3.5 GROUNDWATER POTENTIAL

3.5.1 General

Groundwater volume stored in an unconfined aquifer can be estimated by the equation

$$Q=AhS_y$$

where A is the area of an unconfined aquifer, h is the average thickness of the aquifer (or the average height of water surface above the impervious boundary), and S_y is the specific yield of the aquifer. The estimated volume is helpful to evaluate the potential of aquifer. However the wells in such an area cannot withdraw this amount because of the limitations imposed by groundwater velocities, time, configuration of water movement, and withdrawal techniques.

The above equation can estimate the volume of the change in groundwater storage using dh, the average increase or decrease in water level, instead of h.

3.5.2 Estimated Groundwater Volume

Groundwater volumes stored in aquifers of selected areas for priority development were estimated by the above equation.

The alluvial aquifer of Lower Part of Nalaih is estimated to contain about 102 million cubic meters of water (Table I.3.4, Fig. I.3.12). The area A stores 24 million cubic meters and the area B stores 77 million cubic meters. This estimate was based on a planimetered area of 42.48 km^2, an estimated average saturated thickness of water-bearing material of 12.5-17.5 meters, and an estimated specific yield of 0.15. The average saturated thickness of water bearing materials and the average specific yield of the alluvial aquifer were estimated from the results of the test drilling by JICA and the previous studies. The upper and lower layer were not considered separately because the estimated value of the specific yield was the mean of the both layer. The saturated aquifer one meter thick contains the volume of about 13 million cubic meters of water, the area A contains about 4 million and the area B contains about 9 million.

The alluvium of Buheg River basin is estimated to contain more than 500 million cubic meters of water (Table I.3.4, Fig. I.3.12). This estimate was based on a planimetered area of 237.45 square kilometers, an estimated average saturated thickness of 14.5 - 34.5 meters, and an estimated specific yield of 0.1. The saturated aquifer one meter thick contains the volume of about 23.7 million cubic meters of water.

The alluvium of the lower part of Tuul River, namely Lower Part of Power Plant and the downstream area, is expected to contain many times as large volume of water as the above-mentioned areas, because this lower area is larger and the aquifer is thicker.

The fissure aquifers in North of Ulaanbaatar may be exploited for local use. However, the drilled depth of production wells must be deep and applicable geophysical explorations must be conducted. It is difficult to develop on a large scale.

Table I.3.1 Exploration Wells in the Tributary's Areas (1/4)

Map No.	Well No.	Area	Coordinate X (Long. E)	Coordinate Y (Lat. N)	Total Depth (m)	1st Screen Depth (m)	(Formation(s))	2nd Screen Depth (m)	(Formation(s))	Pumped Rate Q (liter/sec)	S.W.L (m)	Drawdown ; s(m)	TDS (g/liter)	Specific Capacity Q/s (m^3/day/m)	Geological condition: Quaternary deposits	Geological condition: Neogene deposits	Geological condition: Consolidated rocks (K,C,PZ) *
1	10	Bayan Golin	106° 43'00"	47° 58'07"	24.8	?		?		?	?	?	?	######	0-23 **	23-24.8 **	**
2	8088	Bayan Golin	106° 44'00"	48° 00'50"	56	27-38	(PZ)			6.8	19	17	0.3	35	0-27		27-56 (PZ)
3	9992	Bayan Golin	106° 44'00"	48° 01'05"	55	14-27	(Q)			31.0	6	7.4	0.2	362	0-27		27-55 (PZ)
4	9994	Bayan Golin	106° 44'00"	48° 01'03"	45	18-34	(Q)			7.8	16.2	5.4	?	125	0-34		34-45 (PZ)
5	9997	Bayan Golin	106° 44'00"	47° 55'30"	50	9-50	(PZ)			18.0	4	3	0.3	518	0-9		9-50 (PZ)
6	8085	Bayan Golin	106° 44'05"	48° 01'00"	48	21-48	(PZ)			10.0	21	2	0.3	432	0-17		17-48 (PZ)
7	24/80	Bayan Golin	106° 44'15"	47° 54'08"	50	22-50	(N+C)			2.2	22	3	0.4	63		0-44	44-50 (C)
8	6110	Bayan Golin	106° 44'15"	47° 55'15"	40	23-35	(Q)			1.0	23	4.8	?	18	0-35		35-40 (PZ)
9	6144	Bayan Golin	106° 45'00"	47° 55'00"	31	19-27	(Q+PZ)			2.0	19.5	0.9	0.2	192	0-25		25-31 (PZ)
			Average of the area							9.9				218			
10	6117	Tolgoit	106° 47'25"	48° 01'25"	46	32-46	(Q+PZ)			2.6	32	1.5	0.3	150	0-34		34-46 (PZ)
11	20/82	Tolgoit	106° 47'40"	47° 55'15"	70	25-55	(PZ)			0.7	24.6	24	?	3	0-25		25-70 (PZ)
12	4/79	Tolgoit	106° 47'70"	47° 55'35"	40	25-38	(PZ)			0.7	22	13	?	5	0-25		25-40 (PZ)
13	498	Tolgoit	106° 48'50"	47° 55'53"	57	21-45	(Q)			1.5	18.6	15.7	?	8	0-45		45-57 (PZ)
14	12/79	Tolgoit	106° 49'35"	47° 57'45"	26	5-26	(Q+PZ)			2.7	3	14.2	0.2	16	0-16		16-26 (PZ)
15	8	Tolgoit	106° 49'40"	47° 57'18"	124	56-102.5	(PZ)	109.5-121	(PZ)	0.1	10.6	65.4	?	0	0-30		30-124 (PZ)
16	9	Tolgoit	106° 49'48"	47° 58'18"	10.8	?		?		?	?	?	?	######	0-7.5		7.5-10.8 (PZ)
17	10/79	Tolgoit	106° 49'59"	47° 57'20"	74	20-55	(PZ)			5.0	20	12.4	0.3	35	0-13		13-74 (PZ)
18	13/79	Tolgoit	106° 50'24"	47° 56'52"	102	?		?		?	?	?	?	######	0-2		2-102 (K)
			Average of the area							1.9				31			
19	7571	Buheg	106° 30'40"	47° 31'05"	50	36-47	(PZ?)			1.0	22	11	0.3	8	?	?	?
20	6137	Buheg	106° 35'00"	47° 43'45"	50	35-46	(PZ?)			1.5	32.5	4.2	0.3	31	?	?	?
21	10007	Buheg	106° 37'10"	47° 44'10"	57	7-13	(Q)	38-43	(Q+PZ)	13.0	7	2	0.5	562	0-41		41-57 (PZ)
22	17	Buheg	106° 37'50"	47° 43'26"	100	8.5-15	(Q)	25-45	(Q)	15.0	8.5	3.2	?	405	0-52		52-100 (PZ)
23	108	Buheg	106° 39'40"	47° 41'40"	55	37-55	(Q+PZ)			8.5	+1.4	23.4	0.2	31	0-46		46-55 (PZ)
24	14	Buheg	106° 40'35"	47° 41'30"	74	1.2-16.5	(Q)	22-33	(Q)	13.3	1.2	4.1	?	280	0-38		38-74 (PZ)
25	15	Buheg	106° 41'20"	47° 41'03"	120	8-10	(Q)	25-55	(Q)	10.0	8	5.5	?	157	0-70		70-120 (PZ)
26	7530	Buheg	106° 42'10"	47° 29?'31"	50	26-38	(Q+PZ)			1.1	3	22	0.4	4	0-34		34-50 (PZ)
			Average of the area							7.9				185			
27	9983	Turgen	106° 39'10"	47° 47'00"	41	12-29	(Q)			12.8	12.4	4	0.3	276	0-29		29-41 (PZ)
28	9964	Turgen	106° 40'25"	47° 46'45"	49	16.5-38	(Q)			10.0	16.5	1.5	0.3	576	0-49		
29	10014	Turgen	106° 40'40"	47° 45'37"	57	27-57	(Q+PZ)			5.0	14	5	0.3	86	0-46		46-57 (PZ)
30	8060	Turgen	106° 41'35"	47° 44'35"	53	12-31	(Q+PZ)			4.0	11.6	12.4	?	28	0-28		28-53 (PZ)
31	13	Turgen	106° 43'00"	47° 46'24"	60	7-34	(Q)			10.0	7	5	?	173	0-50		50-60 (PZ)
32	12	Turgen	106° 47'10"	47° 45'40"	80	40-54	(PZ)	71-76	(PZ)	0.2	25	36	?	0	0-40		40-80 (PZ)
			Average of the area							7.0				190			

Table I.3.1 Exploration Wells in the Tributary's Areas (2/4)

Map No.	Well No.	Area	Coordinate X (Long. E)	Coordinate Y (Lat. N)	Total Depth (m)	1st Screen Depth (m)	(Formation(s))	2nd Screen Depth (m)	(Formation(s))	Pumped Rate Q (liter/sec)	S.W.L (m)	Drawdown ; s(m)	TDS (g/liter)	Specific Capacity Q/s (m^3/day/m)	Geological condition: Quaternary deposits	Geological condition: Neogene deposits	Geological condition: Consolidated rocks (K,C,PZ) *
33	6127	Nise h	106° 45'00"	47° 51'37"	30	12-23	?			10.0	7.7	1.1	0.1	785	?	?	?
34	9/79	Nise h	106° 45'07"	47° 50'08"	42	24-36	(N)			0.4	17.5	21.5	0.3	2	0-9	9-36	36-42 (PZ)
35	655	Nise h	106° 46'00"	47° 51'40"	50	23-50	(N+PZ)			3.7	12	4	0.3	80	0-11	11-39	39-50 (PZ)
36	5/79	Nise h	106° 46'08"	47° 50'15"	45	28-32	(N)			0.5	13.5	23.5	?	2	0-28	28-45	
			Average of the area							3.7				217			
37	6/79	Yarnag	106° 48'57"	47° 52'13"	172	39-71	(N+PZ)			2.2	12	25	?	8	0-20	20-87	87-172 (PZ)
38	16/80	Yarnag	106° 49?27"	47° 51'33"	123	92-123	(N)			0.2	11.5	?	?	######	0-20	20-123	
39	15/82	Yarnag	106° 49'45"	47° 51'55"	81	15-81	(N+PZ)			2	15	9	?	19	0-10	10-55	55-81 (PZ)
40	40/85	Yarnag	106° 50'10"	47° 52'00"	72	48-72	(N)			0.5	12	48	?	1	0-27	27-72	
41	6146	Yarnag	106° 50'15"	47° 50'10"	44	12-36	(PZ)			1	12	22	0.2	4	0-10		10-44 (PZ)
			Average of the area							1.2				8			
42	8082	Bogduul	107° 02'30"	47° 40'20"	53	30-53	(PZ)			3.6	20	24.3	?	13	0-30		30-53 (PZ)
43	9966	Bogduul	106° 55'00"	47° 53'10"	56	24-39	(Q)	40-42,44-51(Q)		4.4	12	15	0.2	25	0-51		51-56 (PZ)
44	1/69	Bogduul	106° 56'00"	47° 52'00"	25	8-25	(PZ)			11.1	1.4	5.7	?	168	0-8		8-25 (PZ)
45	9956	Bogduul	106° 56'00"	47° 53'00"	42	6-19	(Q)	38-42	(Q)	10	5	6	0.2	144	0-42		
			Average of the area							8.5				113			
46	16	Hol iingol	107° 06'00"	47° 52'45"	33	2-7	(Q)			6	2	2	?	259	0-7		7-33 (PZ)
47	8159	Hol iingol	107° 06'50"	47° 52'00"	21	4-17	(Q)			2	4	8	?	22	4-17		17-21 (PZ)
48	602	Hol iingol	107° 10'15"	47° 49'02"	92	45-92	(PZ)			0.1	+1	1	0.2	9	0-12		12-92 (PZ)
49	6101	Hol iingol	107° 11'30"	47° 48'00"	62	29-39	(N)			0.8	21.4	21	0.2	3	0-15	15-44	44-62 (PZ)
50	22/83	Hol iingol	107° 12'00"	47° 45'05"	110	28-110	(N+PZ)			0.2	+1.8	1.8	0.4	10	0-28	28-61	61-110 (PZ)
51	6098	Hol iingol	107° 12'20"	47° 44'40"	55	33-38	?	44-49	?	0.8	26.5	25.5	0.2	3	?	?	?
			Average of the area							1.7				51			
52	8138	Gor hi	107° 23'50"	47° 53'12"	54	11-38	(PZ)			1	9	14	0.1	6	0-11		11-54 (PZ)
53	6135	Gor hi	107° 26'31"	47° 52'30"	25	12-18	?			8	6.5	5	?	138	?	?	?
54	7534	Gor hi	107° 27'35"	47° 53'15"	24	?		?		2	2	13	0.1	13	0-6		6-24 (C)
			Average of the area							3.7				53			
55	8147	Deen dii	107° 17'25"	47° 53'21"	33	8-22	(Q)			8	8	5	0.2	138	0-33		
56	6131	Deen dii	107° 17'30"	47° 50'35"	32	8-19	?			1.3	6	10.7	0.4	10	?	?	?
57	5	Deen dii	107° 19'40"	47° 56'17"	150	37-127	(PZ)			3	+1	0	?	######	0-22		22-150 (PZ)
			Average of the area							4.1				74			
58	4	Hyandii	107° 14'30"	47° 57'20"	101	25-85	(PZ)			6.2	6	4.1	?	131	0-16		16-101 (PZ)
59	6059	Hyandii	107° 14'40"	47° 57'22"	0-37	13-23	(Q)			2.5	13	8	0.2	27	0-23		23-37 (PZ)
60	8111	Hyandii	107° 15'45"	47° 59'35"	31	18-31	(PZ)			1.6	7	11.3	0.2	12	0-18		18-31 (PZ)
61	6118	Hyandii	107° 18'20"	47° 59'57"	32	4-8	(Q)	20-28	(Q)	2.3	4	13	0.3	15	0-28		28-32 (PZ)
			Average of the area							3.2				46			

Table I.3.1 Exploration Wells in the Tributary's Areas (3/4)

Map No.	Well No.	Area	Coordinate X (Long. E)	Coordinate Y (Lat. N)	Total Depth (m)	1st Screen Depth (m)	(Formation(s))	2nd Screen Depth (m)	(Formation(s))	Pumped Rate Q (liter/sec)	S.W.L (m)	Drawdown ; s(m)	TDS (g/liter)	Specific Capacity Q/s (m^3/day/m)	Geological condition: Quaternary deposits	Geological condition: Neogene deposits	Geological condition: Consolidated rocks (K,C,PZ) *
62	6116	Gachuurt	107° 07'55"	47° 58'30"	23	11-18	(PZ)			2	1.5	9.5	0.3	18	0-4		4-23 (PZ)
63	9982		107° 09'30"	47° 55'40"	29	9-29	(Q+PZ)			7	4	21	?	29	0-19		19-29 (PZ)
64	3		107° 09'37"	47° 56'08"	53	26-48?	(Q)			2	4	13	?	13	0-53		
65	105		107° 10'25"	47° 59'00"	82	11-82	(PZ)			0.5	3.3	9.3	0.3	5	0-11		11-82 (PZ)
66	6082		107° 12'20"	48° 00'45"	40	13-37	(Q)			11.1	9	2	0.2	480	0-37		37-40 (PZ)
67	6097		107° 13'25"	48° 03'35"	40	28-36	(PZ)			1.1	23	8.6	0.2	11	0-28		28-40 (PZ)
68	6120		107° 13'45"	48° 01'10"	30	10-25	(Q)			3.5	8	8.5	0.2	36	0-30		
69	9988		107° 13'55"	48° 05'35"	37	26-37	(PZ)			1.8	5	10.5	0.3	15	0-26		26-37 (PZ)
70	9984		107° 15'45"	48° 02'20"	32	11-28	(Q)			3	4	13.1	0.2	20	0-32		
			Average of the area							3.6				70			
71	8125	Ulia st ai	107° 01'15"	47° 55'50"	41	16-22	(Q)			3	3.5	5	0.3	52	0-33		33-41 (PZ)
72	10000		107° 01'30"	47° 55'15"	46	29-40	(Q)			2	23	1.5	0.3	115	0-40		40-46 (PZ)
73	2		107° 01'38"	47° 57'07"	70	37-48	(PZ)	55-62	(PZ)	5	3.5	26.5	0.2	16	0-27		27-70 (PZ)
74	1		107° 01'50"	47° 57'43"	90	30-55	(PZ)			0.5	2.2	22.8	?	2	0-25		25-90 (PZ)
75	106		107° 02'15"	47° 59'20"	87	11-80	(PZ)			1.3	1.3	5.3	0.1	21	0-11		11-87 (PZ)
76	8070		107° 03'40"	48° 01'35"	24	16-24	(PZ)			2.6	0.7	16.6	0.2	14	0-16		16-24 (PZ)
77	6060		107° 04'30"	48° 02'25"	30	11-30	(PZ)			1.6	12.6	8.9	0.2	16	0-11		11-30 (PZ)
78	10006		107° 05'00"	47° 55'50"	28	13-16	(PZ)			2	4	13.5	0.3	13	0-13		13-28 (PZ)
79	6095		107° 08'12"	48° 05'45"	21	13-21	(PZ)			1	7.7	7.3	0.2	12	0-13		13-21 (PZ)
			Average of the area							2.1				29			
80	6100	Selbe	107° 00'10"	48° 01'55"	33	7-14	(Q)	19-33	(Q)	1	7.2	17.3	0.3	5	0-33		
81	8052		107° 00'10"	48° 03'25"	34	14-34	(Q+PZ)			1	6	14	0.2	6	0-25		25-34 (PZ)
82	8131		106° 52'45"	48° 07'30"	32	14-32	(PZ)			3	0.6	27.7	0.2	9	0-14		14-32 (PZ)
83	6067		106° 53'00"	47° 58'00"	30	18-30	(PZ)			3	13.5	6	0.2	43	0-4		4-30 (PZ)
84	6149		106° 53'07"	48° 03'05"	47	23-31	(PZ)			0.7	3	33	?	2	0-23		23-47 (PZ)
85	6119		106° 53'10"	48° 09'50"	40	21-31	(Q)			7	6.5	14.5	0.2	42	0-31		31-40 (PZ)
86	6063		106° 53'11"	47° 58'50"	15	1-9	(Q)	13-15	(Q)	4	1	8	0.3	43	0-15		
87	8112		106° 53'40"	48° 07'40"	24	14-24	(Q)			5	14	2.7	0.3	160	0-24		
88	8071		106° 53'45"	47° 57'40"	30	11-30	(PZ)			11.7	10.1	10.2	0.3	99	0-11		11-30 (PZ)
89	6062		106° 53'55"	47° 58'20"	23	9-23	(PZ)			5.7	5.5	4.3	0.2	115	0-9		9-23 (PZ)
90	101		106° 54'05"	48° 06'52"	83	56-80	(PZ)			4.4	16.5	7	?	54	0-39		39-83 (PZ)
91	6073		106° 54'12"	48° 06'50"	35	18-23	(Q)			7	6.3	3	?	202	0-35		
92	9/82		106° 54'15"	47° 56'00"	60	30-60	(N)			2.7	11	7	?	33	0-12	12-60	
93	100		106° 54'47"	48° 03'04"	50	4.2-31	(PZ)			1.1	4.2	7.8	0.2	12			0-50 (PZ)
94	632		106° 55'20"	48° 06'40"	22	2.3-27	(Q)			1	2.3	12.8	0.1	7	0-22		
95	10028		106° 55'30"	48° 01'00"	31	13-31	(PZ)			5	3	11.9	0.3	36	0-13		13-31 (PZ)

Table I.3.1 Exploration Wells in the Tributary's Areas (4/4)

Map No.	Well No.	Area	Coordinate X (Long. E)	Coordinate Y (Lat. N)	Total Depth (m)	1st Screen Depth (m)	(Formation(s))	2nd Screen Depth (m)	(Formation(s))	Pumped Rate Q (liter/sec)	S.W.L (m)	Drawdown ; s(m)	TDS (g/liter)	Specific Capacity Q/s (m^3/day/m)	Geological condition: Quaternary deposits	Geological condition: Neogene deposits	Geological condition: Consolidated rocks (K,C,PZ) *
96	14/80	Selbe	106° 55'50"	47° 57'30"	25	18-25	(PZ)			1	4.8	7	0.3	12	0-18		18-25 (PZ)
97	7		106° 55'55"	47° 59'45"	21	2-21	(Q+PZ)			0.1	1.9	12.9	?	1	0-15		15-21 (PZ)
98	6109		106° 55'58"	47° 55'27"	30	3-15	(Q)	19-24	(Q)	9	3	7	0.2	111	0-24		24-30 (PZ)
99	6		106° 56'07"	47° 59'15"	90	38-70	(PZ)			1	1.3	23.1	?	4	0-18		18-90 (PZ)
100	8053		106° 56'30"	48° 07'30"	28	20-28	(PZ)			1.6	15	13	0.2	11	0-20		20-28 (PZ)
101	11/79		106° 56'47"	47° 59'10"	32	20-23	(PZ)			0.4	4	25	?	1	0-20		20-32 (PZ)
102	1026		106° 57'00"	48° 05'00"	82	40-50	(PZ)	65-75	(PZ)	6.2	28	25	?	21	0-8		8-82 (PZ)
103	8054		106° 58'00"	48° 00'00"	32	12-20	(Q)			2	7.7	10.3	0.3	17	0-20		20-32 (PZ)
104	8108		106° 58'15"	48° 07'30"	30	14-30	(Q+PZ)			0.8	8	7.4	0.3	9	0-21		21-30 (PZ)
105	8081		106° 58'30"	48° 00'30"	50	30-50	(Q+PZ)			0.5	6.4	32.6	0.3	1	0-36		36-50 (PZ)
			Average of the area							3.3				41			
106	6150	Bayan	107° 14'00"	47° 41'35"	45	21-23	(K)	33-45	(K)	8	16	3.7	0.2	187	0-9		9-45 (K)
107	8058		107° 14'55"	47° 41'30"	50	26-36	(N)			15	1.5	5.4	?	240	0-5	5-49	49-50 (PZ)
108	50		107° 17'05"	47° 41'22"		?		?		1	?	0	?	######	?	?	?
109	7536		107° 18'25"	47° 39'24"	51	22-46	(C)			2	14	1.5	0.5	115	0-8		8-51 (C)
			Average of the area							6.5				181			
110	170	Nalaih	107° 15'23"	47° 46'20"	148	?	(K?)	?		4.1	36	12.7	?	28			0-148 (K)
111	90		107° 16'35"	47° 47'18"	65	?	(K?)	?		2	6	19	0.4	9			0-65 (K)
112	85		107° 17'10"	47° 45'37"	85	?	(K?)	?		1.7	26.6	30	0.9	5			0-85 (K)
113	36		107° 17'50"	47° 44'38"	191	?	(K?)	?		0.3	44.7	1.2	0.6	22			0-191 (K)
114	76		107° 20'00"	47° 43'32"	99	?	(K?)	?		?	+	?	?	######			0-99 (K)
115	80		107° 22'00"	47° 45'13"	107	?	(K?)	?		?	13	?	?	######			0-107 (K)
116	45		(107° 23'35")	(47° 46'30")	50	34-48	(K)			6.7	14.3	17.4	0.6	33	0-10		10-50 (K)
			Average of the area							3.0				19			
117	7558	Others	105° 38'00"	47° 30'30"	99	61-65	(Q)	70-71,80-87	(Q+PZ)	2	53	5	0.3	35	0-80		80-99 (PZ)
118	7559		105° 57'10"	47° 18'35"	73	54-66	(PZ)			2.6	22.5	7.5	0.3	30	0-40		40-73 (PZ)
119	7563		106° 00'00"	47° 30'15"	70	57-68	?			1.2	55	0.5	0.3	207	?	?	?
120	7569		106° 30'40"	47° 36'45"	45	23-28	?	38-42	?	6.6	20	2	0.3	285	?	?	?
121	8082		107° 30'30"	47° 40'20"	53	42-52	?			1.8	20	12	0.2	13	?	?	?
			Average of the area							2.8				114			

*) K; Cretaceous sediments
C; Carboniferous sediments
PZ; Lower Paleozoic sediments
**) meter

Table I.3.2 Exploration Wells in Tuul River Deposits (1/3)

No. on Map	Well No.		Total Depth (m)	Elevation (m)	Screen Depth (m)	Pumped Rate (liters/sec.)	S.W.L (m)	Drawdown (m)	Specific Capacity (m^3/day/m)	Permeability Coefficient (m/day)	Quaternary deposits: dpQ	Q3-4	Q2-3 (Thickness)	Q2-3	eQ (Thickness)	eQ	Consolidated rocks (C,D)* (Thickness)	Consolidated rocks (C,D)*
1	20	Lower Part of Power Plant	66	1163.9	6-40	60.3	2.6	1.34	3888	122.50	**	35**	(5)	40	(23)	63	3	66 (C)
2	21		64	1164.94	5-50	46.6	1.63	6.92	582	14.10		15	(49)	64	( )			
3	22		51	1165.42	6-46	68.33	1	4	1476	39.70		25	(26)	51	( )			
4	23		84	1166.02	6-60	53.9	1.47	8.1	575	12.10		25	(34)	59	(25)	84		
5	24		93	1166.81	6-60	78.8	2.2	0.72	9456	131.70		24	(37)	61	(32)	93		
6	25		66	1166.67	6.0-61		1.88			120.8-16.1		21	(40)	61	(5)	66		
7	26		33	1167.65	5.3-26	60.3	2.7	1	5210	261.10		18	(8)	26	(7)	33		
15	34		10	1192.24	5.9-10						6		(0)		(2)	8	2	10 (C)
8	27		31	1188.92	5.4-27	54.1	1.55	0.68	6874	139.10		19	(8)	27	(4)	31		
9	28		45	1189.65	5.6-41.0	57.8	1.67	2.12	2356	70.00		20	(21)	41	(4)	45		
10	29		50	1189.72	5-38	51.2	1.41	6.39	692	34.50		15	(23)	38	(12)	50		
11	30		40	1189.97	5.3-28	64.06	1.42	3.4	1628	74.50		18	(10)	28	(12)	40		
12	31		43	1189.6	6-40	78.8	1.25	2.27	2999	91.80		16	(24)	39.5	(3.5)	43		
13	32		35	1189.92	6.0-30	60.3	1.4	1.88	2771	115.00		15	(15)	30	(5)	35		
14	33		30	1189.66	5.7-25	53.9	1.52	0.53	8787	228.40		18	(7)	25	(5)	30		
16	35		29	1216.05	10.0-26	27.2	9.38	1.77	1328	95.30	7	18	(8)	26	(3)	29		
17	36		48	1207.95	5.6-43	40.9	1.97	7.44	475	11.60			(0)		( )			
18	37		44	1209.58	6.0-39	50	2.53	2	2160	58.60		19	(20)	39	(5)	44		
24	100		23		5.2-20	32.7	1.73	3.67	770			13	(7)	20	(1)	21	2	23 (C)
19	38		60	1154.51	5.1-58	76	1.58	3	2189	45.00		19	(39)	58	(2)	60		
20	39		60	1153.76	5.7-47	36	1.45	8.41	370	10.10		47	( )		(13)	60		
21	40		29	1154.12	3.0-9.0	7.3	1.42	6.42	98	28.50		9	(11)	20	(9)	29		
22	41		42	1144.1	6.3-38		1					25	(13)	38	( )		4	42 (C)
23	42		50	1144.8	7.0-44	45.4	2.16	5.25	747	21.20		40	(4.5)	44.5	(5.5)	50		
25	102	Songino	65.5	1227.14	9.0-63		4.07			56.60		37	(23)	60	(5.5)	65.5		
26	105		55	1227.83	8.2-49.5		2.14			75.90		38	(17)	55	( )			
27	107		68	1229.17	8.5-26.6 45.6-65		1.73			19.6-13.0		19	(46)	65	(3)	68		
28	111		61	1233.12	6.0-52		1.56			21.0-20.9		18	(42)	60	(1)	61		
29	112		45	1230.33	6.0-44.5		2.35			25.5-34.2		20	(12)	32	(13)	45	0	45 (C)
30	113		70	1229.97	7---61		2.5			102.10		23	(42)	65	(5)	70		
31	114		52	1228.79	4-49		1.68			13.70		18	(31)	49	(3)	52		
32	115		27	1228.3	2.6		26			74.50		11	(12)	23	(3)	26	1	27 (C)
33	116		48	1237.54	4.0-46		1.81			19.90		20	(25)	45	(3)	48		
34	117		47	1237.58	6.0-45		1.83			58.70		18	(27)	45	(2)	47		

Table I.3.2 Exploration Wells in Tuul River Deposits (2/3)

No. on Map	Well No.		Total Depth (m)	Elevation (m)	Screen Depth (m)	Pumped Rate (liters/sec.)	S.W.L (m)	Drawdown (m)	Specific Capacity (m^3/day/m)	Permeability Coefficient (m/day)	Quaternary deposits: dpQ	Quaternary deposits: Q3-4	Quaternary deposits: Q2-3 (Thickness)	Quaternary deposits: Q2-3	Quaternary deposits: eQ (Thickness)	Quaternary deposits: eQ	Consolidated rocks (C,D)	Consolidated rocks (C,D)
36	2	Upper Water Source	32	1405.24	3.0-26	53.9	1.4	2.9	1606	84.20		23	(6)	29			3	32 (C)
37	3		32	1405.48	3.0-28	3	1.59	13.82	19	(3.5)		13	(11)	24			8	32 (C)
38	4		28	1413.78	4.0-22	48.8	2.14	2.93	1439	88.00		12	(10)	22	(5)	27	1	28 (C)
39	5		10	1365.64	5.5-10		1.7					7	(1)	8			2	10 (C)
41	7		8	1368.49			1.5					5						8 (C)
42	8		10	1358.07	5.0-10		1.5					8						10 (C)
43	9		10	1342.36	5.4-10		2.2					5						10 (C)
35	1		34	1436.01	4.85-28	57	1.24	4.13	1192	54.40		28	(4)	32			2	34 (C)
40	6		40	1434.29	6.0-32	50	2.15	4.55	949	42.40		19	(13)	32	(4)	36	4	40 (C)
44	10		40	1435.62	6.0-36	25	2.57	5.2	415	15.20		30	(6)	36			4	40 (C)
45	11		30	1449.93	6.0-28	8.8	2.76	10.22	74	4.80		8	(20)	28			2	30 (C)
46	12		38	1422.92	17-25	6.25	0.9	5.5	98	14.20		14	(11)	25	(4)	29	9	38 (C)
47	13		35	1443.47	6.0-31	33.3	6.1	5.28	545	28.30		22	(11)	33			2	35 (C)
	301		30	1401.58	4.0-5.0	1.72	1.54	15	10			19	(7)	26			4	30 (D)
	302		32	1400.89	5.7-28	36.4	2.02	3.62	869			16	(12)	28	(2)	30	2	32 (D)
	303		38	1405.29	5.6-7.8 14.8-32	44	1.13	9.39	405			23	(9)	32	(1)	33	5	38 (D)
	304		35	1409.59	5.7-30.9	40.2	1.15	5.76	603			14	(17)	31			4	35 (D)
	305		34	1410.62	6-30.1	51.1	1.11	4.07	1085			16	(14)	30			4	34 (D)
	306		35	1415.86	6.0-25	29.6	1.11	8.98	285			9	(16)	25	(4)	29	6	35 (D)
	307		36	1417.01	6.0-30	51.1	2.37	2.78	1588			13	(17)	30	(1)	31	5	36 (D)
	308		41	1423.1	5.5-34	6.9	2.31	9.57	62			15	(19)	34	(2)	36	5	41 (D)
	309		35	1430.36	5.0-30	17.4	1.18	11.12	135			15	(16)	31			4	35 (D)
	311		32	1439.93	5.5-28	58.81	2.2	4.4	1155			21	(7)	28			4	32 (C)
	312		25	1452.55	3.0-20	20.8	1.61	5.26	342			10	(10)	20	(2)	22	3	25 (D)
	314		38	1446.5	6.5-36	11.4	4.12	5.58	177			15.5	(21)	36			2	38 (D)
	321		34	1401.29	5.7-31.5	40.9	1.6	6.2	570			23	(8.5)	31.5	(0.5)	32	2	34 (D)
	324		32	1404.79	6.0-27	33.2	2.54	5.86	490			21	(9)	30			2	32 (D)
	327		35	1407.12	5.6-28	35.2	1.25	14.05	216			16	(12)	28	(4)	32	3	35 (D)
	330		32	1409.12	5.3-26	27.6	1.25	8.44	283			18	(8)	26	(3)	29	3	32 (D)
	332		30	1410.96	5.5-16.8 28-11.2	14.3	1.2	7.02	176			14	(14)	28	(1)	29	1	30 (D)
	333		31	1410.62	5.5-29	13.4	1.27	12.23	95			14	(15)	29			2	31 (D)
	336		33	1415.06	5.7-30	40.6	1.98	4.63	758			16	(14)	30			3	33 (D)
	339		26	1417.46	4.0-24	22.2	1.38	5.25	365			10.7	(13)	24	(2)	26		
	339a		15	1419.14	4.0-10	28.5	1.47	2.93	840			9	(1)	10			5	15 (D)

Table I.3.2 Exploration Wells in Tuul River Deposits (3/3)

No. on Map	Well No.		Total Depth (m)	Elevation (m)	Screen Depth (m)	Pumped Rate (liters/sec.)	S.W.L (m)	Drawdown (m)	Specific Capacity (m^3/day/m)	Permeability Coefficient (m/day)	Quaternary deposits dpQ	Q3-4	Q2-3 (Thickness)		eQ (Thickness)		Consolidated rocks (C,D)*	
	342		36	1421.05	6.0-31	53.19	2.04	3.36	1368			16	(15)	31			5	36 (D)
	344		31	1422	5.5-28	34.4	1.09	5.85	508			15	(13)	28			3	31 (D)
	347		31	1425.57	5.0-26	30.6	1.39	5.78	457			14	(12)	26	(2)	28	3	31 (D)
	350		33	1428.42	5.0-30	45.6	1.9	3.95	997			21	(9)	30	(3)	33		
	351		33	1429.35	5.5-25	41.7	1.58	5.22	690			17.5	(7.5)	25	(4)	29	4	33 (C)
	353		34	1431.3	6.0-29	41.4	1.54	6.36	562			17	(12)	29	(1)	30	4	34 (C)
	354		37	1431.89	6.0-32	39.91	2	5.55	621			17	(16)	33	(2)	35	2	37 (C)
	356		31	1432.86	5.6-16	35.1	1.7	4.3	705			19	(11)	30			1	31 (D)
					16-28													
	359		35	1436.43	6.0-30	45.5	3.06	4.24	927			22	(9)	31			4	35 (D)
	362		32	1439.37	5.45-27.5	12.4	3.6	8.4	128			17	(11)	28			4	32 (D)
	365		27	1441.69	5.0-25	35.5	2.79	3.4	902			18	(7)	25			2	27 (D)
	368		32	1444.79	5.6-28	23.5	2.88	5.99	339			15	(13)	28			4	32 (D)
	371		28	1447.04	6.0-22	36.4	2.73	4.43	710			13	(9)	22	(2)	24	4	28 (C)
	374		26	1450.81	4.0-23	10.83	2.4	3.2	292			8	(15)	23			3	26 (C)
	313		22									4	(16)	20			2	22 (C)
						32			563									

*) C; Carboniferous sediments
D; Devonian sediments
**) meter

Table I.3.3 The results of water level measurements

Well No.	Well No. (Map.No)	Elevation of water level in meter: The 1st measurement Sep-93	S or P	The 2nd measurement Apr-94	S or P	Difference from the previous measurement	The 3rd measurement Sep-Oct 94	S or P	Difference from the previous measurement	Difference from the First measurement
M5	5	1265.37	P	1262.83	P	-2.54	1264.94	P	2.11	-0.43
M2	2	1262.79	P	1263.37	P	0.58	1266.27	P	2.90	3.48
M3	3	1263.06	P	1259.88	P	-3.18	1264.12	P	4.24	1.06
M1	1	1267.54	S	1265.66	S	-1.88	1268.21	S	2.55	0.67
M6	6	1269.95	P	1268.14	P	-1.81	1270.25	P	2.11	0.30
M7	7	1268.76	P	1267.26	P	-1.50	1269.19	P	1.93	0.43
I11	13	1269.16	P	1268.33	P	-0.83	1269.00	P	0.67	-0.16
I7	9	1269.94	S	1268.19	P	-1.75	1269.89	S	1.70	-0.05
I6	8	1269.32	P	1269.22	S	-0.10	1268.98	P	-0.24	-0.34
I5	7	1270.67	P	1267.91	P	-2.76	1269.77	P	1.86	-0.90
I3	5	1272.07	S	1271.30	S	-0.77	1272.08	S	0.78	0.01
C42	42/63	1286.84	S				1284.56	P		-2.28
C48	48/57	1287.04	P	1286.78	P	-0.26	1287.55	P	0.77	0.51
C46	46/59	1290.18	S	1287.42	S	-2.76	1289.85	P	2.43	-0.33
C40	40/51	1291.27	P				1291.51	P		0.24
C38	38/49	1289.45	P				1290.22	P		0.77
C39	39/50	1292.40	P				1294.01	P		1.61
C8	8	1293.88	S	1291.92	S	-1.96	1294.62	S	2.70	0.74
C7	7	1294.61	S	1292.51	S	-2.10	1295.79	P	3.28	1.18
C4	4	1295.31	P	1294.31	S	-1.00	1296.71	S	2.40	1.40
C13	13	1296.76	P	1293.57	P	-3.19	1297.44	S	3.87	0.68
C14	14	1297.69	P	1293.67	P	-4.02	1297.65	P	3.98	-0.04
C15	15	1299.90	S	1297.67	S	-2.23	1299.65	S	1.98	-0.25
C16	16	1300.91	P	1296.53	P	-4.38	1300.74	P	4.21	-0.17
C17	17	1301.44	P	1299.12	P	-2.32	1301.35	P	2.23	-0.09
C54	4/67	1313.05	P	1311.53	P	-1.52	1314.03	S	2.50	0.98
C53	3/66	1313.21	P	1311.90	P	-1.31	1313.62	S	1.72	0.41
C69	19a	1314.00	S	1312.71	S	-1.29	1313.85	S	1.14	-0.15
C55	5/68	1315.10	P	1311.40	P	-3.70	1313.62	P	2.22	-1.48
C56	6/69	1316.87	S	1314.19	P	-2.68	1315.56	P	1.37	-1.31
U29	29(316Y)	1429.22	S	1428.50	P	-0.72	1429.13	S	0.63	-0.09
U30	30(356)	1426.68	P	1430.43	S	3.75	1430.95	S	0.52	4.27
U31	31(31pn)	1431.06	P	1430.61	S	-0.45	1431.39	S	0.78	0.33
U32	32(32n)	1432.77	S	1427.90	P	-4.87	1432.92	S	5.02	0.15
U33	33(33n)	1428.71	P	1432.26	S	3.55	1427.64	P	-4.62	-1.07
U34	34(359)	1430.58	P	1433.10	S	2.52	1430.05	P	-3.05	-0.53
					Average	-1.48		Average	+1.77	+0.27

Well No. M-: Meat Complex Water Source
I-: Industrial Water Source
C-: Central Water Source
U-: Upper Water Source

S; Static Water Level
P; Pumping Water Level

Table I.3.4 Estimated volume of groundwater

	Lower Area of U.W.S		Buheg				
	A	B	1	2	3	4	5
Area (square kilometers).	12.98	29.50	99.45	59.2	23.15	19.95	35.7
Thickness of the alluvium (meters).	15	20	40	20	30	30	20
Depth to water (meters).	2.5	2.5	5.5	5.5	5.5	5.5	5.5
Saturated thickness (meters).	12.5	17.5	34.5	14.5	24.5	24.5	14.5
Specific Yeild	0.15	0.15	0.1	0.1	0.1	0.1	0.1
Volume of recovarable groundwater (million cubic meters).	24	77	343	86	57	49	52
Total volume of groundwater of the Area (million cubic meter).	102		586				

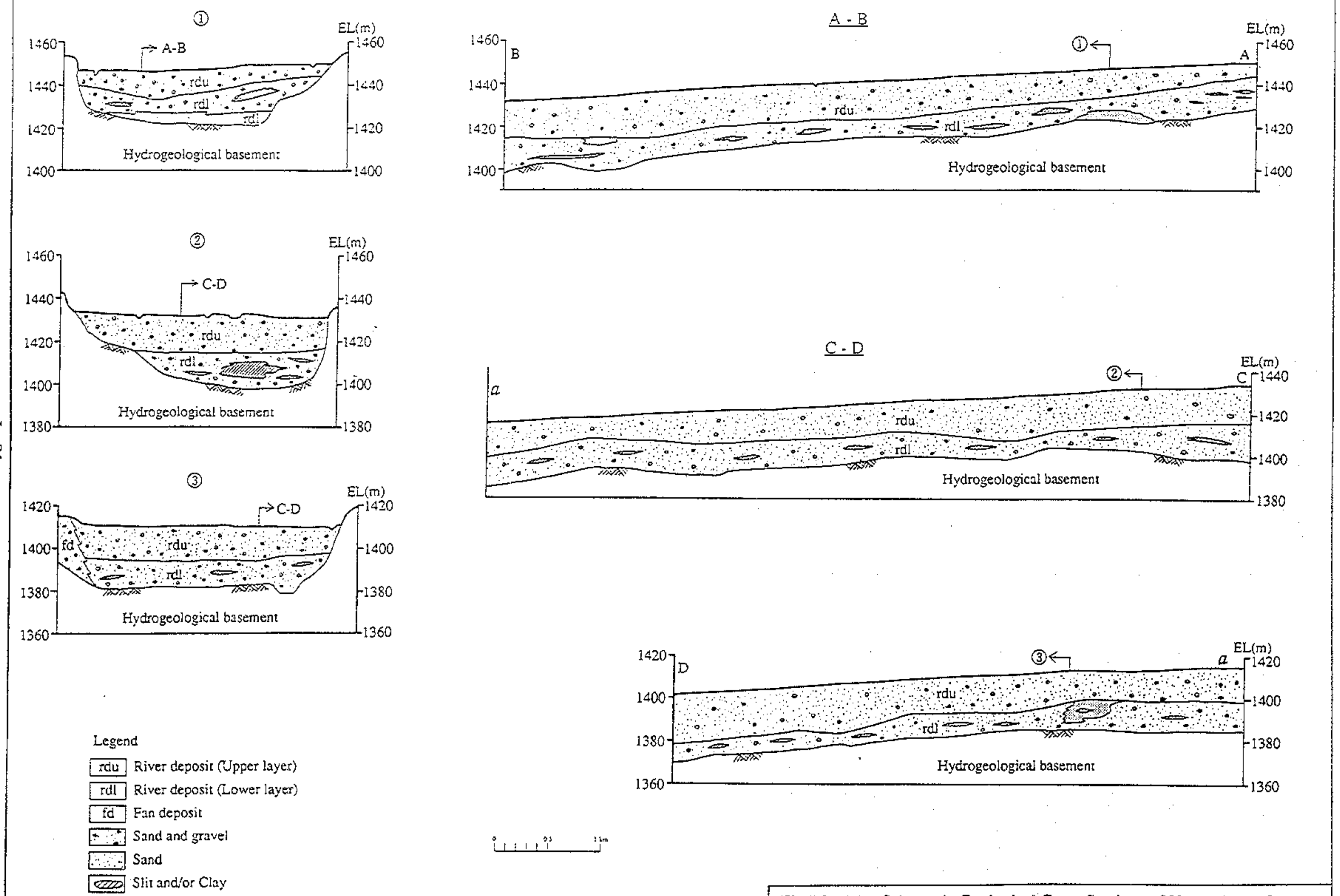


Fig.I.3.1(1) Schematic Geological Cross Sections of Upper Water Source

JICA | The Study on Water Supply System in Ulaanbaatar and Surroundings

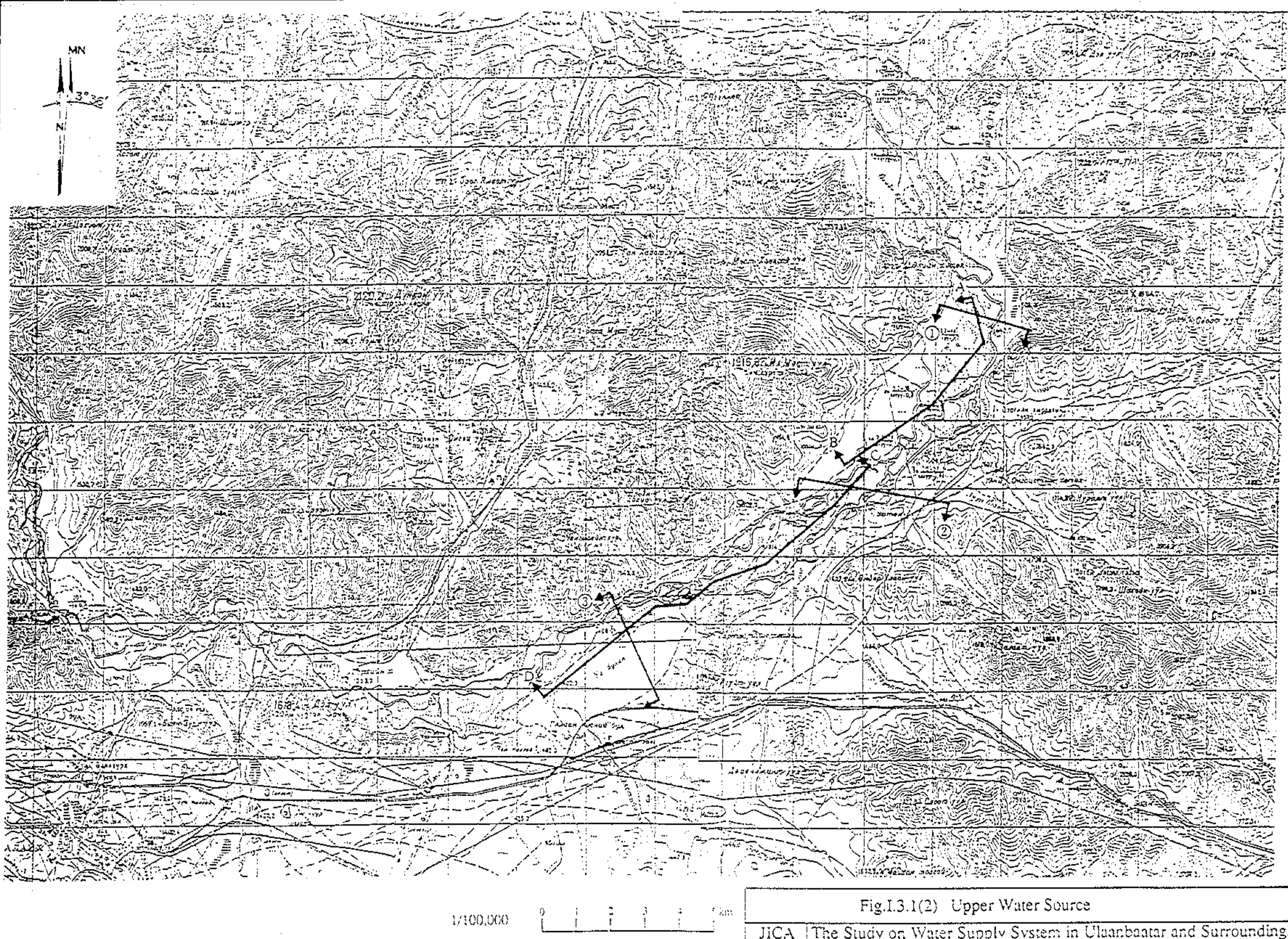


Fig.I.3.1(2) Upper Water Source

JICA | The Study on Water Supply System in Ulaanbaatar and Surroundings

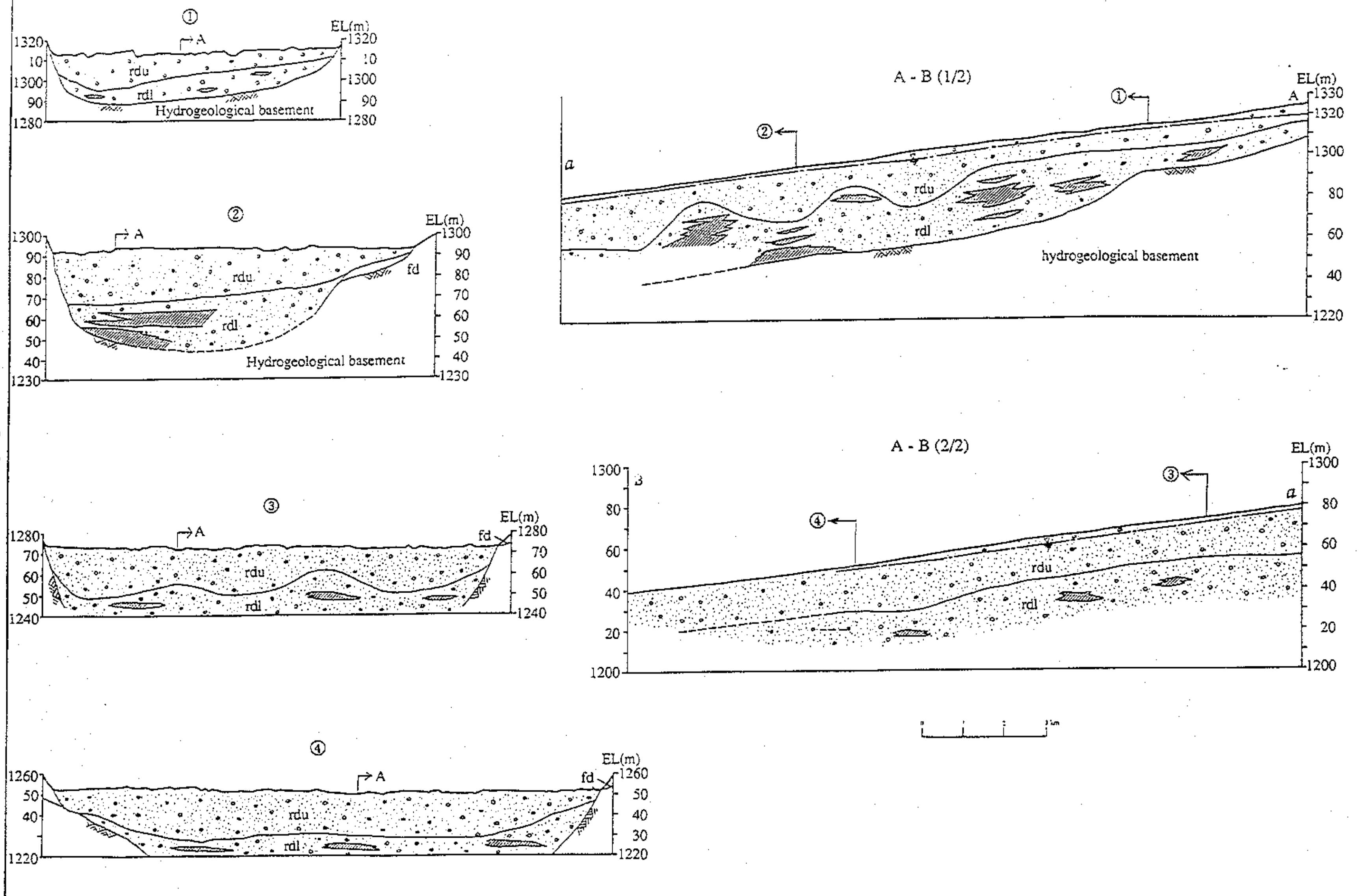
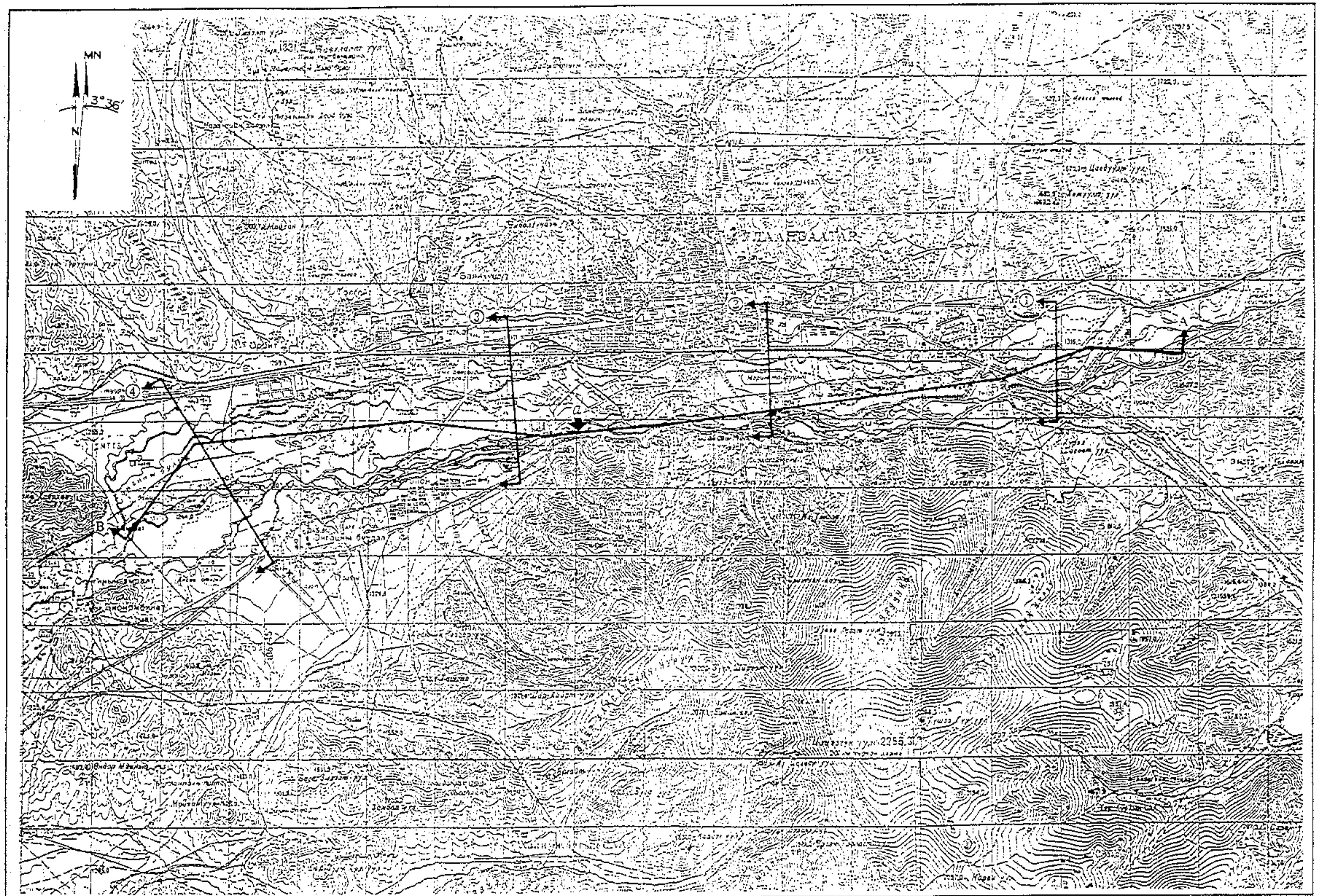


Fig.I.3.2(1) Schematic Geological Cross Sections of Central Water Source

JICA | The Study on Water Supply System in Ulaanbaatar and Surroundings



1/100,000 0 1 2 3 4 5km

Fig.I.3.2(2) Central Water Source

JICA | The Study on Water Supply System in Ulaanbaatar and Surroundings

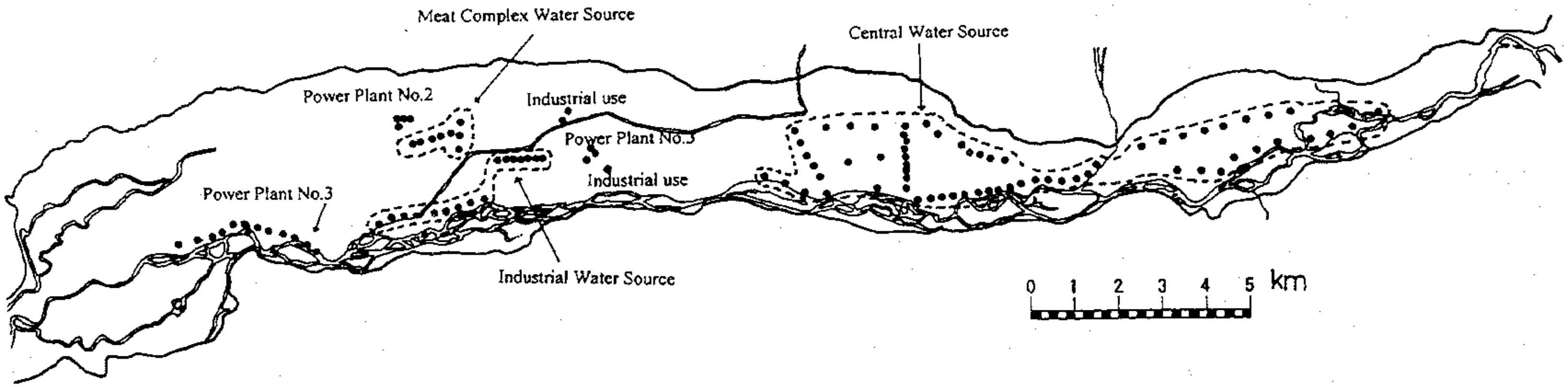
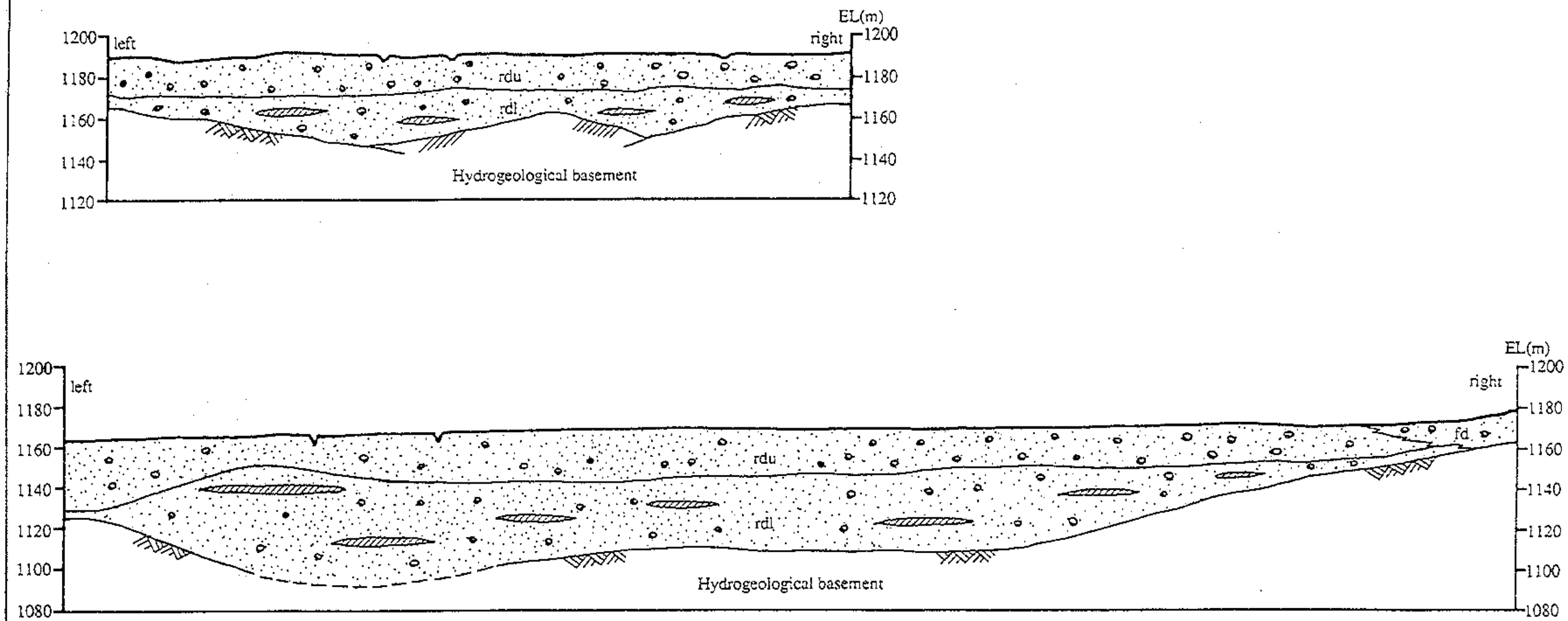


Fig. I.3.3 Location map of production wells in Central Part

JICA	The Study on Water Supply System in Ulaanbaatar and Surroundings



H : 1/20,000
V : 1/ 2,000
0 0.5 1 km

Fig.I.3.4(1)	Schematic Geological Cross Section of Lower Part of Power Plant
JICA	The Study on Water Supply System in Ulaanbaatar and Surroundings

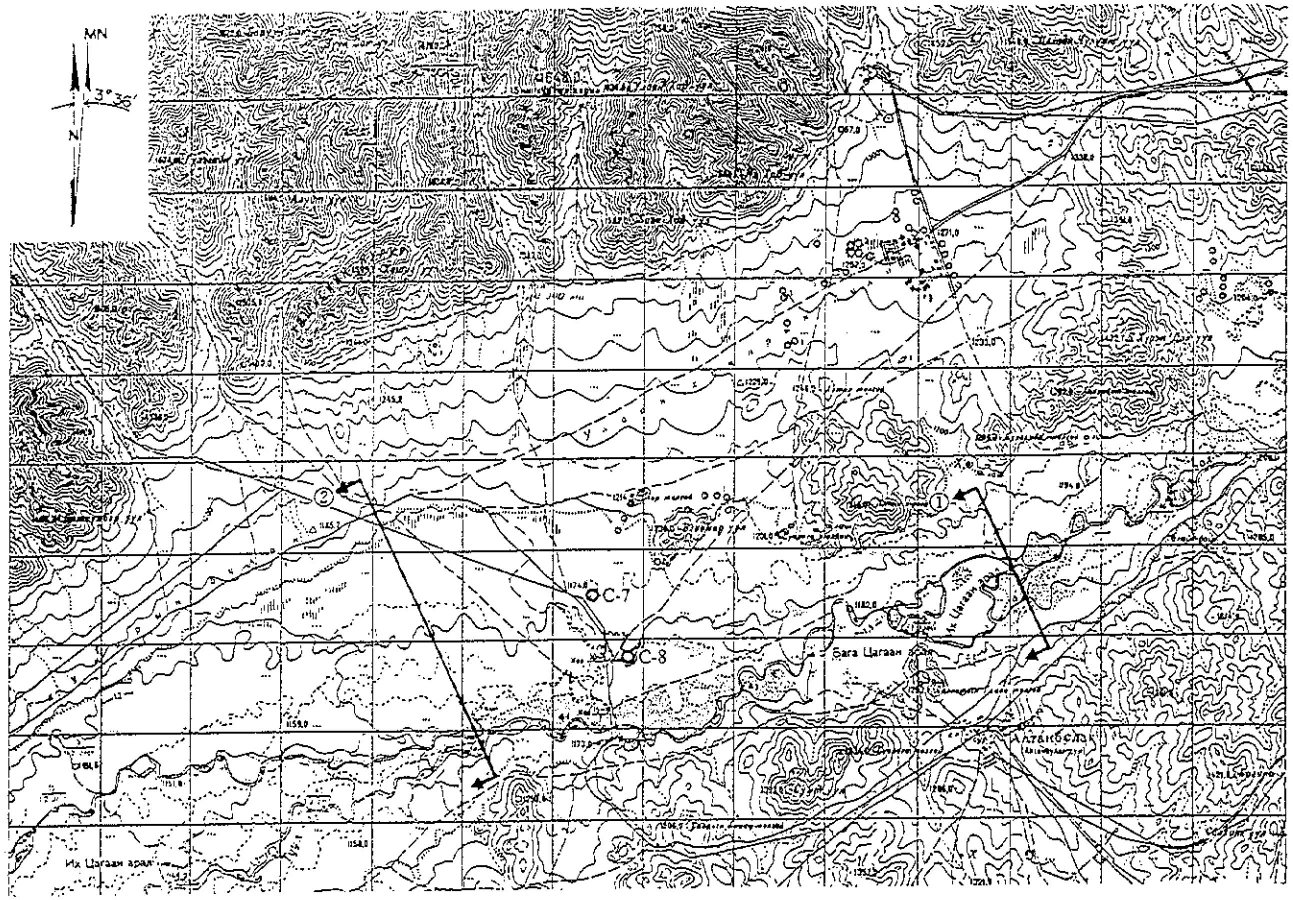
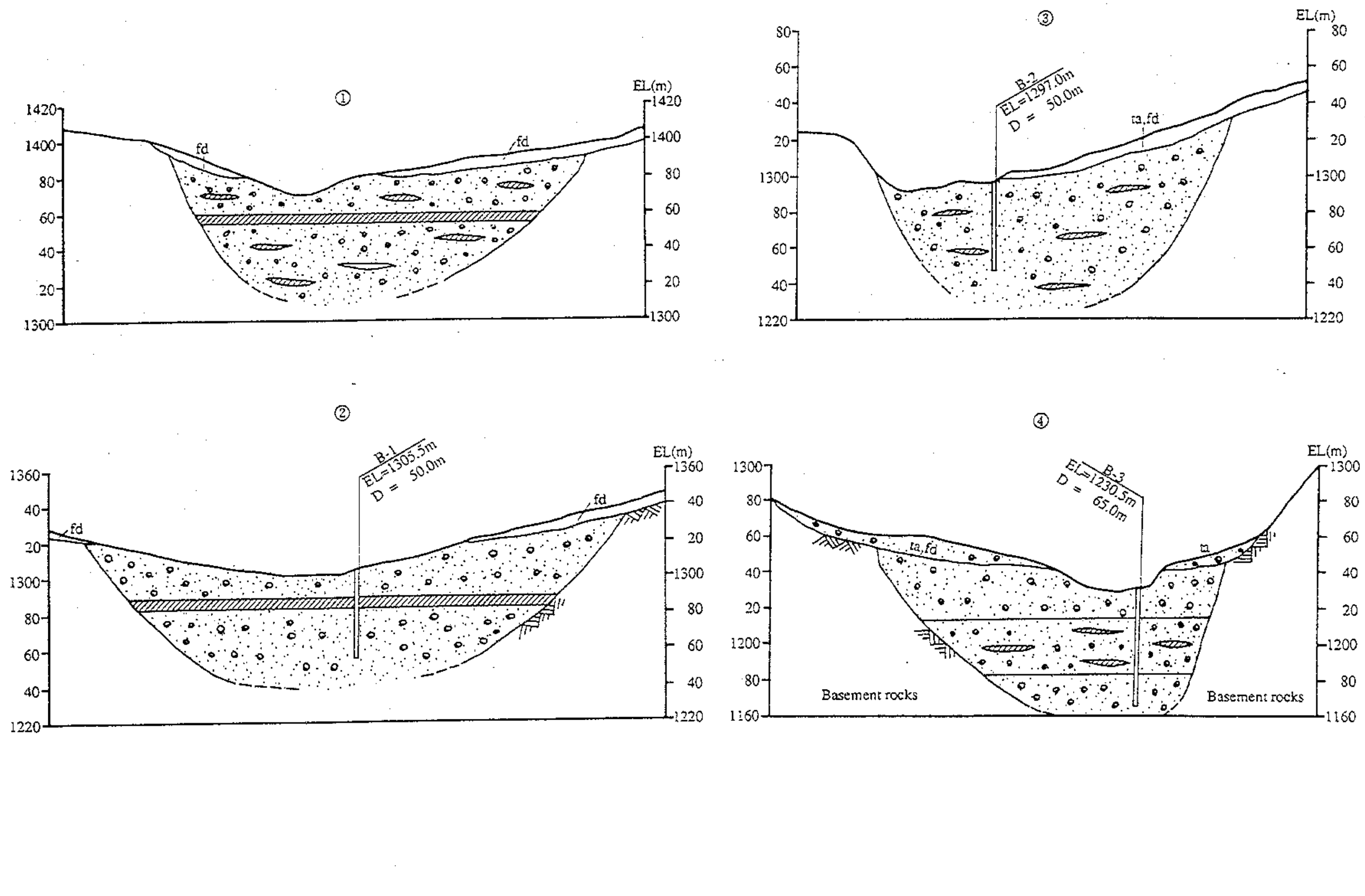


Fig.I.3.4(2) Lower Part of Power Plant

JICA | The Study on Water Supply System in Ulaanbaatar and Surroundings



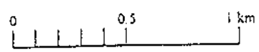


Fig.I.3.5(1) Schematic Geological Cross Sections of Buheg River

JICA | The Study on Water Supply System in Ulaanbaatar and Surroundings

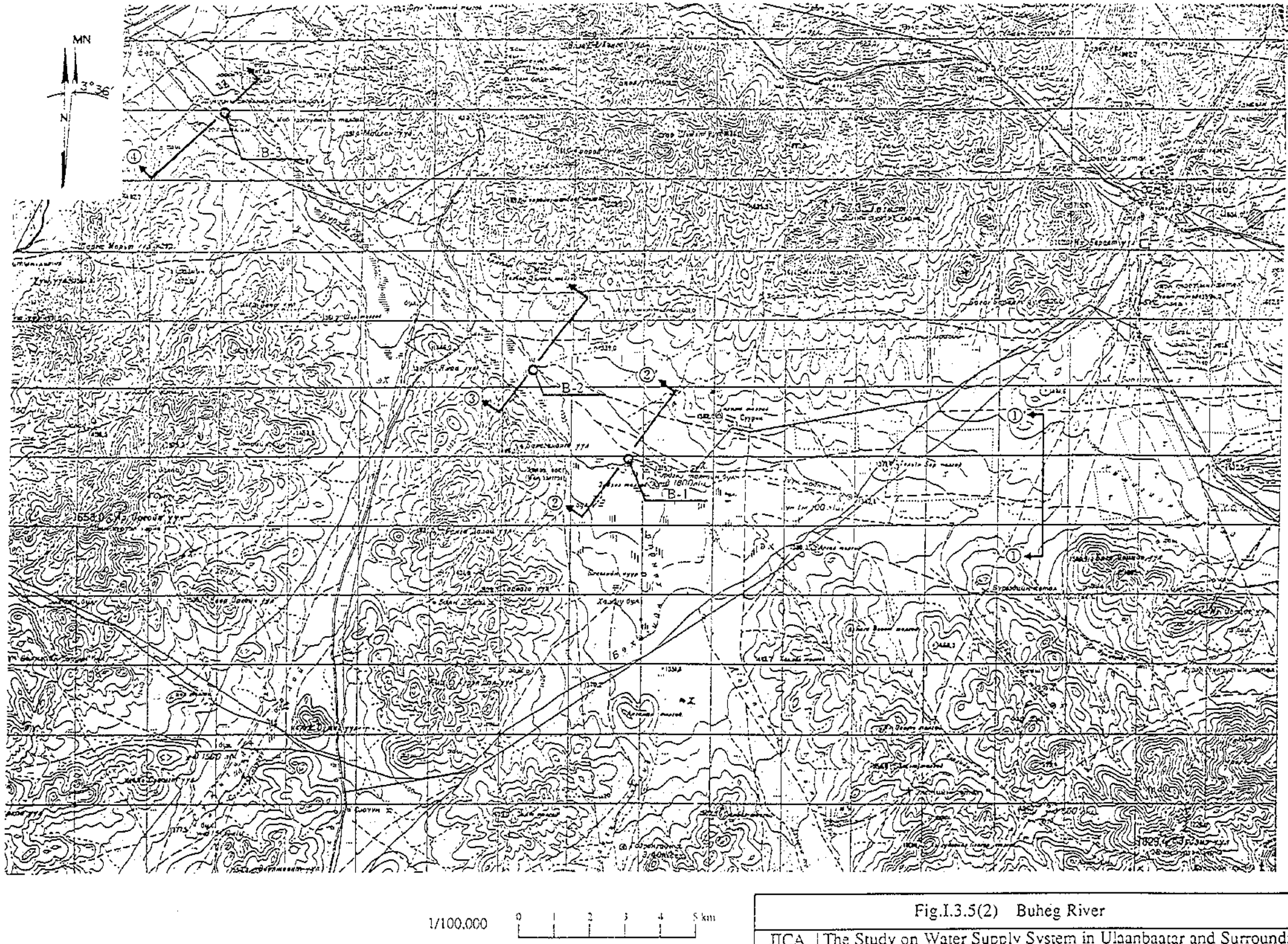


Fig.I.3.5(2) Buheg River

JICA | The Study on Water Supply System in Ulaanbaatar and Surroundings

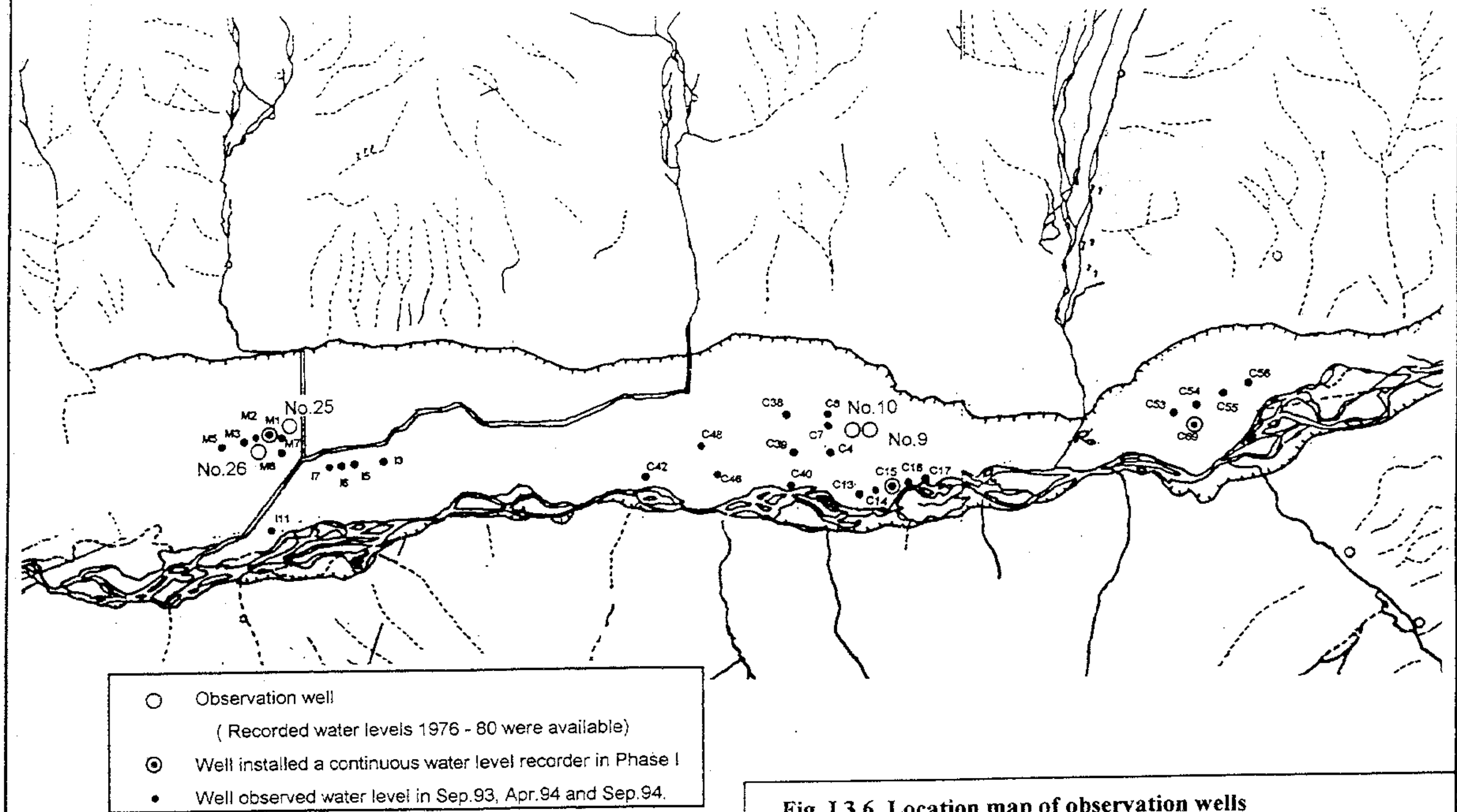
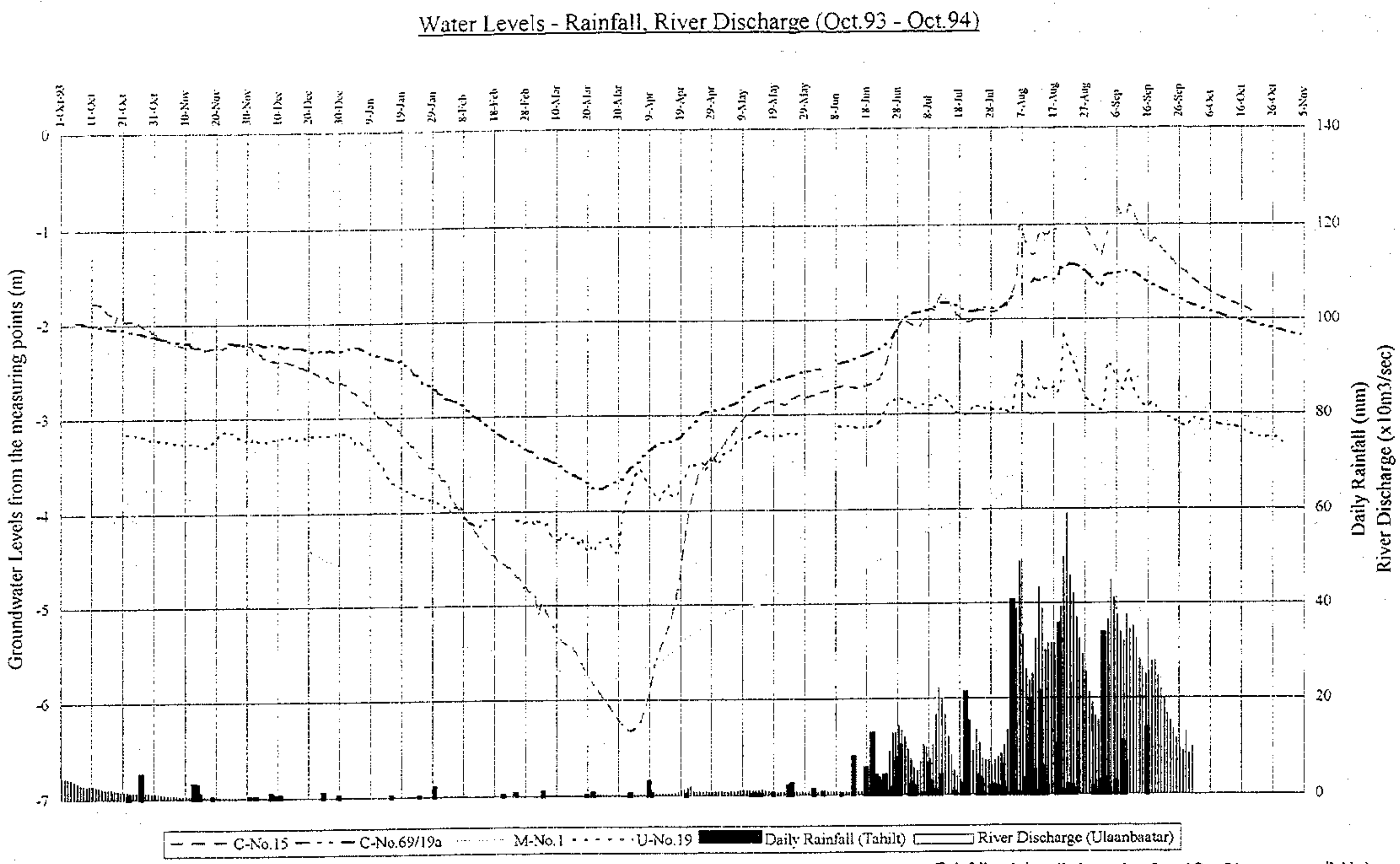


Fig. I.3.6 Location map of observation wells

JICA | The Study on Water Supply System in Ulaanbaatar and Surroundings



(Rainfall and river discharge data from 1Oct. 94 were not available.)

Fig. I.3.7 The results of continuous measurement of water level

JICA	The Study on Water Supply System in Ulaanbaatar and Surroundings

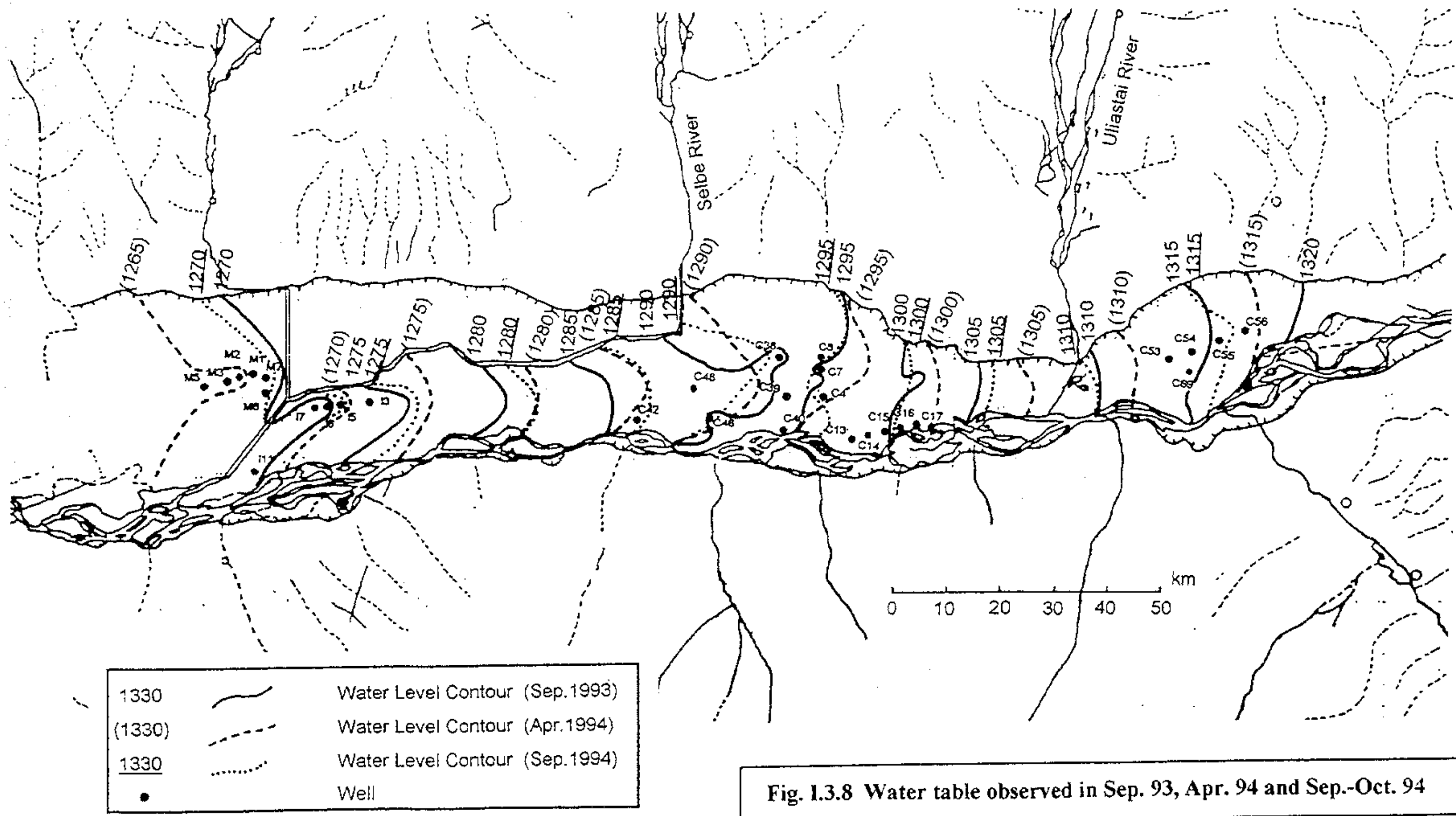


Fig. 1.3.8 Water table observed in Sep. 93, Apr. 94 and Sep.-Oct. 94

JICA | The Study on Water Supply System in Ulaanbaatar and Surroundings

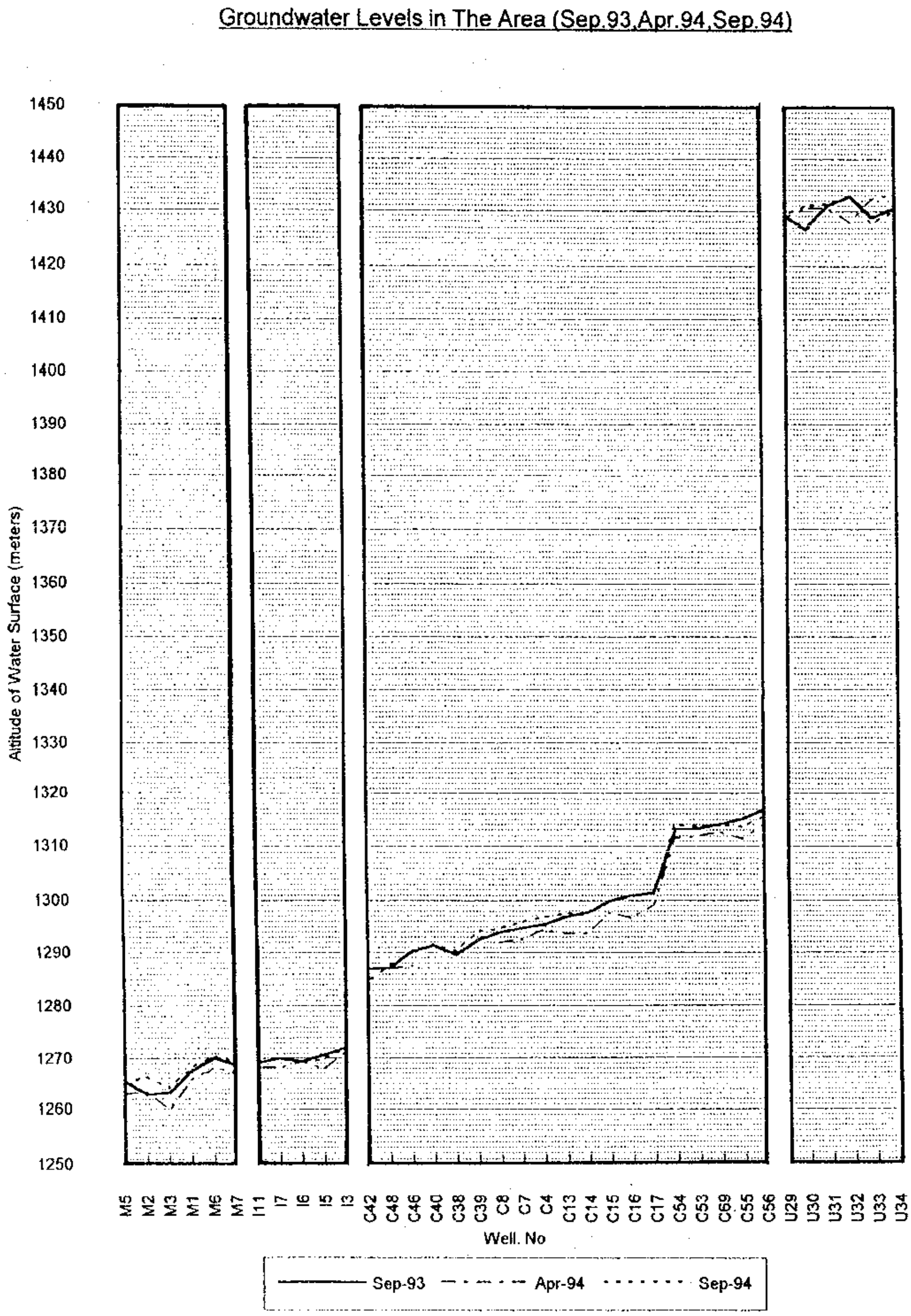


Fig. I.3.9 The results of water level measurement, Sep. 93, Apr. 94, Sep.-Oct. 94	
JICA	The Study on Water Supply System in Ulaanbaatar and Surroundings

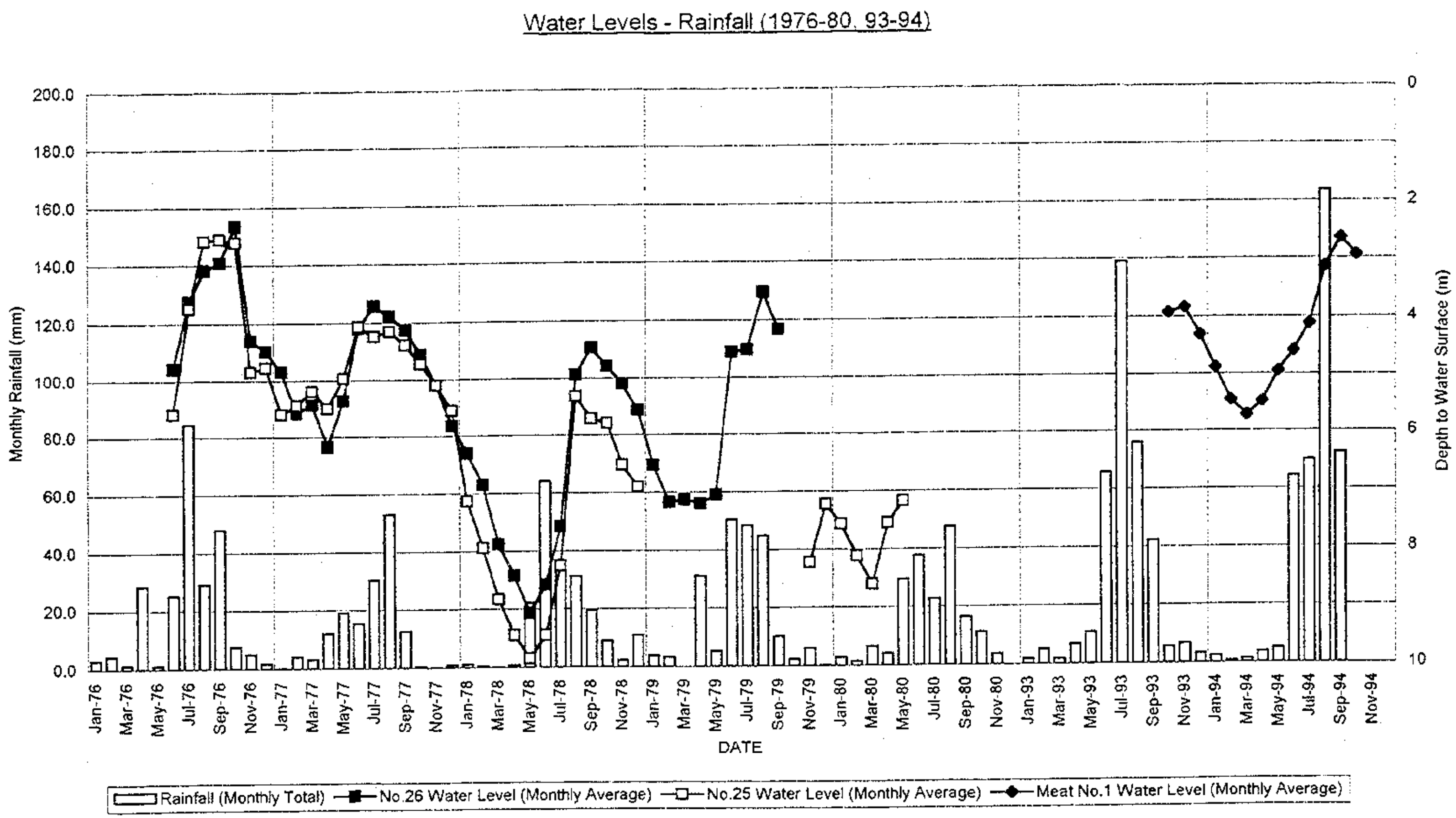


Fig. I.3.10 Water levels and rainfall around Meat Complex Water Source

JICA | The Study on Water Supply System in Ulaanbaatar and Surroundings

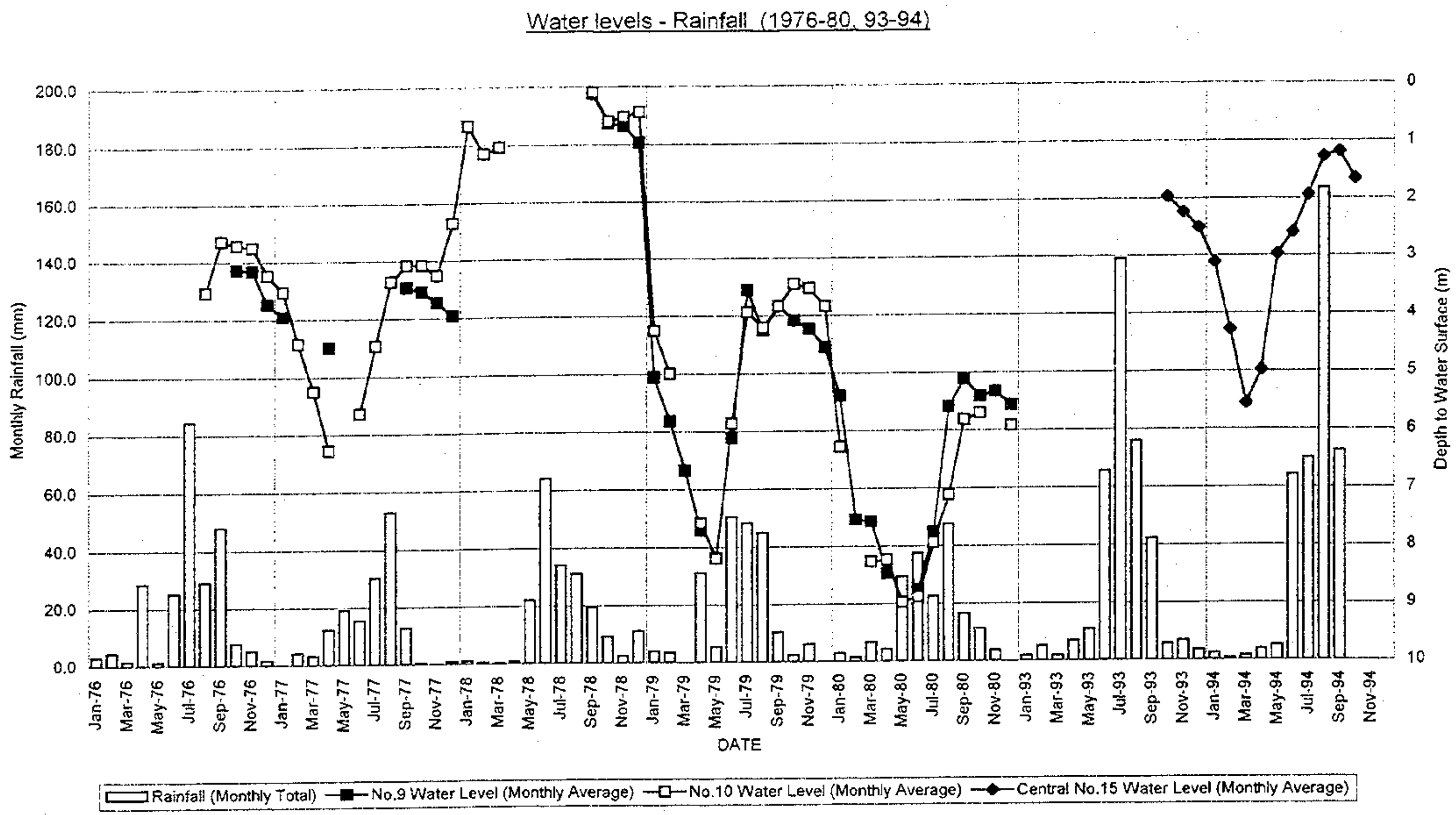


Fig. I.3.11 Water levels and rainfall around the middle of Central Water Source

JICA | The Study on Water Supply System in Ulaanbaatar and Surroundings

Recorded Water Levels in Well C5, 1980-91

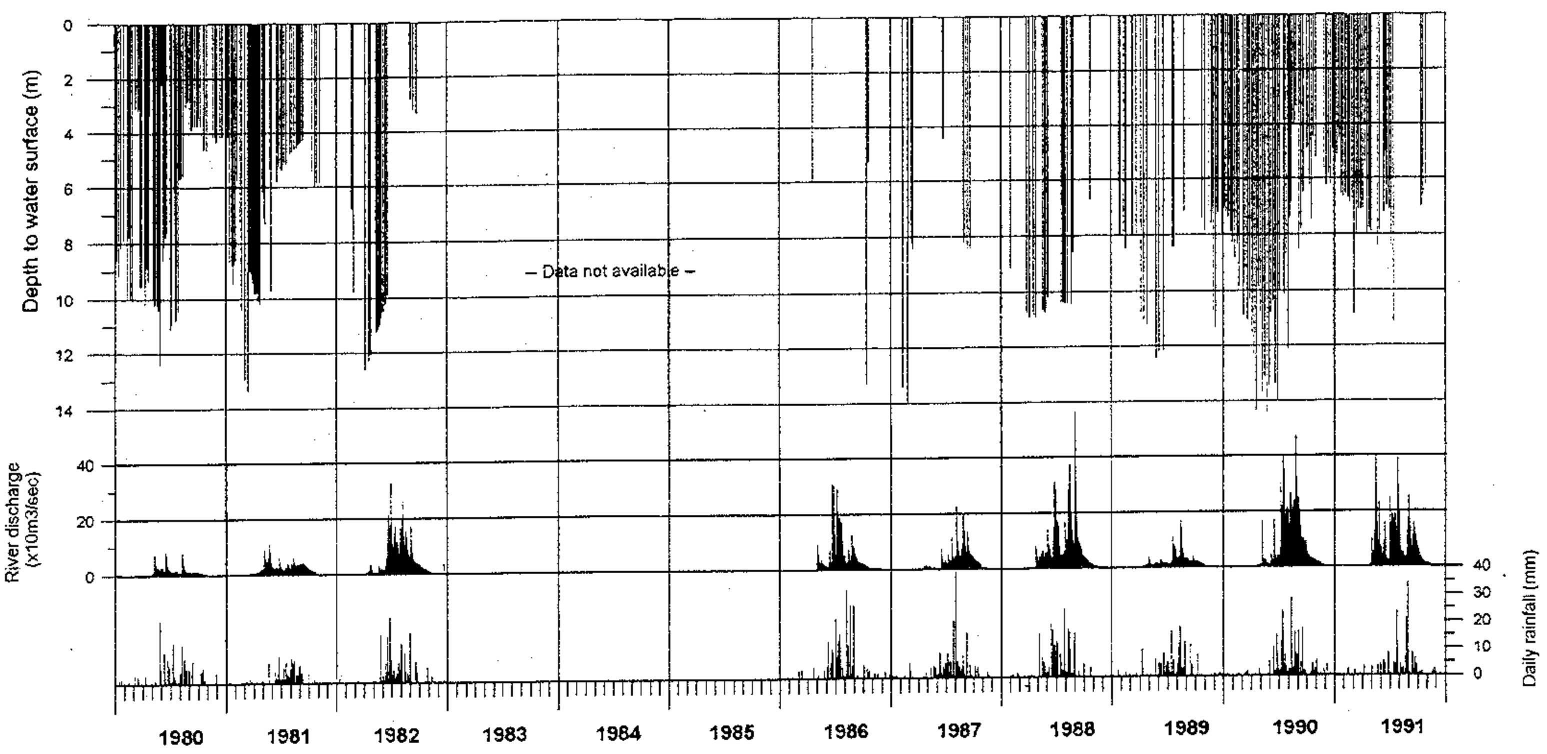


Fig. I.3.12 Recorded water levels in No.5 of Central Water Source

JICA	The Study on Water Supply System in Ulaanbaatar and Surroundings

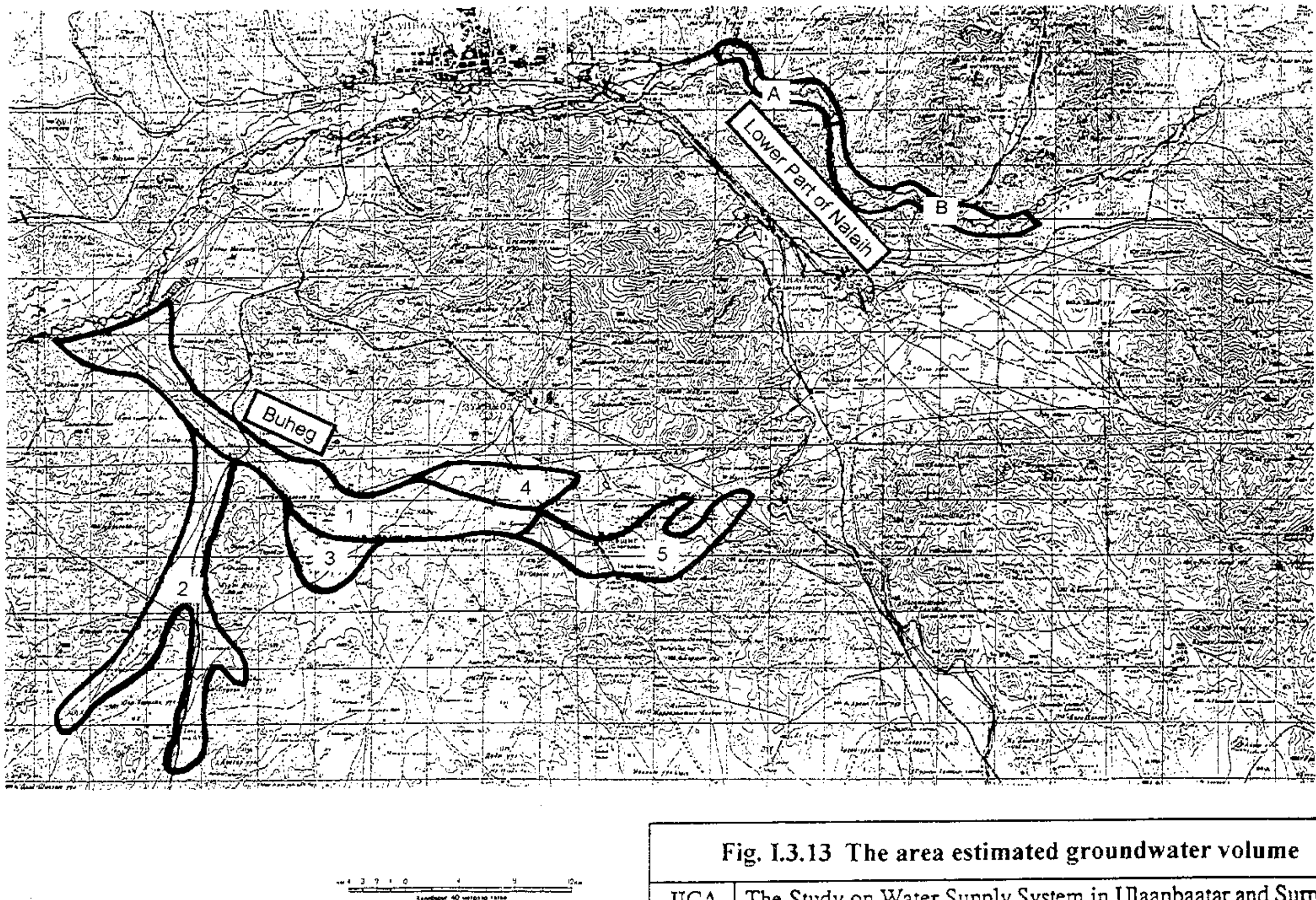


Fig. I.3.13 The area estimated groundwater volume

JICA	The Study on Water Supply System in Ulaanbaatar and Surroundings

CHAPTER 4 GROUNDWATER SIMULATION

CHAPTER 4. GROUNDWATER SIMULATION

4.1 PURPOSE AND PROCESS OF GROUNDWATER SIMULATION

Groundwater simulation is an important means to evaluate a certain groundwater basin or a part of it. Groundwater Simulation which can simulate fluctuation of groundwater table in time and space is suitable to assess the new groundwater development plan in terms of groundwater resources.

A full process of groundwater simulation in this study is shown as a flowchart in Fig. I.4.1. The first step of simulation work is to make a numerical model of present groundwater basin on the basis of some concerned data; geomorphologic, hydrological, hydrogeological and withdrawal data. An applicability of the model is checked with present groundwater table contour map mainly. The second step is to simulate future groundwater condition by changing parameters of the model or inputting new data on the basis of new groundwater development plan. Finally, the impact assessment and the evaluation of the plan were conducted.

4.2 CONSTRUCTION OF GROUNDWATER SIMULATION

4.2.1 Selection of Groundwater Simulation Area

There are four (4) existing water sources in Ulaanbaatar. Central Water Source, the largest one, has supplied approximately 55% of all water demand and 80% of domestic water demand. Recently, it has become difficult to pump up the designed volume of groundwater in winter. Groundwater level has fallen down to the serious level in winter. However, water source of Central Water Source is expected to be sufficient from the hydrogeological point of view. Accordingly, Central Water Source should be reevaluated, and groundwater simulation should be conducted to clarify the operation problem and the suitable disposition of production wells in Central Water Source. The groundwater simulation area is shown in Fig. I.4.2.

4.2.2 Groundwater Simulation Program

The results of the hydrogeological analysis have been conducted, particularly the analysis of groundwater table observation. It suggests that the problem of Central Water Source would be caused mainly by the operation and management of pumping wells but not by its groundwater potential. The excessive groundwater withdrawal is seemed to be done from the limited pumping wells in the limited areas. Therefore, it was considered indispensable to conduct the groundwater simulation effectively applying the program that enables the multiple-layers analysis, both on steady and unsteady state by quisi-dimensional analysis covering wide and vast areas.

In this context, the computer program " UNISSF "; Unified Normal and Inverse Sub-Surface Flow analysis program which was developed by the Information -Technology Promotion Agency, Japan (IPA) was applied to this study.

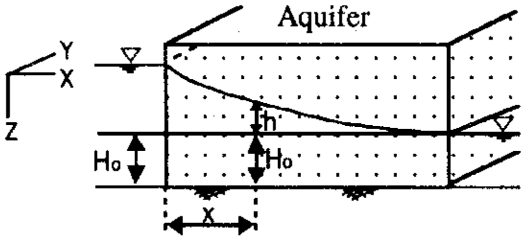
This program is based on the finite element method widely used in numerical analysis and quasi-three-dimensional groundwater analysis. Mathematical model of the program is shown as excerpt from the user's manual report.

(1) Dominant equation

The dominant equation relating to infiltration handled here is based on Dupuit's hypothesis* that the head is equal on the perpendicular section of the aquifer.

Using Dupuit's hypothesis, the continuation formula relating to three-dimensional (x, y, z) flow is, from $Vz = 0$ is, as follows.

$$S\frac{\partial h}{\partial t}+\frac{\partial}{\partial x}\{(Ho+h)Vx\}+\frac{\partial}{\partial y}\{(Ho+h)Vy\}=q \quad \text{......} \quad 1)$$



S : *coefficient of storage*
Vx, Vy, Vz : *apparent flow velocity in* x, y, z *directions*
q : spring flow or discharge per unit time

Putting Darcy's formula of motion (equation 2)) into equation 1) yields:

$$\left.\begin{aligned} Vx &= -Kx\frac{\partial h}{\partial x} \\ Vy &= -Ky\frac{\partial h}{\partial y} \\ Vz &= -Kz\frac{\partial h}{\partial z} \end{aligned}\right\} \quad \text{......} \quad 2)$$

* This hypothesis means that the direction of infiltration flow is mainly on the horizontal plane, that is, the perpendicular components of flow are very small. Therefore, when the perpendicular components are too large to be ignored as compared with the horizontal components, the analysis based on Dupuit's hypothesis is not applicable.

$$S\frac{\partial h}{\partial t} = \frac{\partial}{\partial x}\left\{Kx(Ho+h)\frac{\partial h}{\partial x}\right\} + \frac{\partial}{\partial y}\left\{Ky(Ho+h)\frac{\partial h}{\partial y}\right\} + q$$

$$= \frac{\partial}{\partial x}\left(Tx(h)\frac{\partial h}{\partial x}\right) + \frac{\partial}{\partial y}\left(Ty(h)\frac{\partial h}{\partial y}\right) + q \qquad 3)$$

Where Tx, Ty : coefficients of transmissivity in x, y directions, being functions of heard h

This is the dominant equation relating to infiltration using Dupuit's hypothesis.

From equation 3), after finite element formulation by using the weighted remainder method, the solution is obtained under proper initial conditions and environmental conditions.

(2) Quasi-three-dimensional handling

The analysis by the dominant equation shown here can be easily applied in the multiple-stratum ground, and it is called the quasi-three-dimensional infiltration flow analysis.

That is, using the coefficient of transmissivity and coefficient of storage as the function of level, the multiple-stratum ground can be handled, and not only the confined aquifer but also the unconfined aquifer and transference between the two can be also handled, which is different from the conventional horizontal two-dimensional infiltration flow analysis.

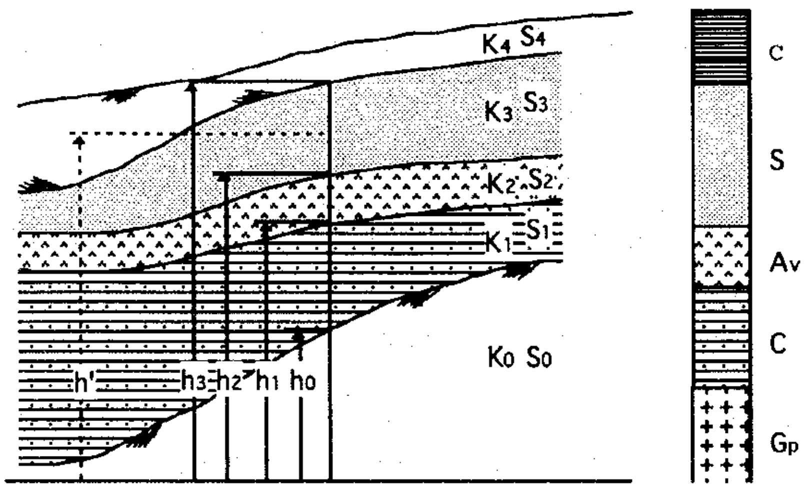
The coefficient of transmissivity T is defined as the sum of products of coefficient of permeability Ki and layer thickness b_i of each aquifer. That is,

$$T = \sum_{i=0}^{n} K_i \cdot b_i$$

Meanwhile, the coefficient of storage S is, in the case of a confined aquifer, defined as the product of the coefficient of specific storage S_S * and the aquifer thickness b of the stratum to be analyzed, and in the case of an unconfined aquifer, it is defined as the volume of water discharged from the gap in the soil of unit volume (= effective porosity) due to lowering of the level.

The stratum section and columnar section of a typical aquifer are shown in following figure.

* Equal to the coefficient of volumetric compression, being expressed as $Ss = 0.001\ \rho h\ (cm^{-1})$



The coefficient of transmissivity, regarding as the function of level, can be expressed as shown below.

a_{11}	a_{21}	a_{31}						
	a_{22}	a_{32}				a_{72}		
		a_{33}		a_{53}		a_{73}		
			a_{44}	0		0		
				a_{55}	a_{65}	a_{75}		
					a_{66}	0	a_{86}	
						a_{77}	a_{87}	a_{97}
							a_{88}	a_{98}
								a_{99}

$\Rightarrow$

a_{11}	a_{21}	a_{22}	a_{31}	a_{32}	a_{33}	a_{44}	a_{53}	0	a_{55}	a_{65}	a_{66}

When handled similarly, the coefficient of storage is as shown above.

i) Confined aquifer

When the free water surface reaches the upper end of the permeable bed, the permeable bed is confined. In the above figures, h is greater than h_3. In this region, the coefficient of transmissivity T is constant, and is expressed as follows.

$$T = K_o b_o + K_1 b_1 + K_2 b_2 + K_3 b_3 (= CONST)$$

Also the coefficient of storage S is constant, being the sum of the products of coefficient of specific storage Ss and layer thickness of each layer, and is expressed as follows.

$$S = S_4 = Ss_0 b_0 + Ss_1 b_1 + Ss_2 b_2 + Ss_3 b_3 (= CONST)$$

ii) Unconfined aquifer

When the free water surface is lowered (h becomes less than $h3$ in Figs. 2 and 3) and the permeable bed becomes unconfined, the coefficient of transmissivity T decreases as the water level drops as the function of groundwater level, and the coefficient of storage becomes the value of the effective porosity* in the area of the location of the level (stratum).

For example, when the level is h' $(h_2 < h' < h_3)$, T' and S' are :

$$T' = K_o b_o + K_1 b_1 + K_2 b_2 + K_3 b_3 (h - h_2)$$

$$S' = S_3$$

When the free water surface is further lowered to the basement (h is less then h_o), the coefficient of transmissivity and coefficient of storage become zero at that point. Such phenomenon is a problem of wide-area groundwater, and is often experienced at the boundary of the mountain and plain field.

(3) Initial conditions and boundary conditions

The theoretical solution is obtained under proper initial conditions and boundary conditions.

1) Initial condition

$$h\,(x_i,\,0) = h\,(x_i)$$

2) Boundary conditions

(i) Boundary with known head

$$h\,(x_i,\,t) = h_b\,(x_i,\,t)$$

.... When the level is constant, or the periodic change of level is known, such as the boundary facing the river, lake or sea.

(ii) Boundary with known in-out flow

$$Q(X_i,\,t) = Q_b\,(X_i,\,t)$$

---

* The coefficient of storage S of the unconfined aquifer is expressed as follows.

$S = Sy + Ssb \cdot b$

where Sy : specific yield, synonymous with effective porosity

Ss : coefficient of specific storage

b : layer thickness

$(Sy >> Ss \cdot b)$

(4) Finite element method

1) Formulation

Dominant equation

$$\frac{\partial}{\partial x}\left(Tx(h)\frac{\partial h}{\partial x}\right)+\frac{\partial}{\partial y}\left(Ty(h)\frac{\partial h}{\partial y}\right)+q=S(h)\frac{\partial h}{\partial t} \qquad (1)$$

When the entire region is divided into a finite number of elements, as far as the structure is continuous, equation (1) is approximately established in each element.

When the weighted remainder method is applied in formulation, it follows that

$$R=\frac{\partial}{\partial x}\left(Tx(h)\frac{\partial h}{\partial x}\right)+\frac{\partial}{\partial y}\left(Ty(h)\frac{\partial h}{\partial y}\right)+q-S(h)\frac{\partial h}{\partial t} \qquad (2)$$

The optimal approximate solution of equation (1) is obtained by minimizing this remainder R in all elements.

The following equation is established by the Galerkin method selecting the shape function as the weight.

$$\iint_s \{N\}R\,ds = 0 \qquad (3)$$

Where N: shape function

Solving equation (3) yields finally the following equation.

$$\left(\frac{1}{4t}[C]+[K]\right)\{h\}_{t+\Delta t}=\{F\}_{t+\Delta t}+\frac{1}{\Delta t}[C]\{h\}_t \qquad (4)$$

where

$$[C]=\iint_{se} S^e\{N\}\{N\}^T ds$$
$$[K]=\iint_{se}[B]^T\left[\begin{smallmatrix} Tx & o \\ o & Ty \end{smallmatrix}\right][B]ds$$
$$[C]=\iint_s Q\{N\}ds-\int r_2 q\{N\}ds$$

For handling of the time term, however, the regression difference was used.

Analysis is possible by solving equation (4) with respect to the total head h.

Since the materials constants handled here, T, S, are the functions of water level, it is necessary to improve the solution by iterative calculation.

To solve the simultaneous linear equations of (4), basically, the Gaussian elimination method is used, but in consideration of saving of memory and increase of calculation speed, the skyline method is employed.

The skyline method is briefly described below.

(2) Skyline method

The skyline method is a kind of band matrix, but it is different from the band matrix in the following points.

1) Data is handled in row unit.
2) Those corresponding to the band width are variable in each row.
3) The product sum type calculation formula is used.

calculation formula ([a] · {x} = [b])

i) LU splitting

K = in the sequence of 2, 3, ..., N

J =in the sequence of 1, ..., K-1

$$a^{\star}_{jk} = a_{jk} - \sum_{i=1}^{j-1} a'_{ij}\ a^{*}_{ik}$$

$$a'_{jk} = a^{\star}_{jk} / a'_{ij}$$

$$a'_{kk} = a_{kk} - \sum_{i=1}^{k-1} a'_{ik}\ a^{*}_{ik}$$

where $a^{\star}_{jk}$: the value before dividing by pivot a'_{ii} (equivalent to component of U of LU splitting)

a'_{jk} the value after dividing by pivot a'_{ii} (equivalent to component of L of Lu splitting)

ii) Calculation of right side

Forward elimination

K = in the sequence of 2, 3, ..., n

$$b'_k = \left(b_k - \sum_{i=1}^{k-1} l_{ki} b'_i \right) / l_{kk}$$

Regression substitution

K = in the sequence of n, n-1, ..., 2

Xk = (b'k at that point)

i =in the sequence of 1, ..., K-1

$$New\ b'_i = b'_i - U_{ki} X_k$$

$$X_1 = (final\ b_1)$$

4.2.3 Parameter of Groundwater Simulation Area

(1) Calculation Mesh System

The northern and southern side of Central Water Source Area is bordered by the basement rocks. However, the eastern and western sides of it have no boundary except for the expedient boundary in order to distinguish the water sources, since the simulation area belongs to the alluvial plane along Tuul River. The area occupies approximately 30.5 km^2.

Fig. I.4.3. shows a calculation network for the groundwater simulation that is formed after consideration of the distribution of production wells, groundwater observation wells and so forth. The network consists of 512 nodes and 592 elements. The interval of large mesh, medium and small one is 500m, 250m and 125m respectively.

(2) Distribution of Aquifer

Data relating to horizontal and vertical distribution of aquifers was established with the illustrated figures listed as follows based on the previous study report (PNIIS (1979): "Technical Report on Engineering Survey - Hydrogeological Investigations for Estimation of Utilization Resources of Groundwater -").

- Geological profiles
- Isopach Map of Upper Aquifer(QIII-QIV) and Lower Aquifer(QII-QIII)
- Contour Map of Bottom Level of Upper Aquifer (QIII-QIV) and Lower Aquifer (QII-QIII)

The data was set up as geological input data at all calculation nodes. Two aquifers; Upper Aquifer (QIII-QIV) and Lower Aquifer(QII-QIII) are recognized from a hydrogeological point of view. A conceptual geological section for simulation is illustrated as Fig.I.4.4. The Upper Aquifer and the Lower Aquifer can be regarded as gravely faces and sandy faces respectively, although each aquifers actually varies in lithofaces. They are conformable to each other without continuous impermeable layer. Therefore, it seems that they are unconfined aquifers as a whole.

(3) Coefficient of Aquifer

In general, coefficient of aquifer is determined by the analysis of drillhole logs, pumping test results and so on. However, it doesn't matter for computer simulation model to classify each aquifer into many sections based on coefficient of aquifer. In case of this simulation, the coefficient of aquifer was adopted as follows. They were established on the basis of hydrogeological analysis.

- Permeability
  Upper Aquifer : $K=1.79 \times 10^{-1}$ cm/sec
  Lower Aquifer : $K=4.48 \times 10^{-2}$ cm/sec
- Specific yield
  Upper Aquifer : Sy=0.20
  Lower Aquifer : Sy=0.15

(4) Discharge of Groundwater

Discharge of groundwater in the simulation area mainly consists of groundwater outflow from the western side of the simulation area and groundwater withdrawal through pumping wells. Groundwater withdrawal volume was estimated by the operation record of pumping wells.

(5) Recharge of Groundwater

Recharge of groundwater to the area comes from several influent streams and basement rocks, and precipitation. Since recharge from them except for precipitation may be regarded as so called "Black Box", it was assumed as next paragraph.

(6) Boundary Condition

There are three (3) kinds of boundary for the simulation, namely 1) Basement rock boundary (northern side of the area), 2) inflow and outflow boundary of groundwater (eastern and western side of the area) and 3) river boundary (Tuul, Selbe and Uliastai River). In this case, it seems that the most important point is how to input the data of the seasonal change of each boundaries' conditions.

The fundamental boundary condition was established through calculations in steady state in October 1993 by the UNISSF. The groundwater recharge and discharge along the simulation boundaries were calculated in the simulation program automatically in the steady state through reproducing the present groundwater level in stead of inputting their values directly. In this case, it is better way in order to construct the simulation model.

On the other hand, the seasonal change of them was accorded with the flow rate fluctuation of Tuul river at Ulaanbaatar Observing Station in same period.

(7) Initial Groundwater Level

Initial groundwater level is necessary for construction of groundwater simulation model in the steady state calculation. It was input according to the static water level contour map in October 1993. (see Fig. I.4.5 (1))

4.3 APPLICABILITY OF SIMULATION MODEL

4.3.1 Establishment of Hydrological Year

Harmonizing with hydrological conditions, groundwater level generally shows daily, seasonal or yearly fluctuation. It is the best model that can reproduce their fluctuation perfectly for the last decades. Unfortunately, it is actually impossible to construct such a model because of enormous calculation volume and time, and shortage of data. Therefore, the hydrological year: October 1993 to September 1994 was established as the simulation period that groundwater condition should be reproduced by the simulation model. This year is the latest and only year when a series of simulation parameters can be prepared mostly and continuous measurement of groundwater level has conducted at NO.15 Well in Central Water Source.

4.3.2 Reproduction of Present Groundwater Conditions

Applying the above-mentioned simulation parameters (4.2), the groundwater simulation model for Central Water Source was established through two calculation procedures namely, (1) Steady State Calculation and (2) Unsteady State Calculation.

The former is for construction of fundamental simulation model and the latter is for reproduction of the groundwater conditions during the established hydrological year.

4.3.3 Applicability of Simulation Model

The constructed simulation model in this study was checked its applicability by two calculation procedures through trial and error.

(1) Steady State Calculation

The result of steady state calculation is illustrated as the contour map of groundwater level with flow vectors in Fig. I.4.5 (2). The figure indicates that this simulation model can reproduce the groundwater conditions in October 1993 practically except for the limited parts of the simulation area.

(2) Unsteady State Calculation

Following the steady state calculation, the unsteady state calculation was carried out to check the applicability of the model during the hydrological year. The applicability was confirmed by the recognition of maximum drawdown on April and recovering it in the end of the hydrological year just like the monitoring result of groundwater level at NO.15 Well.

Fig. I.4.6 (1) illustrates the simulated drawdown in April 1994 compared with October 1993 when the maximum drawdown 5 m was recorded at NO.15 Well.

4.4 REEVALUATION OF CENTRAL WATER SOURCE

As mentioned above, the simulation results indicate that Central Water Source is sustainable water source at present and have a possibility of new groundwater development, particularly in the eastern or the western part of the simulation area where the drawdown is less than one meter as shown in Fig. I.4.6, except for the area along Tuul river.

4.5 ESTIMATION OF SAFETY YIELD IN CENTRAL WATER SOURCE AREA

When a new development plan of groundwater resource is projected, it is very important to maintain the groundwater source to be sustainable, in other words, to meet a safety yield of groundwater.

It is strongly desired to know how much the safety yield is or how much ground volume can be developed additionally in Central Water Source, but it is not easy to determine the value. Because it is necessary to calculate numerous cases to get final answer. Then, one of the case studies is shown in Fig. I.4.6 (2) that the additional developing groundwater volume is 2,1000 m3/day (1,500 m3/day x 14 new wells). The distribution of proposed wells in Fig. I.4.3.

The simulated drawdown of April 1994 compared with October 1993 is illustrated in Fig. I.4.6 (2).

Although the effected area where the drawdown is more than one meter is enlarged considerably by the additional withdrawal, it was confirmed that the effected area was recovered in the end of the hydrological year. This suggests that the proposed withdrawal is acceptable.

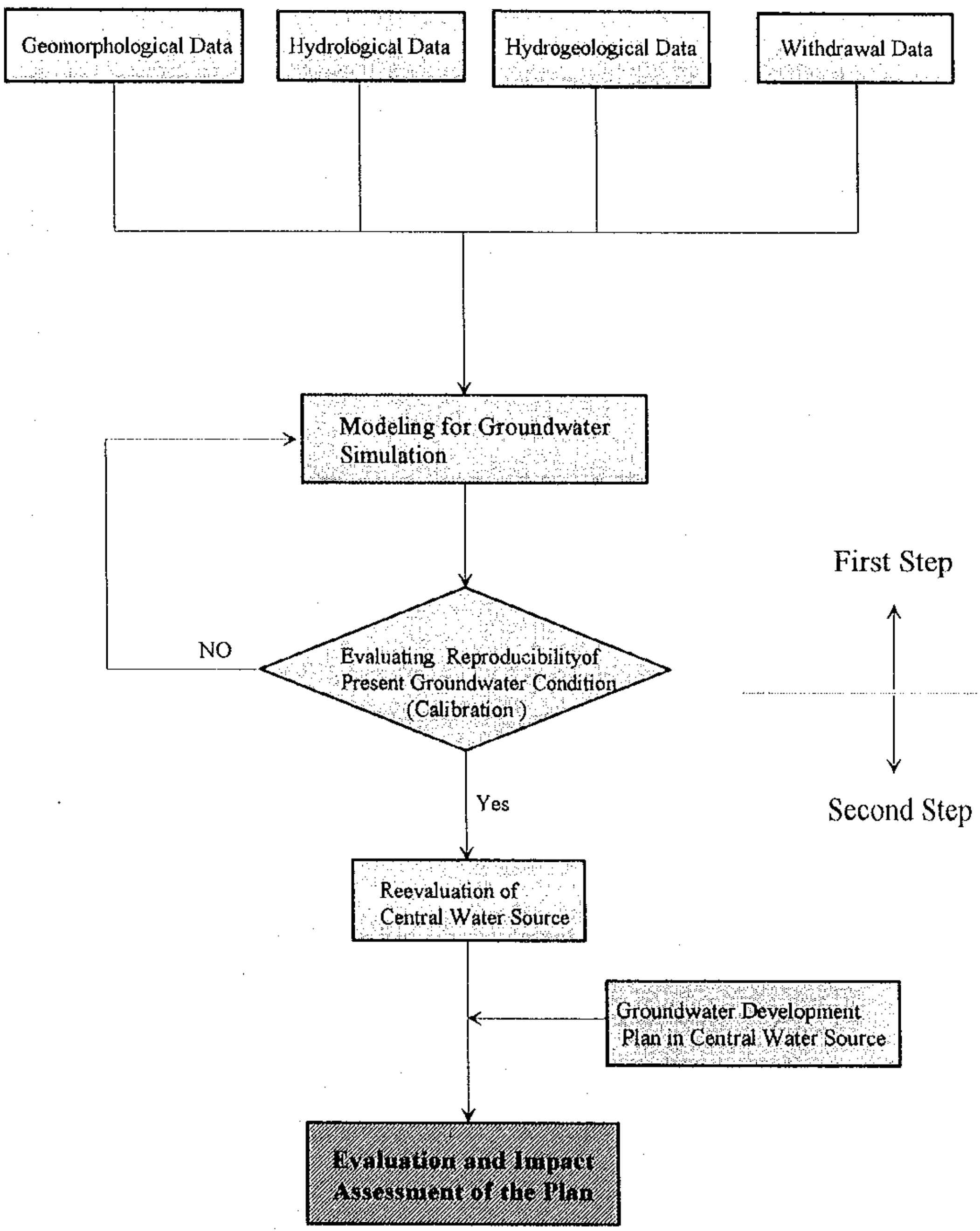


Fig. I.4.1 Flow Chart of Groundwater Simulation in Central Water Source

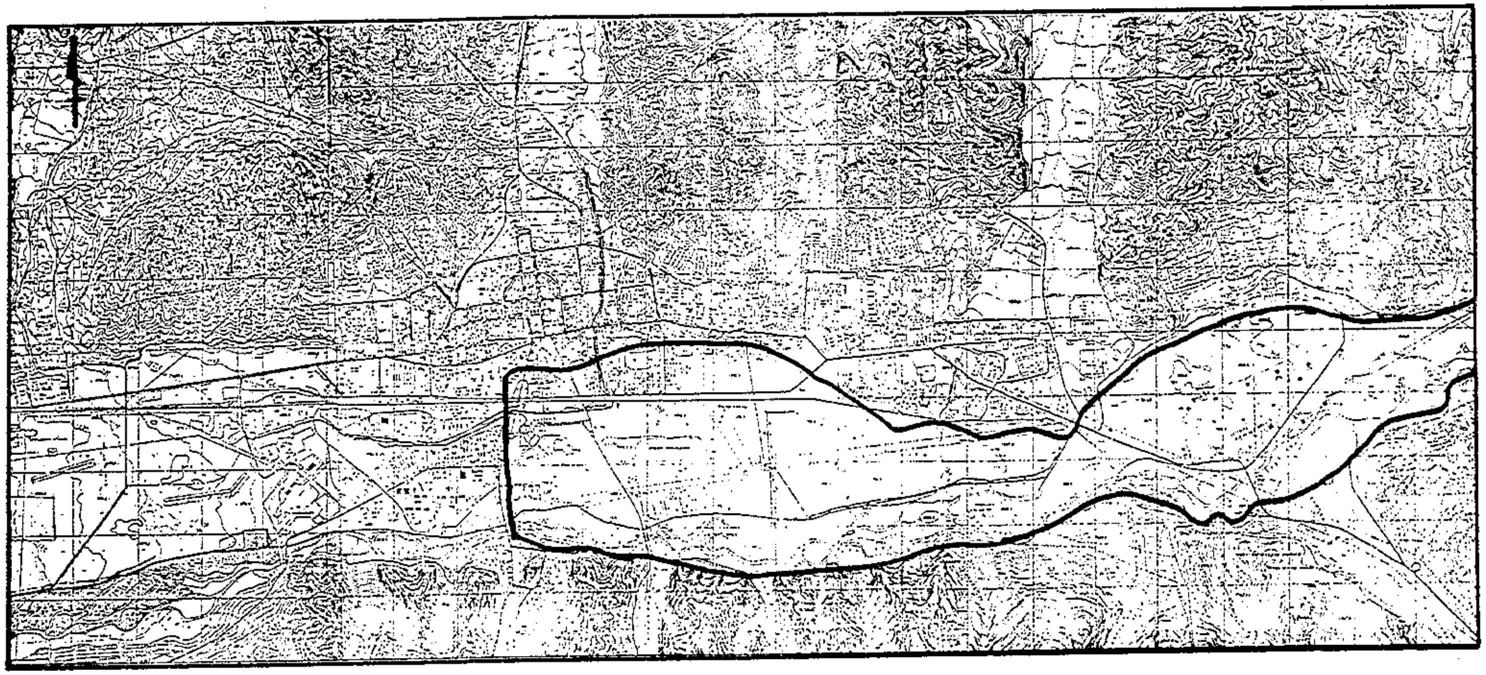


Fig. I.4.2 Location Map of Groundwater Simulation Area

JICA	The Study on Water Supply System in Ulaanbaatar and Surroundings

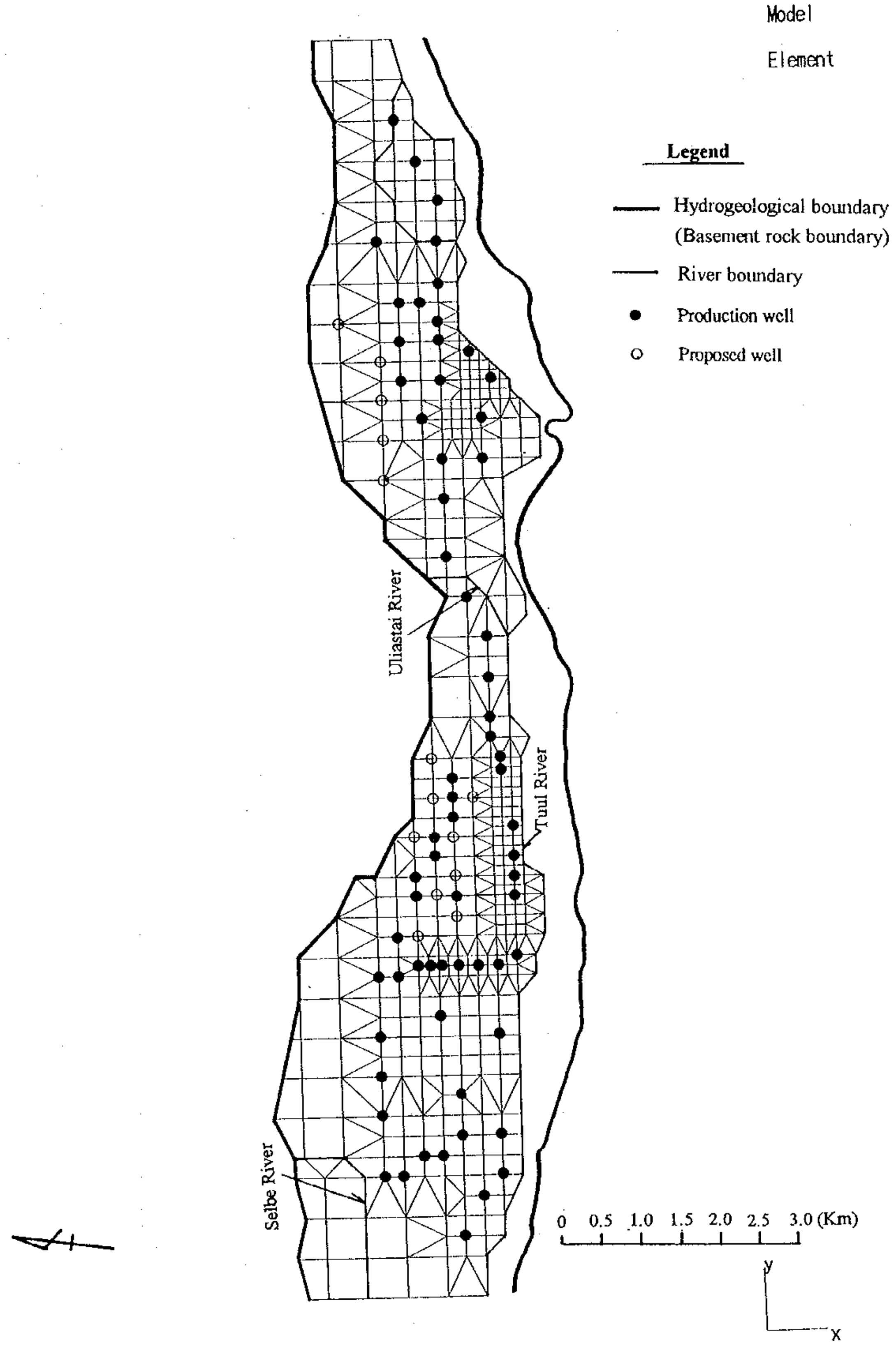


Fig. I.4.3	Calculation Mesh System and Distribution of Present Production Wells and Proposed Wells for Groundwater Simulation
JICA	The Study on Water Supply System in Ulaanbaatar and Surroundings

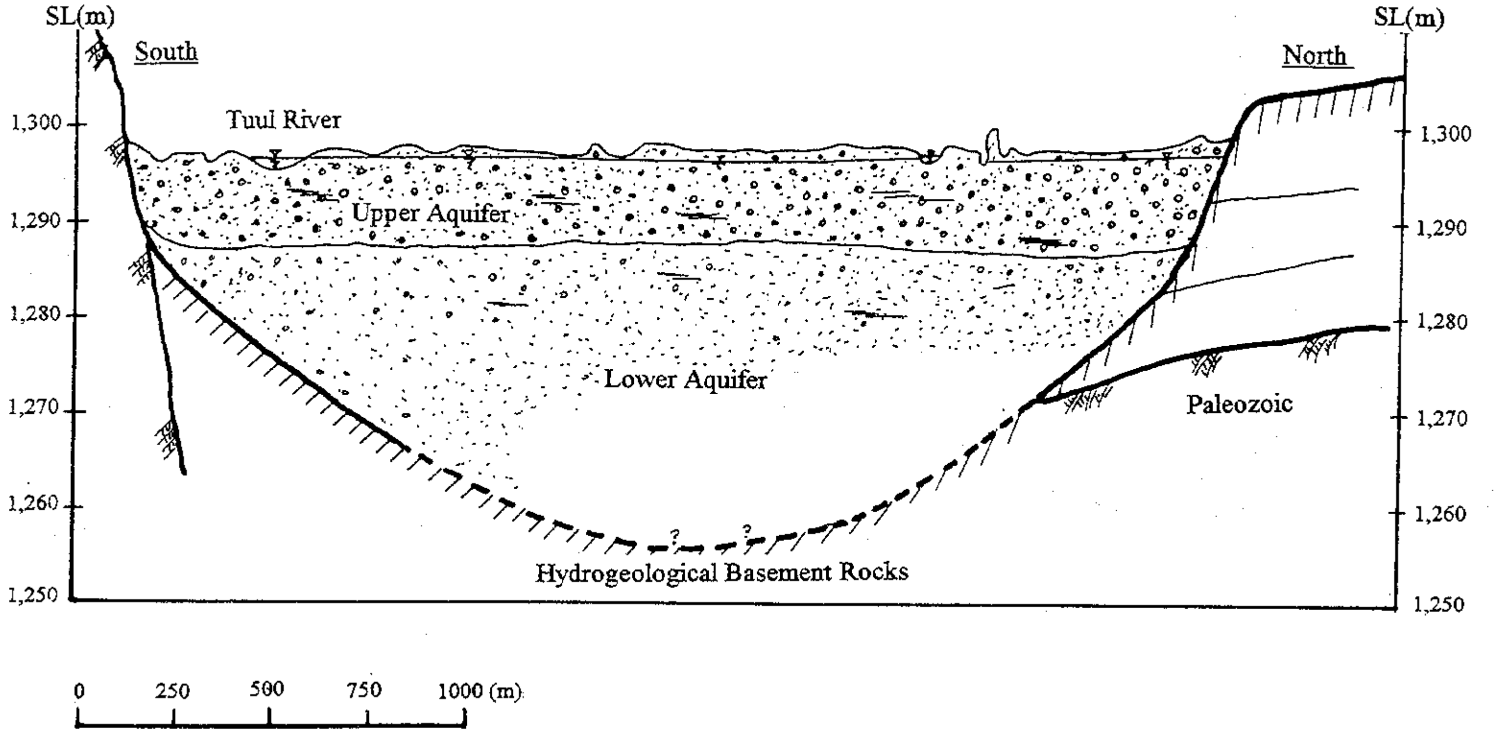


Fig. I.4.4	Conceptual Hydrogeological Section for Groundwater Simulation in Central Water Source
JICA	The Study on Water Supply System in Ulaanbaatar and Surroundings

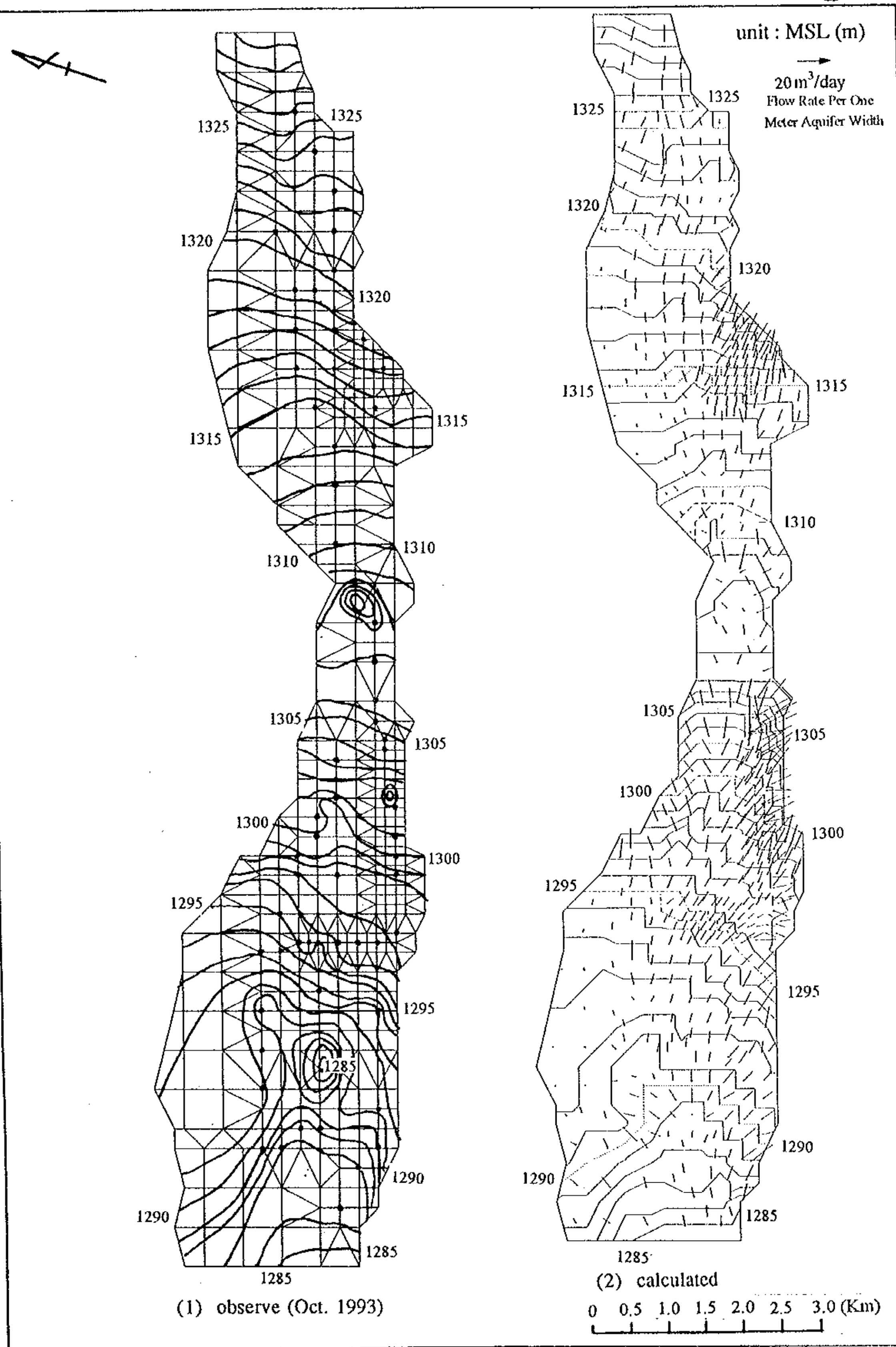


Fig. I.4.5 Comparison between Observed and Calculated Groundwater Level

JICA	The Study on Water Supply System in Ulaanbaatar and Surroundings

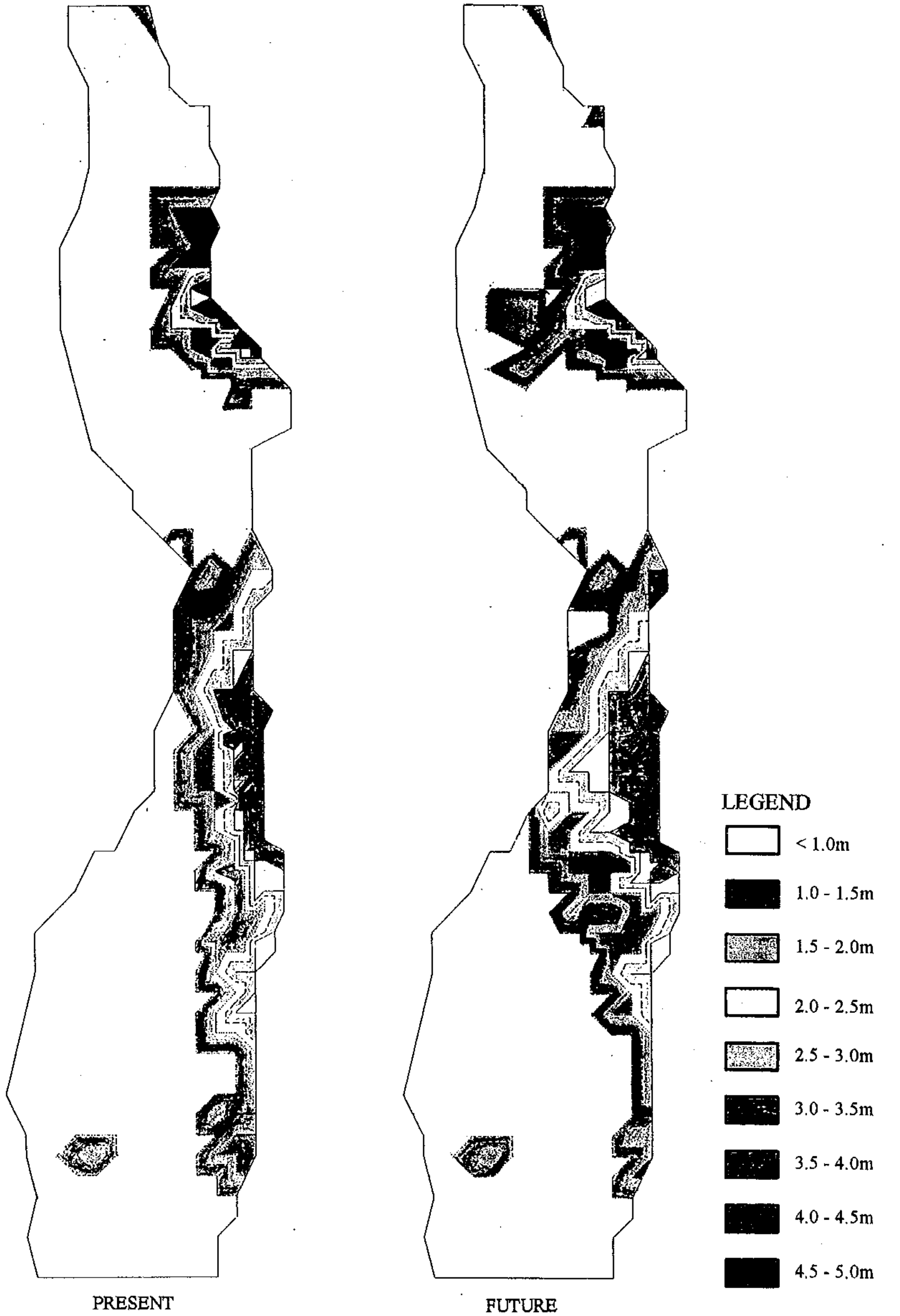


Fig. I.4.6 Simulated Drawdown on April Compared With October

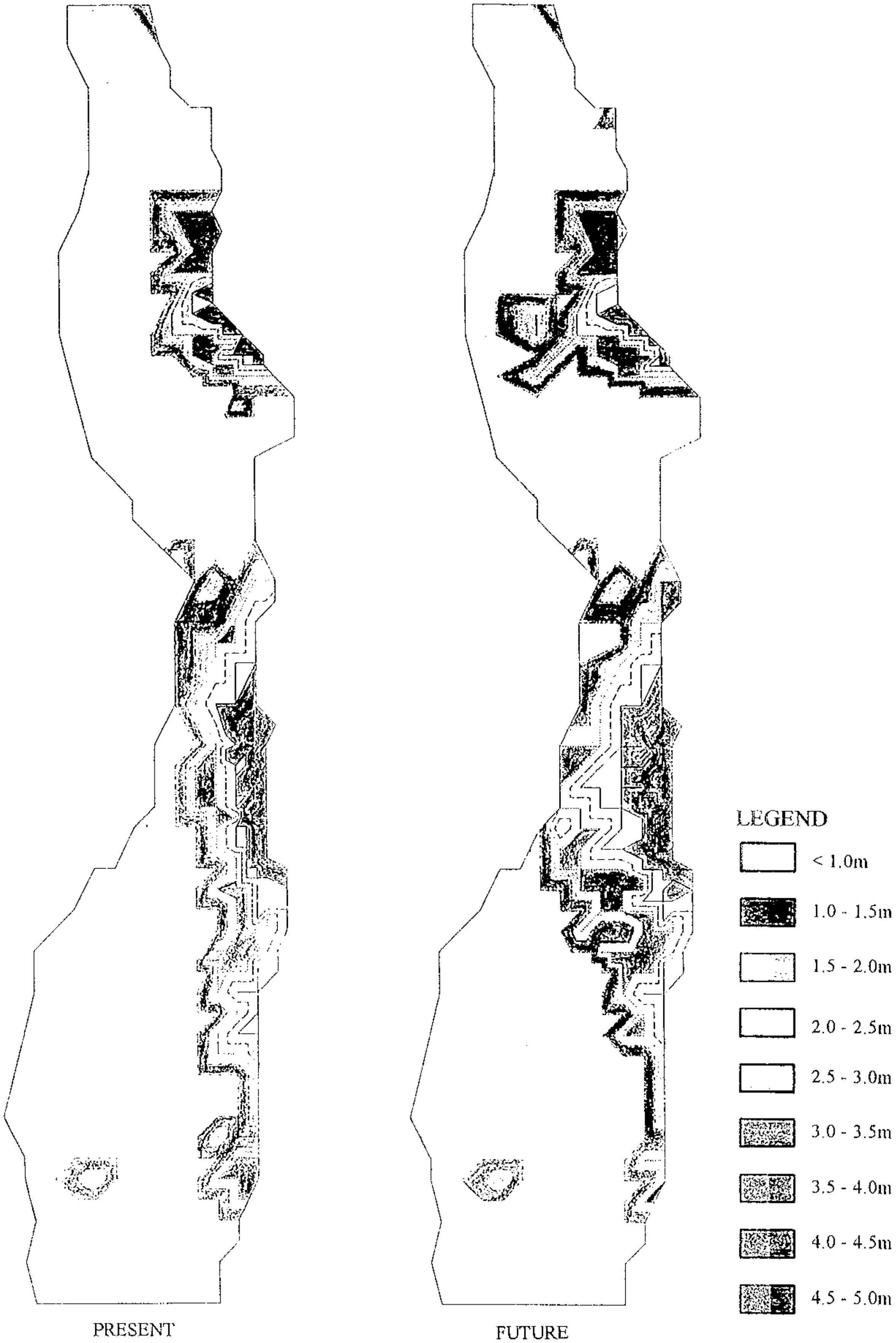


Fig. I.4.6	Simulated Drawdown on April Compared With October
JICA	The Study on Water Supply System in Ulaanbaatar and Surroundings

II METEOROLOGY AND HYDROLOGY

CHAPTER 1 INTRODUCTION

CHAPTER 1. INTRODUCTION

1.1 OBJECTIVES OF THE STUDY

It is one of the Study objectives to prepare a water supply master plan for Ulaanbaatar City with a target year of 2010 exploring mainly groundwater resources available in and around the city area. A groundwater simulation model will be established to examine the groundwater potential in the respective water source areas available for supply municipal water of Ulaanbaatar City. It is also considered important to clarify the overall meteo-hydrological conditions in and around the study area, and to provide hydrological values for the further study and planning of the water resources development in the area.

1.2 SUMMARY OF THE STUDY

The meteo-hydrological study and analysis are conducted generally in the following aspects.

- Collection and review of the meteo-hydrological data recorded in and around the study area such as precipitation, temperature, humidity, wind, evaporation and river discharge.
- Meteo-hydrological observation such as rainfall and river discharge: three (3) sets of automatic rain gauge and three (3) water level staff gauges are installed in the area.
- River discharge measurement in Tuul River at the locations of the installed water level staff gauges.
- Preparation of simple data base on the collected meteo-hydrological records as well as on the observed rainfall and river discharge records.
- Study and analysis on the collected and observed hydrological and meteorological data.
- Probability analysis on maximum and minimum precipitation as well as river discharge to facilitate preparation of water resources development plan.
- Water balance study to grasp the available water for utilization.

The results of the above mentioned study and analysis are discussed in the succeeding sections.

CHAPTER 2 DATA COLLECTION

CHAPTER 2. DATA COLLECTION

2.1 LOCATION OF METEO-HYDROLOGICAL OBSERVATION STATIONS

2.1.1 Meteorological Stations

There exist eight (8) meteorological stations under operation in and around the area, and various meteorological parameters are observed as shown in Table II.2.1. Three (3)-hour observation is conducted in Ulaanbaatar, Tahilt, Terelj and Ih Surguuli stations, while the observation is made three (3) times a day in Batsumber, Altanbulag, Erdene and Mungunmorit stations according to Water Policy Institute of Ministry of Natural Environment which is responsible for collecting, processing and distributing meteorological and hydrological data.

In Ulaanbaatar station, the meteorological observation has been conducted over 50 years since 1936, and valuable data are accumulated. The parameters such as temperature, rainfall, humidity, air pressure, wind and sunshine hours are being observed in this station. The other stations were established after 1970s.

The locations of the above meteorological stations are indicated in Fig. II.2.1.

2.1.2 Hydrological Stations

As shown in Table 2.1, six (6) hydrological stations are available in and around Upper Tuul River Basin, and river water level and discharge are observed in these stations. Out of these stations, two (2) stations are available for obtaining river discharge records of Tuul River; Ulaanbaatar (Zaisan Bridge) and Ondershireet Stations. In Bosgin Station, only river water level is observed. The continuous daily observation is being conducted in Terelj Station also.

The locations of the above hydrological stations are presented in Fig. II.2.1.

2.2 DATA AVAILABILITY

The availability of existing meteorological and hydrological data and the collected data are explained below.

2.2.1 Meteorological Data

(1) Precipitation

The precipitation including both rainfall and snowfall have been observed daily since the meteorological stations were established. Daily precipitation records after 1972 to date are collected for Ulaanbaatar, Terelj, Tahilt and Ih Surguuli Stations, and monthly records before 1971 are collected for Ulaanbaatar Station. The monthly precipitation records for Batsumber, Altanbulag, Erdene and Mungunmorit stations are also collected, but the continuous data are not available in these stations. The data of these stations will be used for further studies only as the reference. Snowfall data were not collected, because its volume is not considered so heavy as it affects the study results to substantial extent though it lies throughout a winter season due to cold weather.

(2) Temperature

The mean monthly maximum and minimum temperature records after 1972 are collected for eight (8) stations.

(3) Humidity

Mean monthly humidity records after 1972 are collected for Ulaanbaatar, Terelj, Tahilt and Ih Surguuli Stations.

(4) Wind Velocity and Direction

Average of monthly wind velocity and direction observed in Ulaanbaatar and Terelj Stations are collected.

(5) Evaporation

As for evaporation, there is no station observing it except Tahilt Station where some intermittent records are available for the period from May to September only. It is, however, considered that such data available in this station contains lack of records and give rather larger values than ordinary ones. Then, the evaporation data estimated for Ulaanbaatar and Terelj stations by Water Policy Institute based on the other meteorological parameters such as temperature, humidity and wind velocity are provided for the convenience of further studies.

The parameters and periods of meteorological data which are collected for each station are illustrated in Fig. II.2.2.

2.2.2 Hydrological Data

The daily mean discharge observed in Ulaanbaatar and Terelj Stations over 20-years period from 1972 to date are collected. Since Ulaanbaatar Station which was established in 1946 provides continuous data without lacking, the monthly mean discharge before 1971 are also collected for this station. The kind and period of the collected data are indicated in Fig. II.2.2.

CHAPTER 3 RAINFALL AND RIVER DISCHARGE OBSERVATION

CHAPTER 3. RAINFALL AND RIVER DISCHARGE OBSERVATION

3.1 RAINFALL OBSERVATION

3.1.1 Location and Observation Period

(1) Location

There exist eight (8) rainfall gauging stations in and around Upper Tuul River Basin; Ulaanbaatar, Terelj, Tahilt, Ih Surguuli, Batsumber, Altanbulag, Erdene and Mungunmorit Stations. During the field survey period, three (3) sets of rainfall gauging equipment are installed in the basin in order to grasp the rainfall distribution in the basin as stated below.

- Two (2) for the existing stations of Tahilt and Terelj where the existing equipment are considered old and inconvenient in observation.
- One (1) for new gauging station in Selbe where the establishment of a new meteorological station is scheduled for the near future.

In determining these locations, a series of discussions is held among the Mongolian officials concerned including counterparts, and the following items are considered.

- The site should be located in open space where the air current is uniform.
- Neither flood nor water stagnation occur.
- The site should be located in the area convenient for the observation staff.

Approximate altitude of the sites where the gauging equipment is installed are shown below.

Site of Installation	Approximate Altitude (m)
Terelj Station	1,540
Tahilt Station	1,300
Selbe Station	1,500

The locations of the above sites are presented in Fig. II.3.1.

(2) Period of Observation

All the equipment was installed in each respective site in September 1993, and rainfall data were recorded until the beginning of winter season. The equipment was once not installed and kept in the store during the winter season, because it does not meet the observation under cold weather according to the attached manuals. After the winter season, the equipment was installed again, and the recording was commenced. The period of data obtained is presented in bar chart form in Fig. II.3.2 together with that for river discharge observation.

(3) Manner of Observation

The operation and maintenance of the installed rainfall gauging equipment were conducted by Town Planning Department of Ulaanbaatar City Municipality in cooperation with Meteorological Institute of Ministry of Nature and Environment. The recorded data were collected in the Second Phase of the Study, and examined and processed for the study.

When the equipment is installed, the operation guidelines are explained and instructed the observation staff at the site. Since the equipment is auto-recording type, the recording paper was replaced every three (3) months by the staff of the Town Planning Department according to the instructions provided at the time of installation.

3.1.2 Results of Observation

(1) Recorded Rainfall

The rainfall recording has been conducted since the middle of September 1993, and the recorded data are processed in the daily rainfall as shown in Data Book. Table II.3.1 shows the monthly and the monthly maximum and minimum rainfalls. The complete monthly data are obtained in the period from June to September 1994 and from June to August 1994 for Terelj and Selbe Stations and Tahilt Station, respectively. Comparing with the other rainfall data, only a little rainfall is observed during the period when a month of data period is broken or the recording was not conducted as seen in Table II.3.1. The maximum daily rainfall is recorded in August in all the site of recording, and the daily maximum rainfall reaches 41.0mm in Terelj. The rainfall patterns are considered similar to each other among the recording stations as shown in Fig. II.3.3.

(2) Relationship between Gauging Stations

The monthly rainfall of the recording stations are compared with that of Ulaanbaatar Station using those recorded from May to August 1994 as shown in Fig. II.3.4. The linear regression is calculated and the following relationship is obtained.

- Ulaanbaatar vs Selbe $R_{Selbe} = 1.282 \times R_{Ulaanbaatar}$
- Ulaanbaatar vs Terelj $R_{Terelj} = 1.131 \times R_{Ulaanbaatar}$
- Ulaanbaatar vs Tahilt $R_{Tahilt} = 0.9116 \times R_{Ulaanbaatar}$

where; R_{Selbe} :Monthly Rainfall of Selbe Station (mm)
$R_{Ulaanbaatar}$:Monthly Rainfall of Ulaanbaatar Station (mm)

R_{Terelj}	:Monthly Rainfall of Terelj Station (mm)
R_{Tahilt}	:Monthly Rainfall of Tahilt Station (mm)

3.2 RIVER DISCHARGE OBSERVATION

3.2.1 Location and Observation Period

There are two (2) river discharge observation stations in Upper Tuul River Basin; Terelj and Ulaanbaatar (Zaisan Bridge) Stations. During the field survey period, three (3) river discharge observation stations were established at Bosgin, Gachuurt and Tavantolgoi in Tuul River in order to grasp the discharges in various points of Tuul River, and to confirm the discharge records having been observed so far.

(1) Location of the Established Observation Station

The observation sites were selected so as to satisfy the following conditions.

- The river flow should be uniform at the observation site.
- It is possible to observe the discharge safely during flood time.
- Drought discharge is able to be measured.
- Observation staff who is measure the water levels daily is available near the site.
- The site should be accessed easily even during the flood.

The locations of such observation sites are indicated in Fig. II.3.1, and their catchment areas and approximate altitudes are summarized below.

Station	Catchment Area (km^2)	Approximate Altitude (m)
Bosgin Station	2,158	1,508
Gachuurt Station	5,397	1,340
Tavantolgoi Station	7,312	1,220

Since the flow of Tuul River is frozen during winter and the gauging staff may damaged, the iron stakes are used for measuring river water levels especially low water level. After the installation of gauging staff and iron stakes, cross-sectional survey is conducted at the site of station to calculate flow area of the respective flow discharges.

(2) Period of Observation

The observation stations were established in September 1993, and since then daily data have been recorded as shown in Fig. II.3.2. In Bosgin Station, the water discharge measurement was not able to be conducted during the winter season because it was considered quite difficult to access the site due to cold climate.

(3) Manner of Observation

The established observation stations were well operated and maintained by Town Planning Department of Ulaanbaatar City Municipality in cooperation with Institute of Hydrology of Ministry of Nature and Environment. The results of observation were collected when the Second Phase of the Study is commenced, and were assessed and processed for the further studies.

An observer was assigned for each station among the villagers staying near the station, and all the necessary observation tools are provided in accordance with the ordinary ways of the Institute of Hydrology. The assigned observer should submit the record book to the staff of the institute who periodically visits the site for maintenance inspection and/or discharge measurement. The recorded data were assessed and processed by the staff of the institute with the rating curves for the respective stations. The rating curves were calibrated based on the results of discharge measurements periodically conducted by the staff of the institute.

3.2.2 Results of Observation

(1) Discharge Measurement and Rating Curve

Flow velocity is measured with an electro-magnetic (EM) current meter to prepare the proper rating curves for the respective gauging stations. The measurement is conducted at the site of gauging station. In order to obtain rating curves as accurately as possible, these flow velocity measurements were conducted periodically covering various ranges of discharges.

Almost 30 times of discharge measurements were carried out throughout a year from September 1993 to November 1994 as presented in Table II.3.2. More than ten (10) times of measurements were carried out covering the range from winter discharge less than one (1) m^3/s to flood discharges exceeding $100m^3/s$. The number and coverage of the measurement having been conducted are, therefore, considered sufficient for preparing the proper rating curves for each station except for Bosgin Station for which only three (3) times of discharge measurements were able to be conducted due to cold climate during the winter season and its remote location.

Based on the above measurement results, the rating curves are established as presented in Fig. II.3.5. The high flood portion of the rating curve is drawn estimating the discharge based on the surveyed cross-section and roughness coefficients thereof. As for the rating curve for Bosgin Station, it is proposed to conduct more measurements to prepare the proper rating curve for it, since three (3) times of measurements are considered insufficient for so doing.

(2) Recorded Discharge

The river discharge observation was commenced on 10 and 14 September, and 1 October, 1993, for Tavantolgoi, Gachuurt and Bosgin Stations, respectively, and has been continued to date as per Data Book. The discharge of the winter season is estimated applying the discharges measured at site periodically, because such discharge that flows between ices in the winter season are not able to be measured by reading the staff gauge.

The monthly mean discharge of each station is tabulated below together with that of Ulaanbaatar (Zaisan Bridge) Station, based on the daily records having been collected so far.

(m^3/s)

Station	1993				1994								
	Sep.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	[redacted]			Sep.
Bosgin	-	8.1	4.9	-	0.0	0.0	0.0	-	17.9	-	-	170.7	119.9
	-	*3.8*	*2.3*	-	*0.0*	*0.0*	*0.0*	-	*8.3*	-	-	*79.1*	*55.6*
Gachuurt	79.9	22.3	7.5	0.6	0.3	0.3	0.9	2.9	3.2	21.4	80.8	212.6	155.4
	14.8	*4.1*	*1.4*	*0.1*	*0.1*	*0.1*	*0.2*	*0.5*	*0.6*	*4.0*	*15.0*	*39.4*	*28.8*
Tavantolgoi	210.5	47.0	18.6	3.7	1.3	2.2	3.4	5.3	9.8	42.0	81.6	410.3	266.6
	20.2	*6.4*	*2.5*	*0.5*	*0.2*	*0.3*	*0.5*	*0.7*	*1.3*	*5.8*	*11.2*	*56.1*	*36.5*
Ulaanbaatar	129.4	24.0	4.6	0.3	0.0	0.0	0.3	6.4	9.0	32.8	88.7	307.4	245.5
	20.5	*3.8*	*0.7*	*0.1*	*0.0*	*0.0*	*0.1*	*1.0*	*1.4*	*5.2*	*14.1*	*48.8*	*39.0*

Note: The figures in lower rows expressed in *Italic characters* are specific discharges ($l/s/km^2$).

Monthly maximum, mean and minimum discharges of each station are summarized in Table II.3.1, and their variation throughout a year is illustrated in Fig. II.3.6.

The river flow stopped at the middle of December 1993 due to freezing, and started at the end of March 1994 as snow melting started. The discharge of river flow is gradually increased in June and July it is reaching the peaks over $100m^3/s$. In August when the maximum rainfall was recorded, the flood discharges were also recorded. In this observation period, the maximum discharge of $419m^3/s$ and $681m^3/s$ were observed in August for Gachuurt and Tavantolgoi Stations, respectively. The discharge is decreased in September, October and in December the flow is stopped by freezing.

(3) Variation of Discharge along Tuul River

The monthly mean discharges of Gachuurt, Ulaanbaatar and Tavantolgoi Stations are compared each other as shown in Fig. II.3.4. As shown in the figure, the linear regression is calculated and nice results are obtained in the relation of the Ulaanbaatar and Gachuurt Stations and Ulaanbaatar and Tavantolgoi Stations with the following equations.

- Ulaanbaatar vs Gachuurt $D_{Gachuurt} = 0.6809 \times D_{Ulaanbaatar}$
- Ulaanbaatar vs Tavantolgoi $D_{Tavantolgoi} = 1.2256 \times D_{Ulaanbaatar}$

where; $D_{Gachuurt}$:Monthly mean discharge of Gachuurt Station (m^3/s)

$D_{Ulaanbaatar}$:Monthly mean discharge of Ulaanbaatar Station (m^3/s)

$D_{Tavantolgoi}$:Monthly mean discharge of Tavantolgoi Station (m^3/s)

It is, however, considered that the above calculated difference of discharge is rather large comparing with the difference of their catchment areas as shown in the following table.

Station	Catchment Area (km^2)	Ratio of Catchment Area (Ulaanbaatar = 1.0)	Calculated Coefficient of Discharge Variation (Ulaanbaatar = 1.0)
Gachuurt Station	5,397	0.86	0.68
Ulaanbaatar Station	6,300	1.00	1.00
Tavantolgoi Station	7,312	1.16	1.23

CHAPTER 4 METEOROLOGY

CHAPTER 4. METEOROLOGY

The climate of Mongolia is determined by the geographical location, geomorphology and altitude above sea level, and varies widely from desert in southern part called Gobi to Subarctic along the boundary with Russian territory. Upper Tuul River Basin is located in the steppe zone which lays west to east along the country's territory.

The meteorological characteristics of Upper Tuul River Basin is characterized by the rainy season from June to August, of which rainfall shares about 74% of the annual rainfall. The average annual rainfall of Ulaanbaatar and Terelj stations are calculated to be 243.1mm and 402.5mm. The rainfall in the other months is less than 50mm. The average temperature in the basin varies from the minimum of -2.1°C in January to the maximum of 16.7°C in August in Ulaanbaatar Station. The average annual temperature is calculated to be -2.1°C, while in Terelj -3.8°C. The humidity is high in winter, but low in rainy season of summer. The annual average humidity is calculated to be 69% and 79% in Ulaanbaatar and Terelj stations. The climate in Ulaanbaatar, Terelj, Tahilt and Ih Surguuli stations is illustrated in Fig. II.4.1, and summarized in Table II.4.1.

The details of each meteorological parameter are discussed below.

4.1 PRECIPITATION

Based on the collected precipitation data, the seasonal variation of precipitation is calculated for each station as tabulated below and illustrated in Fig. II.4.2.

	Mean Monthly Precipitation (Unit: mm)												
Station	Jan.	Feb.	Mar.	Apr.	May	[redacted]			Sep.	Oct.	Nov.	Dec.	Total
Ulaanbaatar	1.4	1.9	2.4	7.7	14.4	48.8	69.5	57.0	27.6	6.5	3.8	2.1	243.1
Terelj	1.1	2.8	3.9	11.6	17.6	70.8	122.2	106.5	46.3	9.7	6.9	3.2	402.5
Tahilt	2.1	2.0	3.7	7.6	12.5	53.3	66.6	81.9	27.5	8.9	4.7	3.0	273.8
Ih Surguuli	1.8	2.1	2.6	8.1	10.3	54.5	79.8	83.9	35.4	10.7	4.4	1.9	295.5

The annual precipitation varies from 243.1mm to 402.5mm depending upon the altitude of station sites as shown in the following table. The annual precipitation seems to reach more than 500mm in the mountainous areas in the upstream of Tuul River, where the altitude exceeds 2,000m.

Station	Altitude (m)	Annual Precipitation (mm)
Terelj	1540	402.5
Ih Surguuli	1300	295.5
Tahilt	1300	273.8
Ulaanbaatar	1266.5	243.1
Mungunmorit	1000	221.9
Batsumber	1200	217.6
Erdene	1550	159.3
Altanbulag	1210	104.8

As tabulated below, about 74% of precipitation concentrates into rainy season from June to August in average.

Station	Annual Precipitation	Precipitation in Rainy Season from June to August	Percent to Annual Precipitation
Ulaanbaatar	243.1mm	175.3mm	72%
Terelj	402.5mm	299.5mm	74%
Tahilt	273.8mm	201.8mm	74%
Ih Surguuli	295.5mm	218.2mm	74%
Average	-	-	74%

4.2 TEMPERATURE

Monthly mean, maximum and minimum temperature records are collected as presented in Table II.4.2, and those annual mean, maximum and minimum values are tabulated below.

(Unit: °C)

Station	Average Temperature			Maximum Temperature			Minimum Temperature		
	Mean	Max.	Min.	Mean	Max.	Min.	Mean	Max.	Min.
Ulaanbaatar	-2.1	16.7	-24.2	15.5	30.8	-6.5	-18.1	2.9	-37.8
Terelj	-3.8	13.1	-24.1	14.0	27.8	-6.8	-20.8	-0.2	-39.2
Tahilt	-0.8	17.0	-21.5	15.3	30.8	-7.2	-14.5	5.6	-33.4
Ih Surguuli	-1.0	16.3	-20.9	15.1	30.7	-6.8	-14.7	3.9	-31.9

The annual average temperature is in the range from -3.8°C in Terelj to -0.8°C in Tahilt. The average temperature widely changes throughout a year from the minimum of about -24°C in January to the maximum of about 16°C in August. The absolute maximum temperature is as high as 15°C in low land such as Ulaanbaatar, Tahilt and Ih Surguuli, while that for Terelj in mountainous area reaches only about 13°C. The absolute minimum temperature in January reaches lower than -30°C, and in Terelj it becomes about -39°C. In Ulaanbaatar the absolute minimum reaches about -38°C though it is located in low land. It is considered to be caused by its site condition, suggesting that the temperature may be different from place to place depending on its site condition such as topography, altitude, wind, etc. The average temperature in each station are illustrated in Fig. II.4.2.

4.3 OTHER PARAMETERS

4.3.1 Humidity

The monthly mean humidity records are collected and the following table shows those average values of each meteorological station in and around the basin.

Station	Average Monthly Humidity (%)												
	Jan.	Feb.	Mar.	Apr.	May	[redacted]			Sep.	Oct.	Nov.	Dec.	Ave.
Ulaanbaatar	81	78	67	54	50	59	68	70	68	69	78	83	69
Terelj	91	83	81	68	64	71	80	76	79	78	85	91	79
Tahilt	79	74	63	52	48	57	63	67	63	63	73	79	65
Ih Surguuli	79	74	62	52	48	59	67	71	66	65	73	79	66

The average humidity is within a range between 65% to 69% in low land while that in mountainous area is 79%, about 10% wetter. The humidity reaches its minimum of about 50% in May and increase to the maximum of about 80% in December in low land. Those in mountainous area are 91% for the maximum in December and 64% for the minimum in May. The average values are illustrated in Fig. II.4.1 for each station together with the other parameters.

4.3.2 Wind

The average data for wind direction and velocity are collected for Ulaanbaatar and Terelj Stations. The records are illustrated in Fig. II.4.3 and Fig. II.4.4. These average data were calculated by Water Policy Institute based on the observed records from 1970 to 1992 for Ulaanbaatar Station and 1987 to 1992 for Terelj Station. The following table shows the summary of the wind records for both stations.

Station	N	NE	E	SE	S	SW	W	NW	Calm
Annual Mean Wind Direction Frequency (%)									
Ulaanbaatar	18.7	8.3	21.6	5.7	3.8	9.8	11.7	21.8	38.4
Terelj	26.3	1.7	3.8	5.2	5.0	11.7	32.6	13.8	63.5
Annual Mean Wind Velocity (m/sec)									
Ulaanbaatar	5.3	3.6	4.0	3.3	3.6	3.7	4.2	4.6	-
Terelj	4.2	2.3	2.3	2.7	2.6	3.3	4.2	4.0	-

In Ulaanbaatar station, the northwestern and eastern wind is prevailing throughout a year, though northern wind is also prevailing from April to August. In Terelj Station, western to northern wind is prevailing throughout a year, and about 70% of wind is considered western to northern ones in average. Terelj is considered calmer than Ulaanbaatar in terms of the recorded rate of calm days. The wind velocity is generally stronger in winter season than summer season, and Terelj is milder than Ulaanbaatar in this aspect.

4.3.3 Evaporation and Evapotranspiration

Monthly pan evaporation data are collected in Tahilt Station, but the collected data series is intermittent containing lacking. To supplement and confirm the observed data, the data estimated for Ulaanbaatar and Terelj Stations by Water Policy Institute were collected, but the method of estimate and the kind and data period of the applied parameters were not clear. The estimated data indicate that from November to February the evaporation becomes minimum as low as almost zero (0)%, and increase to the maximum of about 60% in Ulaanbaatar Station and 90% in Terelj Station. The maximum evaporation period lasts in September.

In addition, the evapotranspiration was estimated for Ulaanbaatar and Terelj Stations applying the other meteorological parameters such as relative humidity, temperature, etc. as shown in Table II.4.3. The Blaney-Criddle Method was employed for the calculation. The results of calculation are presented below.

	Evaporation Estimated by Water Policy Institute (mm)												
Station	Jan.	Feb.	Mar.	Apr.	May	[redacted]			Sep.	Oct.	Nov.	Dec.	Total
Ulaanbaatar	-0.8	1.8	21.7	75.5	95.5	86.3	87.5	96.1	89.8	41.2	3.3	0.5	598.0
Terelj	-1.1	1.3	18.0	52.5	59.2	57.6	43.1	45.7	60.2	44.2	2.6	0.3	383.8

	Evapotranspiration Estimated by Blaney Criddle Method (mm)												
Station	Jan.	Feb.	Mar.	Apr.	May	[redacted]			Sep.	Oct.	Nov.	Dec.	Total
Ulaanbaatar	0.0	0.0	23.3	49.5	116.3	184.5	193.0	162.8	101.3	27.9	9.0	0.0	866.6
Terelj	0.0	3.6	14.1	31.2	82.6	103.4	120.9	102.8	78.0	32.2	5.9	0.0	574.7