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HANOVER- REPORT ON AQUIFER TESTING OF MUNICIPAL BOREHOLES

by

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ABSTRACT

Two aquifer tests were carried out at Hanover to study the geo-hydrological conditions in the vicinity of the municipal production wellfield and to obtain an estimate of the long term sustainable abstraction rate of the groundwater resource.

The municipal production boreholes that supply the white population of Hanover tap the same fractured aquifer unit. It is recommended that the combined abstraction rate from the two production zones should not exceed 864 kl per day. Only two production boreholes, one in each zone, should be pumped simultaneously.

If the municipality keeps records of abstracted volumes and waterlevel fluctuations in boreholes on a regular basis, it will in due time be possible to make a better estimate of the exploitation potential of the production aquifer.

SAMEVATTING

Twee waterdraertoetse is uitgevoer te Hanover om die geohidrologiese kenmerke in die omgewing van die munisipale produksieboorgate te bestudeer en om 'n beraming van die langtermyn volgehoue lewering van die grondwaterbron te bepaal.

Alle produksieboorgate wat water aan die blanke dorp lewer is in dieselfde genate waterdraer geleë. Dit word aanbeveel dat die onttrekking uit die twee produksie - areas gesamentlik nie 864 kl/dag oorskry nie. Slegs twee boorgate, een in elke area, moet gelyktydig gepomp word.

'n Beter beraming van die ontginningspotensiaal van die grondwaterbron sal in die toekoms slegs moontlik wees indien die Munisipaliteit op 'n gereëlde basis rekord hou van beide die volumes water wat onttrek word en die watervlakskommelings in die boorgate.

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1 INTRODUCTION

Hanover's municipal water requirements are met from a number of boreholes and a fountain situated within the Municipal Allotment area. In March 1987, Bouwer and Viljoen (Eng.) made an application on behalf of the Municipality (Ref. V500/87/185), to the Department of Water Affairs for subsidy on a planned scheme to expand the existing wellfield. However, subsidy was not granted by the Department (Ref. B13/1/169) as Special Condition 9 of the subsidy requirements had not been fulfilled. This condition requires that prior to subsidy being granted a geohydrological investigation of the groundwater source(s) be carried out.

On instruction of the Director : Geohydrology (note dated 21/4/1987), a series of aquifer tests were conducted on the municipal production boreholes during August 1987. The purpose of the tests was to gain a better understanding of the geohydrological conditions in the immediate vicinity of the municipal abstraction boreholes.

2 BACKGROUND INFORMATION

2.1 LOCATION

Hanover is situated in the northern interior of the Cape Province between De Aar and Middelburg, some 60 kilometres south of De Aar. The town lies at an average elevation of 1400 m a.m.s.l.

2.2 POPULATION

The official population figures for the period 1904 to 1985 are presented in Table 1.

TABLE 1 : OFFICIAL POPULATION CENSUS STATISTICS
(1904 - 1985)

YEAR	WHITE	COLOURED	BLACK	TOTAL
1904	644	474	114	1232
1911	635	373	52	1060
1921	680	418	76	1174
1936	610	520	158	1288
1946	617	558	368	1543
1951	562	650	536	1748
1960	470	914	700	2084
1970	300	1149	1044	2493
1980	267	1398	1658	3323
1985	202	1349	1521	3072

Source : Department of Statistics.

The number of Whites has progressively declined over the last few decades, while the Non - white population has increased considerably. Bouwer and Viljoen (1986) made the following estimates of future population numbers :

YEAR	WHITE	COLOURED	BLACK	TOTAL
1987	248	1640	2270	4158
1997	225	1910	3200	5335
2002	214	2050	3730	5994

small decline 1980-85

do

3 MUNICIPAL WATER RESOURCES AND REQUIREMENTS

The municipal water supply is obtained from a number of boreholes and a fountain which are situated within the Allotment Area (Figure 1). The fountain is used for irrigation purposes in town.

The Whites and Non - whites are supplied separately from boreholes HR 1 to HR 6 and HR 7 to HR 9, respectively. The Municipality has no record of either water consumption nor abstraction. Bouwer and Viljoen (1986) have estimated the present municipal consumption and future requirements (Table 2).

TABLE 2 : PRESENT MUNICIPAL WATER CONSUMPTION AND FUTURE REQUIREMENTS (daily mean)

YEAR	WATER CONSUMPTION (kl/day)			
	WHITE	COLOURED	BLACK	TOTAL
1987	97	164	204	465
1997	118	248	384	750
2002	138	297	504	933

The estimated future population levels in Table 2 were used. Water consumption for the Whites was calculated assuming a per capita consumption of 220 l/ day. Also included in the White's consumption figures are the industrial and municipal water usage. The Coloured consumption for the years 1987,1997 and 2002 was calculated assuming per capita consumptions of 100, 130 and 145 l/day, respectively. Black consumption for the years 1987, 1997 and 2002 was calculated assuming per capita consumptions of 90, 120 and 135 l/ day.

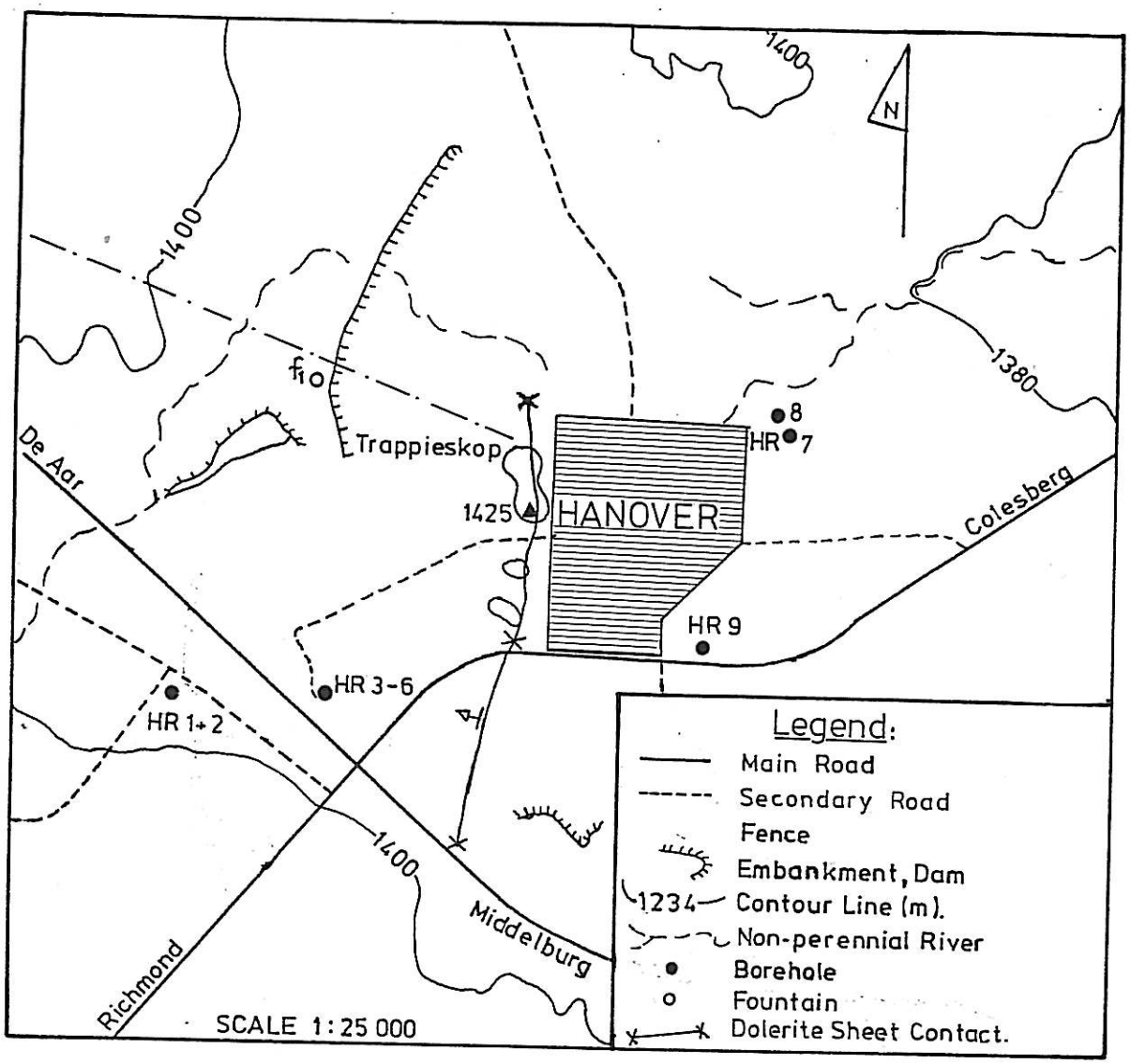


FIGURE 1 : HANOVER — LOCATION OF MUNICIPAL BOREHOLES

4 PREVIOUS GEOHYDROLOGICAL INVESTIGATIONS

Bouwer and Viljoen (1986) conducted tests on the municipal boreholes during July 1986. The relevant results of the tests are presented in Table 3. Unfortunately the tests were not performed according to standard aquifer testing procedures and as a result minimal information can be gleaned from the results.

TABLE 3 : RESULTS OF PUMP TESTS PERFORMED BY BOUWER & VILJOEN (ENG.) ON MUNICIPAL BOREHOLES.

TEST NUMBER 1

BOREHOLE NUMBER	YIELD (l/s)	DURATION TEST(hrs)	REST WATER - LEVEL (m)	TOTAL DRAWDOWN (m)
HR 3	1.4	13	no access	-
4	10.5	30	3.5	0.7
5	1.6	13	4.2	0.4

Note - Borehole HR 4 was initially pumped for 17 hrs, whereafter boreholes HR 3 to HR 5 were pumped simultaneously for 13 hours.

TEST NUMBER 2

BOREHOLE NUMBER	YIELD (l/s)	DURATION TEST(hrs)	REST WATER - LEVEL (m)	TOTAL DRAWDOWN (m)
HR 2	10.5	48	5.2	2.3

Mr Havenga of the Directorate : Geohydrology carried out a borehole survey within the Municipal Allotment Area. The pertinant results of the inventory are contained in Table 4.

TABLE 4 : INVENTORY OF MUNICIPAL GROUNDWATER ABSTRACTION POINTS

BOREHOLE NUMBER	DEPTH (m)	WATERLEVEL (m)	REPORTED YIELD(l/s)	CONDUCTIVITY (mS/m)	EQUIPMENT (Cyl.Size)
HR 1	37	6.49	15.2	-	WP(75 mm)
2	37	6.27	15.2	77	WP(75 mm)
3	30	4.24	-	-	WP(100mm)
4	17	-	15.2	75	M(75 mm)
5	30	-	15.2	-	WP(100mm)
6	30	4.59	15.2	-	Open
7	30	6.10	1.3	-	WP(75 mm)
8	46	-	5.0	-	M(50 mm)
9	21	6.10	-	90	M(50 mm)
F 1	-	-	10.1	-	Fountain

Note - WP = Windpump M = Mono Engine

5 DISCUSSION OF AQUIFER TEST RESULTS

Two constant rate discharge tests were carried out on the municipal boreholes during August 1987. The objectives of the testing programme were twofold :

(1) Assess the nature and extent of the fractured aquifer(s) in which the existing production boreholes are located.

(2) Determination of an optimal abstraction rate from the aquifer(s).

Initially a constant discharge test was performed on boreholes HR 4 and HR 6 simultaneously. However, after 400 minutes the test was halted as the yield of borehole HR 6 had declined by a third and the waterlevel was drawn down to the pump inlet at 12m. A second aquifer test lasting 72 hours was conducted on borehole HR 2. The recovery of the waterlevels was also monitored. The positions of the boreholes tested are indicated on Figure 2. Bouwer and Viljoen (Eng.) and the Municipality helped with the monitoring of waterlevels during testing. Full details of the results of the two aquifer tests are contained in Appendix 1. A summary of the relevant information of the aquifer tests is presented in Table 5.

TABLE 5 : SUMMARY OF AQUIFER TESTS RESULTS

TEST NUMBER 1 (Duration 400 min.)				
BOREHOLE NUMBER	YIELD (l/s)	REST WATER - LEVEL(m)	TOTAL DRAWDOWN(m)	WATERLEVEL DEFICIT (m)
HR 4 (P)	3.5	4.272	0.898	0.226
6 (P)	9.9*	4.410	11.500	0.246
1 (O)	-	6.206	0.023	-
2 (O)	-	6.017	0.019	-
3 (O)	-	4.100	0.142	0.133
5 (O)	-	4.551	0.898	0.225
TEST NUMBER 2 (Duration 72 hours)				
BOREHOLE NUMBER	YIELD (l/s)	REST WATER - LEVEL(m)	TOTAL DRAWDOWN(m)	WATERLEVEL DEFICIT (m)
HR 2 (P)	3.5	6.042	2.155	0.030
1 (O)	-	6.234	1.821	0.043
3 (O)	-	4.129	0.199	0.018
4 (O)	-	4.302	0.193	0.034
5 (O)	-	4.589	0.171	0.020
6 (O)	-	4.442	0.175	0.019

Note - P = Pumped Borehole O = Observation borehole.

* Ater 400 minutes the waterlevel dropped to the pump intake and the yield declined rapidly to 3.4 l/s.

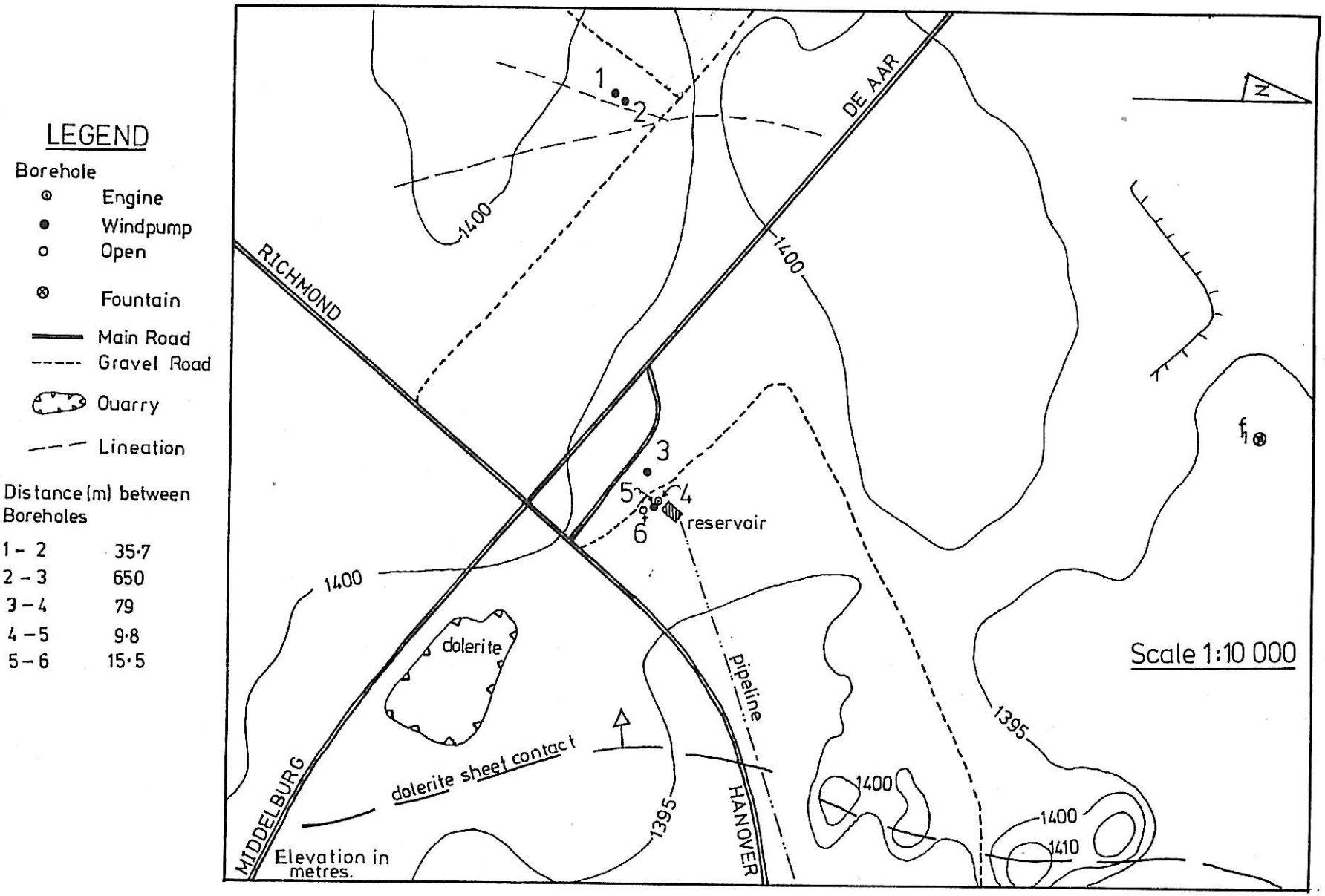


FIGURE 2 : HANOVER - PLAN INDICATING POSITION OF MUNICIPAL BOREHOLES PUMP TESTED.

The hydraulic characteristics of the aquifer unit are presented in Table 6. The following was learned from the aquifer testing programme :

(1) Boreholes HR1 and HR2 are situated within the same fractured aquifer unit as boreholes HR 3 to HR 6. Pumping at HR 2 indeed produced a drawdown in boreholes HR 3 to HR 6 (Table 5).

TABLE 6 : HYDRAULIC CHARACTERISTICS OF THE AQUIFER

BOREHOLE NUMBER	METHOD ANALYSIS	TEST 1 TRANSMISSIVITY (m /day)	STORAGE	REMARK
HR5		T1 439	0.038	T2<T1
	Departure	T2 391	-	Semi - Imp.
HR3	Curve	T1 516	0.014	Boundary
		T2 360	-	

BOREHOLE NUMBER	METHOD ANALYSIS	TEST 2 TRANSMISSIVITY (m /day)	STORAGE	REMARK
HR1	Boulton	TA 211	0.00002	B = 375m
		TY 195	0.0051	
HR2	Boulton	TA 212	-	
		TY 195	-	
HR3	Theis	603	0.0069	

(2) The transmissivity of the fractured aquifer is higher in the vicinity of boreholes HR 3 to HR 6 than in the vicinity of boreholes HR 1 and HR 2 (Table 6). This is probably due to better developed fractures in this particular area.

(3) The waterlevel deficits calculated following recovery indicate more favourable storage conditions in the proximity of boreholes HR 1 and HR2 (Table 5).

(4) Aquifer test 1 indicated the presence of boundary conditions in the vicinity of boreholes HR 3 to HR 6 (Table 5). Semi - impervious boundary conditions are commonly encountered in Karoo fractured aquifers associated with dolerite intrusives.

(5) During test 1 the yield of borehole HR 6 declined rapidly after a drawdown of approximately 0.9m was reached (Table 5). This is probably the depth of the main water interception (5.0m) at this locality. The yield stabilised at about 3.5 l/s. During the test carried out by Bouwer and Viljoen (Table 3) the waterlevel was not drawn down to this critical level of 5m.

(6) During test 1 the waterlevel in the quarry (Figure 2) dropped by approximately 20 mm. Dumping of refuse in the quarry poses a pollution hazard to the groundwater resource.

It is impossible to estimate the exploitation potential of the aquifer unit as no information concerning the storage, extent of the aquifer, boundary conditions, groundwater interceptions and recharge characteristics are avaliable. Furthermore, no record of abstraction from municipal boreholes has been kept.

However, an estimate of the optimal rates of abstraction and distribution of boreholes can be made from the aquifer tests. Based on the above observations it is recommended that :

(1) The combined yield of the boreholes should never be in excess of 10 l/s.

(2) A greatest number of boreholes should be pumped at the lowest yields practically possible to more evenly distribute drawdown within the aquifer. Furthermore, abstraction points should be as widely located as possible within the aquifer. It is proposed that a single borehole from each of the two groups of boreholes (HR 1 to HR 2 and HR 3 to HR 6), be utilised simultaneously.

6 CONCLUSIONS AND RECOMMENDATIONS

The municipal production boreholes are situated in the same fractured aquifer unit. In order to optimally exploit the groundwater resources it is proposed that :

(1) A single abstraction point located within each of the two groups of production boreholes be utilised simultaneously (Chapter 5).

(2) The abstraction from the aquifer should never exceed 864 kl (10 l/s) per day.

(3) The Municipality should keep record of waterlevels and abstraction from individual boreholes. This information will in due time enable the calculation of the exploitation potential of the aquifer unit.

(4) The municipality should seriously consider incorporating the fountain water into the municipal water supply.

REFERENCES

Bouwer and Viljoen (Eng.), 1986 : Hanover - Water Voorsiening, Technical Report U500/86/422.

APPENDIX I

AQUIFER TEST DATA

CONSTANT DISCHARGE AQUIFER TEST NUMBER 1
(DRAWDOWN)

TECHNICAL SPECIFICATIONS : Borehole No - HR 4 HR 6
Pump Type - Mono 75mm Mono 50mm
Depth of Inlet - 12m 12 m
Water Discharge - Reservoir Reservoir

DATE : 07-08-1987
TIME : Start - 09h15 Completion - 15h33
DURATION OF TEST : 400 min.
FLOWMETER : HR 6 Start - 9.8 l/s End - 3.4 l/s
HR 4 Start - 3.7 l/s End - 3.6 l/s
TOTAL QUANTITY PUMPED : 221kl (HR6) + 85kl = 306 kl

TIME	WATERLEVEL (m)						YIELD (l/s)	
(min)	HR4	HR6	HR5	HR3	HR2	HR1	HR4	HR6
0.25	-	-	4.555	-	-	-	-	-
0.50	-	-	4.556	-	-	-	-	-
0.75	-	-	4.558	-	-	-	-	-
1	-	-	4.559	-	-	-	-	-
1.5	-	-	4.565	-	-	-	-	-
2	-	-	4.575	-	-	-	-	-
2.5	-	-	4.577	-	-	-	-	-
3	-	-	4.580	-	-	-	-	-
4	-	-	4.580	-	-	-	-	-
5	-	-	4.585	-	-	-	-	-
6	-	-	4.589	4.102	-	-	-	-
8	-	-	4.593	4.104	-	-	-	-
10	-	-	4.601	4.106	-	-	-	-
12	4.332	-	4.606	4.108	-	-	-	-
15	-	4.570	4.616	4.109	-	-	-	9.8
18	4.356	-	4.631	4.111	-	-	3.7	-
21	-	4.595	4.636	4.115	-	-	-	-
25	4.369	4.602	4.652	4.118	-	-	-	-
30	4.394	4.616	4.666	4.120	-	-	3.6	10.0
35	4.407	4.637	4.682	4.122	-	-	-	-
40	4.422	4.650	4.700	4.124	-	-	-	-
50	4.451	4.680	4.729	4.126	-	-	-	-
60	4.484	4.710	4.758	4.128	-	-	3.5	10.0
70	4.509	4.741	4.786	4.131	6.017	6.215	-	-
85	4.551	4.785	4.830	4.135	-	-	-	-
100	4.595	4.820	4.875	4.143	-	-	3.6	10.2
120	4.642	4.862	4.923	4.149	6.017	6.218	-	-
140	4.685	4.903	4.966	4.158	-	-	-	-
160	4.722	4.935	4.995	4.165	-	-	-	-
185	4.761	4.970	5.030	4.172	6.027	6.218	3.5	10.0
210	4.810	5.026	5.080	4.180	-	-	-	-
240	4.869	5.095	5.139	4.190	6.029	6.220	-	-
270	4.940	5.165	5.213	4.199	-	-	-	-
300	4.994	5.230	5.270	4.207	6.031	6.222	3.5	10.0
350	5.110	5.265	5.366	4.222	6.034	6.226	3.5	5.6
400	5.170	11.5	5.449	4.242	6.036	6.229	3.5	3.4
RWL	4.272	4.410	4.551	4.100	6.016	6.215		

Note - the conductivity of both boreholes remained throughout the test at 0.90 mS/cm

CONSTANT DISCHARGE AQUIFER TEST NUMBER 2
(DRAWDOWN)

TECHNICAL SPECIFICATIONS : Borehole No - HR 2
Pump Type - Mono 75 mm.
Depth of Inlet - 27m
Water Discharge - 90 m onto ground.
DATE : 19/08/87 -22/08/87
TIME : Start - 09h30 Completion - 09h30
DURATION OF TEST : 72 hours.
FLOWMETER : HR 2 Start - 9.0 l/s End - 9.6 l/s
TOTAL QUANTITY PUMPED : 2436 kl.

TIME	WATERLEVEL (m)						YIELD(l/s)	
(min)	HR2	HR1	HR3	HR4	HR5	HR6	HR2	REMARKS
0.25	-	6.611	-	-	-	-	-	
0.50	7.163	6.811	-	-	-	-	-	
0.75	-	6.891	-	-	-	-	-	
1	7.353	6.965	-	-	-	-	-	
1.5	7.454	7.110	-	-	-	-	-	
2	7.498	7.190	-	-	-	-	-	
2.5	7.536	7.250	-	-	-	-	-	
3	7.591	7.292	-	-	-	-	-	
4	7.615	7.356	-	-	-	-	-	
5	7.627	7.406	-	-	-	-	-	
6	7.655	7.443	-	-	-	-	-	
8	7.675	7.496	-	-	-	-	-	
10	7.675	7.545	-	-	-	-	-	
12	7.690	7.546	-	-	-	-	-	
15	7.705	7.569	-	-	-	-	-	
18	7.727	7.596	-	-	-	-	-	
21	7.771	7.631	-	-	-	-	-	
25	7.793	7.656	4.127	4.305	4.589	4.442	9.1	
30	7.805	7.660	-	-	-	-	-	
35	7.806	7.665	-	-	-	-	-	
40	7.810	7.677	-	-	-	-	-	
50	7.811	7.685	4.125	4.306	4.589	4.443	9.1	
60	7.891	7.741	-	-	-	-	-	
70	7.901	7.736	-	-	-	-	-	
85	7.732	7.623	4.130	4.308	4.590	-	9.1	
100	7.687	7.583	-	-	-	4.441	-	
120	7.682	7.584	-	-	-	-	-	
140	7.595	7.701	-	-	-	-	-	*discharge
160	7.845	7.712	4.133	4.308	4.591	-	9.6	pipe bursts.
185	7.873	7.734	-	-	-	4.442	-	water disch-
210	7.880	7.736	-	-	-	-	9.6	arged 90m
240	7.875	7.744	4.133	4.305	4.591	4.445	9.6	from pump
270	7.892	7.752	-	-	-	-	-	onto ground.
300	7.895	7.755	4.140	4.312	4.591	4.446	-	
350	7.921	7.784	4.142	4.312	4.594	4.452	9.6	
400	7.928	7.799	4.146	4.320	4.596	4.452	9.6	
500	7.960	7.830	4.151	4.323	4.599	4.454	-	
600	8.135	7.954	4.156	4.327	4.607	4.460	9.5	
700	8.161	7.981	4.165	4.342	4.613	4.464	9.6	
850	8.148	7.834	4.175	4.435	4.623	4.474	9.6	* pump off
1000	8.157	7.829	4.185	4.354	4.627	4.480	9.6	for 4 min.

TIME	WATERLEVEL (m)						YIELD(l/s)	
(min)	HR2	HR1	HR3	HR4	HR5	HR6	HR2	
1200	8.102	7.947	4.193	4.362	4.642	4.494	9.6	
1400	8.076	7.934	4.206	4.376	4.649	4.501	9.6	
1600	8.025	7.897	4.215	4.377	4.657	4.510	9.6	
1850	7.942	7.864	4.223	4.378	4.666	4.521	-	
2100	8.125	7.978	4.236	4.403	4.677	4.531	9.6	
2400	7.985	7.986	4.251	4.413	4.693	4.548	9.6	
2700	8.170	8.020	4.264	4.430	4.704	4.556	9.6	
3000	8.182	8.030	4.277	4.436	4.713	4.570	-	
3400	8.090	7.962	4.291	4.451	4.731	4.585	-	* pump off
3800	8.154	8.020	4.307	4.463	4.747	4.600	-	for 7 min
4320	8.197	8.055	4.328	4.498	4.760	4.617	9.5	

Note - Conductivity of groundwater increased from 0.94 mS/cm to 0.97 mS/cm.

CONSTANT DISCHARGE AQUIFER TEST NUMBER 2
(RECOVERY)

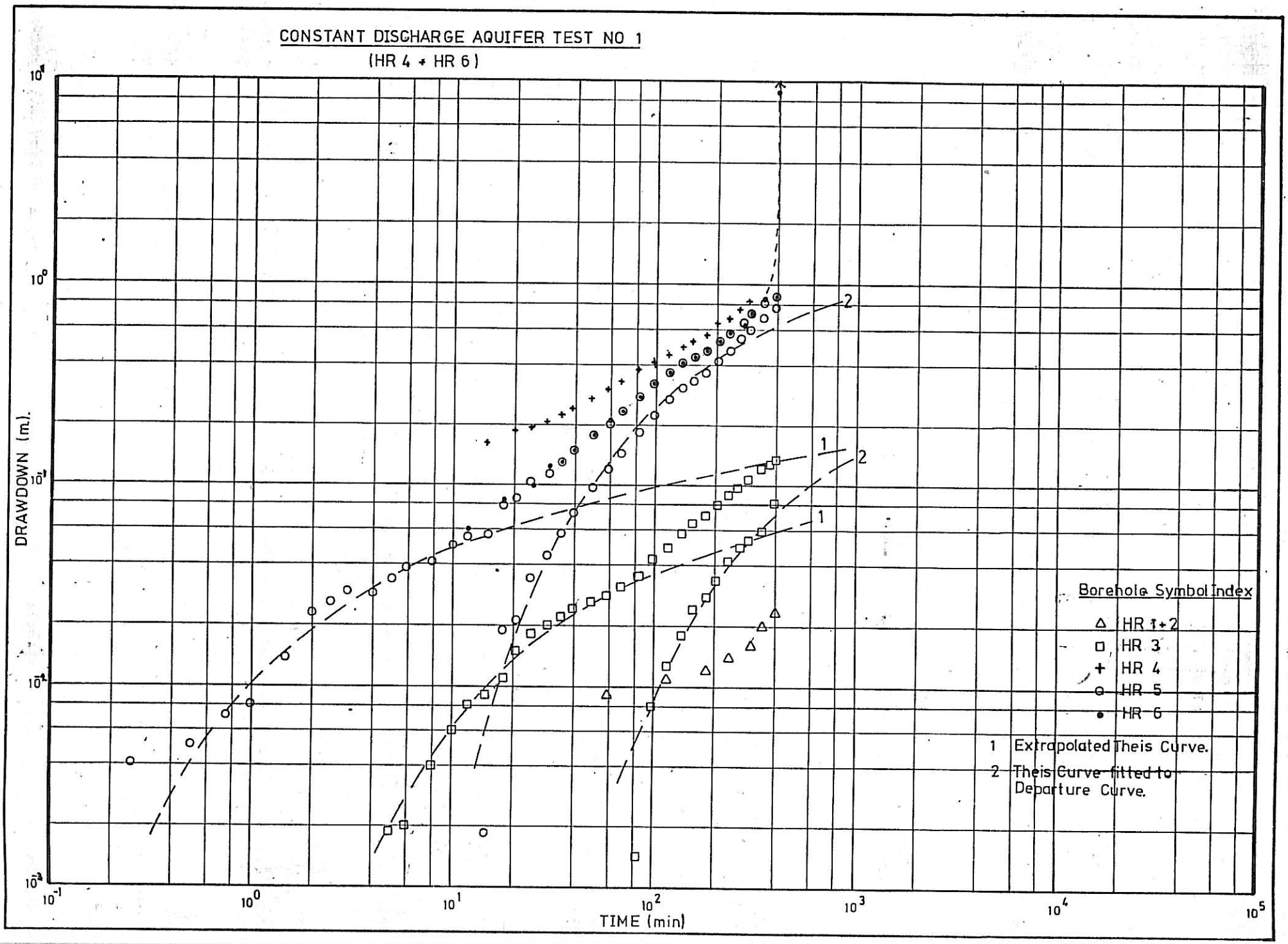
DATE : 22/08/87 - 25/08/87
TIME : Start - 09h30 Completion - 09h30
DURATION OF TEST : 72 hours.

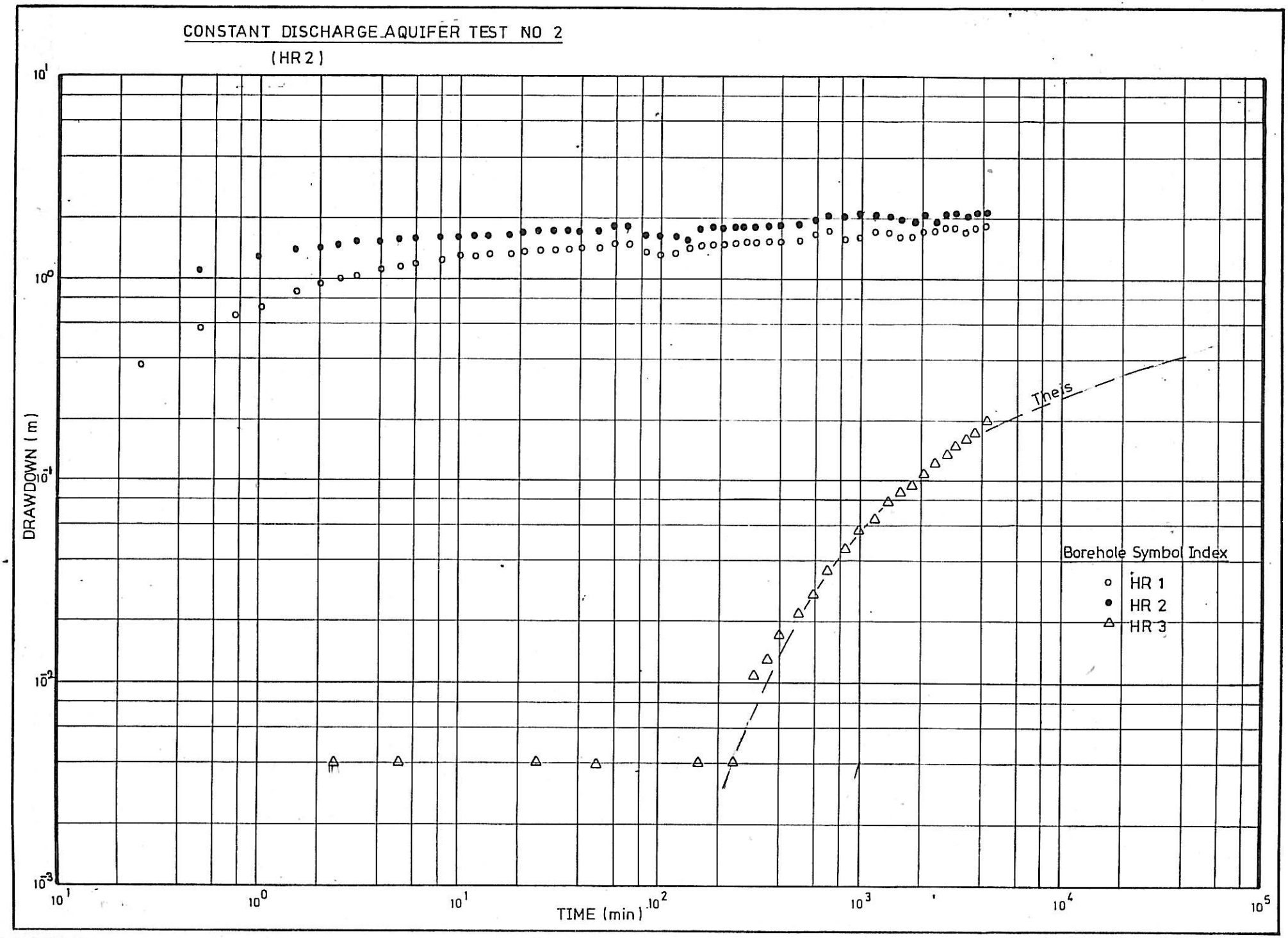
TIME	WATERLEVEL (m)					
(min)	HR2	HR1	HR3	HR4	HR5	HR6
0.25	-	-	-	-	-	-
0.50	6.671	7.381	-	-	-	-
0.75	6.550	-	-	-	-	-
1	-	6.811	-	-	-	-
1.5	-	6.733	-	-	-	-
2	6.478	6.720	-	-	-	-
2.5	-	6.710	-	-	-	-
3	-	6.704	-	-	-	-
4	-	6.698	-	-	-	-
5	-	6.691	-	-	-	-
6	6.466	6.688	-	-	-	-
8	-	6.680	-	-	-	-
10	-	6.674	-	-	-	-
12	-	6.665	-	-	-	-
15	6.457	6.651	-	-	-	-
18	6.433	6.644	-	-	-	-
21	6.424	6.631	-	-	-	-
25	6.412	6.620	-	-	-	-
30	6.405	6.610	-	-	-	-
35	6.396	6.601	-	-	-	-
40	6.390	6.594	4.322	4.479	4.760	4.613
50	6.374	6.577	-	-	-	-
60	6.367	6.574	-	4.490	4.760	4.613
80	6.354	6.558	4.316	4.481	4.760	4.613
100	6.338	6.544	4.312	4.484	4.760	4.614
120	6.327	6.531	4.312	4.487	4.760	4.615
140	6.320	6.525	4.310	4.487	4.760	4.615
160	6.310	6.517	4.308	4.487	4.760	4.615
185	6.298	6.507	4.305	4.484	4.760	4.615

TIME	WATERLEVEL (m)					
(min)	HR2	HR1	HR3	HR4	HR5	HR6
210	6.285	6.489	4.303	4.480	4.760	4.612
250	6.275	6.482	4.303	4.480	4.760	4.612
300	6.266	6.471	4.303	4.480	4.753	4.608
350	6.254	6.460	4.297	4.473	4.753	4.607
400	6.246	6.452	4.295	4.468	4.751	4.605
500	6.232	6.437	4.292	4.468	4.748	4.601
600	6.217	6.424	4.288	4.468	4.746	4.597
700	6.204	6.416	4.280	4.464	4.739	4.593
850	6.202	6.402	4.275	4.454	4.736	4.591
1000	6.182	6.389	4.270	4.442	4.727	4.582
1200	6.160	6.376	4.256	4.435	4.715	4.567
1400	6.154	6.362	4.241	4.430	4.710	4.561
1600	6.147	6.352	4.238	4.425	4.700	4.550
1850	6.136	6.339	4.228	4.407	4.691	4.544
2100	6.129	6.332	4.216	4.401	4.680	4.535
2400	6.117	6.332	4.216	4.395	4.672	4.522
2700	6.110	6.314	4.194	4.380	4.659	4.512
3000	6.103	6.305	4.186	4.370	4.648	4.501
3400	6.091	6.295	4.174	4.354	4.635	4.489
3800	6.078	6.284	4.163	4.340	4.625	4.478
4320	6.072	6.277	4.147	4.336	4.609	4.461

APPENDIX II

AQUIFER TEST - TIME vs DRAWNDOWN CURVE


CONSTANT DISCHARGE AQUIFER TEST NO 1
(HR 4 + HR 6)
DRAWDOWN (m).
TIME (min)
Borehole Symbol Index
HR 1+2
HR 3
HR 4
HR 5
HR 6
1 Extrapolated Theis Curve.
2 Theis Curve fitted to Departure Curve.


CONSTANT DISCHARGE AQUIFER TEST NO 2
(HR2)
DRAWDOWN (m)
TIME (min)
Theis
Borehole Symbol Index
HR 1
HR 2
HR 3

COMMENT ON Gh 3552 - HANOVER
(aquifer testing of municipal boreholes)

I read the above report and could make the following remarks.

1. Aquifer test no. 1, pumping boreholes HR 4 and HR 6.

   (a) plotted time-drawdown data of two pumped boreholes (HR 4 and HR 6) show that data points approach the straight lines (on log-log paper) which is a typical linear flow or fracture flow condition in the jointed-fissured rock aquifer. In this situation groundwater flow takes place along the fissures-fractures zone towards the pumping area.

   (b) The early time-drawdown curves of HR 3 and HR 5 (observation boreholes) follows the Theis' type curve which indicates a radial flow condition in the jointed-fissured rock aquifer at the early stage of pumping. The later data deviates from theis' curve and follows on a straight line which again indicating a linear (fracture) flow condition similar to pumped boreholes.

   This can also be concluded that deviation of time-drawdown data from theis' curve is due to a low permeability of some joints-fractures which limits the rock aquifer system at this particular pumping site.

   (c) borehole HR 6 overpumped and some fractures/fissures which possibly have high storage potential were dewatered and consequently pumping rate declined after certain time and pumping level reached close to pump inlet.

   (d) borehole HR 6 was pumped with greater rate, 10 ℓ/s (2,85 times greater than HR 4) and showed less or no effect on pumping rate at HR 4 where the pumping rate was fairly constant (3,5 ℓ/s). This indicates that in spite of common joints-fractures system in which HR 4 and HR 6 were intersected, these are some other joints-fractures which contribute water to pumping borehole, HR 6.

   (e) care should be taken in analysing aquifer test data for T and S from HR 3 to HR 6 which drawdown at each borehole affected by two pumping rates (two pumped boreholes). In a multiple well systems when two or more boreholes are operating, the drawdown at any point in the area of influence of these boreholes equals to the sum of the drawdowns caused by each pumped borehole individually.

(f) hydraulic connection does exist between two well field areas, HR 1-2 and HR 3-6. This noticed during pumping HR 4 and HR 6 and observed some drawdown in HR 1 and HR 2.

(g) in general, linear flow condition leads to dewatering fractures/joints with time.

2. Aquifer test no. 2, pumping borehole HR 2.

(a) plotted time-drawdown data of pumped borehole (HR 2) and observation borehole (HR 1) lie on Boulton's type curves. This indicates that well developed joints/fractures in the rock aquifer act as an unconfined aquifer with gravity drainage. A relatively high specific capacity (Q/D) of 4,45 ℓs/m was obtained at HR 4 after 3 -day pumping with no effect of any low permeable zone on deviating drawdown data from matched curves. This also suggests that geohydrological condition is much better at this area compared with area of test no. 1 and 22% of the total drawdown at HR 2 was recovered after 12 hours termination of pumping.

(b) observation boreholes HR 3 to HR 6 showed some effects from pumped borehole HR 2. This reveals that two pumping sites 1 and 2 are hydraulically connected through the joints-fractures system.

3. Conclusions and recommendations

(a) as it was stated by mr. Woodford, the municipal production boreholes are situated in jointed-fractured rock aquifer which is hydraulically connected.

(b) groundwater abstraction can be made from two well points, HR 1 - HR 2 and HR 3 & HR6 in the following way

- simultaneous pumping of HR 4 and HR 6 with 3,5 ℓ/s and 2,5 ℓ/s respectively for a period of 12 hrs per day.

- pumping HR 2 at a rate of 7 ℓ/s for a period of 12 hrs per day.

The above pumping schedule provides municipality with 561,6 (6,5 ℓ/s)m^3/ day of water supply.

(c) a deficit of 4,5 ℓ/s (11-6,5) of water supply to meet the municipal demands up to year 2002 needs to be met from groundwater by drilling some minimum 4 additional boreholes yielding 2 to 3 ℓ/s each, within the two well field points.

(d) in my view there is a great groundwater potentiasl in the area that can meet the municipal watersupply demands up to year 2002. This due to well developed joints and fractures in the rock aw-quifer and possibly better aquifer recharge during rainy poeriod where groundwater level is relatively shallow (± 6 metres).

(e) related geohydrological information needs to be collected for better groundwater resources assesment and future studies of the jointed-fractured rock aquifer in this area. This information are as follows:

- record of local rainfall
- record of groundwater abstraction
- monitoring groundwater levels
- record of spring flow (to find relationship between rainfall and recharge), installation of 90° V-notch is necessary.

(f) re-testing borehole HR 8 and monitorin HR 7 as an observation borehole (24 hrs test is sufficient).

M. Fayazi

16.11.1987.