:	219.10
Effective unit length (mm)	:	5,924
Opening ratio (%)	:	More than 20%

b) For Observation Well

Nominal size	:	ASTM 5-1/2"
Screen outside diameter (mm)	:	138.8
Effective unit length (mm)	:	5,924
Overall unit length (mm)	:	6,000
Materials	:	Galvanized steel (SAE 1010/15)
Slot size (mm)	:	1.0
Opening ratio (%)	:	More than 20%

ii) Packing Materials

The following packing materials were used for both test and observation wells.

(i) Cement Grouting

Mixture of 50% Portland cement and 50% casting plaster.

(ii) Gravel Pack

Uniformly-graded, well-sorted and well rounded river gravel with 3 - 5mm grain size.

3) Results of Boring Test

The well data for each well, lithological column, casing design, well logging and drilling rate, are shown in Fig. B-II, 2.12 and Fig. B-II, 2.13 for test well and Fig. B-II, 2.14 and Fig. B-II, 2.15 for observation well.

(1) Well No. J-A (see Fig. B-II, 2.12)

i) Lithology

The well was drilled up to 150m depth. Two (2) formations, Fluvial Deposits and Oxaya Formation, were observed at the depth from surface to 106m and from 106m to 150m respectively. Based on the results of geophysical logging and lithology observed, the following four (4) major layers were classified.

(J-A)

Layer	Depth (m)	Classification	Lithology	Period	Formation
1 st	0 - 56	Shallow Aquifer	clayey to sandy gravel	Quaternary	Fluvial Dep.
2 nd	56 - 59	Impermeable layer	tuff		
3 rd	59 - 101	Deep Aquifer	sand, sandy to clayey gravel		
4 th	101 - 150	Impermeable Bed	clay, ignimbrite	Quaternary Tertiary	Fluvial Dep. Oxaya Form.

ii) Well Logging

Spontaneous potential (SP) indicates a range of 985 to 1040 mv. Considering the lithology, the relative basement line (relative 0 line) is established as 1025 mv. The line indicates the boundary of permeable formation (gravel, sand) and impermeable formation (mud). Resistivity indicates a high range of 20 to 100 Ω-m at surface, a short range of 10 to 30 Ω-m at below 60m depth. Temperature is 28 to 28.5 °C in general.

iii) Determination of Casing Design

The position of screen pipes was determined at the depth between 59.93 m and 101.98 m on the basis of interpretations of lithological and well logging data. The details of interpretation are mentioned below. For the casing design, see Fig. B-II, 2.12.

(i) 1 st layer (Shallow Aquifer)

The layer consists mainly of clayey, sandy gravel and is intercalated with sand at some minor parts. The layer is interpreted as an aquifer by the value of SP and resistivity, except the top surface (0 to 12m in depth). The temperature curve shows a surface water permeation to the groundwater at depth from 15 to 30m. Gamma ray value shows a range of 60 to 100 cps from surface to 76m depth. This value is relatively higher than others, therefore, the layer is considered to be rather rich in clay.

(ii) 2 nd layer (Impermeable Layer)

The layer is composed totally of tuff. Both SP and resistivity values indicate that the layer is impermeable. The layer acts as a boundary of the shallow and the deep aquifer.

(iii) 3 rd layer (Deep Aquifer)

Based on the values of SP and resistivity, the layer is classified as the most promising aquifer in the sequence. Especially, resistivity value shows a range of 15 to 30 Ω-m which is similar to the results of TEM survey (12 to 26 Ω-m). Compared to that of shallow aquifer, the value of gamma ray is more lower (50 - 70 cps) at the depth from 66 to 100 m. It is considered that the layer is much permeable than shallow aquifer. A slow increasing rate of water temperature also characterizes a promising aquifer. It is observed at a zone of 50 to 100 m depth.

The screen pipes were installed in this layer.

(iv) 4 th layer (Impermeable bed)

The layer consists of clay at upper part and ignimbrite at lower part. Judging from the lithology, the layer is clearly impermeable. This is supported by the following logging data; The value of SP exceeds basement line (1025 mv) and Gamma ray value shows relatively high cps ranging form 50 to 90 for clay and 60 to 100 for ignimbrite.

(2) Well No. J-B (see Fig. B-II, 2.13)

i) Lithology

The total drilling depth was 200.4m. Two (2) formations, Quaternary Fluvial Deposits and Tertiary Oxaya Formation, were observed at a depth of 89m from surface and from 89 to 200m respectively. Based on the results of the geophysical logging and lithological observation, following six (6) layers were classified.

(J-B)

Layer	Depth (m)	Classification	Lithology	Period	Formation
1 st	0 - 46	Shallow Aquifer	sandy to clayey gravel, sand	Quaternary	Fluvial Dep.
2 nd	46 - 53	Impermeable Layer	clayey tuff		
3 rd	53 - 89	Deep Aquifer	sandy to clayey gravel, sand		
4 th	89 - 104	Impermeable Layer	silty clay	Tertiary	Oxaya Form.
5 th	104 - 147	Fissured zone	ignimbrite		
6 th	147 - 200	Impermeable Bed	ignimbrite		

ii) Well Logging

Values of the spontaneous potential (SP) indicate minus (-) in all the sequences. Based on the lithology and cps curve of gamma ray, relative basement line of SP is estimated as - 8.4 mv. Layers are clearly classified into three (3) units by the cps curve of gamma ray; From surface to 63m depth as impermeable (muddy gravel or alternation of mud and gravel), from the depth of 64 to 140m as permeable , and from 140m to the bottom as impermeable (ignimbrite). The infiltration from surface water is identified by the temperature curve, at the depth of 15 to 70m .

iii) Determination of Casing Design

Casing design is determined as shown in Fig. B-II, 2.13, based on the following interpretation for each layer. The range of screen pipes are from 60.05 m to 90.1 m and from 102.1 m to 144.17 m.

(i) 1 st layer (Shallow Aquifer)

The layer is composed mainly of sandy and clayey gravel. Surface of this layer is considered as a boulder formation due to the slow drilling rate (less than 60 min./m). Because high resistivity (60 to 150 Ω-m) appears from the surface to 23m the surface is dry. From the depth of 17 to 46m, SP value is located on the permeable side of the basement line. The infiltration from the surface water is clearly observed on the temperature curve. The gamma ray shows high value (50 -100 cps) which means that the layer predominates in mud. Therefore, it is considered that the layer has a small scaled alternation of mud.

(ii) 2nd layer (Impermeable Layer)

The layer is composed of clayey tuff. The thickness of the layer is 7 m. The boundaries of the layer are very clear; The drilling rate varies at the boundaries with other layers. The layer is classified as impermeable.

(iii) 3 rd layer (Deep Aquifer)

All the geophysical logging data indicate that the layer is a promising aquifer, except the high value of gamma ray in the upper part (53m - 63m). Especially, the value of Gamma Ray shows a low value (25 to 50 cps). Thus, it is considered as a high permeable layer.

The screen pipes were installed in this layer.

(iv) 4 th layer (Impermeable Layer)

The layer is composed of silty clay having 15m in thickness. The layer is judged as impermeable by the value of SP and gamma ray.

(v) 5 th layer (Fissured Zone)

The layer consists of ignimbrite of Tertiary Oxaya Formation. The layer forms basement rock of the area. However, the resistivity range (15 - 30 Ω-m), a gentle increasing rate of temperature and gamma ray value indicates that the layer is permeable. Therefore, joints are well developed in this layer.

The screen pipes were also installed in this layer at the depth from 102.1 m to 144.17 m.

(vi) 6 th layer (Impermeable Bed)

The layer consists of ignimbrite of the same formation as in the 5 th layer. However, considering the high value of resistivity and gamma ray, the layer is considered as dry.

(3) Well No. J-1 (see Fig. B-II, 2.14)

i) Lithology

The well was drilled up to 145m. Based on the lithology and well logging data, the following four (4) major layers are classified. These are correlated with Quaternary Fluvial Deposit and the Tertiary Oxaya Formation.

(J-1)

Layer	Depth (m)	Classification	Lithology	Period	Formation
1 st	0 - 29	Shallow Aquifer	clayey to sandy gravel	Quaternary	Fluvial Dep.
2 nd	29 - 31	Impermeable Layer	clay		
3 rd	31 - 101	Deep Aquifer	sandy gravel, clay at bottom		
4 th	101 - 145	Impermeable Bed	clay, ignimbrite	Tertiary	Oxaya Form.

ii) Well Logging

Resistivity shows a rather low range of 10 to 30 Ω-m in general. Several reversal relation of long and short normal resistivity value are observed at the surface to 29m depth. Gamma ray shows a boundary of upper and lower strata at 83m depth. The cps value is high (50-110) at upper, low (20 -80) at lower strata. A relative basement line of the spontaneous potential is established at 935 mv, based on the resistivity value and lithology. A large scale of groundwater flow into the borehole is confirmed by the temperature curve from 30 to 90m depth.

iii) Determination of Casing Design

Casing design was determined as shown in Fig. B-II, 2.14, based on the following interpretation. The screen pipes were installed at the depth from 31m to 91m.

(i) 1 st layer (Shallow Aquifer)

The layer is mainly composed of clayey gravel and sandy gravel. The layer is considered as highly permeable judging from the SP value. Surface water infiltration is observed at depths from 5 to 10m and 26 to 29m by the temperature curve.

(ii) 2 nd layer (Impermeable Layer)

The layer is composed of a single thin (3m thick) stratum of Quaternary clay. The layer is the impermeable unit between the upper and the deep aquifers.

(iii) 3 rd layer (Deep Aquifer)

The layer consists mainly of gravel and sandy gravel. The resistivity range is 25 to 35 Ω-m. The surface water inflow to the groundwtaer is confirmed by the temperature curve. The range of SP value is also located in the permeable side from the relative basement line. The layer is considered as the most promising aquifer within the sequence.

The screen pipes were installed in this layer.

(iv) 4 th layer (Impermeable bed)

The layer is composed of ignimbrite of Tertiary Oxaya Formation. At the top of the bed, clay of 9m thickness is confirmed. According to the SP range, the layer is expected to be permeable by the developed fissure. However, a low resistivity value of less than 10 Ω-m indicates high contamination.

(4) Well No. J-2 (see Fig. B-II, 2.15)

i) Lithology

Within 225m of total depth, two (2) formations are confirmed ; one is Quaternary Fluvial Deposit at a depth of 158m from surface, and the other one is Tertiary Oxaya Formation at depth from 158m to the bottom. The following three (3) major layers are classified by the interpretation of lithology and geophysical logging.

(J-2)

Layer	Depth (m)	Classification	Lithology	Period	Formation
1 st	0 - 30	Surface Deposit	gravel to clayey gravel	Quaternary	Fluvial Dep.
2 nd	30 - 158	Aquifer	gravel, sandy to clayey	Quaternary	Fluvial Dep.
3 rd	158 - 225	Impermeable Bed	clay, Ignimbrite	Tertiary	Oxaya Form.

ii) Well Logging

An homogeneous curve is observed at each logging of SP, resistivity and gamma ray. The gamma ray range in this area shows an abnormal value. At gravel layer, a high range of 60 to 110 cps is observed. So it is considered that the permeability is not reflected by the cps value of the gamma ray in this case. Considering the lithology and resistivity curve, a line of 1100 mv is estimated as a relative basement line of spontaneous potential. A temperature curve displays gentle increment of the whole sequence. Thus, a groundwater flow at thick sequence is expected.

iii) Determination of Casing Design

In order to determine the position of screen pipes, following interpretations were made. For details of the casing design, see Fig. B-II, 2.15.

(i) 1 st layer (Surface Deposit)

The layer consists of gravel and clayey gravel. The layer is considered as permeable by the lithological observation and SP. However, a high resistivity value (30 to over 100 Ω-m) confirms the layer to be dry. Blank casing pipes are installed in this layer.

(ii) 2 nd layer (Aquifer)

Based on a permeable indication of SP and typical range (20 - 30 Ω-m) of resistivity, the layer is classified as most promising aquifer in the sequence. The resistivity range is almost the same as TEM result (17 - 30 Ω-m). Groundwater flow indication is also visible at 45 to 85m depth by the temperature curve.

Screen pipes were installed at depth from 64.02m to 154.01m of this layer.

(iii) 3 rd layer (Impermeable Bed)

The layer is composed of clay at upper part, and ignimbrite at lower part. Low SP value indicates that the layer is impermeable. Moreover, low resistivity range of less than 10 Ω-m indicates that the layer has no groundwater potential. Blank casing pipes were installed in this layer.

2.3.3 Pumping Test

1) Methodology of Pumping Test

Three (3) different kinds of pumping tests; step drawdown test, constant discharge test and recovery test were conducted for both test and observation wells, after completion of drilling work and air lifting development.

(1) Pumping

Based on the casing size installed, following submersible pumps were used for pumping.

for test wells	:	1,500 l/min. x 50m head
for observation wells	:	240 l/min. x 50m head

The pumps was installed in the casing pipes with a setting depth of 90 mBGL, through rising main and delivery pipes. A valve and flow meter were installed on the delivery pipe works.

(2) Method of Test

Each test was carried out following the standard method mentioned below.

Step drawdown test	:	At least seven (7) round steps (discharge increased and decreased) are carried out and duration of each step is 120 minutes.
Constant discharge test	:	24 hours measurement is conducted as soon as the water level has recovered its original static water level after the completion of the step drawdown test.
Recovery test	:	The test starts immediately after completion of the constant discharge test and continues until the water level recovers its static water level.

However, in order to meet the hydrogeological conditions at each well, discharge rate, test duration, number of steps and time interval were altered by the Hydrogeologist of the Study Team.

(3) Measurement

The static water level is measured just before the commencement of the any pumping test. Throughout the duration of each test, the water level was measured and recorded following observation time schedule listed below;

Time from start of pumping or increase of pumping rate (minutes)	Time interval between observations (minutes)
0 - 5	1/2
5 -10	1
10 - 20	2
20 - 30	3
30 - 60	5
60 - 120	10
120 - 240	20
240 - 360	40
360 and longer	60

The flow rate of all water pumped from the well during the pumping test is measured by both a flow meter in the delivering pipe works and a triangular weir. Discharge rate is recorded during the pumping test at intervals mentioned above.

(4) Method of Analysis

i) Aquifer Constants

Aquifer constants necessary for the hydrogeological evaluation are transmissibility, storage coefficient and permeability. These aquifer constants were analyzed by using the results of the constant discharge and recovery tests. For the above analyzation, Theis and Jacob methods were applied. The aquifer constants are given by the following formulas;

(i) Theis Equation

Transmissibility (T) = Q x W(u) / 4π x s

Where Q = pumping rate (m^3/day)
W(u) = well function of u
s = drawdown (m) at matching point

Permeability (K) = T/L

Where T = transmissibility (m^3/day/m)
L = thickness of aquifer (m : total length of screen pipes)

(ii) Jacob's Equation

Transmissibility (T) = 0.183 x Q / Δs

Where Q = pumping rate (m^3/day)
Δs = draw down on one log cycle (m)

Permeability (K) = T/L

Where T = transmissibility (m^3/day/m)
L = thickness of aquifer (m : total length of screen pipes)

ii) Well Efficiency and Area of Influence

In order to estimate critical discharge and safe yield, well efficiency and area of influence are calculated by the data of step drawdown test.

Critical discharge is determined by the slope of the Q (Discharge Rate) - Sw (drawdown) chart. Maximum pumping rate which does not cause a large drawdown is defined as critical discharge. On the other hand, safe yield is estimated by the ratio of well efficiency and area of influence as described below ;

$$\text{Well Efficiency (\%) } Ew = BQ/(BQ+CQ^2) \times \frac{BQ}{BQ+CQ^2}$$

Where B = aquifer loss
C = well loss
Q = discharge rate (l/s)

In this report, the following criterion is determined for well efficiency.

Well Efficiency : more than 85%

Radius of influence is discussed in Chapter III.

2) Results of Pumping Test

(1) Aquifer Constants

Aquifer constants are analyzed by the graphs as shown in Fig. B-II, 2.16 (1) to (4). The tables include the pumping data and the aquifer constants calculated by two (2) equations mentioned above. The aquifer constants for four (4) wells are summarized in Table B-II, 2.4.

The average of the transmissibility of four (4) wells is calculated as 212.73 m^3/day/m. The highest value of 368.06 m^3/day/m is found at J-1 which has the highest specific yield. J-1 is considered to have high groundwater potential. On the other hand, the lowest transmissibility is found at J-A (22.72 m^3/day/m). The well has also the lowest specific yield (0.24 l/s/m). The well is considered to have low groundwater potential.

Permeability of the four (4) wells are similar. The highest value is 1.93×10^{-3} cm/sec at J-2, and the lowest is 6.25×10^{-4} cm/sec at J-A. The average of permeability is calculated as 3.64×10^{-3} cm/sec. This value is lower than permeability usually expected in this lithology mainly consisting sand, gravel and clayey to sandy gravel.

Storage coefficients are in a range from 3.31×10^{-6} to 1.93×10^{-3}, averaging 7.26×10^{-4}.

There are three (3) existing deep wells near the entrance to Route 11 (Road to Bolivia) from Panamerican. Two (2) wells out of these, are operating. The distance of both wells is approximately 500m. No influence is recognized during operating of these wells. This shows that radius of influence of both wells is less than 250 m (=500÷2).

(2) Well Capacity

Well capacity is evaluated by the amount of critical discharge and safe yield. The Q-Sw chart for to examine the critical discharge and the Q-s/Q chart for to obtain the well efficiency and area of influence are shown in Fig. B-II, 2.17 (1) to 2.17 (4). The detailed results of the analysis for step drawdown tests are described in Table B-II. The capacities for four (4) wells are summarized as follows;

Well No.	Critical Discharge (l/s)	Safe Yield (l/s)
J-A	15.30	7.50
J-B	20.30	13.00
J-1	more than 4.40	2.25
J-2	3.85	2.25

The average critical discharge of test wells and observation wells are estimated as 17.80 l/s and 4.13 l/s respectively. On the other hand, the average safe yield of test wells and observation wells are 10.25 l/s and 2.25 l/s respectively. Safe yield is approximately the half of critical discharge for both types of well.

2.3.4 Carbon-14 Analysis

The purpose of the C-14 Analysis is to decide the age of groundwater for interpretation of groundwater recharge mechanism and for evaluation of the groundwater potential. Two (2) samples were taken from the well No. 101-0 and 102-9 located near the Panamerican Road (see, Fig. B-II, 2.1).

The radiocarbon technique is based on the general law of radioactive decay:

$$t = \gamma / \log 2 \times \log A_O / A_t$$

where γ is the half life in time units, equal to 5,730 ± 30 years in case of ^{14}C. A_O is referred as the ^{14}C content of the atmospheric CO_2 and A_t is the ^{14}C content of the sample. In dating organic remains, it is assumes that the ^{14}C activity of the living plant at time zero was equal to that of the atmospheric CO_2. Then, the age of the sample is determined by measuring A_t expressed as percent carbon modern (pmc) with respect to A_O, which is equal to 100% of modern carbon.

Several goechemical models have been developed to adjust ^{14}C data in groundwaters (e.g. Ingerson an Pearson, 1964; Mook, 1972; Tamers 1975; Fontes and Garnier, 1979; and Reardon and Fritz, 1978). Each model has some defects for groundwater age determination. Therefore, Modeified Pearson Model was adopted for the estimation of the groundwater age.

Results are shown in following table.

Well No. Sampled	Tritium (TU)	C - 14 (pmc)	Age (Y.BP)*
101-0 (A-4)	<0.8	118.9	modern (40<)
- (N-5)	1.1±0.6	122.7	modern (40<)

Note Y.BP* : years before present

Estimated groundwater ages are both modern. However, the tritium data are below or close to the detection limit, therefore, age of the groundwater is older than 40 years. The C-14 values show more than 100 pmc. These do not mean the ages are modern, but reflect the influence of the return flow of surface water from the irrigation area in the agricultural area.

The river water of the Lluta is lead to irrigation area at the lower reach of Tocontasi and returns to the river through drainage system. The surface water of the Lluta is influenced by agricultural activities. Accordingly, the groundwater in the Lower Lluta Valley is also influenced by the return flow of irrigation water.

2.4 Configuration of Aquifer

The aquifer of the Lower Lluta Valley is mainly in the Fluvial Deposits. The boring test by the Study Team revealed that the aquifers in the Fluvial Deposits are divided into two (2) units, the upper and the lower, separated by thin tuff beds (Ref. 2.3 of this Chapter). Profile and cross sections of the two units are shown in Fig. B-II, 1.2 and 1.3 respectively. The distribution of tuff layers is restricted up to Chacabuco. Towards the upper stream from here, the Fluvial Deposits form a single aquifer; there is no impermeable layer between the upper and the lower units.

Although the aquifer in the Lower Lluta Valley is divided into two aquifers, there is no significant difference of groundwater quality between the aquifers. Furthermore, continuity of the tuff bed sometimes become unclear. Therefore, groundwater of both aquifers can be leaked each other.

2.4.1 Shallow Aquifer

No water level data is available on the shallow aquifer except Villa Frontera area. Therefore, thickness of this aquifer is described in this report assuming the water level is same as that of the deep aquifer.

It is thin at Chacabuco, about 10 m and increases toward the downstream; it is 30 to 40 m between Sascapa and Chuilona, and less than 10 m at Villa Frontera. It is 800 to 1000 m in width at Bocanegra to Chacabuco area, and increases toward the downstream from Sascapa. Reaching to Chuilona and Villa Frontera, the Concordia Formation is widespread toward the north and no boundary is recognized with deposits from other rivers such as the Gallinazo and the Concordia Rivers. Therefore, the limit to the north is temporarily supposed up to the Gallinazo River; the width is estimated 3 to 4 km.

2.4.2 Deep Aquifer

The deep aquifer is distributed from Chacabuco to the downstream. Fig. B-II. 2.28 is an isopach map of the deep aquifer. Width of the valley is narrow in the area between Chacabuco and Poconchile, approximately 800 m. It increase its width toward the downstream. It is approximately 70 m in thickness and 800 to 1000 m in width at Chacabuco. Thickness decreases to 50 m at Sascapa, however, increases again up to 100 m at Chuilona and Villa Frontera. Width of the aquifer is 1500 m at Sascapa, 2800 to 3000 m near Chuilona and more than 3000 m at Villa Frontera.

Fig. B-II, 2.29 is a contour map which shows depth of the deep aquifer from the ground level. Depth of the deep aquifer is shallow at Chacabuco, 15 m and is deep between Sascapa and Chuilona, 30 m. Gradient of the top of aquifer changes to gentle at Chuilona.

Fig. B-II, 2.30 shows the elevation of the base of the deep aquifer. The base of the aquifer is above the sea level at Sascapa and Chacabuco, and below at Chuilona and Villa Frontera. Elevation of the base of the aquifer is 0 m MSL at about 5.5 km eastward from the Panamerican Road.

Details of the deep aquifer is summarized in the following table.

Area	Thickness (m)	Width (m)	Top of Aquifer (mBGL)	Base of Aquifer (mMSL)
Chacabuco	70	800 to 1000	15	110
Sascapa	50	1500	30	90
Chuilona	100	2800 to 3000	30	-25
Villa Frontera	100	3000	20 to 25	-80 to -90

note: Aquifer means the deep aquifer.

2.5 Hydrogeological Characteristics of Aquifer

2.5.1 Shallow Aquifer

All the wells penetrated into the shallow aquifer are dug wells at Villa Frontera and no pumping test was executed at the completion of construction. Thus, no data is available. However, the lithofacies of the shallow aquifer is almost same as that of the deep aquifer. Therefore, it seems that the hydrogeological characteristics of this aquifer is also same as that of the deep aquifer.

In the lower reaches of the Lluta River (mainly in Villa Frontera area), groundwater is extracted from the upper member of the Concordia Formation. It is composed mainly of gravel and sand, and its matrix is rich in volcanic ash and mud. Lithology is almost similar to that of the Fluvial Deposits. The permeability coefficient of the aquifer is estimated to be in the order of 10^{-3} cm/sec (about 1 m/day) considering the lithofacies. Judging from the pumping test result of JICA wells, permeability is seemed in a order of 10^{-3} cm/sec.

2.5.2 Deep Aquifer

The bed of deep aquifer is composed mainly of sand and gravel, and the matrix is abundant in mud. As mentioned in 2.4, it is sometimes separated from the shallow aquifer by impermeable tuff beds and the tuff beds end between Chacabuco and Rosario. Therefore, the deep aquifer is recharged from the surface water of the Lluta River mainly in the upstream of Sascapa. In the downstream of Sascapa, the surface water recharges the shallow aquifer. However, since the deep aquifer directly contacts with the shallow aquifer in places where no tuff bed exists, the groundwater of both aquifers can be leaked each other.

Reflacting these condition, there is a difference in the water quality; NO_3 content of the deep aquifer is low while the shallow aquifer shows high contents. This is also supported by the results of the C-14 analysis.

The deep aquifer has an interfinguring relation with the Concordia Formation at Chuilona. The Concordia Formation is also permeable but distributed below the sea level. If a large quantity of groundwater extraction is continued, the sea water intrusion to this aquifer will be happened. Therefore, the Concordia Formation is not considered to be a prospective aquifer.

Aquifer constants of JICA wells and existing wells are shown in following table.

Well No.	Specific Yield (l/sec/m)	Transmissibility (m^3/day/m)	Permeability (cm/sec)
J-1	1.44	368	7.01×10^{-3}
J-A	0.24	23	6.25×10^{-4}
J-2	0.73	150	1.93×10^{-3}
J-B	0.62	310	4.98×10^{-3}
100-2	0.36	-	-
101-0	2.60	-	-
102-9	0.99	-	-
103-7	2.70	-	-
104-5	4.26	-	-
average	1.72	213	3.63×10^{-3}

Permeability coefficients are in a order of 10^{-3} cm/sec. This order is common one as a aquifer. Considering the lithofacies of the aquifer, however, permeability coefficient is rather small as that of gravel bed.

Specific yield changes from place to place; it ranges from 0.24 (J-1) to 4.26 l/sec/m (104-5). This means that productivity of the deep aquifer is different in places.

1) At Rosario, specific yield is very small in the well 100-2 (Rosario), 0.24 l/sec/m. It shows low productivity of the aquifer. This well penetrated into the Fluvial Deposits. However, it is not clear in which horizon screens are installed.

2) JICA wells installed screens strictly in the deep aquifer. Therefore, specific yields of those represent that of the deep aquifer; 024 to 1.44 l/sec/m, averaging 0.76 l/sec/m

3) Remaining four (4) wells are mainly located in Villa Frontera. The Fluvial Deposits (the deep aquifer) changes to the Concordia Formation around the Panamerican Road. Therefore, there is a possibility that these wells penetrated to the Concordia Formation. Specific yields of those show ordinary values; they range from 0.99 to 4.26 l/sec/m, averaging 2.64 l/sec/m.

2.6 Estimation of Groundwater Storage

Groundwater storage of the Lower Lluta Valley is shown in Table B-I, 2.5 and Fig. B-I, 2.21. These figures present the estimated groundwater storage in the area from Chacabuco to the Panamerican Road near the river mouth of the Lluta River. Total volume of the groundwater storage is estimated as follow;

$$S_{Total\ Storage} = 107 \times 10^6 \ m^3.$$

The estimation was made based on the one (1) geological profile and six (6) geological sections dividing the area into five (5) zones as shown in the following table;

Zone	Geological Section	Area
1	sect. A-A to B-B'	Panamerican Road. to J-B (Chuilona)
2	sect. B-B' to C-C'	J-B to J-2 (Chuilona)
3	sect. C-C' to D-D'	J-2 to J-A (Sascapa)
4	sect. D-D' to E-E'	J-A to J-1
5	sect. E-E' to F-F'	J-1 to Well No. 100 (Rosario)

Conditions applied in the estimation are as follows;

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

2) The extent of the estimation is limited to the area from the Panamerican Road to Rosario, because no stratigraphic column of well is available toward the upper reaches from Rosario.

3) Groundwater stored below the sea level is included in the storage.

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

5) Effective porosity of aquifer is assumed to be 20 % as a whole, considering the materials which compose the aquifer.