THE PROJECT FOR DEVELOPMENT OF NEW WATER SOURCES FOR DAMASCUS CITY
TECHNICAL NOTE ON HYDROGEOLOGY

1. HYDROGEOLOGICAL SETTING OF THE PROJECT AREA

The Project areas of Maadar II, Yaboos, and Dier Al Ashayer sites are located in the west of Damascus, at around 24 to 36 km far apart. All of them are very close to the border with Lebanon. Among the tree sites, the Maadar II site locates on the western slope of the Massayat Mountain Ranges which is far western mountain ranges between two ranges running parallel with the Anti-Lebanon Mountain Ranges on its western side. Farther western side of the site is already "Bekaa Highland" in Lebanon. The Yaboos site is in the just opening of the Maadar valley at the western exit of gorge which is separating the Chir Mannsour Mountain Ranges, another western parallel ranges to the Anti-Lebanon Mountain Ranges, and the Hermon Mountain Ranges. The Dier Al Ashayer site is situated in the south of the highway running along the gorge above mentioned, at the northern end of the Hermon Mountain Ranges.

Among the three target sites, the Yaboos and the Dier Al Ashayer sites are belonging to the "Barada Basin" which includes Damascus. While, the Maadar II site is included in the "Litani Basin" of Lebanon.

The Barada Basin is underlain by Limestones and Dolomites of Jurassic Age as an actual base rocks, overlaid by Cretaceous Limestones, Tertiary sediments (Conglomerates and Sandstones) and Quaternary deposits (See Fig. 1.1). Structural characteristics in the areas are NE-SW lineament in parallel with the Anti-Lebanon Mountain Ranges. Several mountain ranges and valleys in parallel each other formed a "Basin and Ridge Structure" as results of heavy geological activities such as folding and faulting along this lineament. The Barada cuts across the structures in SE direction, almost right angle to the lineament, excepting it uppermost stretch.

Passed through the Maadar valley, the Barada flows toward southeast involving the "Figeh Spring" around 20 km downstream and passes through Damascus after further 20 km downstream. Then, the river turns its direction to east and pours into the "Ateibeh Lake." The Ateibeh is an inland lake without outlet to the sea. Thus, the Barada is a crossed basin with the total length of 70 km and the catchment area of 2,359 km^2. Inland closed basin was formed based on the quite sensitive balance between inflow and outputs for long period. Now the balance is falling into crisis due to the heavy intakes of water, both surface and underground, not only for agriculture and water supply but for industrial use recently.

In the basin, there are numerous springs of various sizes (See Fig. 1.1). The Figeh and the Barada Springs are the largest among them overwhelmingly. Furthermore, in the west of the Anti-Lebanon Mountain Ranges, beneath the Maadar II site, there are two large and famous springs of "Anjar" and Chamsine" in Lebanese territory. These situations are caused by an exceptionally large precipitation in the Near East and highly karstic limestones/dolomites underlain. The limestones distributing widely in this area have very high infiltration ratio and innumerable sync-holes, karst caves, and water channels underground. Blessed rainfall are easily seepages into the ground through karstic limestones, passes through caves and/or channels and flows out to the ground again as springs everywhere in downstream. Once the Figeh Spring had huge spring yield more than enough to cover the water demand of Damascus and its vicinity. Such plenty of yield is, however, getting smaller and smaller recently and groundwater table in the basin is also declined drastically.

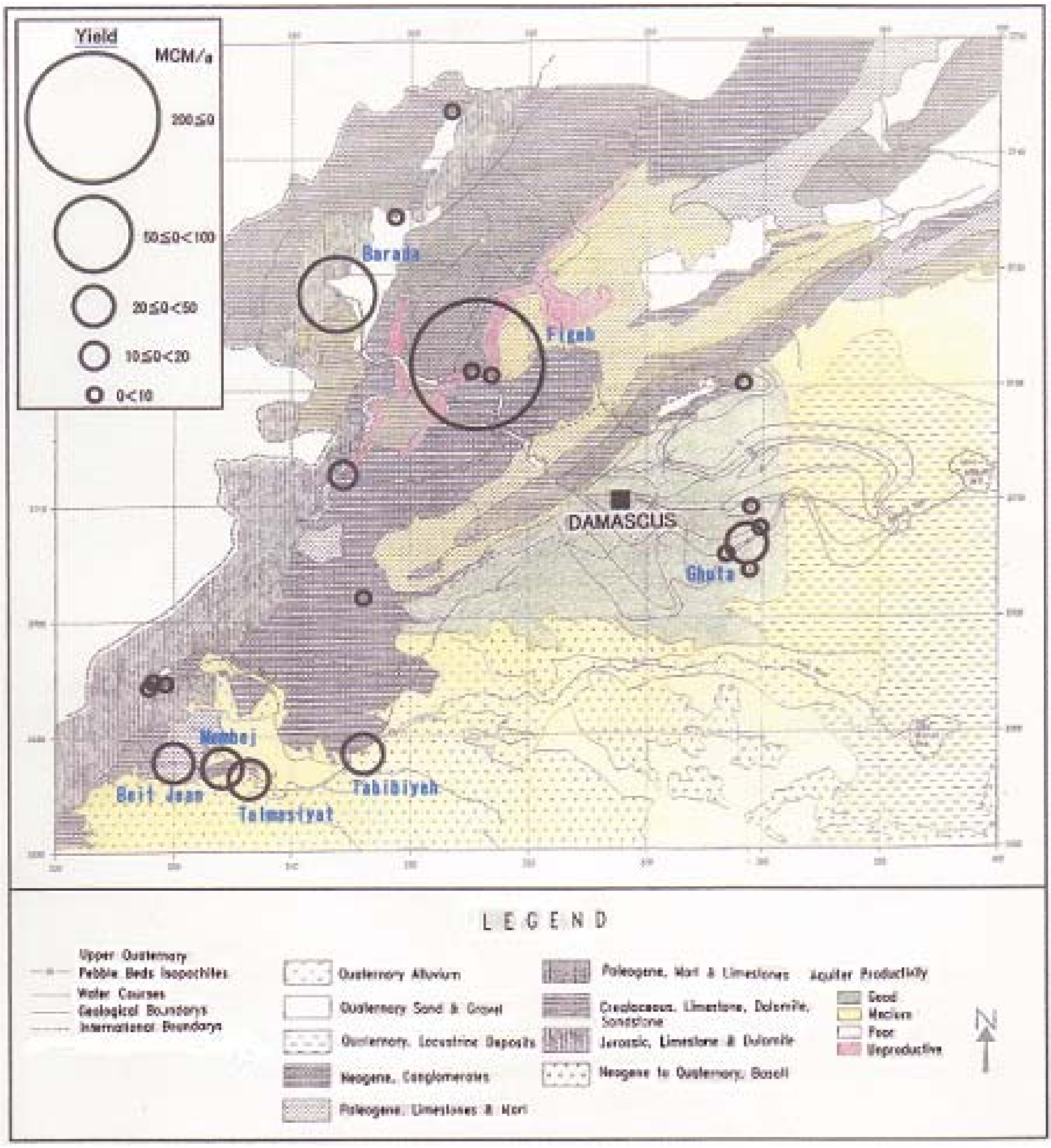


Figure 1.1 HYDRGEOLOGICAL MAP AND MAJOR SPRINGS

2. PUMPING TEST AND WATER QUALITY ANALYSIS (by the Team)

2-1. Outlines of the Tests

Two kinds of hydrogeological studies were conducted by the Study Team as a sub-contract work during the first field survey period, these were Pumping Tests and Water Quality Analyses in both Yaboos and Dier Al Ashayer sites.

Outlines and quantities of the tests are introduced below:

Pumping Tests

・Contents a. Preliminary pumping test
b. Step drawdown test
c. Constant discharge test, and
d. Recovery test

・Quantity Yaboos site 3 times
Dier Al Ashayer site 3 times

Water Quality Analyses

・Contents In-situ tests: Temp. EC, pH
Laboratory analysis: Ca, Mg, Na, K, HCO_3, SO_4, CO_3, Cl, NO_3, NO_2, NH_4, Color, Turbidity, Total Hardness, Total Dissolved Solid.
Hygiene test: Bacteria, Coliform group, Residual Chlorine
Potable water test: Zn, Fe, Cu, Mn, Taste, Odor.

・Quantity Yaboos site 3 samples

2.2. Results of Pumping Tests

(1) Location of the Tests

In Yaboos site, some wells drilled by MOI and transferred to DAWSSA were adopted as the test wells. Table 2.2.1 shows the mane of test wells, and Figure 2.2.1 shows the test wells situations.

Table 2.2.1 Test Wells（Yaboos Site）

Test No.	Pumping Well	Observation Well No.1	Distance (m)	Observation Well No.2	Distance (m)
No.1	No.7	M40	75.4	No.38	60.1
No.2	M40	No.7	75.4	No.38	98.6
No.3	M37	M14	82.6	-	-

(2) Procedures and Results

As shown in the table above, the pumping well was “No.7 well” and observation

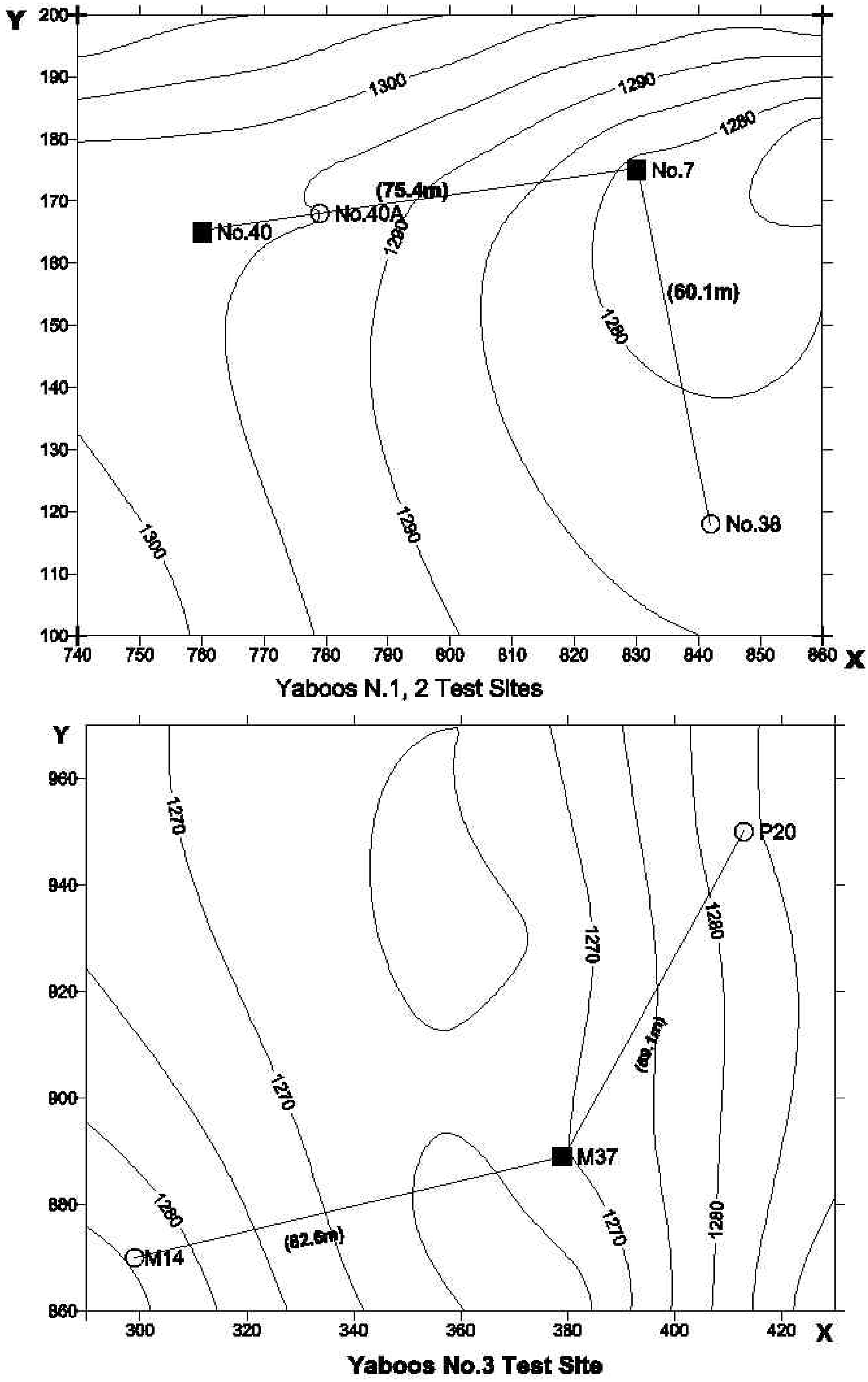


Fig.2.2.1　Situation of Test Wells（Yaboos Site）

well were “M40 well” and “No.38 well” in the first test. While in the second test, “M40 well” was used as the pumping well and both “No.7 well” and “No. 38 well” were applied as observation wells. In the case of the third test, “No.37 well” was selected as the pumping well. Originally “P10 well” was selected as the observation well but it was replaced by “M14 well” because the former was out of order.

Test No.1

The utmost cares were paid for a preliminary test in this site because it was the first test of all. Since the statistic water level of “No.7 well” was rather deep as around Gl-60 m, a test pump was set at the depth of Gl-160 m. After the setting of a large notch box for measuring a pumping rate and an accumulating flow meter for cross checking, and the assembling of all pipes and wires had been completed, the first preliminary pump was carefully run out. Run at rather small pumping rate at first to check the piping and the meter, then increased the rate gradually up to the full pumping rate of 61m^3/h. Based on the result that the dynamic water level was around Gl-70 m at the full pumping rate (61m^3/h), the pumping rates in the following Step Drawdown Test was decided as “35→50→60→55→45 m^3/h”.

After the water level in “No.7 well” has been recovered to the original level, the step drawdown test was conducted in the above mentioned pumping rates. However, the actual pumping rates were 37.2→51→61→54.5→45 m^3/h, and the pumping time keeping the each rate constant was 4 hours as a rule. As results, drawdown at each pumping rate was 6.28, 11.61, 15.06, 13.10, and 7.9m, respectively. Referred from the results of step drawdown test, the pumping rate for following constant discharge test was decided as around 40 m^3/h, which can be operated quite steadily and expected to cause around 7, 8 m of drawdown.

The recovery of water level in the pumping well was carefully checked again, and after it recovered to the static water level, the constant discharge test at the rate of 40 m^3/h had been conducted. Constant discharge was continued for 48 hours and water level at the pumping well and two observation wells were measured exactly. On the course of the test, an in-situ water quality test and water sampling were performed on the second day. Dynamic water levels after 48 hours pumping in the pumping well, “M40 well” and “No.38 well” were 7.65, 3.55, and 3.87m respectively.

Test No.2

In the second test, the pump was inserted at the deep depth of Gl-165 m as almost same with the first test. And as same with the previous test all pipes, notch, meter, and wires were carefully set out. Preliminary test was conducted by around 30 m^3/h and 61 m^3/h of pumping rates. Referred to the drawdown of around 25 m at the maximum pumping rate (61 m^3/h), the pumping steps of 30→50→60→45→35 m^3/h were decided for the following step drawdown test.

After checking the water level recovery, the step drawdown test was carried out. The actual pumping rates were 32→52→62→45→35 m^3/h, a continuous pumping rate at each step was 4 hours. Dynamic water level at each pumping rate was 8.1, 18.3, 27.45, 14.25, and 9.85 m, respectively.

Constant discharge test had been conducted after water level in the pumping well had been recovered. The pumping rate was 50 m^3/h in accordance with the results of step drawdown test. In-situ water quality test and water sampling had been done as same as the previous ones. Final drawdown after 48 hours discharge was 19.78, 3.70, and 4.54 m at "M40", "No.7 well" and "No.38 well" respectively.

<u>Test No.3</u>

The third test in Yaboos site was done at the wells along the trunk road to Lebanon, "No. 37 well" as a pumping well and "M14 well" as an observation well. Depth of the pump installation was around 160 m, and all pipe system and tools were same to the previous test. Results of the preliminary test indicated the drawdown was 25 ~ 25 m at the pumping rate of around 60 m^3/h, therefore, the pumping rates for step drawdown test were set as 25→45→60→50→40 m^3/h.

A step drawdown test was, then, carried out but the actual pumping steps were 24→45→60→50→37 m^3/h, and the drawdown at each step after 4 hours pumping was 7.42, 18.24, 28.01, 20.07, and 14.27m, respectively.

Pumping rate in the following constant discharge test was 60 m^3/h, referred to the step drawdown test results. In-situ water quality test and water sampling had been conducted in the same manner with the previous tests. Final drawdown at the pumping and observation wells was 27.13 and 3.78 m.

All of the pumping test results (observation records) are attached in the Appendix altogether.

2-3. Results of Water Quality Analyses

Results of water quality analyses are sown in the following table and the analysis charts are attached in the Appendix.

Table 2.3.1 Results of Water Quality Analises

		Yaboos			
Item	Unit	M37	No.7	M40	Ave.
A. In-situ test					
Temp.	°C	15.8	16.0	16.1	16.0
EC.	μS/cm	37.5	35.8	36.2	36.5
pH		7.46	7.76	7.71	7.6
B. Laboratory Test					
for potable water					
1 Turbidity	NTU	3.5	2.5	4	3.3
2 Colors	Deg.	n	n	n	n
3 Taste	TT	n	n	n	n
4 Odor	TON	n	n	n	n
5 Total Hard	mg/lit	21	24	22	22.3
6 T.D.S	ppm	235	260	235	243.3
7 Residue Cl	ppm	0	0	0	0.0
8 pH		7.7	7.5	7.7	7.6
chemical analysis					
9 Ca	mg/lit	72	80	80	77.3
10 Mg	mg/lit	7	10	5	7.3
11 Na	mg/lit	5	4	4	4.3
12 K	mg/lit	0.5	0.5	0.5	0.5
13 HCO3	mg/lit	232	268	224	241.3
14 CO3	mg/lit	0	0	0	0.0
15 SO4	mg/lit	16	14	18	16.0
16 Cl	mg/lit	8	8	6	7.3
17 NO3	mg/lit	7	6	7	6.7
18 NO2	mg/lit	0	0	0	0.0
19 NH4	mg/lit	0	0	0	0.0
heavy metal					
20 Zn	mg/ﾘｯﾄﾙ	n	n	n	n
21 Fe	mg/ﾘｯﾄﾙ	n	n	n	n
22 Cu	mg/ﾘｯﾄﾙ	n	n	n	n
23 Mn	mg/ﾘｯﾄﾙ	n	n	n	n
hygine item					
24 Coliform	pcs/100ml	100	200	500	266.7
25 Bacteria	pcs/100ml	2000	500	6000	2833.3

2-4. Examination on the Tests Results

2.4.1. Step Drawdown Test

Step drawdown test has important objectives to calculate a well efficiency, to estimate a specific yield, and to predict the optimal pump depth, beside to decide the pumping rate for constant discharge test. The latter was already explained in the previous sections for pumping test results, therefore, the former shall be explained hereafter.

Drawdown in the pumping well (shown as s) is usually larger than the drawdown outside of the casing (shown as s') because of several losses and interferes. Efficiency of Well (*We*) is explained as the ratio between the actually observed drawdown inside of the pumping well and theoretical drawdown outside of the well casing.

Generally, the drawdown (*s*) caused by pumping is:

$$s = aQ + BQ^n \cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots \quad (1)$$

where, a: aquifer-loss coefficient, B: well-loss coefficient,

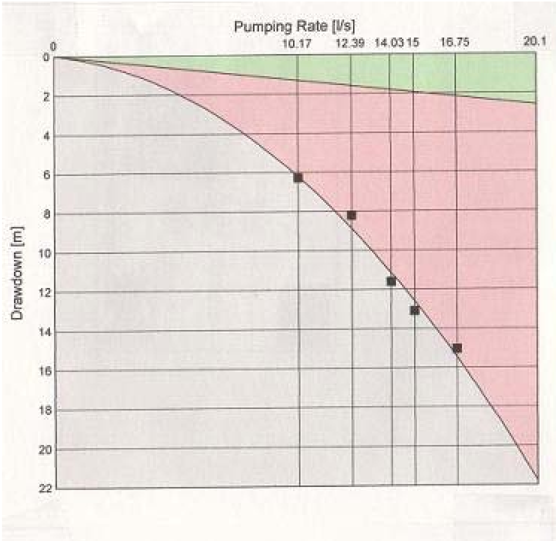
Q: pumping rate

Efficient of Well (*We*) is explained as follow:

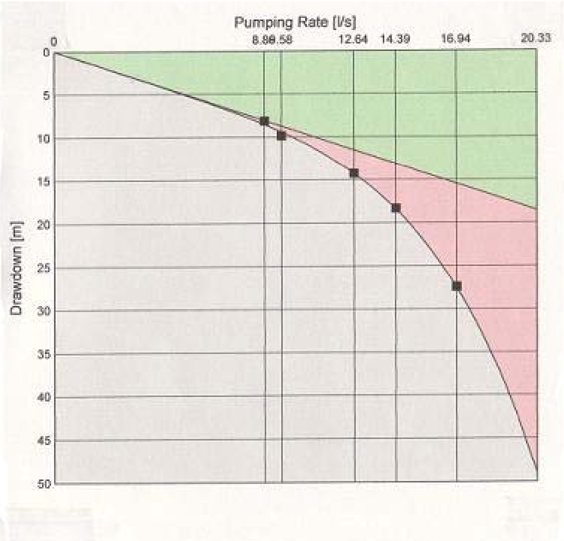
$$We = \frac{aQ}{aQ + BQ^n} \cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots \quad (2)$$

Thus, a, B, n, and consequently "Efficient of Well" can be calculated from the results of step drawdown test of more than three steps. Herein, "aQ" is called as "Aquifer loss" and "BQ^n" is called as "Well Loss". Results of the analysis on each test are shown in the Figure 2.4.1.(1)～(2).

As shown in the figures, the wells in Yaboos show generally low efficient, in particular "No.7" or "No.37 well" indicate as low as less than 35% of Efficient. However, the fact that the drawdown in these wells are still small even though their Efficient are very low suggests the actual specific yield should very large if the well could properly be completed.

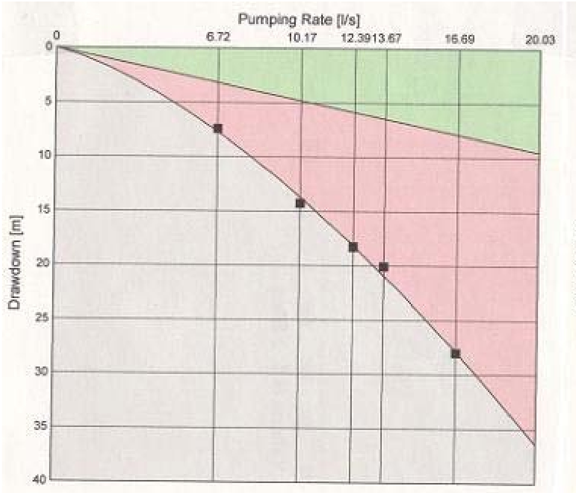


No.7	Yaboos		a=0.1288	B=0.04738	P=2.0	We=19.58%	
Pump Rate	ℓ/s	10.17	12.69	14.03	15.00	16.75	20.10
Drawdown	m	6.21	8.20	11.61	13.10	15.05	21.73
Aquifer Loss	m	1.31	1.60	1.81	1.93	2.16	2.59
Well Loss	m	4.90	7.27	9.33	10.06	13.29	19.40
Efficency	%	20.9	19.5	15.6	14.7	14.3	11.9



M40	Yaboos		a=0.9119	B=7.01e-6	P=5.07	We=79.56%	
Pump Rate	ℓ/s	8.86	9.58	12.64	14.39	16.94	20.33
Drawdown	m	8.10	9.89	14.25	18.30	27.45	48.94
Aquifer Loss	m	8.08	8.74	11.53	13.12	15.45	18.54
Well Loss	m	0.45	0.67	2.73	5.27	12.05	30.40
Efficency	%	99.7	88.7	80.9	71.7	56.3	37.9

Fig. 2.4.1. (1)　Analysis of Step Drawdown Test-1　"No.7well", "M40well"



No.37	Yaboos		a=0.4754	B=0.1996	P=1.64	We=34.37%	
Pump Rate	ℓ/s	6.72	10.17	12.39	13.67	16.69	20.03
Drawdown	m	7.24	14.27	18.24	20.07	28.01	36.40
Aquifer Loss	m	3.19	4.83	5.89	6.50	7.93	9.52
Well Loss	m	4.50	8.87	12.26	14.39	19.95	26.89
Efficancy	%	43.1	33.9	32.3	32.4	28.3	26.2

Fig. 2.4.1. (2) Analysis of Step Drawdown Test-2 "No.37 well"

2.4.2. Constant Discharge Test (include Recovery Test)

Through the constant discharge test, a series of Aquifer Constants such as Transmissivity *(T)*, Storativity *(S)*, Permeability *(k)*, or Leakance *(L)* is to be obtained. Since the aquifer in Limestone, like as the situations in Yaboos or Dier Al ashayer, is usually a confined aquifer, the results of constant discharge tests were analyzed through Theis, Hantush-Jacob, and Recovery Analysis. Then, these results were totally examined and finally the representative values were estimated referring the error designation. A typical analysis chart is shown in Figure 2.4.2.

Pumping Test

Well Ident	Description		
M14			
Obs. Well Distance [m]	Average Pump. Rate [m3/day]	Duration [min]	Initial Sat. Thickness [m]
82.60	16.66139	4020.000	

			Results
Transmissivity [m2/day]	Storage Coefficient	Leakance [1/day]	Estimation Error [m]
121.3881	0.0002168680	0.0004626043	0.14
Fit Method			Hantush Method

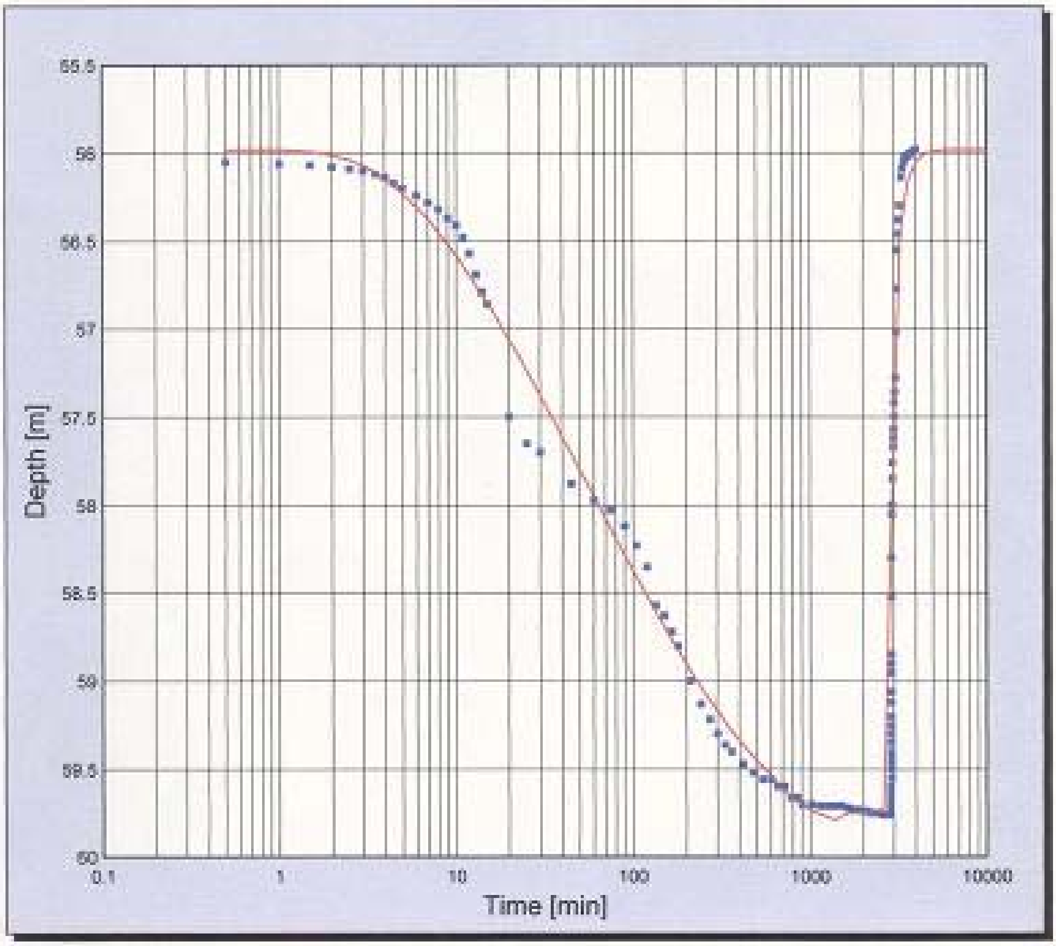


Fig. 2.4.2.　A Sample of Analysis Chart for Constant Discharge Test（M14）

Although every analysis chart has its result, the analysis results are shown in Table 2.4.1, altogether.

Table 2.4.1. Results of Constant Discharge Test

A. Yaboos Site

Test No.	Analyzed well Pump.	Analyzed well Observ.	Distance (or Dia.) m	Analysis	Discharge *Q*:(lit/sec)	Transmissivity *T*: (m2/day)	Storativity *S*: (−)	Permeability *k*: (cm/sec)	Aquifer thick. *d*:(m)	Leakance *L*:(1/day)
YBS−1	M37		(0.13)	Theis	16.66	72.456	−	1.40E−03	60	−
				Huntush		22.904	−	4.42E−04		8.756
				Recovery		67.770	−	1.31E−03		−
		M14	82.64	Theis		220.898	7.83E−04	4.26E−03		−
				Huntush		121.388	2.17E−04	2.34E−03		4.63E−04
				Recovery		229.292	−	4.42E−03		−
YBS−2	No.7		(0.13)	Theis	10.89	139.020	−	2.68E−03	60	−
				Huntush		113.172	−	2.18E−03		0.0999
				Recovery		139.120	−	2.68E−03		−
		M40	75.42	Theis		111.590	4.67E−04	2.15E−03		−
				Huntush		103.051	6.37E−04	1.99E−03		4.16E−18
				Recovery		128.513	−	2.48E−03		−
		No.38	60.08	Theis		85.722	6.74E−04	1.65E−03		−
				Huntush		73.952	8.23E−04	1.43E−03		1.87E−04
				Recovery		103.807	−	2.00E−03		−
YBS−3	M40		(0.13)	Theis	13.59	110.857	−	1.51E−03	85	−
				Huntush		51.605	−	7.03E−04		0.0287
				Recovery		96.039	−	1.31E−03		−
		No.7	75.42	Theis		137.493	4.82E−04	1.87E−03		−
				Huntush		140.746	4.40E−04	1.92E−03		7.77E−18
				Recovery		162.549	−	2.21E−03		−
		No.38	98.62	Theis		106.125	3.04E−04	1.45E−03		−
				Huntush		88.064	3.91E−04	1.20E−03		1.11E−04
				Recovery		127.808	−	1.74E−03		−
Representative Value						129.400	5.22E−04	2.21E−03		2.54E−04

As shown in the table, the aquifer in Yaboos site is surely confined aquifer from their Storativity and Leakance.

The thickness of aquifer and confining layer are not clear from existing well log, and if the aquifer thickness is assumed as 100 m, aquifer constants of these sites are estimated as follows:

Yaboos Site

Main Aquifer : Upper Jurassic, Callovian Stage (J3K) Limestone/Dolomite
Type of Aquifer : Confined Aquifer with Leakance (as m' = 100m)
Transmissivity : T = 130 m^2/day
Permeability : k = 1.3 m/day (1.50 x 10^{-3} cm/sec) (as m=100m)
Storativity : S = 5.22 x 10^{-4}
Leakance : L = 2.54 x 10^{-4} /day

2.4.3. Water Quality Analysis

Based on the analysis results, Tri-linear Diagram (or Piper Diagram) can be drawn as shown in Figure 2.4.3. In the figure, all of the water quality analysis results obtained from the sites and the figure obviously shows that the water qualities in the site are almost same.

Water quality type is so-called "Calcium Bicarbonate Type: $Ca(HCO_3)_2$"

which is quite common in the limestone area. Then, several heavy metals were analyzed for potable water items and the results showed no contamination of metal. Thus, the groundwater in these sites has no problem for physical and chemical properties. Problems are, however, in hygiene (or biochemical) properties. Both Coliform group and Common Bacteria were detected from almost all samples, and rather many samples were marked as “non potable”.

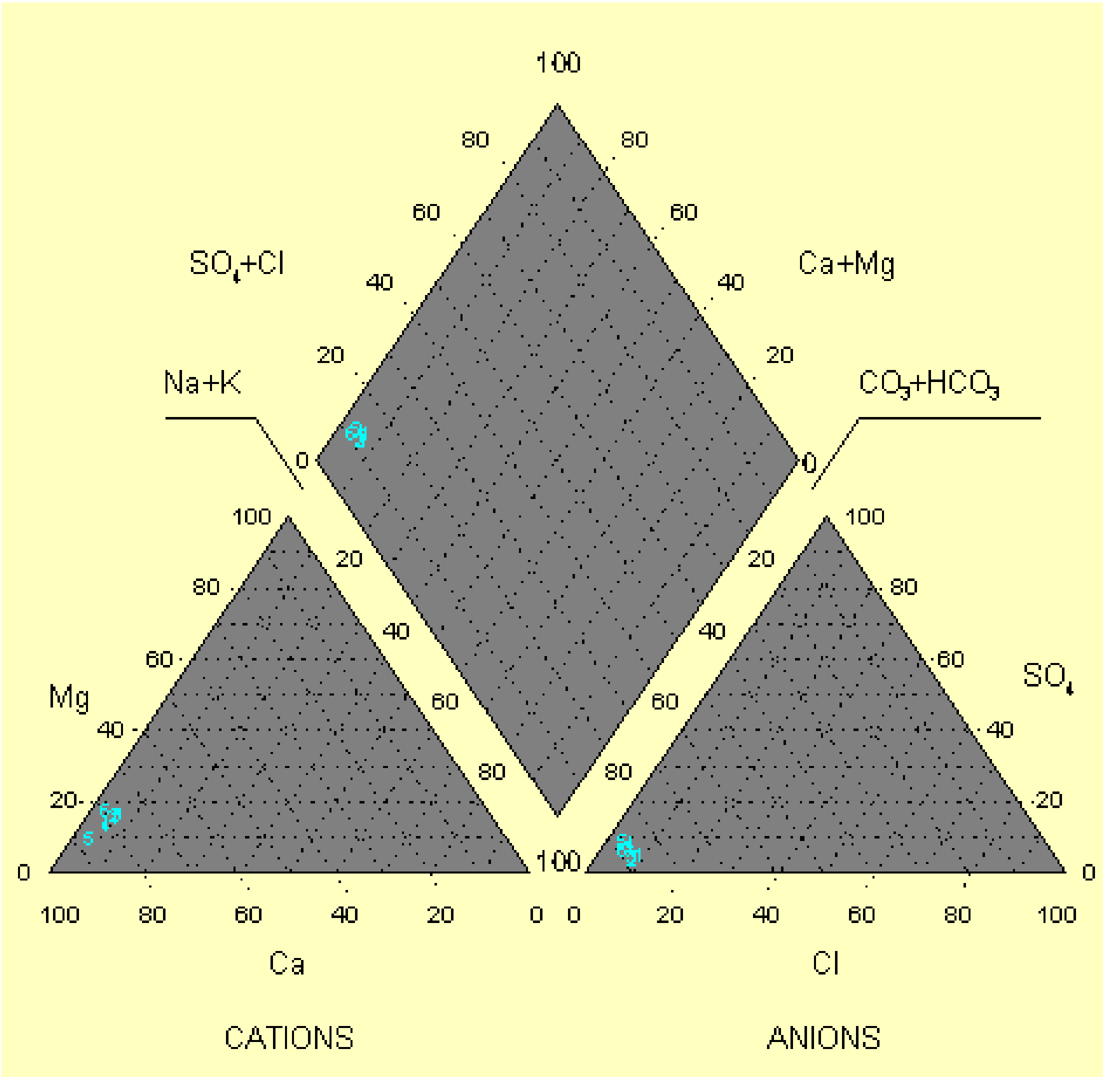


Fig. 2.4.3. Tri-linear Diagram (all samples)

3. PUMPING TEST BY DAWSSA

3.1. Outlines of the Tests

During the first and the second JICA Study Periods, DAWSSA could not complete the construction work of planned 25 production wells. Consequently, DAWSSA conducted pumping tests and water quality analyses immediately after the completion of drilling work of each well by himself, to examine the availability for a production well, to estimate the permissible pumping rate and dynamic water level when operated. Furthermore, DAWSSA is going to conduct group well pumping tests in the three sites after the completion of well construction to assess the environmental impact of full operation of well fields, also by him.

Pumping tests by DAWSSA were also conducted applying the specifications prepared by the Study Team for their own tests under a sub-contract work; consisted of a series of preliminary, step drawdown, constant discharge, and recovery tests. Water quality analyses were also carried out under the same specification prepared by the Team during the first field survey period, excepting the analyses of heavy metals.

Because the Project includes only the Yaboos site for its first phase, following explanations are just for the Yaboos site.

3.2. Results of Pumping Tests

In Yaboos site 11 production wells were planned out originally. Among the eleven wells completed at first, two wells (Ya10 and YA11) were found to have rather small yield, and therefore, another two wells (Ya12 and Ya13) were drilled additionally. All of the wells drilled were targets of the pumping tests. Results of these tests shall be described below.

3.2.1. Step drawdown test

In most of the wells, the steps of pumping rate were five including the rate of 50 m^3/h and higher and lower of it. Results of the tests are summarized in the Table 3.2.1. The test results were analyzed as same as the ones done by the Team before (refer to chapter 2.2) and shown in the Appendix.

In contrast with the results of previous tests carried out using the existed monitoring well of Ministry of Irrigation, the wells newly drilled by DAWSSA showed excellent situation of well indicating quite high well-efficiency, not all but mostly. However, some of the tests showed reverse trend on discharge-drawdown relation suggesting the shortage of pumping duration in each step.

Table 3.2.1 Summary of Step Drawdown Test (Yaboos)

Well	Items	1st	2nd	3rd	4th	5th	S.Yield*3	Efficiency*4
Ya1	Discharge*1	21.5	40	58	46.5	30.1	5.89	98.8
	Drawdown*2	3.65	6.85	9.95	8	5.15		
Ya2	Discharge*1	24.5	40.8	59	48.5	35.8	12.05	98.3
	Drawdown*2	2.05	3.3	4.85	4	2.9		
Ya3	Discharge*1	21.6	36.5	60.1	50.7	31.7	2.5	97.9
	Drawdown*2	8.8	13.7	23.5	20.1	12.2		
Ya4	Discharge*1	18	40	61	51	29	1.97	94
	Drawdown*2	8.81	20.85	31.72	25.75	14.59		
Ya5	Discharge*1	18.5	34	60	48	31	4.37	95.4
	Drawdown*2	4.15	7.55	13.7	11.05	7.45		
Ya6	Discharge*1	23	37.2	60.5	48.5	33	6.96	98.5
	Drawdown*2	3.35	5.1	8.55	6.9	4.6		
Ya7	Discharge*1	18	35.5	65	50.7	30.6	2.01	66.6
	Drawdown*2	8.6	16.75	36	26.15	13.85		
Ya8	Discharge*1	44	60.9	72			4.73	51.8
	Drawdown*2	8	13	17.8				
Ya9	Discharge*1	18	40.9	60	50.7	26	2.22	70.7
	Drawdown*2	7.5	19.6	33	22.65	11		
Ya10	Discharge*1	11.5	16.1	20	15.3	13.6	0.29	63.9
	Drawdown*2	36.7	53.4	76.65	54.5	44		
Ya11	Discharge*1	18.9	28	44.5	36	22.9	0.85	94.1
	Drawdown*2	22.3	32.3	52.4	45.4	25.85		
Ya12	Discharge*1							
	Drawdown*2							
Ya13	Discharge*1							
	Drawdown*2							

Unit: *1: m3/h, *2: m, *3: m3/h/m, *4: %

3.2.2. Constant discharge test, Recovery test

Results of the constant discharge and recovery tests were analyzed also as same as the tests done by the Team but sub-contract basis; using "GWW", a software prepared by the UNDP for their development project. Details of the analyses are attached in the Appendix and only the summary is shown in Table 3.2.2.

Table 3.2.2. Summary of Pumping Tests

Well Name	Depth (m)	S.W.L (m)	S.Yield* (m3/h/m)	D.Down** (m)	D.W.L** (m)	W.Effic.* (%)	*T* (m2/day)	*S* (-)	*L* (1/day)	*k* (m/day)
Ya1	397.1	97.0	5.84	8.56	105.56	99.4	108.49	0.000655	0.00346	1.085
Ya2	400	101.5	12.20	4.10	105.60	98.7	369.13	0.00158	3.44E-16	3.691
Ya3	400	93.2	2.56	19.52	112.72	98.0	63.49	0.000783	0.00288	0.635
Ya4	386	111.6	1.97	25.38	136.98	96.9	39.22	4.68E-05	0.00089	0.392
Ya5	400	99.3	4.37	11.44	110.74	97.4	156.95	0.000088	0.000637	1.570
Ya6	396.6	87.0	7.09	7.05	94.05	98.5	51.84	0.000257	0.00224	0.518
Ya7	400	90.7	2.03	24.60	115.30	79.1	191.68	0.000131	1.31E-11	1.917
Ya8	400	57.5	4.74	10.54	67.99	33.4				0.000
Ya9	400	107.0	2.18	22.90	129.90	70.7	38.56	0.000272	0.000704	0.386
Ya10	425	117.8	0.29	170.58	288.38	64.0	62.76	0.000259	0.000219	0.628
Ya11	450	127.7	0.85	58.93	186.63	96.7	92.03	0.000444	2.15E-19	0.920
Ya12	185	95.4	1.58	31.65	127.05	89.0				
Ya13	190	86.5	0.29	50.00	136.50	92.0				
Ave.	404.97	99.11	4.01	16.761	132.17	84.79	120.18	0.000468	0.000907	1.067

Note: *: from Step dd-test, **: at pumping of 50 m^3/h

3.3. Results of Water Quality Analysis

In all of the wells, DAWSSA took a water sample during its pumping test period and sent it to their laboratory for water quality analysis. The items of analysis were almost same with the specification prepared by the Team but the analysis of heavy metals. Results are attached in the Appendix altogether, and their summary is shown below.

Table 3.3.1. Summary of Water Quality Analysis by DAWSSA

Item	Unit	Ya1	Ya2	Ya3	Ya4	Ya5	Ya6	Ya7	Ya8	Ya9	Ya10	Ya11	Ya12	Ya13
Color	TCU		n	n			n	n		n	n	n		
Odd.			n	n			n	n		n	n	n		
Turbidity	NTU		2	30			8.5	70		65	25	55		
Temp.	°C		20	22			19	21		18	25	20		
EC	μs/cm		400	410			400	440		440	450	455		
pH			7.6	7.6			7.5	7.7		7.6	7.7	7.9		
Cl_2	mg/l													
$KMnO_4$	mg/l													
NO_3	mg/l		9	11			10	11		13	10	13		
NO_2	mg/l													
NH_4	mg/l													
CO_2	mg/l													
T.Hardness	mg/l		24	24			25	25		25	23	25		
TH Mg	mg/l		4	4			5	5		5	4	5		
THp			2	3			2	3		4	2	4		
TA	mg/l													
TAC	mg/l		22	21			23	22		21	21	21		
CO_2	mg/l													
HCO_3	mg/l		268	256			281	268		256	256	256		
CO_3	mg/l													
SO_4	mg/l		12	16			16	16		19	13	19		
Cl	mg/l		8	8			8	8		10	10	10		
NO_3	mg/l		9	11			10	11		13	10	13		
Ca	mg/l		80	80			80	80		80	76	80		
Mg	mg/l		10	10			12	12		12	10	12		
Na	mg/l		5	4			5	5		5	5	5		
K	mg/l		1	0.5			0.5	0.5		0.5	1	0.5		
Fe	mg/l													
TDS	mg/l		260	260			275	270		270	255	270		
Bacterium	/100ml		610	8000			8000	10000		10000	20000	30000		
Coliform	/100ml		10	3500			4000	5000		4000	10000	20000		

As shown in the Figure, the water quality type is so-called "Calcium Bicarbonate Type: $Ca(HCO_3)_2$" which is quite common in the limestone area. The groundwater in these sites has no problem for physical and chemical properties. Problems are, in this time also, in hygiene (or biochemical) properties. Both Coliform group and Common Bacteria were detected from most of the samples. Supposedly, it has come from the situation that some of old and incomplete wells constructed by the Ministry of Irrigation are still remained near the production wells drilled newly. These old wells must be buried and sealed completely.

4. GROUP WELL PUMPING ANALYSIS

4.1. Outlines

During the first field survey period the Study Team carried out a series of pumping tests in Yaboos site, using three sets of existing wells (pumping and observation wells) by sub-contract basis. The series of tests includes a step drawdown test with five steps, a constant discharge test for 48 hours with a recovery test consequently. Results of these tests were explained in the previous section (in Chapter 2). After that, DAWSSA also conducted by themselves a series of pumping tests and water quality analysis in every well they drilled, under almost same technical specifications ever prepared by the Study Team for his work.

Based on both pumping tests, done by the Study Team and DAWSSA, aquifer characteristics in Yaboos were figured out as shown below, several suppositions were included though:

Main aquifer:	Upper Jurassic (Callovian Stage) – j3k Limestone/Dolomites
Type of aquifer:	Confined aquifer with leakance
Transmissivity:	T = 120 m^2/day
Strativity:	S = 4.68 x 10^{-4}
Leakance:	L = 9.62 x 10^{-4} /day
Permeability:	k = 1.20 m/day (1.39 x 10^{-3} cm/sec)

In this chapter, an influence of sole well pumping is to be examined at first, then an environmental impact to the surrounding area by a full operation (group well pumping) shall be assessed through the drawdown of groundwater level finally.

4.2. Sole Well Pumping Analysis

In the case of confined aquifer with leakance, the drawdown *(s)* at a certain discharge can be calculated by "Hantush-Jacob's Equation" as shown below. (In the case of ideal aquifer having enough equally extended aquifer)

$$s = \frac{Q}{4\pi T} W\left(u, \frac{r}{B}\right) \quad \cdots\cdots\cdots\cdots\cdots\cdots\cdots \quad (1)$$

where, s :drawdown, Q :Discharge, T :Transmissivity, $W()$:Well function, r :distance from well, B :Leakage factor {1/B=$(L/T)^{1/2}$}, L: Leakance, u :as shown below.

$$u = \frac{Sr^2}{4Tt} \quad \cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots \quad (2)$$

where, S :Strativity, t :pumping time.

Well function, $W\left(u,\frac{r}{B}\right)$ can be obtained from the "Hantush-Jacob's function table" through the values of u and r/B. Based on the equations, the drawdown at the points of 1, 50, 100, 500, 1000, 2000, 3000 m apart from the pumping well, under 50m^3/hof pumping rate for 1, 5, 10, 30, and 60 days was calculated.

Table 4.2.1. Drawdown by Sole Pumping, Q=50m^3/h (Yaboos) Unit: m

Period	r = 1.0m	r = 50	r = 100	r = 500	r =1,000	r =2,000	r =3,000
1day	9.54	3.29	2.24	0.32	0.05	0.001	-
5days	9.54	3.31	2.27	0.39	0.07	0.002	0.0001
10days	9.54	3.33	2.28	0.40	0.07	0.003	0.0001
30days	9.54	3.33	2.28	0.40	0.07	0.003	0.0001
60days	9.54	3.33	2.28	0.40	0.07	0.003	0.0001

As shown in the table, the drawdown by one well pumping is going to almost equilibrium after around 10 days pumping, and furthermore, the drawdown becomes very small at the distance around 2.0 km from the pumping well.

Dier Al Ashayer

In this site, the aquifer seems to be a complex aquifer combined unconfined and confined aquifer types, thereby, the drawdown by pumping is calculated through "Thaïs's Non-equilibrium Equation". The equation gives the drawdown *(s)* as follows:

$$s = \frac{Q}{4\pi T} W(u) \quad \cdots\cdots\cdots\cdots\cdots\cdots\cdots \quad (3)$$

where, s:drawdown, Q:discharge, T:Transmissivity,
W(u): Thaïs's well function, u:given as follows;

$$u = \frac{Sr^2}{4Tt} \quad \cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots \quad \text{(same with 2)}$$

where, S:Storativity, r:distance from well, t:pumping time.

Well function, $W(u)$ can be read from the Thaïs's Well Function Table through the value of *u.* As same as the manner of Yaboos site, the drawdown at several points, in several time after continued pumping were calculated and shown in the table 4.2.2.

Table 4.2.2. Drawdown by One-well Pumping, Q=50m³/h (D.A.A) Unit: m

Time	r = 1.0m	r = 50	r = 100	r = 500	r =1,000	r =2,000	r =3,000
1 day	2.20	0.58	0.32	0.001	-	-	-
5 days	2.54	0.91	0.63	0.08	0.004	-	-
10 days	2.68	1.06	0.77	0.17	0.12	0.001	-
30 days	2.91	1.28	0.99	0.35	0.12	0.01	0.001
60 days	3.05	1.43	1.13	0.48	0.22	0.05	0.01

As easily readable, the drawdown in this site, under the same discharge, is farther small than the one of Yaboos site. The reasons are by far larger values of both Transmissivity and Strativity than those of Yaboos site, and also difference of aquifer type. While, the drawdown can not become equilibrium even after 60 days pumping. Thus, the situations are somewhat different from the case of Yaboos but the influence by one-well pumping is reduced into only 5 cm, almost negligible, at the point apart from the well by 2 km.

4.3. Group-well Pumping Simulation

Then, the case of group pumping is to be considered about. Equation of "Theis" or "Hantush-Jacob," mentioned above, is a kind of "Diffusivity Equation", and therefore, so-called "Principle of Superposition" is work out. It means the influence by group pumping is just same with the sum of the results (influence) of each well pumping. Thus, the drawdown of each production well when all of them started pumping coincidently shall be examined at first, and the environmental impact to the surrounding area through group well pumping by all production wells shall be estimated from the view point of decreasing groundwater table.

4.3.1. Mutual interference by group-well pumping

When all of the production wells have been operated coincidently, groundwater table in every well shall be reduced in accordance with its own well efficiency and aquifer condition near around it. Furthermore, the water table shall be lowered by interference from the nearest production well, and then interfered by the other wells gradually depending upon their mutual distances. The influences from faraway wells occur lately and their magnitudes are small, however, the one from near well is rather severe, reaching several meters sometimes.

Table 4.3.1 shown below indicates the drawdown of water table in every production well when all 11 wells in Yaboos site are operated in same time by the pumping rate of 50 m³/h.

Table 4.3.1. Drawdown in Production Wells (Yaboos) Unit: m

No.	Well Elev.	S.W.L	Own-D.D	Interfere	Total D.D	Total Head
Ya1	1280.62	97	8.56	9.48	18.04	115.04
Ya2	1285.32	101.5	4.1	9.6	13.7	115.2
Ya3	1277.69	93.2	19.52	10	29.52	122.72
Ya4	1308.59	111.6	25.38	5.53	30.91	142.51
Ya5	1282.13	99.3	11.44	8.8	20.24	119.54
Ya6	1268.49	87	7.05	7.09	14.14	101.14
Ya7	1272.07	90.7	24.6	7.16	31.76	122.46
Ya8	1281.19	100	10	6.94	16.94	116.94
Ya9	1287.19	107	22.9	5.54	28.44	135.44
Ya12	1276.88	100	15.44	7.09	22.53	122.53
Ya13	1275.38	100	15.44	8.36	23.8	123.8

4.3.2. Group-well pumping simulation

An environmental impact by group well pumping shall be assessed through a consideration on the drawdown of groundwater table near around the well field. For the exact assessment or to confirm the influence, of course, the actual group pumping test using the production wells is required. Before that, the impact by group pumping shall be simulated hereafter, applying "Principle of Superposition" based on the averaged aquifer constants obtained through the pumping tests.

Procedures of the simulation are as follows. At first, the drawdown at every production well by its own pumping and by the interference from other wells is to be examined. Then, the target area for the simulation is given a grid reference on the map. Influence to a certain grid node by group pumping shall be estimated to sum up the all interference from every production well (refer to Figure 4.3.1). Thus, the drawdown of groundwater table at each grid node by the group pumping shall be estimated one by one. After enough number of the nodes covering the target area has been estimated, smooth iso-drawdown contour lines are to be drawn through any geographical software. In this case,

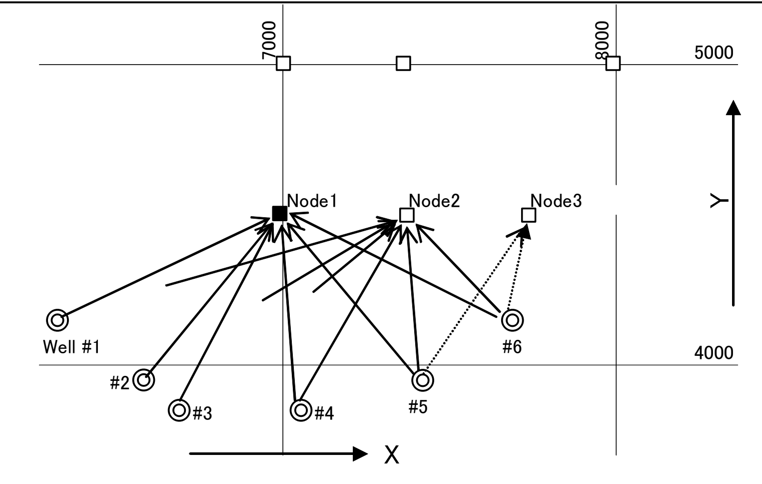


Fig. 4.3.1. Influence from Production Wells

"SURFER for Windows, ver7 (Golden Software Inc.)" has been applied.

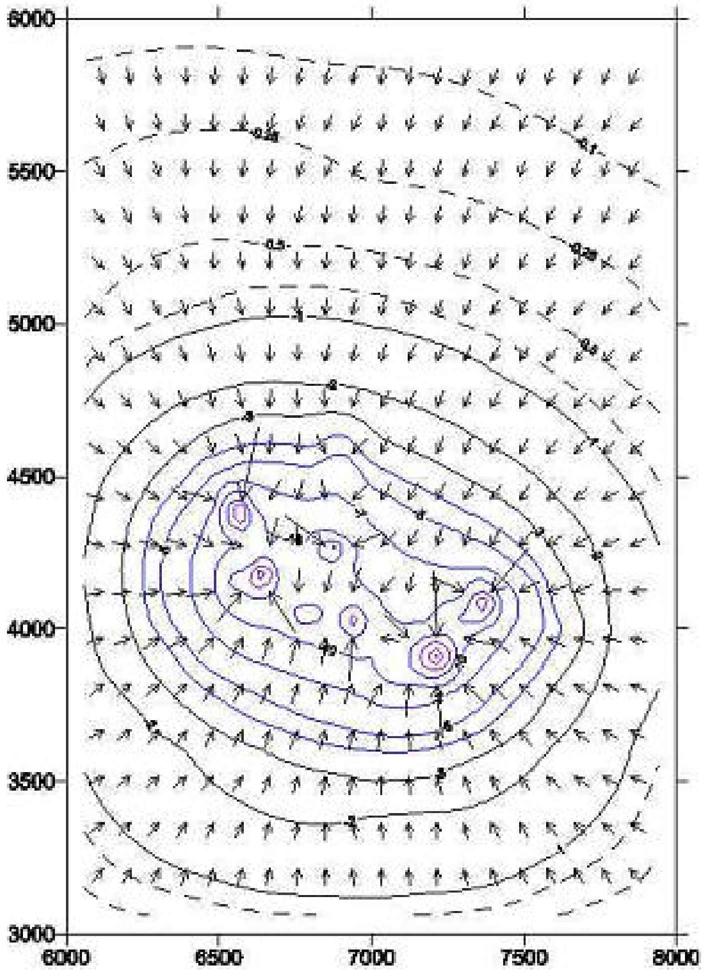


Figure 4.3.2. Estimated Drawdown Contour

As the result of the simulation, it was found out that the groundwater drawdown near the production wells reaches lower than 15m or more from the ground surface but it becomes small and small rapidly in accordance with the distance from the center of well field, being less than 1.0m at around 1 km, less than 0.25m at 1.5km and less than 0.1m at about 2.0km apart from the well field. Figure 4.3.2 shows the situation of drawdown together with vector lines toward the production wells, and Figure 4.3.3 at the next page shows the iso-drawdown contour lines overlapping the topo-map near around the Yaboos site.

4.4. Group-well Pumping Test

The simulation results mentioned above are just estimation under the supposition that the aquifer conditions near around the site is homogeneous and nearly equal to the average of all pumping tests results ever conducted. However, the natural ground conditions are never homogeneous, rather in variety. Results of the simulation and the actual response of the ground are usually different much or less. Therefore, an actual group-well pumping test using the production wells constructed must be conducted to confirm the influence of the pumping actually and to assess the environmental impact more exactly.

Technical specification on the group pumping test was prepared by the Team and handed to DAWSSA during the first field survey period and additional recommendation on the test was also handed to DAWSSA in the second survey period. In the beginning of 2005, DAWSSA carried out te group pumping test just following theses recommendation and specification. The results are attached in Appendix but the they are mostly conformed with the analysis mentioned above.

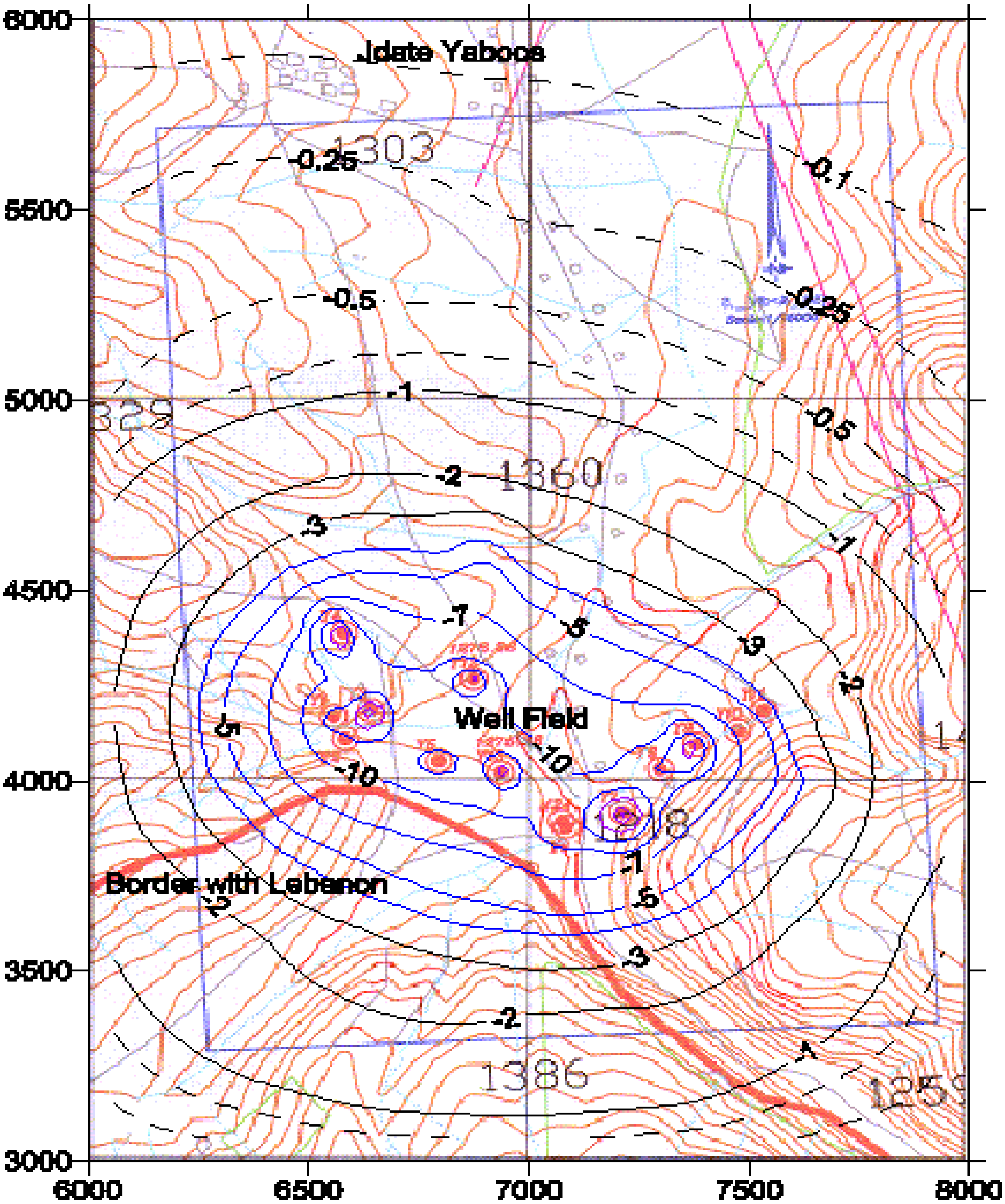


Figure 4.3.3. Results of Group-well Pumping Simulation

5. WATER RESOURCES DEVELOPMENT POTENTIAL

5.1. Background

As mentioned before, the Yaboos and Dier Al Ashayer sites among three of target sites are including "Barada/Awaji Basin," which includes Damascus city also in it. The Maadar II site is belonging to "Litani Basin" flowing down the Bekaa Valley of Lebanon and pouring into the Mediterranean Sea.

Since 1998 to 2000, JICA conducted the Development Study of Water Resources Development on Northwest and Central Regions of Syria. The study report of its phase II study described that the water balance of Barada/Awaji Basin was now facing severe crisis because of over-intake of water, and it shall be sure the basin should be undergone by serious water shortage in the future.

The report analyzed the water balance of the basin as of the study period as follows. Among the average rainfall of 255.0mm in the basin, 191.7mm is lost by an evapotranspiration. Around 62.7mm which is the most part of the remaining portion (63.3mm), converted into the volume of 537 MCM, recharges groundwater, and only 0.6mm of the rest contributes to the groundwater storage. For underground system, 64.1mm is pumped out and 4.9mm is flowing out. The sum of groundwater loss is, thus, 69.0mm and this is beyond the groundwater recharge of 62.7mm for about 6.2mm (converted into around 53 MCM; refer to Figure 5.1.1). The deficit was supplemented from the groundwater storage, causing general depreciation of groundwater level. Considerable inclination of the groundwater table near around Damascus and its vicinity was observed in the middle of 90s.

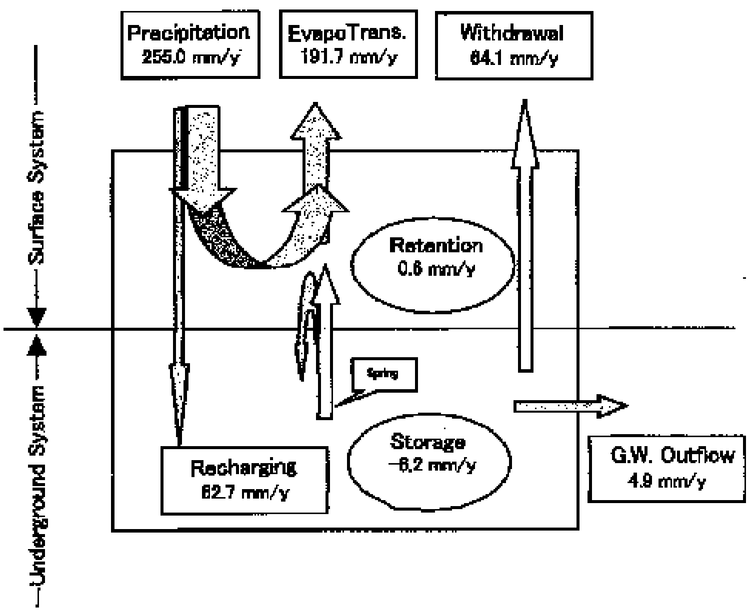


Fig 5.1.1 CURRENT WATER BALANCE

Groundwater system in the basin was in minus balance as a total, and around 145,200 m^3/d of groundwater was over-pumped already, the report said. Because of such situation, a property of the Project was originally defined as an emergency treatment until drastic counter measures of water supply for Damascus city have been established.

Total water volume planned to be developed under the Project (the original request) is 10.95 MCM/year, simply converted to around 30,000 m^3/day in total from the three sites, which is still far less than the volume of water shortage of Damascus of around 139,000 m^3/day in 2004. The water sources are, however, just for emergency water supply and to be operated fully in two months of October and November、although it starts from August, pumping totally around 1.8 MCM, and the amount is 3.4% of the current (1989-1998) groundwater over-withdrawal in the basin. The Project area (Yaboos) locates in the upstream of the basin where is a main recharging zone of the basin, and therefore, the groundwater level near around the site is almost steady since 90s, and rising of groundwater level was found in 2003 when it had enough rainfall.

In any rate, the situation of water balance in the basin is already in risky condition, and the implementation of the Project may give any damages to the groundwater storage. Thus, it shall be said that the less development the better from a view point of area water balance.

Due to such situation, DAWSSA is planning or considering several measures not to get farther burden into groundwater system and to improve the water supply condition on Damascus, as listed below. Among them, the water diversion plan from the other basin to the Barada basin or directly to Damascus is only a drastic counter measure for water shortage of Damascus but the implementation of the plan needs some more times.

a. The water diversion plan from the Mediterranean Coastal Region to Damascus and its vicinity,
b. The water diversion plan from the Asad Lake in the Euphrates River,
c. Re-using plan of waste water,
d. Re-using plan of excess water from Barada and Figeh springs, and
e. The projects to improve leakage water from the transmission tunnel and from the water supply network in Damascus.

As mentioned above, a new water resources development is positively required from a view point of supply/demand balance and, on the contrary, it must severely be restrained from a view point of water balance of the whole basin. Based upon such delicate condition, the design pumping rate shall be examined through an evaluation of water resources potential and permissible pumping rate of the site, taking the basic concept that the Project is just for an emergency measures till the drastic countermeasures shall be implemented in future into the consideration. Of course, it shall be needed to watch over the water balance of the whole basin carefully through a monitoring of groundwater table and a tuning up the water balance model of the basin.

5.2. Estimation of Water Resources

Excepting the Maadar II site, Yaboos and Dier Al Ashayer sites belong to the Barada Basin. Most part of the Maadar II site is included in the Litani Basin. Maadar I and Sergaya sites which are included in the future development plan by DAWSSA are also included in the Barada Basin. In the section, water resources volume shall be estimated through the consideration on groundwater recharge.

Groundwater resources is, in general, the total water volume stored in the ground in a certain area (usually groundwater basin), which was historically accumulated and huge amount in most of the cases. While, a part of rainfall which recharges groundwater to increase a groundwater storage is called as "recharging amount." Recharging is repeated every year in the natural water circulation, therefore, the recharging amount is called as "renewable water resources." Target of water resources for so-called "Sustainable Water Resources Development" is usually this portion. A groundwater resources development potential is applied this volume sometimes, but the volume of development potential must be reduced the current water use from it in exactly saying.

Groundwater recharge amount (Q) can be estimated from rainfall (R), infiltration ratio (P) and area of recharging (A):

$$Q = A \times R \times P$$

Rainfall (R) is an average precipitation in the recharge area (m/year), which can be read from the isohyets map (refer to Figure 5.2.1, come from JICA Master Plan in'97). The infiltration ratio of the area is applied the value of 0.246 which is figured out from the JICA Study Report on Water Resource (1998 – 2000) mentioned before as the average infiltration ratio in the Barada Basin (It is not sure now because the Yaboos site has around 1,000mm of rainfall which is almost four times of the average value mentioned above, so it shall be rechecked later). Then, how to estimate the area of recharging is a problem. In the area underlain by karstic carbonates like the Project area, the recharging area for groundwater does not coincide with the catchment area for surface water. Groundwater recharged by rainfall is usually managed by a sequence of the same geologic layer or hydrogeological unit, flowing in or out just depending upon the relative height of water level or piezometric head beyond the surface catchment boundary. In this study, the area of groundwater recharging for each site was evaluated taking the extension of same hydrogeological unit to the upper stream and large topographic relieves into account. Results of the estimation are listed in Table 5.2.1. The figures are, however, only the estimation on groundwater recharge amount and the actual development potential shall be examined through the consideration of spring water and current groundwater intake amount.

Table 5.2.1. ESTIMATION OF GROUNDWATER RECHARGE

	(a)	(b)	(c)=(a)*(b)	(d)	(e)=(c)*(d)	(f)=(e)/365	(g)=(f)/86.4
Site	R. Area (km^2)	Rainfall (mm/a)	Amount (MCM/a)	Infiltration Ratio	Recharge/a (MCM/a)	Recharge/d (m^3/d)	Recharge/s (lit/sec)
Srgaya	46	700	32.2	0.246	7.921	21,702	251.2
Maadar I	32	900	28.8	0.246	7.085	19,410	224.7
Maadar II *1	46	1100	50.6	0.246	12.448	34,103	394.7
Yaboos *2	67	1000	67.0	0.246	16.482	45,156	522.6
D. A. Ashayer	51	800	40.8	0.246	10.037	27,498	318.3

備考: (a) Recharging area supposed from an extention of same hydrogeological strata and large topographic chracteristics.
(b) Average rainfall in the recharge area read from Fig 5.2.1.
(d) Referred from JICA Development Study Reort (2000).
(f),(g) Only a recharging volume, not a development potential.
*1: Maadar I can be included into II site if no well is developed there.
*2: Ma8 is included in this area.

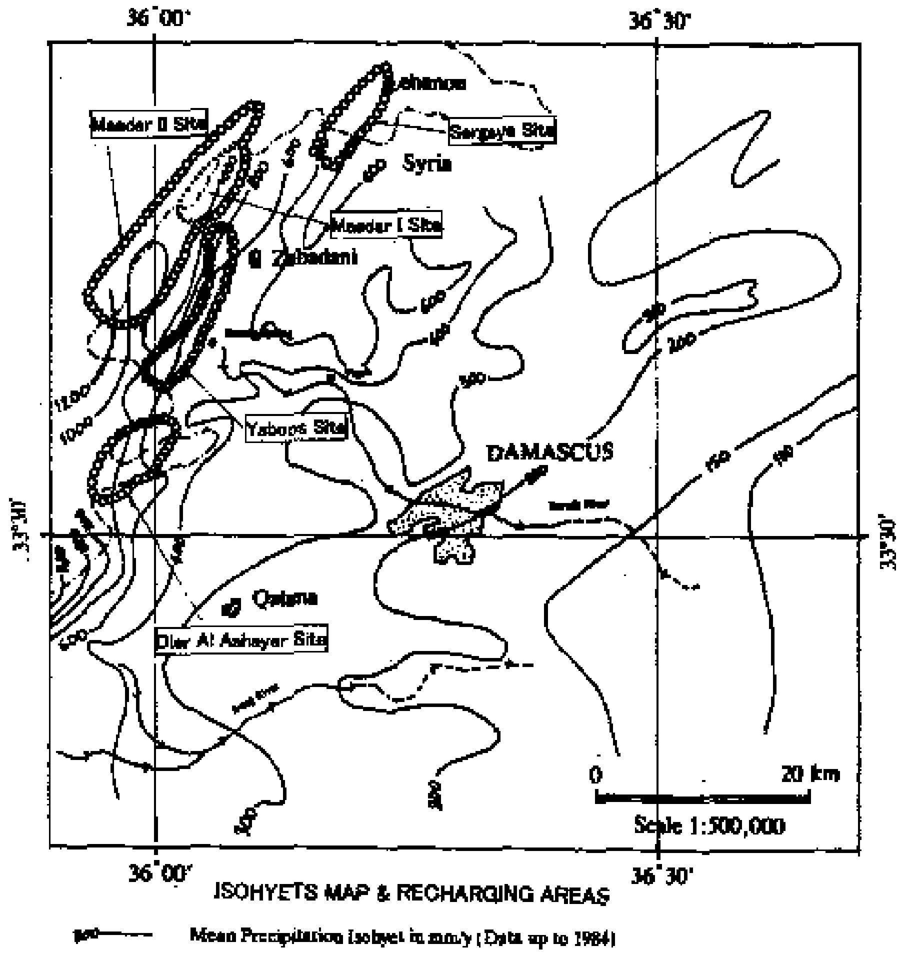


Figure 5.2.1. Isohyets Map of the Basin (with recharging areas)

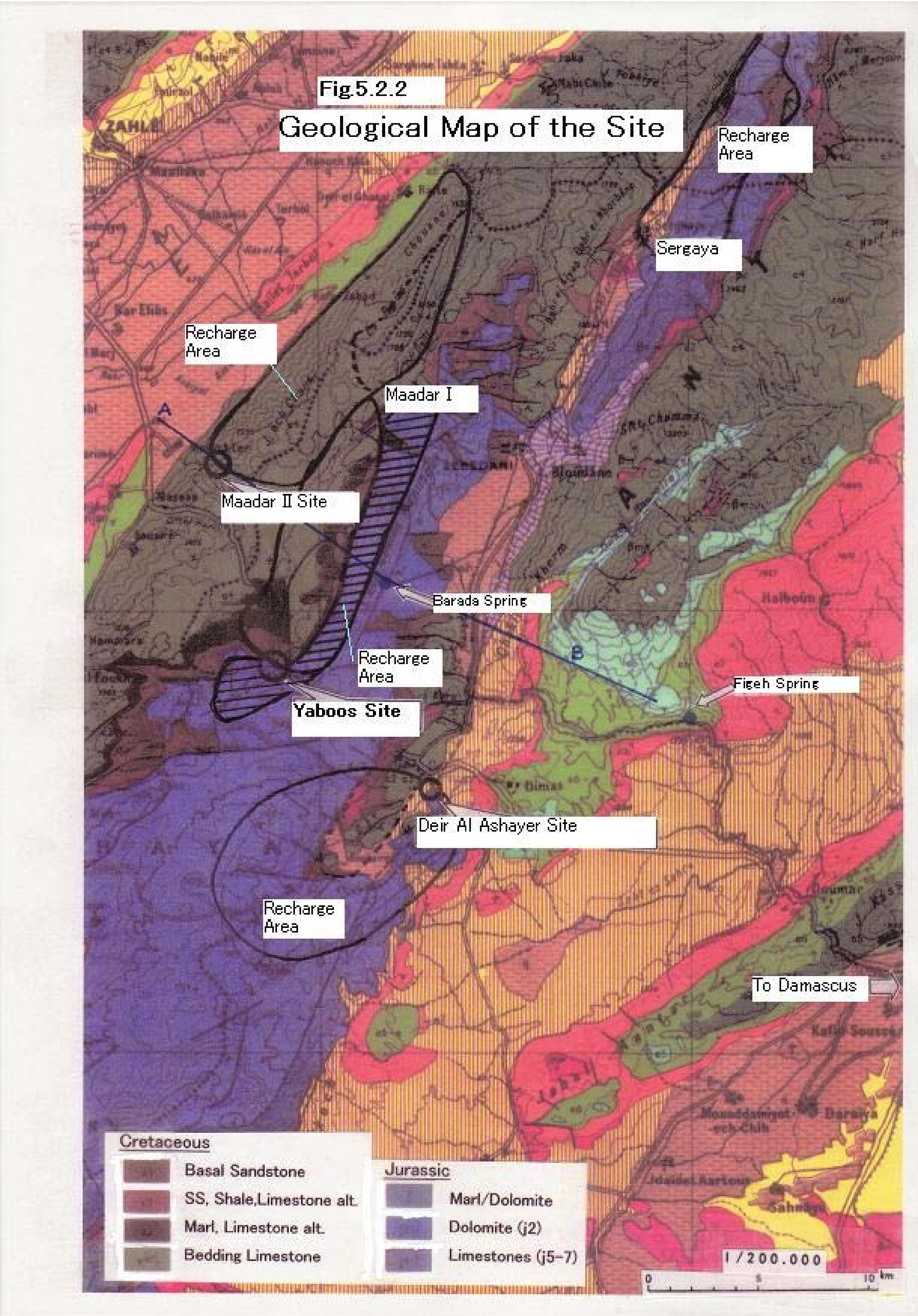


Fig.5.2.2
Geological Map of the Site
Recharge Area
Sergaya
Recharge Area
Maadar I
Maadar II Site
Barada Spring
Recharge Area
Yaboos Site
Figeh Spring
Deir Al Ashayer Site
Recharge Area
To Damascus
Cretaceous
Basal Sandstone
SS, Shale,Limestone alt.
Marl, Limestone alt.
Bedding Limestone
Jurassic
Marl/Dolomite
Dolomite (j2)
Limestones (j5-7)
1/200.000

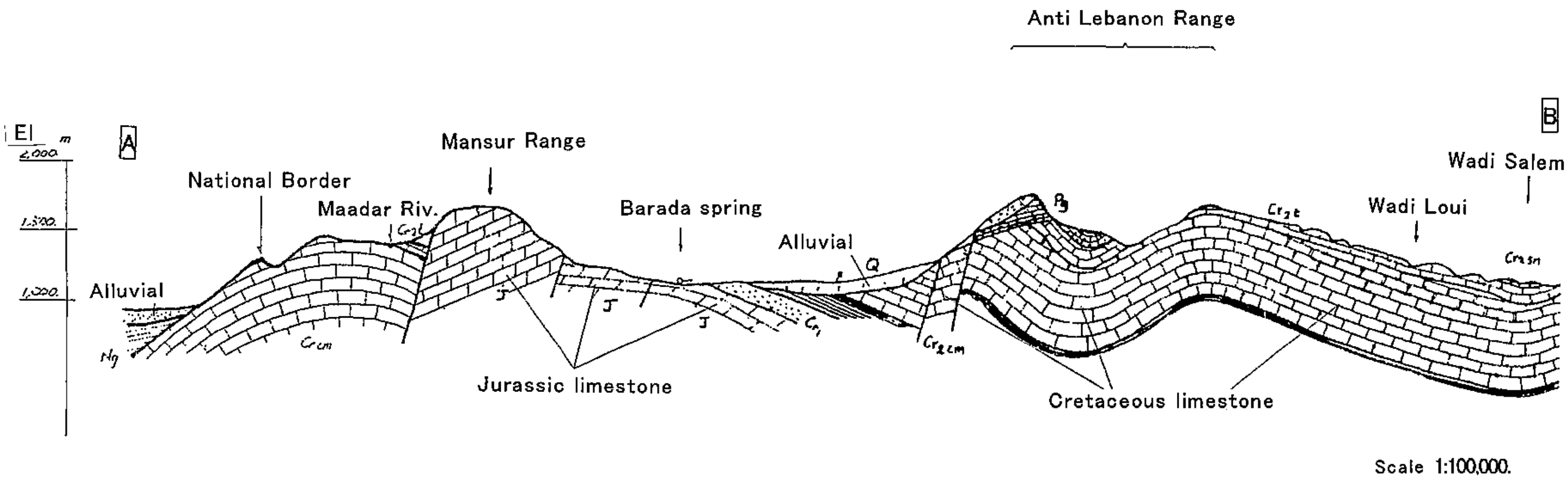


Fig. 5-2-3 Supposed Geological Cross Section

Source: Geological Map of Syria, Sheet I37-VII (1964), revised.

5.3. Optimum and Permissible Pumping Rate

Total water balance in the Barada Basin was already minus, as repeatedly mentioned. The situation indicates that an optimum pumping rate never exist in the basin. However, if the Project must be promoted considering about the seriousness of water shortage in Damascus, the capital of Syria, the pumping rate in each well field shall be limited within a permissible pumping rate. Fortunately, the target sites in this Project locate in the area where has exceptionally high precipitation of 700 – 1,100 mm/a within very dry Barada Basin which has average rainfall of only 255 mm/a (refer to Figure 5.2.1).

A permissible pumping rate is a concept defined from both natural and social sciences; fulfilling the following five conditions ("Groundwater Resources and Environment," Groundwater balance study group, 1995, Kyoritu Publishing):

① it does not cause unfavorable results (economical condition),

② water balance shall be stable (natural recharging condition),

③ in compliance with law and regulations (legal condition),

④ never cause land subsidence or groundwater contamination (geo-environmental condition), and

⑤ maintain amenities of citizen such as water front (water related environmental condition).

Among the conditions above mentioned, the condition of ③ is almost no problem because DAWSSA already obtained a water-right from the Ministry of Irrigation and remaining is to clear the Environmental Decree, which is on progress. For the condition ④, it is no need to consider because there is no strata having possibility of subsidence, and the production wells were constructed completely to avoid contamination. Condition ⑤, water related environment shall be considered about where permanent river or spring exist, and the Yaboos site has not permanent river nor spring. Thus, the permissible pumping rate in the Yaboos site shall be considered through the condition of ① of economical and ② of natural recharging conditions.

At first the economical condition shall be considered, through the view points of managing water table in the production well and drawdown of groundwater table in surrounding area and defined it as limit pumping rate. Then the limit pumping rate shall be examined from the condition of natural recharging to estimate the permissible pumping rate.

In the JICA Development Study mentioned above, the managing water table in the newly constructed production well was referred in two levels of 100m and 150m. Reasons hwy are those most of the pumps available in the market have 100m of pumping head, and it becomes costly drastically when the managing water table exceeds 150m. In Yaboos site natural water tables of most of production wells are nearly 100m, therefore, to make the managing water level at 100m is almost impossible. Thus, the managing water level in Yaboos shall be considered as 150m.

(1) Limit pumping rate in Yaboos site

Through the group well pumping simulation it was suggested that the dynamic water level in the all production wells shall be kept within 150m when all the wells have been operated under the rate of 50 m^3/h. In these wells, considering the managing water level of 150m (actually 142.5 accounting the error of 5%), a limitation of pumping rate which does not exceed 142.5m of drawdown shall be examined and defied the volume as tentative limited pumping rate.

Table 5.3.1 shows the total drawdown of each production well when the pumping rate was increased by 10 m^3/h pitch. As easily understandable from the table the yield capacity of each well varies heavily but the maximum pumping rate can be estimated through summing up the rates which does not exceed 142.5m of drawdown. The maximum pumping rate is, thus, estimated as 1,030 m^3/h (286 lit/sec), and it is converted as 93.6 lit/sec/well in an average.

Table 5.3.1. ESTIMATION OF LIMIT PUMPING RATE

Well	Q (m^3/h)	60	70	80	90	100	110	120	130	140	150	160	170	180	190	200
Ya1	Own D.D	10.47	12.73	15.19	17.09	19.43	21.37	23.85	26.46	29.18	32.05	35.06	38.24	41.58	45.11	48.84
	Interfere	11.38	13.28	15.17	17.07	18.97	20.87	22.76	24.66	26.56	28.45	30.35	32.25	34.14	36.04	37.94
	Total D.D	21.85	26.01	30.37	34.17	38.39	42.23	46.61	51.11	55.74	60.50	65.41	70.48	75.72	81.15	86.78
	T. Head	118.85	123.01	127.37	131.17	135.39	**139.23**	143.61	148.11	152.74	157.50	162.41	167.48	172.72	178.15	183.78
Ya2	Own D.D	5.02	5.98	6.98	8.02	9.11	10.25	11.44	12.69	13.99	15.37	16.81	18.33	19.94	21.63	23.42
	Interfere	11.53	13.45	15.37	17.29	19.21	21.13	23.05	24.97	26.89	28.81	30.73	32.66	34.58	36.50	38.42
	Total D.D	16.54	19.42	22.34	25.31	28.32	31.38	34.49	37.66	40.89	44.18	47.55	50.99	54.51	58.13	61.84
	T. Head	118.04	120.92	123.84	126.81	129.82	132.88	135.99	139.16	**142.39**	145.68	149.05	152.49	156.01	159.63	163.34
Ya3	Own D.D	23.92	28.48	33.24	38.21	43.40	48.83	54.51	60.45	66.69	73.24	80.13	87.38	95.02	103.08	111.61
	Interfere	12.00	14.00	16.00	18.00	20.00	22.00	24.00	26.00	28.00	30.00	32.00	34.00	36.00	38.00	40.00
	Total D.D	35.92	42.48	49.24	56.21	63.40	70.83	78.50	86.45	94.69	103.24	112.13	121.38	131.02	141.08	151.61
	T. Head	129.12	135.68	**142.44**	149.41	156.60	164.03	171.70	179.65	187.89	196.44	205.33	214.58	224.22	234.28	244.81
Ya4	Own D.D	31.08	37.01	43.20	49.66	56.40	63.45	70.83	78.56	86.67	95.18	104.13	113.55	123.47	133.95	145.03
	Interfere	6.63	7.74	8.84	9.95	11.05	12.16	13.26	14.37	15.47	16.58	17.68	18.79	19.89	21.00	22.10
	Total D.D	37.71	44.75	52.04	59.60	67.45	75.61	84.09	92.93	102.14	111.75	121.81	132.33	143.37	154.95	167.14
	T. Head	149.31	156.35	163.64	171.20	179.05	187.21	195.69	204.53	213.74	223.35	233.41	243.93	254.97	266.55	278.74
Ya5	Own D.D	14.01	16.69	19.48	22.39	25.43	28.60	31.93	35.41	39.07	42.91	46.94	51.19	55.66	60.39	65.38
	Interfere	10.56	12.32	14.08	15.84	17.60	19.36	21.13	22.89	24.65	26.41	28.17	29.93	31.69	33.45	35.21
	Total D.D	24.57	29.01	33.56	38.23	43.03	47.97	53.06	58.30	63.71	69.31	75.11	81.11	87.35	93.83	100.59
	T. Head	123.87	128.31	132.86	137.53	**142.33**	147.27	152.36	157.60	163.01	168.61	174.41	180.41	186.65	193.13	199.89
Ya6	Own D.D	8.64	10.28	12.00	13.80	15.67	17.63	19.68	21.83	24.08	26.45	28.93	31.55	34.31	37.22	40.30
	Interfere	8.51	9.93	11.35	12.77	14.19	15.61	17.02	18.44	19.86	21.28	22.70	24.12	25.54	26.96	28.37
	Total D.D	17.15	20.22	23.35	26.57	29.86	33.24	36.70	40.27	43.94	47.73	51.63	55.67	59.84	64.18	68.67
	T. Head	104.15	107.22	110.35	113.57	116.86	120.24	123.70	127.27	130.94	134.73	**138.63**	142.67	146.84	151.18	155.67
Ya7	Own D.D	30.16	35.92	41.92	48.19	54.73	61.58	68.74	76.24	84.10	92.36	101.05	110.19	119.82	129.99	140.75
	Interfere	8.59	10.03	11.46	12.89	14.32	15.76	17.19	18.62	20.05	21.49	22.92	24.35	25.78	27.22	28.65
	Total D.D	38.75	45.95	53.38	61.08	69.06	77.33	85.93	94.86	104.16	113.85	123.97	134.54	145.61	157.21	169.39
	T. Head	129.45	**136.65**	144.08	151.78	159.76	168.03	176.63	185.56	194.86	204.55	214.67	225.24	236.31	247.91	260.09
Ya8	Own D.D	15.15	18.05	21.07	24.21	27.50	30.94	34.54	38.31	42.26	46.41	50.77	55.37	60.21	65.32	70.72
	Interfere	8.33	9.72	11.11	12.50	13.89	15.28	16.67	18.05	19.44	20.83	22.22	23.61	25.00	26.39	27.78
	Total D.D	23.49	27.77	32.18	36.71	41.39	46.22	51.20	56.36	61.70	67.24	73.00	78.98	85.21	91.71	98.50
	T. Head	123.49	127.77	132.18	136.71	**141.39**	146.22	151.20	156.36	161.70	167.24	173.00	178.98	185.21	191.71	198.50
Ya9	Own D.D	28.08	33.45	39.04	44.87	50.97	57.34	64.01	70.99	78.32	86.01	94.10	102.61	111.58	121.05	131.06
	Interfere	6.64	7.75	8.86	9.96	11.07	12.18	13.29	14.39	15.50	16.61	17.71	18.82	19.93	21.04	22.14
	Total D.D	34.73	41.20	47.90	54.84	62.04	69.52	77.29	85.39	93.82	102.62	111.81	121.43	131.51	142.09	153.21
	T. Head	**141.73**	148.20	154.90	161.84	169.04	176.52	184.29	192.39	200.82	209.62	218.81	228.43	238.51	249.09	260.21
Ya10	Own D.D	20.41	24.31	28.37	32.61	37.04	41.67	46.51	51.59	56.91	62.50	68.38	74.56	81.08	87.96	95.24
	Interfere	8.50	9.92	11.34	12.76	14.17	15.59	17.01	18.43	19.84	21.26	22.68	24.09	25.51	26.93	28.35
	Total D.D	28.91	34.23	39.71	45.36	51.21	57.26	63.52	70.01	76.75	83.76	91.05	98.66	106.59	114.89	123.58
	T. Head	128.91	134.23	**139.71**	145.36	151.21	157.26	163.52	170.01	176.75	183.76	191.05	198.66	206.59	214.89	223.58
Ya11	Own D.D	20.41	24.31	28.37	32.61	37.04	41.67	46.51	51.59	56.91	62.50	68.38	74.56	81.08	87.96	95.24
	Interfere	10.03	11.71	13.38	15.05	16.72	18.40	20.07	21.74	23.41	25.08	26.76	28.43	30.10	31.77	33.45
	Total D.D	30.44	36.01	41.75	47.66	53.76	60.06	66.58	73.33	80.32	87.58	95.13	102.99	111.18	119.74	128.68
	T. Head	130.44	136.01	**141.75**	147.66	153.76	160.06	166.58	173.33	180.32	187.58	195.13	202.99	211.18	219.74	228.68

The volume of total 1,030 m^3/h (286 lit/sec) is around 1.9 times of the planned pumping rate (planned pumping rate is 50 x 11 = 550 m^3/h), nearly double. Then, the drawdown of groundwater level around Jdate Yaboos, the nearest village from the Yaboos well field, when the production wells are operated under the rate shall be examined. Drawdown of groundwater table around Jdate Yaboos under the planned pumping rate (after continuous 60 days pumping) is less than 25cm from a reading of Figure 4.3.3. The magnitude of influence by a group pumping relates to the pumping amount, therefore, the drawdown around Jdate Yaboos shall be less than 50cm when the pumping rate in the well field is increased double. Full operation in the Yaboos site shall be conducted in only two months of November and December, and this period is not an irrigation period, so the drawdown of less than 50 cm in this season shall be acceptable. Thus, the limit pumping rate in Yaboos is to be defined as 1,030 m^3/day or 286 lit/sec.

(2) Permissible pumping rate in Yaboos

The recharge amount of this site was estimated as 522.6 lit/sec (refer to the previous section). And the limit pumping rate in the site is figured out as 286 lit/sec as explained above. Thus, the limited pumping rate is around 55% of the recharging amount. Although there is no large spring and no other well field in this site, a small scale spring exists at the village of Kfere Yaboos, more than 10 irrigation wells are located and a production well for water supply to the village operating throughout the year is working. Total amount of these current water usage sum up to approx. 4.0 MCM/a (1.6 of spring, 2.1 of irrigation and 0.3 of domestic uses), and it shares around 25% of the recharge amount. Based on these situations, the pumping amount in the well field must be less than 40% of the recharging amount because the recharging amount varies year by year, even though the full operation seasons for irrigation and water supply are not overlapped. As a conclusion, the permissible pumping rate in Yaboos site shall be around 209 lit/sec or 752.4 m^3/h. When pumping of full permissible amount is required, the increased pumping amount must be withdrawn through the newly drilled production wells equivalent to the additional amount. The amount of 752.4 carried out through m^3/h is equivalent to 15 standard wells (752.4 ÷ 50 = 15.0), so that another 4 wells shall be permissible in this site.

The permissible pumping rate is, however, the maximum allowable pumping rate under the special local hydrogeological condition of this site when such high pumping rate is inevitably required. It must be reconsidered that such heavy pumping in this site may lose quite precious groundwater recharge for the downstream zone of the basin.

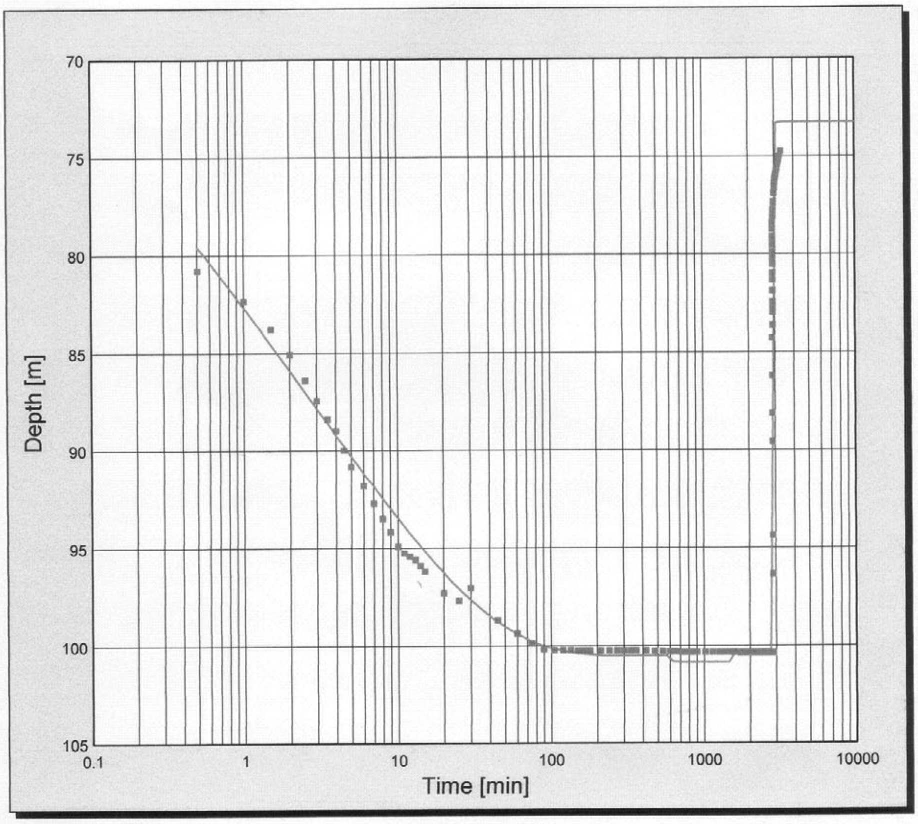
Appendix-1　Pumping Test Analysis

Yaboos M37（Pumping Well）

Pumping Test

Well Ident	Description		
M37			
Obs. Well Distance [m]	Average Pump. Rate [m3/day]	Duration [min]	Initial Sat. Thickness [m]
0.13	16.66139	3300.000	

			Results
Transmissivity [m2/day]	Storage Coefficient	Leakance [1/day]	Estimation Error [m]
22.90440		8.756396	1.29
Fit Method			Hantush Method

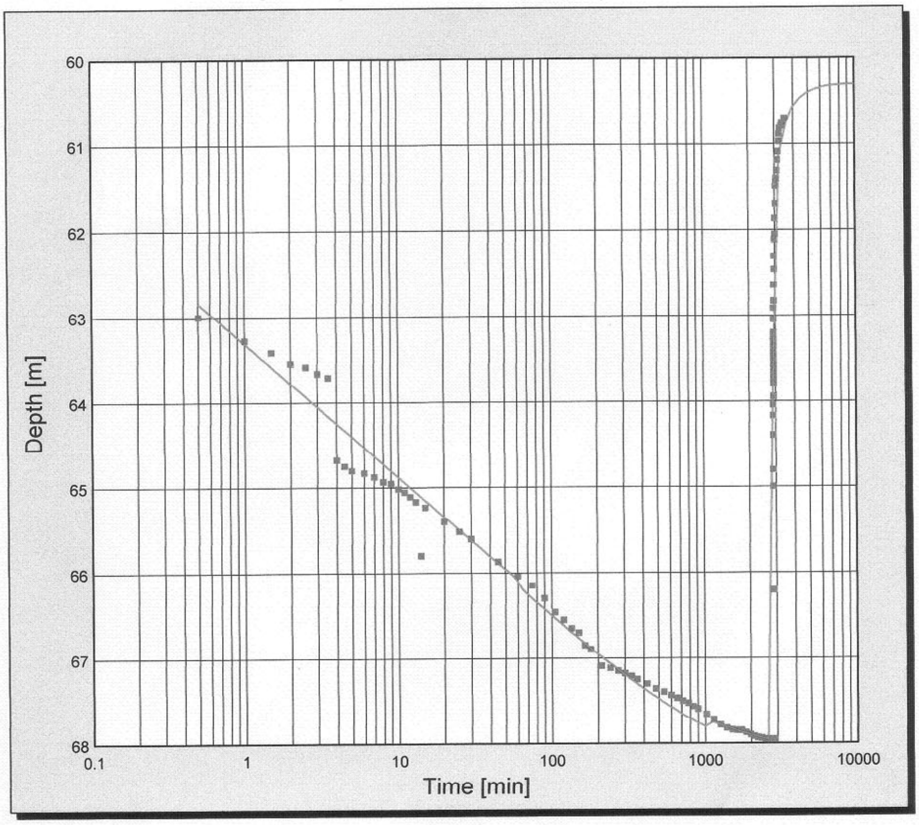


Yaboos No.7well （Pumping Well））

Pumping Test

Well Ident	Description		
No.7			
Obs. Well Distance [m]	Average Pump. Rate [m3/day]	Duration [min]	Initial Sat. Thickness [m]
0.13	10.88666	3480.000	

Results			
Transmissivity [m2/day]	Storage Coefficient	Leakance [1/day]	Estimation Error [m]
113.1723		0.09991609	0.19
Fit Method			Hantush Method



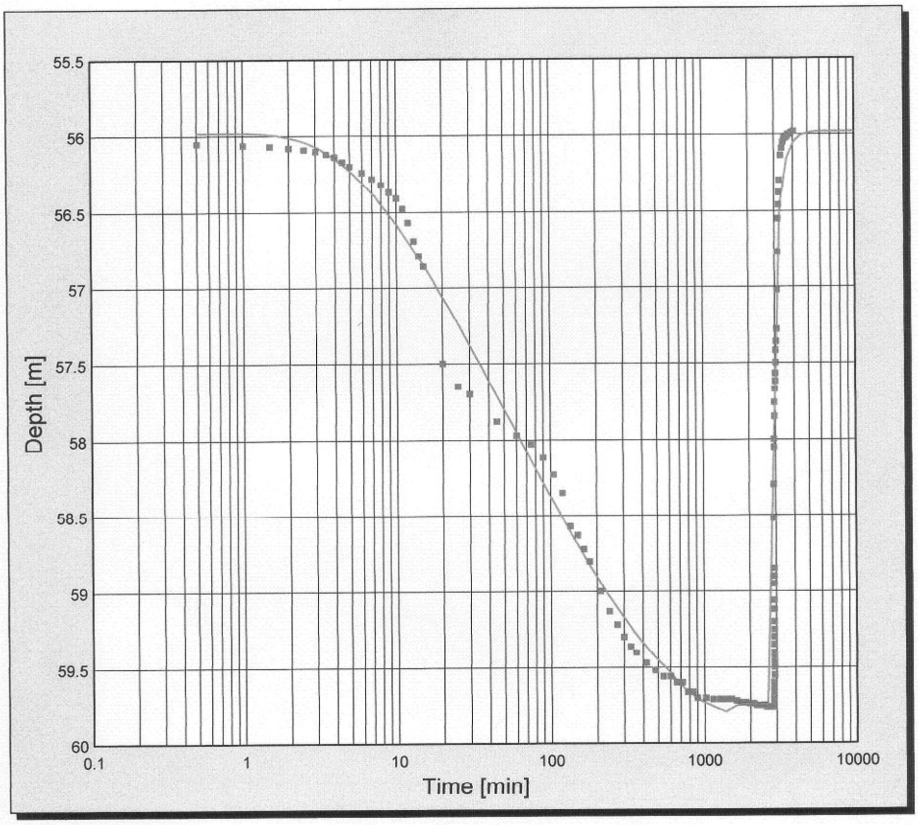
Yaboos M14well（Observation Well）

Pumping Test

Well Ident	Description		
M14			
Obs. Well Distance [m]	Average Pump. Rate [m3/day]	Duration [min]	Initial Sat. Thickness [m]
82.60	16.66139	4020.000	

Results

Transmissivity [m2/day]	Storage Coefficient	Leakance [1/day]	Estimation Error [m]
121.3881	0.0002168680	0.0004626043	0.14
Fit Method			Hantush Method



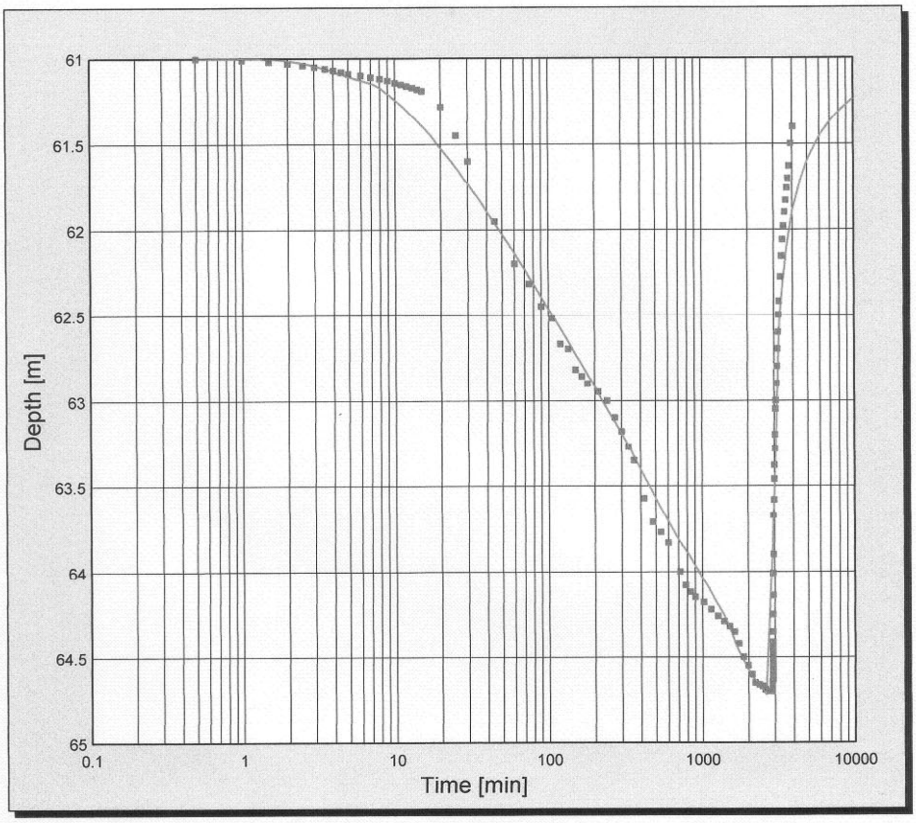
Yaboos No.7well（Observation Well）

Pumping Test

Well Ident	Description		
No.7			
Obs. Well Distance [m]	Average Pump. Rate [m3/day]	Duration [min]	Initial Sat. Thickness [m]
75.42	13.58500	4020.000	

Results

Transmissivity [m2/day]	Storage Coefficient	Leakance [1/day]	Estimation Error [m]
137.4931	0.0004824527		0.14
Fit Method			Theis Method

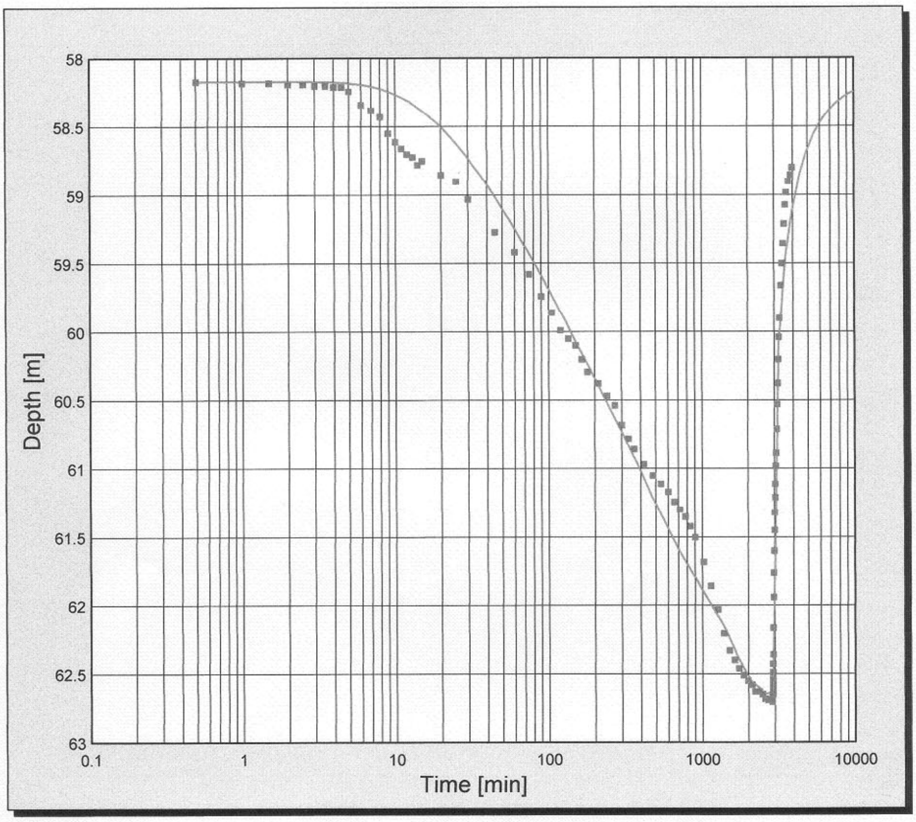


Yaboos M38 well（Observation Well）

Pumping Test

Well Ident	Description		
No.38			
Obs. Well Distance [m]	Average Pump. Rate [m3/day]	Duration [min]	Initial Sat. Thickness [m]
98.62	13.58500	3960.000	

Results			
Transmissivity [m2/day]	Storage Coefficient	Leakance [1/day]	Estimation Error [m]
88.06426	0.0003910696	0.0001107898	0.20
Fit Method			Hantush Method

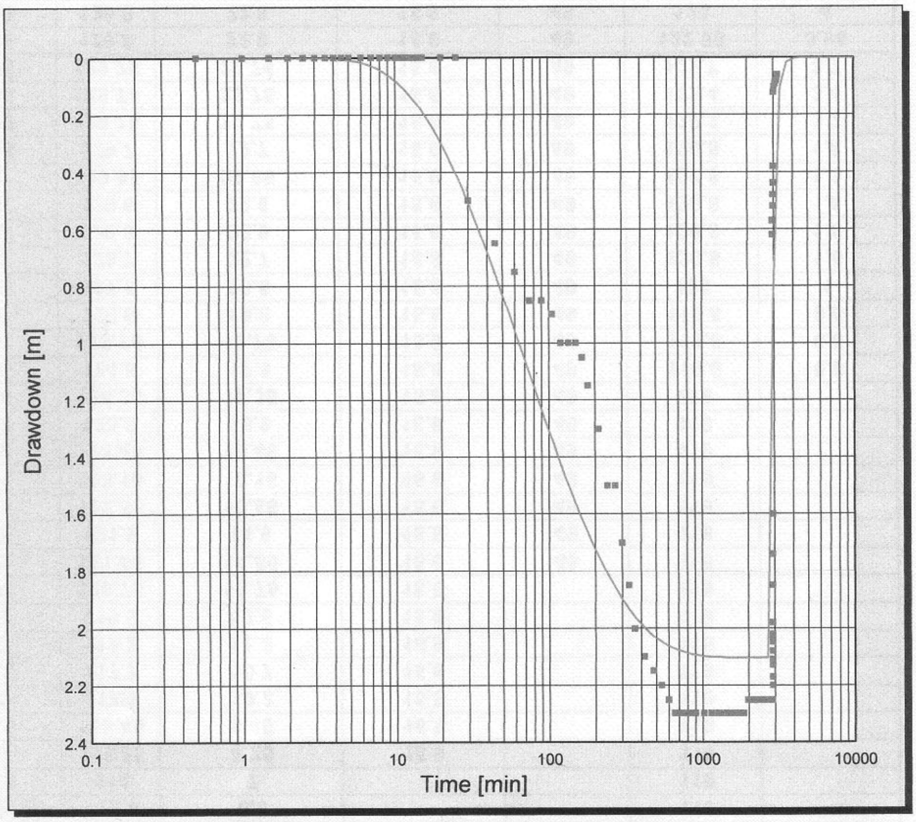


Yaboos Ya-1 well（Observation Well）

Pumping Test

Well Ident	Description		
Ya1-obs			
Obs. Well Distance [m]	Average Pump. Rate [m3/day]	Duration [min]	Initial Sat. Thickness [m]
88.00	17.50000	3180.000	

Results			
Transmissivity [m2/day]	Storage Coefficient	Leakance [1/day]	Estimation Error [m]
108.4942	0.0006549245	0.003455610	0.26
Fit Method			Hantush Method

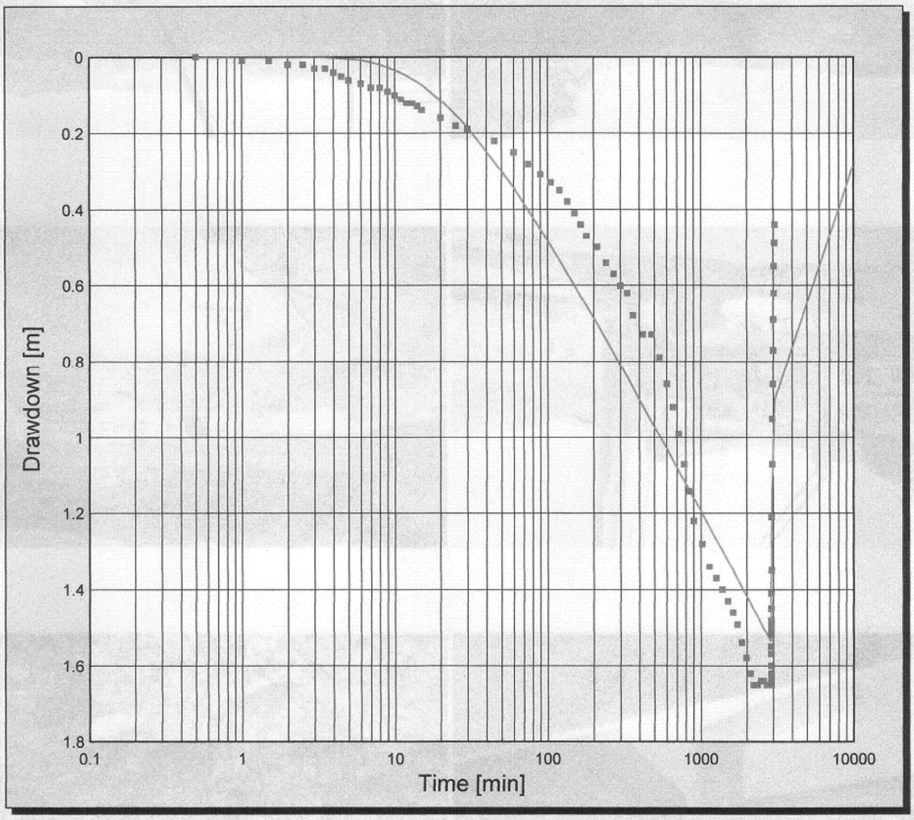


Yaboos Ya-2 well（Observation Well）

Pumping Test

Well Ident	Description		
Ya2-obs			
Obs. Well Distance [m]	Average Pump. Rate [m3/day]	Duration [min]	Initial Sat. Thickness [m]
96.10	16.90000	3060.000	

			Results
Transmissivity [m2/day]	Storage Coefficient	Leakance [1/day]	Estimation Error [m]
369.1311	0.001577223	3.436491E-16	0.15
Fit Method			Hantush Method



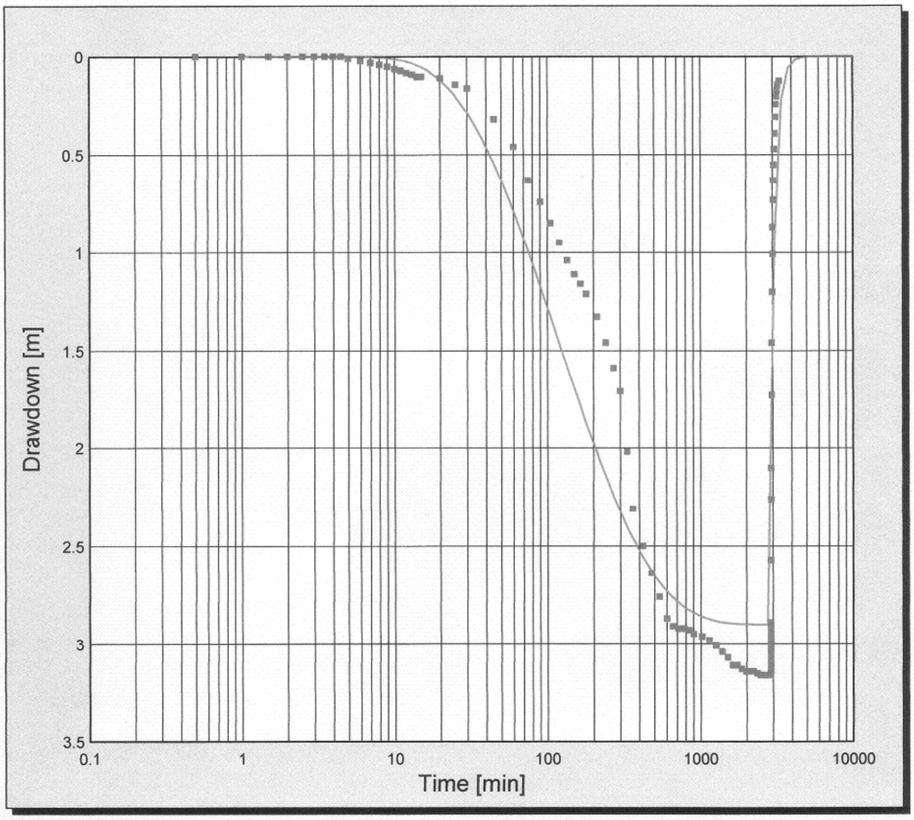
Yaboos Ya-3 well（Observation Well）

Pumping Test

Well Ident	Description		
Ya3-obs			
Obs. Well Distance [m]	Average Pump. Rate [m3/day]	Duration [min]	Initial Sat. Thickness [m]
88.00	16.70000	3300.000	

Results

Transmissivity [m2/day]	Storage Coefficient	Leakance [1/day]	Estimation Error [m]
63.48579	0.0007831824	0.002877638	0.31
Fit Method			Hantush Method



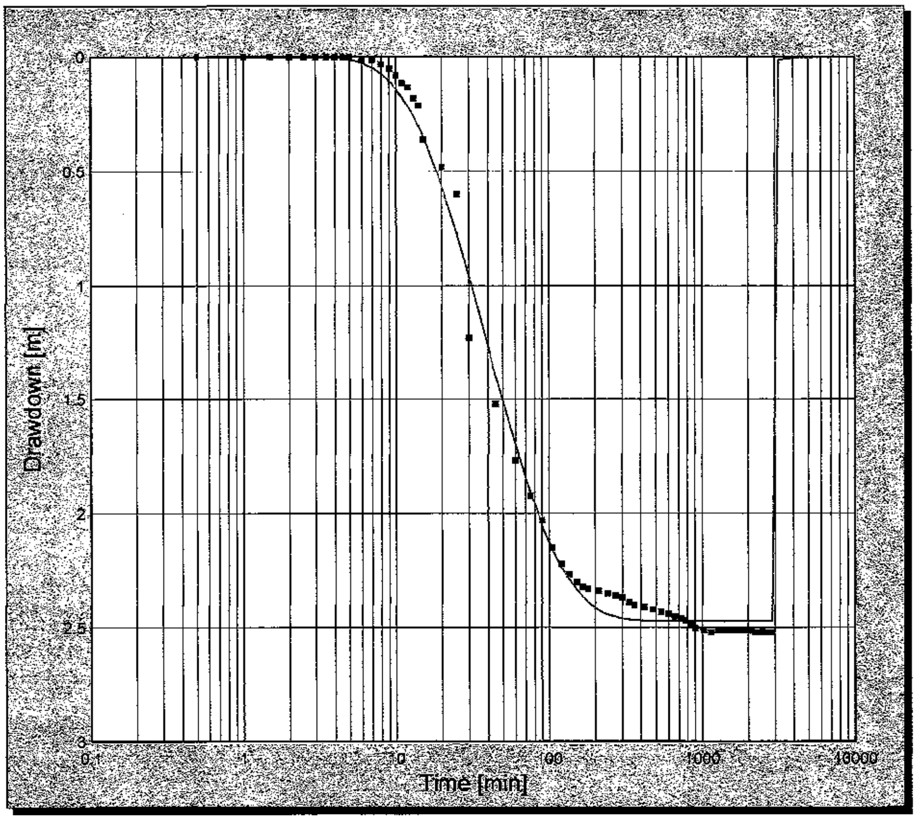
Yaboos Ya-4 well (Observation Well)

Pumping Test

Well Ident	Description		
Ya4-obs			
Obs. Well Distance [m]	**Average Pump. Rate [m3/day]**	**Duration [min]**	**Initial Sat. Thickness [m]**
211.00	16.70000	2880.000	

Results

Transmissivity [m2/day]	Storage Coefficient	Leakance [1/day]	Estimation Error [m]
39.21865	0.00004677314	0.0008904913	0.06
Fit Method			Hantush Method



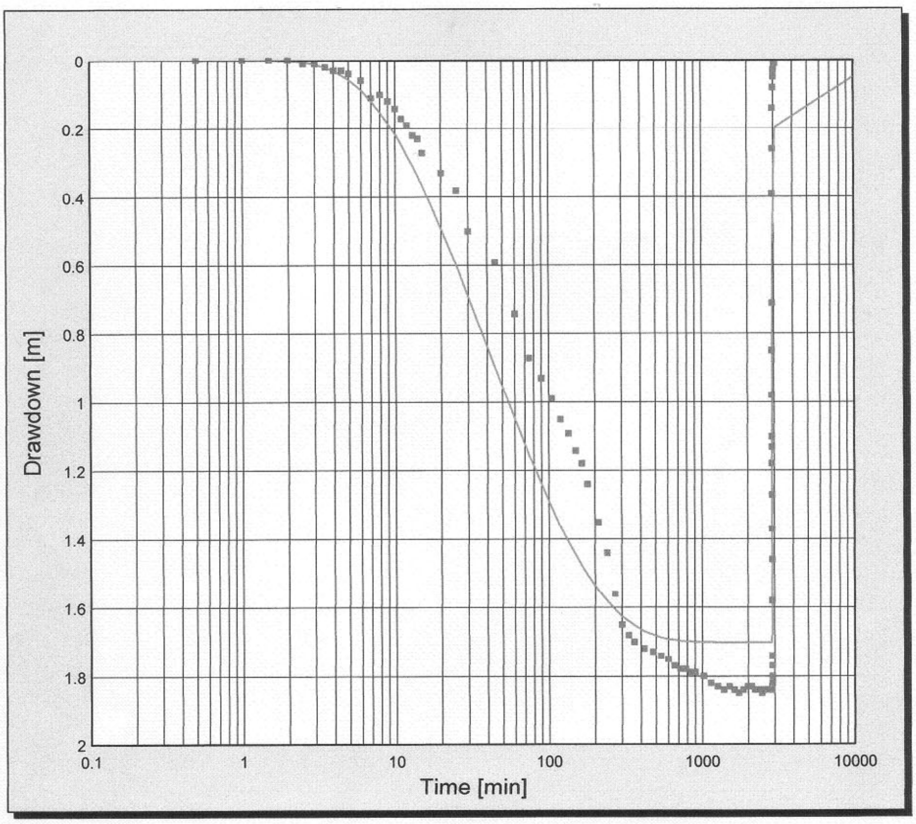
Yaboos Ya-5 well（Observation Well）

Pumping Test

Well Ident	Description		
Ya5-obs			
Obs. Well Distance [m]	Average Pump. Rate [m3/day]	Duration [min]	Initial Sat. Thickness [m]
201.00	17.20000	3060.000	

Results

Transmissivity [m2/day]	Storage Coefficient	Leakance [1/day]	Estimation Error [m]
156.9536	0.00008799817	0.0006365557	0.18
Fit Method			Hantush Method

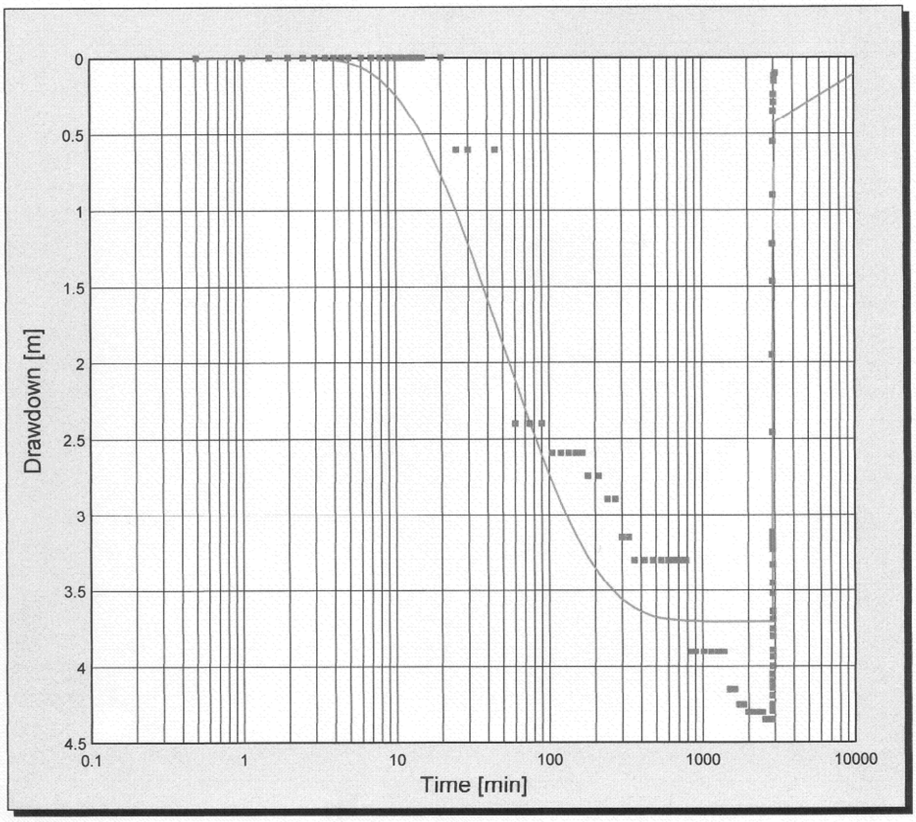


Yaboos Ya-6 well（Observation Well）

Pumping Test

Well Ident	Description		
Ya6-obs			
Obs. Well Distance [m]	Average Pump. Rate [m3/day]	Duration [min]	Initial Sat. Thickness [m]
89.00	17.20000	3060.000	

Results			
Transmissivity [m2/day]	Storage Coefficient	Leakance [1/day]	Estimation Error [m]
51.84459	0.0002567334	0.002241837	0.44
Fit Method			Hantush Method



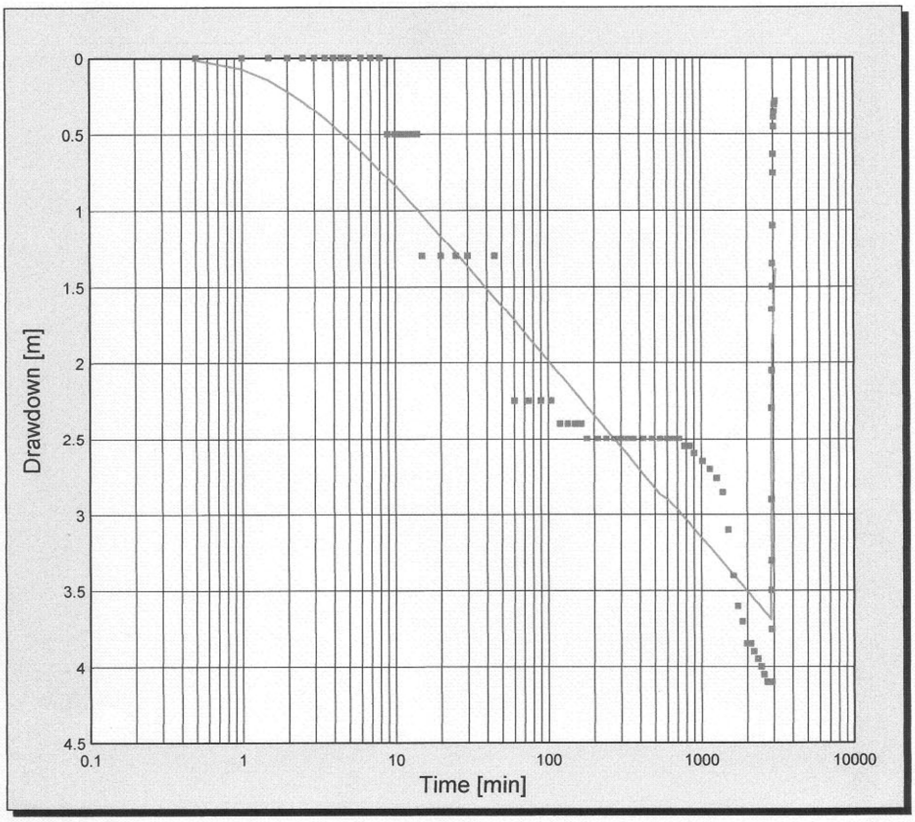
Yaboos Ya-7 well（Observation Well）

Pumping Test

Well Ident	Description		
Ya7-obs			
Obs. Well Distance [m]	Average Pump. Rate [m3/day]	Duration [min]	Initial Sat. Thickness [m]
71.00	13.93750	3090.000	

Results

Transmissivity [m2/day]	Storage Coefficient	Leakance [1/day]	Estimation Error [m]
191.6793	0.0001314423	1.307131E-11	0.51
Fit Method			Hantush Method

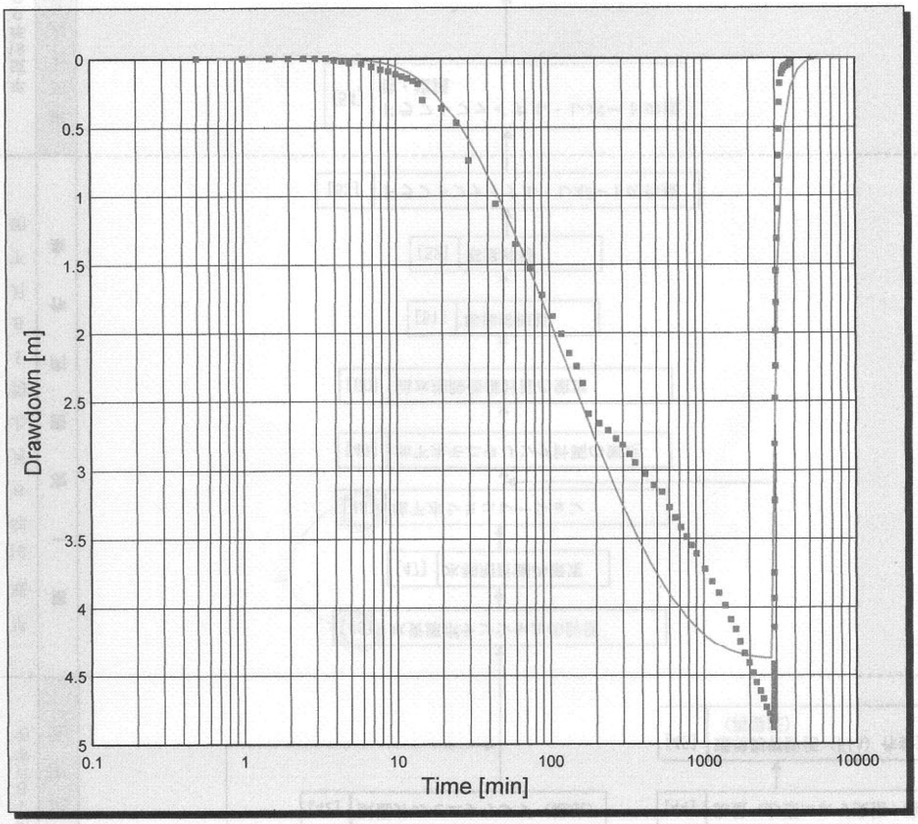


Yaboos Ya-8 well（Observation Well）

Pumping Test

Well Ident	Description		
Ya8-obs			
Obs. Well Distance [m]	Average Pump. Rate [m3/day]	Duration [min]	Initial Sat. Thickness [m]
102.00	16.11421	3780.000	

			Results
Transmissivity [m2/day]	Storage Coefficient	Leakance [1/day]	Estimation Error [m]
60.67812	0.0003752463	0.0008160109	0.35
Fit Method			Hantush Method



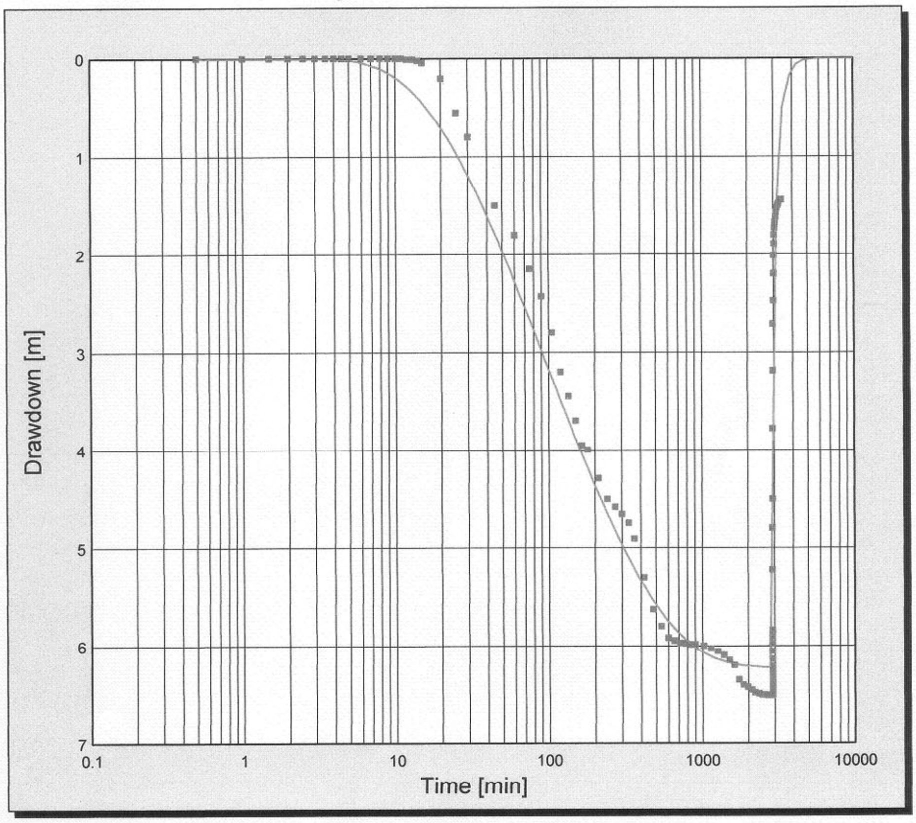
Yaboos Ya-9 well（Observation Well）

Pumping Test

Well Ident	Description		
Ya9-obs			
Obs. Well Distance [m]	Average Pump. Rate [m3/day]	Duration [min]	Initial Sat. Thickness [m]
80.00	13.60000	3360.000	

Results

Transmissivity [m2/day]	Storage Coefficient	Leakance [1/day]	Estimation Error [m]
38.55914	0.0002718612	0.0007040359	0.32
Fit Method			Hantush Method



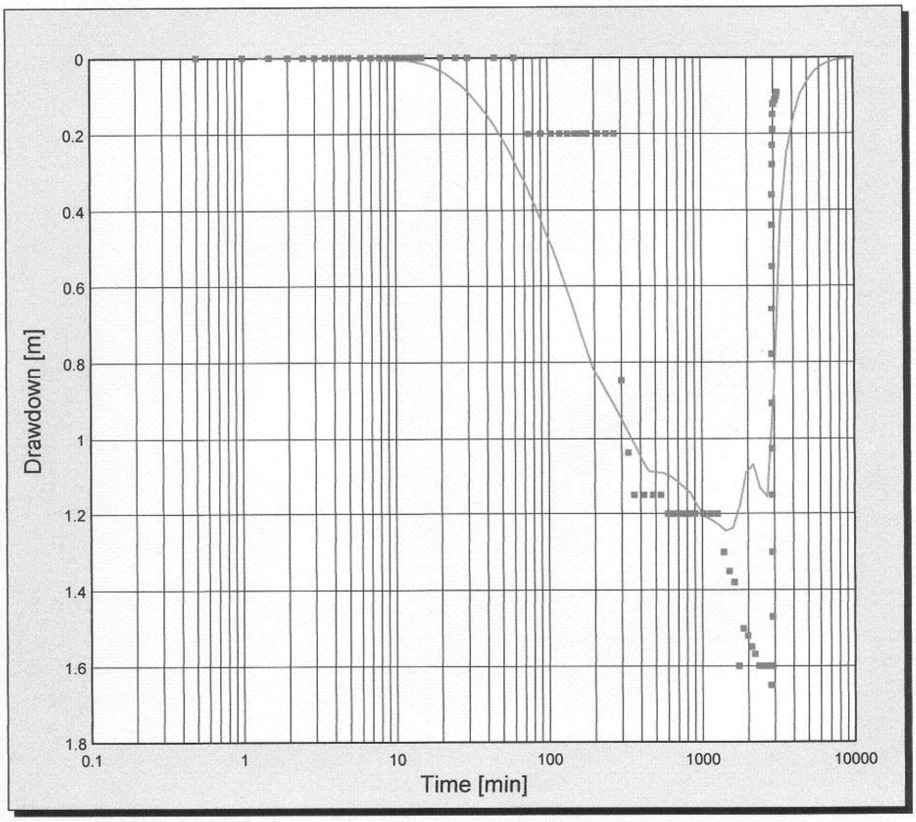
Yaboos Ya-10 well（Observation Well）

Pumping Test

Well Ident	Description		
Ya10-obs			
Obs. Well Distance [m]	Average Pump. Rate [m3/day]	Duration [min]	Initial Sat. Thickness [m]
165.00	4.360536	3180.000	

Results

Transmissivity [m2/day]	Storage Coefficient	Leakance [1/day]	Estimation Error [m]
62.75651	0.0002590501	0.0002191610	0.36
Fit Method			Hantush Method



Yaboos Ya-11 well（Observation Well）

Pumping Test

Well Ident	Description		
Ya11-obs			
Obs. Well Distance [m]	Average Pump. Rate [m3/day]	Duration [min]	Initial Sat. Thickness [m]
255.00	6.656074	3180.000	

			Results
Transmissivity [m2/day]	Storage Coefficient	Leakance [1/day]	Estimation Error [m]
92.03126	0.0004440598	2.154721E-19	0.23
Fit Method			Hantush Method