THE GEOHYDROLOGY OF THE CROCODILE RIVER VALLEY (WESTERN TRANSVAAL) G.W.S., THABAZIMBI DISTRICT

REPORT No.: Gh 3198

BY

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DIVISION GEOHYDROLOGY
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SUMMARY

The alluvial deposits of the Crocodile River Valley in the study area encompass an area of some 74,3 km^2. Four distinct sub-areas, each bearing a relationship to the geology of the area, and each exhibiting the differing geohydrological nature of the aquifer, can be delineated. Field observations, exploration drillings and aquifer tests provided information concerning the geohydrological nature of the aquifer, and enabled the author to determine the groundwater potential of each of the sub-areas to be as follows:

sub-area A:	$0,33 \times 10^6$ m^3
sub-area B:	$10,12 \times 10^6$ m^3
sub-area C:	$20,02 \times 10^6$ m^3
sub-area D:	$1,28 \times 10^6$ m^3
TOTAL:	$31,75 \times 10^6$ m^3

Furthermore, river-stage and observation-well data indicate that groundwater-levels are controlled primarily by river-stage fluctuations and abstraction of groundwater for irrigational purposes. An investigation of the nature of the river-bed revealed the presence of an impermeable clay layer at depths varying from 2 metres to 8 metres below the surface of the river-bed, being overlain by unconsolidated and saturated coarse quartzitic sands and gravels. It is suggested that the river be regarded as a semi-pervious boundary only partly penetrating the adjacent alluvial aquifer.

It is further observed that major recharge of the alluvial aquifer coincides with, and follows, extensive flooding in the valley. Recharge from precipitation, and bedrock-recharge, are deemed minor influences to recharge from the river.

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ANNEX IV contd.

Sample Bh. No	pH	Cond mS/m	TDS mg/l	HCO$_3$		Cl		SO$_4$		Ca		Mg		Na + K	
				mg/l	meq/l	mg/l	meq/l	mg/l	meq/l	mg/l	meq/l	mg/l	meq/l	mg/l	meq/l
DF 17	7,6	96,9	687,21	348,13	5,71	117,64	3,32	19,18	0,40	49,20	2,46	48,70	4,01	92,18	3,97
DF 21	7,4	82,6	690,95	436,90	7,17	25,62	0,72	13,79	0,29	42,02	2,10	19,51	1,60	133,97	5,80
HD 1	7,7	97,5	680,20	324,72	5,33	92,01	2,60	59,35	1,24	77,52	3,87	48,70	4,01	63,88	2,72
HD 2	7,9	134,9	981,45	469,65	7,70	189,84	5,36	35,97	0,75	63,57	3,17	47,47	3,90	166,06	7,16
HD 3	7,1	60,0	442,92	251,83	4,13	42,43	1,20	19,57	0,41	37,25	1,86	30,06	2,47	50,94	2,18
HD 10	7,5	682,7	4041,12	420,88	6,90	2088,98	58,93	99,57	2,07	203,44	10,15	141,00	11,60	1079,73	46,92
OK 4	7,8	332,8	2246,40	662,28	10,86	661,76	18,67	205,80	4,28	182,89	9,13	189,27	15,57	298,07	12,88
OK 7	8,0	275,2	1930,58	597,04	9,79	533,10	15,04	185,10	3,85	118,93	5,93	92,71	7,63	378,64	16,37
OK 9	7,9	118,0	855,26	326,57	5,36	115,03	3,24	84,14	1,75	127,29	6,35	46,87	3,86	77,36	3,31
OK 10	8,1	218,2	3250,27	2426,24	39,	143,13	4,04	121,27	2,52	46,21	2,31	58,02	4,77	437,37	18,96
OK 11	8,0	224,0	1390,97	435,59	7,21	449,29	12,67	64,31	1,34	140,19	6,99	137,29	11,29	136,44	5,91
OK 20	8,0	281,6	1723,25	462,18	7,58	471,37	13,30	152,84	2,62	137,26	6,85	122,65	10,09	318,62	13,78
OK 40	7,9	96,0	697,22	399,63	6,56	94,28	2,66	6,77	0,14	27,37	1,37	57,65	4,74	102,69	4,44
OK 42	7,9	140,0	993,38	417,32	6,85	169,69	4,79	90,91	1,89	111,10	5,54	68,57	5,64	106,92	4,60
OK 44	8,0	101,0	775,70	414,43	6,80	80,59	2,27	48,46	1,01	93,83	4,68	55,94	4,60	63,99	2,74
OK 71	8,0	190,0	1279,14	455,28	7,47	254,31	7,17	128,58	2,68	96,75	4,83	101,83	8,38	179,40	7,74
LP 2	8,0	108,0	774,24	334,82	5,49	102,47	2,89	89,96	1,87	79,45	3,96	59,51	4,89	80,41	3,44
LP 4	7,8	74,4	524,85	196,15	3,22	73,06	2,06	93,79	1,95	52,46	2,62	29,19	2,40	72,71	3,04
LP 13	7,7	82,7	587,84	274,98	4,51	91,44	2,58	64,31	1,34	47,12	2,35	41,80	3,44	64,12	2,74
LP 29	7,4	82,8	527,82	236,30	3,88	132,41	3,73	7,59	0,16	36,78	1,84	42,13	3,46	67,78	2,89
LP 31	7,2	255,2	1487,18	219,19	3,60	584,87	16,49	239,81	4,99	170,91	8,53	148,08	12,18	113,21	4,82
LP 39	7,8	114,9	908,04	485,55	7,96	108,39	3,06	64,76	1,35	83,22	4,15	63,23	5,20	82,54	3,54
LP 51	8,1	175,0	1390,58	619,02	10,15	185,22	5,22	170,72	3,55	102,49	5,11	80,84	6,65	190,20	8,24
G 32651	7,4	224,7	1248,11	149,01	2,44	517,13	14,58	213,11	4,44	49,92	2,49	145,29	11,95	164,89	7,08
BL 5	7,3	89,5	561,38	249,97	4,10	83,00	2,34	22,37	0,47	120,36	6,01	24,77	2,04	24,36	1,01
BL 7	7,2	74,6	545,60	320,19	5,25	40,58	1,14	17,31	0,36	122,50	6,11	18,00	1,48	10,04	0,40
BL 11	7,7	219,3	1501,06	473,03	7,76	311,38	8,78	237,62	4,95	137,73	6,87	116,72	9,60	175,49	7,52
BL 13	7,6	232,3	1654,63	637,69	10,46	285,00	8,04	191,05	3,98	162,56	8,11	147,22	12,11	157,97	6,69
BL 28	7,5	96,2	661,49	280,58	4,60	86,28	2,43	83,27	1,73	66,31	3,31	43,00	3,54	89,63	3,75
BL 33	7,8	145,7	977,25	417,64	6,85	183,32	5,17	85,66	1,78	66,88	3,34	79,65	6,55	105,99	4,51
BL 52	7,7	175,6	1228,78	423,78	6,95	287,89	8,12	110,68	2,30	153,10	7,64	99,87	8,22	96,65	3,97
G 32653	7,3	84,2	591,28	296,41	4,86	72,18	2,04	38,04	0,79	120,31	6,00	23,27	1,91	24,78	1,05

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SUMMARY contd.

Since the commissioning of the upstream reservoirs, the monthly discharge of the river has seldom dropped below 2×10^6 m³, and it is observed that this reservoir-influenced flow in the river serves to maintain the groundwater-level in the aquifer in close proximity to the river.

The hydraulic parameters of the alluvial aquifer, as determined from aquifer-test analyses, can be summarised as follows:

ave. transmissivity (T): ranges from 300 to 600 m²/day
lowest = 57 m²/day
highest = 1073 m²/day

ave. storage coefficient (S_y = specific yield) for unconfined conditions: $5{,}88 \times 10^{-2}$

ave. storage coefficient (S) for semi-unconfined conditions: $6{,}0 \times 10^{-3}$

ave. storage coefficient (S) for semi-confined conditions: $3{,}9 \times 10^{-4}$

It was further observed that, in certain localities, the aquifer undergoes a transition from semi-unconfined to unconfined conditions with pumping.

Finally, the chemical analyses of groundwater samples revealed the similar composition of especially the alluvial groundwater to that of the river, this relationship becoming less evident in those samples obtained from boreholes tapping the bedrock aquifers adjacent to the alluvial aquifer and far removed from the river.

TABLE OF CONTENTS

contd. overleaf

TABLE OF CONTENTS contd.

LIST OF FIGURES

LIST ....../(ii)

LIST OF FIGURES contd.

ENCLOSURE

LIST OF TABLES

LIST OF ANNEXES

ANNEX I : Groundwater-level measurements, May 1980.

ANNEX II : Periodical water-level measurements.

ANNEX III : Data obtained from aquifer tests, and analysis thereof.
    ANNEX III.1 : Aquifer test on borehole G32647. 2427 CD21
    ANNEX III.2 : Aquifer test on borehole G32648. CD28
    ANNEX III.3 : Aquifer test on borehole G32655.
    ANNEX III.4 : Re-analysis of BRGM aquifer test on borehole LP31.
    ANNEX III.5 : Re-analysis of BRGM aquifer test on borehole OK39.

ANNEX IV : Chemical analyses.

1. INTRODUCTION:

The object of this investigation can be summed up as follows:

- i) to evaluate the geohydrological potential of the alluvial aquifer adjoining the river, and
- ii) to determine the geohydrological relationship between surface and groundwater with a view to
- iii) the effective management and control of the combined system.

Under the latter is also understood the optimum development andutilisation of the respective resources as a single combined source.

The field programme commenced in March 1980, was completed in November of the same year, and entailed the following:

- i) a detailed borehole survey,
- ii) field observation and mapping of the extent and occurrence of the alluvial deposits and related geohydrological features;
- iii) the assimilation of water level data and the levelling of boreholes;
- iv) the collection of groundwater and surface water samples for chemical analysis,
- v) a geohydrological investigation of the nature of the river bed,
- vi) the drilling of exploration boreholes to gain geological information concerning the nature of the aquifer, to be used in the execution of aquifer tests, and subsequently to be used as long-term groundwater level observation wells.

1.1 THE STUDY AREA:

1.1.1 Location:

The area under study forms the valley of the Crocodile River immediately south of Thabazimbi in the Western Transvaal, and lies between latitudes 24°40' and 25°17' S, and 27°22' and 27°36' E (see location map, Fig. 1). The study area encompasses an area some 80 km in length, the width thereof roughly conforming to the width of the alluvial deposits and/or the zone of river-aquifer interaction.

1.1.2 General Background:

The area is the scene of intensive agricultural activity, mainly irrigational, and as such relies heavily on both surface and groundwater resources.

The area was proclaimed a Government Water Control Area in 1968 (Proclamation 111 of 10 th May 1968), thereby effecting control over the abstraction and usage of surface (public) water. Subsequent development, therefore, was established on the availability of groundwater resources present mainly in the alluvial deposits adjoining the river. As development on this basis proceeded, grave concern was exhibited by the authorities as to the possible effect the resulting large-scale abstraction of groundwater might have on the limited surface water reserves impounded in the upstream reservoirs were recharge of the aquifer to take place from the river.

Crocodile ....../3

Accordingly, the "Bureau de Recherches Géologiques et Minières" (hence referred to as BRGM), was awarded a contract to carry out a geohydrological investigation of the area in 1976. This investigation confirmed the fact that the aquifer and river are indeed in close connection, thus necessitating the need for effective control over the existing groundwater reserves of the area.

1.2 PREVIOUS INVESTIGATIONS:

Previous geohydrological investigations of the area were carried out by Bredenkamp and Porsasz (1967) and BRGM (1976), the results of both these investigations being summarised below.

1.2.1 BREDENKAMP, D.B. and PORSASZ, K., An Investigation of the Groundwater Resources of the Alluvial Aquifer of the Crocodile River near Thabazimbi, July 1967:

This investigation covered an area immediately north of the present study area. Geohydrological conditions are seen to be similar in both these areas. The authors arrived at the following results and conclusions:

i) the relatively coarse alluvial deposits (sands and gravels) constitute the primary aquifer in the area;
ii) the overlying impermeable clays severely limit the vertical infiltration of water to the aquifer;
iii) the underlying bedrock (mainly shale, quartzite, banded ironstone and dolomite) is mostly weathered and broken, enhancing the water-bearing potential of the aquifer;
iv) the aquifer and the river are in close connection;
v) aquifer-recharge is derived mainly from the river during floods;
vi) the hydraulic parameters of the aquifer were determined as posessing the following values:

average ..../5

average transmissivity (T) = 1478 m^2/day
" storativity (S) = 1,25%
" storage capacity = 3,1 x 10^6 m^3

1.2.2 BRGM, Groundwater Study in the Crocodile River, July 1976:

This investigation covered the same area as that of the present. The following results and conclusions were arrived at:

i) sandy formations of ill-defined lateral extent, and bordered by weathered outcrops of bedrock (granite, norite), constitute the groundwater reservoir;

ii) the alluvial formations reach their maximal extent in the extreme north of the study area, narrowing discontinuously southwards in the presence of outcrops of bedrock nearer the river;

iii) the deeper wells tapping the bedrock-aquifer show smaller yields than the shallower wells tapping the alluvial aquifer;

iv) the aquifer is semi-confined to unconfined;

v) the hydraulic parameters of the aquifer were calculated to be:

transmissivity = 130 to 3110 m^2/day
storage coefficient = 5 x 10^{-3} for semiconfined to 10^{-2} for unconfined conditions;

vi) the aquifer and the river are in close connection;

vii) north of the farm Buffelskraal 544 KQ, aquifer-recharge takes place from the river, while south thereof to the farm Nooitgedacht 22 JQ the river is seen to be effluent;

viii) the use of irrigational water ammounts to 142 x 10^6 m^3/year, 22% thereof (31 x 10^6 m^3) being derived from groundwater.

2. PHYSIOGRAPHY .../6

2. PHYSIOGRAPHY, GEOLOGY and HYDROLOGY:

2.1 PHYSIOGRAPHY (including Vegetation and Climate):

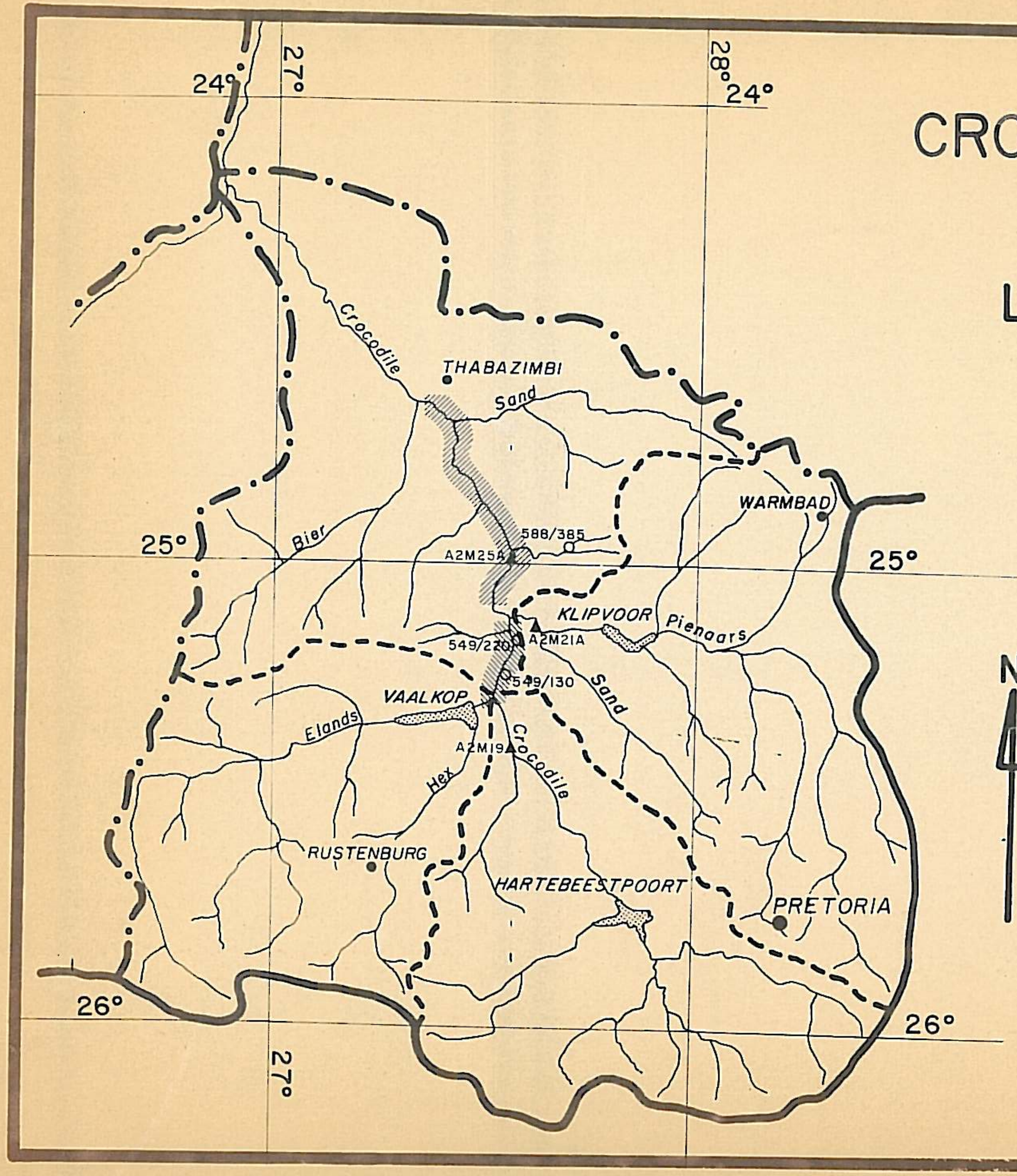
The Crocodile River rises on the Witwatersrand north of Johannesburg, and flows in a north-westerly direction to eventually discharge into the Limpopo River as the Marico River. Main tributeries include the Elands and Pienaars Rivers, these rivers draining the western and eastern sub-catchment basins respectively (see Fig. 1).

The gentle topography evident in the valley, and varying between 900 - 950 m in elevation, reflects the effects of peneplanation. Isolated ridges and kopjes mark the presence of harder weathering banded ironstones and quartzites. The river has an average slope of 0,5 m per km through the study area, and exhibits features indicative of those of a mature river ie. cut-off meanders, floodplains and natural levees. These features are especially evident in the northern portion of the study area ie. from the farm Liverpool 543 (designated LP) to Wachteenbietjesdraai 350 (WB) KQ. From Liverpool southwards to the farm Nooitgedacht 22 JQ (NG), the floodplain is less well-developed.

The rapid rate of development of the agricultural potential in the study area has resulted in the large-scale deforestation of most of the arable land in the valley. This is especially true of the extensive and very fertile zone adjoining the right bank bank of the river on the farms Haakdoorndrift 373 (HA) and 374 (HT) KQ in the extreme north. The natural vegetation, which is of the Mixed Bushveld type (Acocks, 1975), is therefore observed to cover those areas relatively far removed from the river, and where the soil cover is shallow and outcrops of the surrounding country rock are in evidence.

The study area falls within a summer rainfall region with an annual rainfall of 500 - 600 mm (Fig. 2). Although only some 20% of the yearly rainfall occurs in the dry winter months, the region is able to produce two crops per year, with water for irrigation of the winter crop being obtained from reservoir-sustained flow in the river, and boreholes.

CROCODILE RIVER VALLEY LOCATION MAP



LEGEND.

- ▲ Flow gauging stations.
- ▨ Main dams.
- Limits of the sub-catchment basins.
- ▨ Study - area.
- Limits of the drainage basin.
- o Rainfall stations.

SCALE 1 : 1 500 000

FIGURE I.

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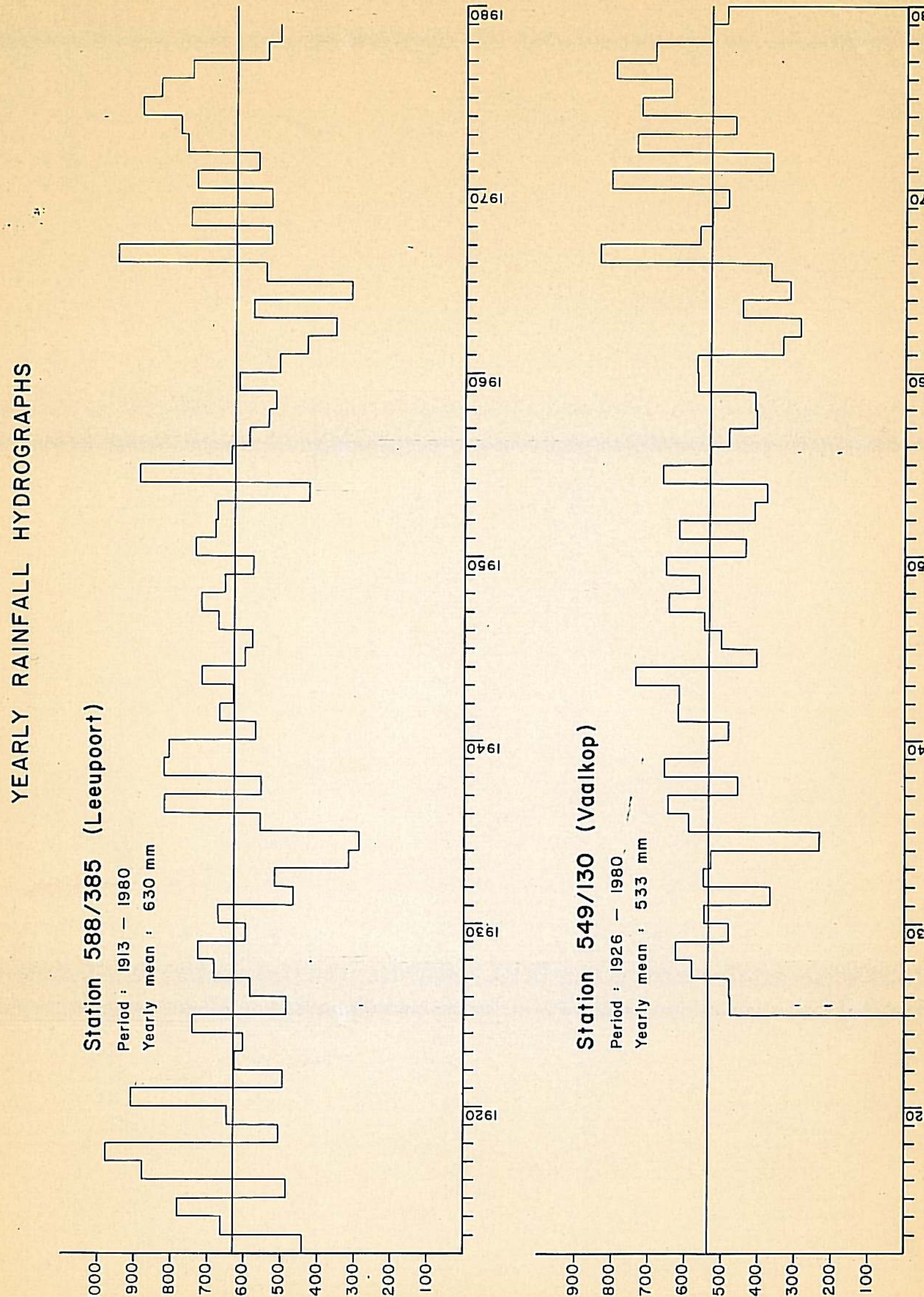

YEARLY RAINFALL HYDROGRAPHS

FIGURE 2.

2.2 GEOLOGY:

The study area is located in the centre of the Bushveld Igneous Complex, where sediments of the Transvaal Sequence (dolomite, quartzite, shale and banded ironstone) outcrop over a large area termed the Crocodile River fragment (Hall, 1932), and which is almost entirely surrounded by Bushveld Granite.

2.2.1 Geology of the study area:

Much of the area has been mapped in the past, amongst others by Verwoerd (1962) and Iannello (1966-67). Figure 3 represents a combination of both these maps together with additional geohydrological information ie. the extent and occurrence of the alluvial deposits gained during the course of this investigation.

The most prominent geological feature of the area is a large normal fault striking in a NNW- SSE direction, and forming the eastern boundary of the above-mentioned fragment. The fault enters the valley on the farm Knoppieskop 547 (KK) KQ, from there largely determining the course of the river nothwards to the farm Kromdraai 424 (KD). From here the fault assumes a more northerly strike direction, veering to the west in the extreme north of the study area. South of the farm Kromdraai, the fault brings typical red Bushveld Granite on the east to lie against the sediments of the Transvaal Sequence on the west. From Kromdraai northwards to the farm Haakdoorndrift 373, along a strike length of approximately 12 km, gabbro on the west is brought to lie against the granite. On overburden of alluvium, on average some 16 m thick, effectively conceals the position of the fault (which is only clearly visible on the farm Knoppieskop) throughout most of the study area.

Although extensive outcrops of bedrock are generally only visible further away from the river, on average +500 m in the south to + 1000 m in the extreme north, many exceptions are apparent.

For example, outcrops of gabbro are visible in the river-bed at Grootkuil 376 (GK), and also in the alluvial plain close to the river on the northern and southern portions of Middeldrift 379 (MD) and Elandskuil 376 (EK) respectively. On the farm Wachteenbietjesdraai in the extreme north, quartzite ridges intersect the valley, effectively defining groundwater compartments (Bredenkamp and Porsasz, 1967). In the south, granite outcrops close to the river along the right bank, being especially visible on the farm Haakdoornbult 542 (HD) and in the river-bed at Buffelskraal drift. Quartzite ridges outcrop in close proximity to the river on the farms Krokodilkraal 545 (KL) and Knoppieskop.

The extensive outcrops of dolomite, and to a lesser extent granite, reasonably well-defines the lateral extent of the alluvium in the southern part of the study area. Previous work on these dolomites (Bosazza, !953 and Keyser, 1955) suggests that it is essentially uncaverned, although isolated solution cavities might occur. The exploration boreholes G32653 (Buffelskraal), G32657 (Nooitgedacht 135) and NG23 (Nooitgedacht 22) indicate very little weathering of the dolomite below the alluvial overburden.

2.3 HYDROLOGY:

2.3.1 General:

As has already been mentioned, two relatively large rivers discharge into the Crocodile River immediately south of the study area. Flow in the lower reaches of these two rivers is regulated by two dams, namely Vaalkop (capacity 57,9 million m³) on the Elands River, and Klipvoor (capacity 44,5 million m³) on the Pienaars River. The presence of these dams ensures perennial flow in the Crocodile River through the study area.

River discharge data for the period 1960 - 1980 is presented in Table 1. Table 1(a) represents the monthly discharge as monitored at

TABLE 1(a) ..../10

TABLE 1(a): Monthly river discharge in $10^6 \times m^3$ as gauged at Station A2M25A.

MONTH / YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1960	7,38	4,19	1,59	5,29	4,30	1,86	1,85	1,06	0,00	0,00	28,38	96,32
1961	17,08	9,37	21,72	74,70	11,52	9,65	4,60	2,78	0,58	0,13	3,80	8,91
1962	3,69	4,05	0,70	2,02	0,72	0,00	0,00	0,00	0,00	0,00	1,29	0,91
1963	0,66	0,91	0,00	0,03	0,00	0,02	0,75	0,00	0,00	0,67	4,10	3,93
1964	2,58	4,13	0,70	0,00	0,00	0,00	0,00	0,00	0,00	51,49	13,66	23,72
1965	11,19	2,56	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	1,13
1966	3,28	11,07	0,03	0,00	0,00	0,00	0,00	0,00	0,00	15,35	5,16	115,54
1967	185,37	46,98	227,55	302,61	69,64	19,97	9,96	8,72	2,96	1,26	5,87	2,14
1968	2,16	0,64	8,99	7,99	5,04	3,07	1,86	0,59	0,45	0,28	2,84	2,62
1969	0,30	1,53	41,95	7,51	4,65	2,15	0,72	0,41	0,02	1,41	2,54	11,37
1970	0,93	1,10	0,77	0,03	0,44	1,30	0,98	1,60	2,89	1,90	0,21	3,83
1971	55,20	80,60	15,20	76,50	7,30	1,59	2,38	1,50	1,97	3,09	5,35	62,70
1972	188,00	42,50	17,20	7,89	2,91	1,64	1,94	2,03	2,66	4,32	3,98	5,02
1973	3,04	5,37	2,10	4,06	1,66	0,91	10,47^{x}	2,40	3,45	5,93	3,50	92,11
1974	75,94	71,06	25,21	44,65	11,24	3,26	4,12	3,17	4,37	3,49	16,66^{x}	17,53^{x}
1975	142,00^{+}	380,00^{+}	184,00	325,00^{+}	70,74^{x}	22,40	15,40	7,36	3,07	3,97	3,83	23,30
1976	236,00	118,74^{x}	370,33^{x}	133,57^{x}	212,63^{x}	49,46^{x}	39,52^{x}	21,90	13,58^{x}	102,00	82,72^{x}	31,47^{x}
1977	29,81^{x}	126,18^{x}	166,10^{x}	76,25^{x}	29,05^{x}	17,97^{x}	20,90^{x}	15,18^{x}	16,96^{x}	16,77^{x}	13,03^{x}	8,42
1978	328.00^{+}	488,00^{+}	283,00^{+}	108,00	43,40	25,10	21,30	13,20	11,30	9,57	6,96	6,30
1979	8,66	4,80	5,57	3,25	2,14	1,80	3,36	4,15	4,40	6,29	75,10	33,40
1980	65,10	99,50	31,30	8,75	4,72	3,33	5,96	4,70	6,45	6,70	9,80	66,50

(+) = Gauging capacity of station exceeded.

(x) = Discharge corrected according to the equation $y = 1,28(x) + 4,12$ (see text).

surface gauging station A2M25A, an open-channel flow gauging station located at Buffelskraal drift (Figs. 1 and 3). Table 1(b) represents the sum of the discharges from the dams and at station A2M19A, a gauging station situated on the Crocodile River upstream of the confluence with the Elands River (Fig. 1). It is clear that both sets of data can be divided into a pre-1970 and a post-1970 period after taking into consideration the commissioning of the dams (Klipvoor in May 1970 and Vaalkop in May 1971). The respective contributions of these dams and the upstream portion of the river to flow in the lower Crocodile River for the post-1970 period is detailed in Table 1(c).

It is unfortunate that no gauging station exists at or near the northern (downstream) extremity of the study area, and the construction of such a station merits urgent and immediate attention. One of the most important factors governing this consideration is the effective determination of aquifer-replenishment from the river during periods of relatively low flow, if not during periods of high river discharge. A second factor, that of base-flow, is discussed in Section 2.3.3.

2.3.2 Analysis of river discharge:

The incomplete data, especially evident for station A2M25A (eg. 1976 and 1977), and the questionable accuracy of gauging at both stations A2M25A and A2M19A, discourages a quantitative analysis of river discharge.

In order to obtain a more complete record for the discharge at station A2M25A, it was assumed that a linear relationship existed between the discharge at this station and the sum of the discharges of the upstream stations viz. Klipvoor, Vaalkop and A2M19A. This assumption was tested for the period January 1960 to April 1970, a period representative of flow conditions unaffected by artificial influences, the summed discharge being obtained from stations A2M19A, A2M20 and A2M21A located on the Crocodile, Elands and Pienaars

Table 1(b) ..../12 -

TABLE 1(b): Summed monthly upstream river discharge in 10^6 x m^3.

MONTH / YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1960	8,21	3,96	7,85	5,43	4,56	2,49	2,46	1,79	0,67	0,61	25,00	117,51
1961	13,86	8,86	19,01	73,78	12,89	14,48	4,85	3,19	1,14	1,24	5,31	12,75
1962	2,89	4,95	1,59	2,86	1,41	0,85	0,77	0,51	0,05	0,06	4,79	2,14
1963	3,99	1,71	0,05	1,96	0,12	1,09	2,16	0,29	0,06	1,94	5,58	7,68
1964	6,06	7,24	0,77	0,82	0,12	0,21	0,58	0,42	0,11	51,25	14,01	28,16
1965	14,77	4,81	0,06	0,71	0,51	0,33	0,41	0,44	0,09	0,01	0,36	2,50
1966	12,52	30,78	0,14	0,00	0,00	0,03	0,10	0,12	0,10	22,09	7,19	120,48
1967	172,86	362,59	208,68	213,86	48,08	23,01	9,74	9,71	3,77	2,24	7,73	2,09
1968	2,14	1,65	10,69	8,31	4,40	3,08	2,90	1,97	0,36	0,68	2,99	3,60
1969	1,19	1,57	28,03	8,89	6,55	2,05	1,39	1,06	1,07	0,34	3,22	9,77
1970	2,40	1,73	2,24	1,11	2,16	2,24	2,53	3,89	3,55	4,30	1,34	3,58
1971	5,06	45,63	11,93	32,43	5,88	3,06	3,78	3,46	4,22	5,71	5,38	44,50
1972	68,75	11,27	13,07	5,14	2,56	2,08	2,47	4,51	6,32	9,12	6,04	6,53
1973	5,54	3,83	3,01	2,63	2,12	2,50	4,96	5,26	7,14	6,69	4,80	42,90
1974	36,46	35,02	16,32	24,60	7,05	3,87	5,50	5,86	7,04	8,78	9,80	10,48
1975	108,88	187,73	98,20	160,02	52,05	16,10	13,54	8,54	6,84	8,26	5,53	18,31
1976	109,36	$89,55^{x}$	$286,10^{x}$	101,13	162,90	35,42	27,66	13,59	7,39	66,70	61,41	21,37
1977	20,07	95,36	126,55	56,36	19,48	10,82	13,11	8,64	10,03	9,88	6,96	5,84
1978	399,66	384,00	161,20	67,92	30,19	25,25	24,63	17,34	18,67	14,78	11,08	10,77
1979	13,51	10,95	9,91	5,82								
1980												

(x) = Gauged value includes period of no record.

Table 1(c) ..../13

TABLE 1(c): Respective contributions of the reservoirs and upstream portion of the Crocodile River, in million m^3, per month.

Year/Month		Station A2M19A	Klipvoor Dam	Vaalkop Dam	Total
1970	J				
	F				
	M				
	A				
	M		2,45		2,45
	J		1,66		1,66
	J		2,40		2,40
	A		4,15		4,15
	S		3,69		3,69
	O	1,81	2,49		4,30
	N	0,20	1,14		1,34
	D	0,08	3,50		3,58
1971	J	3,88	1,18		5,06
	F	3,63	42,00		45,63
	M	1,19	10,74		11,93
	A	7,33	25,10		32,43
	M	1,71	4,17		5,88
	J	0,88	2,18	0,03	3,09
	J	0,90	2,88	0,37	4,15
	A	0,71	2,75	0,00	3,46
	S	1,17	3,05	0,00	4,22
	O	0,42	5,29	0,00	5,71
	N	4,18	1,20	0,00	5,38
	D	3,54	40,96	0,00	44,50
1972	J	15,52	53,23	0,00	68,75
	F	3,26	8,01	0,00	11,27
	M	4,85	8,22	0,00	13,07
	A	1,76	3,38	0,00	5,14
	M	0,73	1,83	0,00	2,56
	J	0,49	1,42	0,17	2,08
	J	0,70	1,80	0,35	2,85
	A	0,66	2,90	0,95	4,51
	S	0,34	4,43	1,55	6,32
	O	0,26	5,19	3,67	9,12
	N	3,02	1,32	1,70	6,04
	D	3,99	1,30	1,24	6,53
1973	J	3,39*	1,28	0,87	5,54
	F	2,21	1,13	0,49	3,83
	M	1,00	1,27	0,74	3,01
	A	0,96*	1,22	0,45	2,63
	M	0,42*	1,24	0,46	2,12
	J	0,43	1,22	0,85	2,50
	J	0,55	3,61	0,80	4,96
	A	0,45	3,76	1,05	5,26
	S	0,33	5,20	1,61	7,14
	O	1,91	3,98	0,80	6,69
	N	2,11	2,21	0,48	4,80
	D	10,68	31,64	0,58	42,90

TABLE 1(c) contd. ..../14

TABLE 1(c) contd.

Year/Month		Station A2M19A	Klipvoor Dam	Vaalkop Dam	Total
1974	J	9,10	26,91	0,45	36,46
	F	6,96	24,03	4,03	35,02
	M	4,32	6,61	5,39	16,32
	A	10,12	7,29	7,19	24,60
	M	3,28	3,55	0,22	7,05
	J	1,04	2,25	0,58	3,87
	J	1,10	3,54	0,86	5,50
	A	0,93	3,79	1,14	5,86
	S	0,95	4,49	1,60	7,04
	O	1,20	5,41	2,17	8,78
	N	6,73	1,51	1,56	9,80
	D	7,71	1,16	1,61	10,48
1975	J	28,90*	71,97	3,91	104,78
	F	40,00*	134,49	13,24	187,73
	M	30,00*	52,49	11,71	94,20
	A	51,10*	69,84	38,08	159,02
	M	27,40	14,68	9,97	52,05
	J	7,45	8,23	0,42	16,10
	J	6,44	6,63	0,47	13,54
	A	3,60	4,44	0,50	8,54
	S	1,82	3,64	1,38	6,84
	O	1,41	4,62	2,23	8,26
	N	1,42	2,36	1,75	5,53
	D	6,21	11,10	1,00	18,31
1976	J	21,00*	17,90	70,46	109,36
	F	–	50,65	38,90	89,55
	M	–	30,10	254,00	284,10
	A	0,43*	25,10	75,60	101,13
	M	$98,60^{+}$	14,80	49,50	162,90
	J	22,10	7,00	6,32	35,42
	J	17,40	6,79	3,47	27,66
	A	6,58	4,59	2,42	13,59
	S	2,63	2,99	1,77	7,39
	O	46,20	8,04	12,46	66,70
	N	25,70	32,02	3,69	61,41
	D	6,83	12,87	1,67	21,37
1977	J	12,40*	4,19	1,08	17,67
	F	$70,40^{+}$	13,58	11,38	95,36
	M	76,50	17,76	32,29	126,55
	A	39,30	11,00	6,06	56,36
	M	13,80	4,56	1,12	19,48
	J	5,86	4,12	0,84	10,82
	J	7,59	4,59	0,93	13,11
	A	3,75	3,91	0,98	8,64
	S	3,27	4,74	2,02	10,03
	O	4,78	2,52	2,58	9,88
	N	1,89*	3,23	1,84	6,96
	D	1,31*	3,05	1,48	5,84

TABLE 1(c) contd. ..../15

TABLE 1(c) contd.

Year/Month		Station A2M19A	Klipvoor Dam	Vaalkop Dam	Total
1978	J	157,00*	114,00	128,66	399,66
	F	137,00	111,00	136,00	384,00
	M	87,20	39,90	34,10	161,20
	A	48,80	11,50	7,62	67,92
	M	21,60	7,14	1,45	30,19
	J	16,40	7,99	0,86	25,25
	J	17,40	6,36	0,87	24,63
	A	11,30	4,74	1,30	17,34
	S	11,90	5,02	1,75	18,67
	O	7,66	4,91	2,21	14,78
	N	6,66	2,93	1,49	11,08
	D	3,93	4,75	2,09	10,77
1979	J	6,53	4,97	2,01	13,51
	F	3,83	6,07	1,05	10,95
	M	3,48	5,23	1,20	9,91
	A	3,00	1,78	1,04	5,82
	M	2,84	0,55		
	J	3,52	0,81		
	J	3,90	4,01		
	A	4,26	5,80		
	S	4,15	6,83		
	O	8,40	4,82		
	N	45,50	0,96		
	D	21,80	8,88		
1980	J	37,30	14,70		
	F	44,40	23,00		
	M	20,70	11,60		
	A	13,40	2,82		
	M	9,49	1,57		
	J	7,50	2,59		
	J	7,45	7,45		
	A	6,54	6,78		
	S	7,31			

(*) = Incomplete data
(+) = Measuring capacity of gauging station exceeded.

Rivers respectively. Linear regression by the method of least squares applied to the data for this period yielded a correlation coefficient r = 0.98 (covariance = 1375,27).

The accuracy of gauging at station A2M21A was tested by applying a linear regression analysis to the post - 1970 discharge data for Klipvoor Dam and station A2M21A (located below the dam), yielding a correlation coefficient r = 0.99. (No similar check can be made on the accuracy of gauging at stations A2M19A, A2M20 or, for that matter, A2M25A).

Linear regression applied to the data for the period May 1970 to April 1979, and excluding months containing incomplete data, yielded a correlation coefficient r = 0.92 (covariance = 5248.46), the linear relationship being described by the regression equation,

$$y = 1.28x + 4.12,$$

where y = monthly discharge at A2M25A in million m^3 and
x = summed discharge, as described above also in million m^3

The most complete period of gauging extends from only as far back as January 1978 for both sets of data. Outflow data for Vaalkop Dam after April 1979 is unobtainable, although it is known that the dam has overflowed continuously since then.

Figure 4 represents the monthly discharge as presented in Tables 1(a), (b) and (c). It is evident that the average monthly discharges at station A2M25A varies considerably, but has seldom dropped below ± 2×10^6 m^3 per month since the commissioning of the dams. Also evident is the fact that the monthly discharge at this station does not accurately reflect the summed discharge from the dams and station A2M19A. It is observed that for discharges (at A2M25A) upwards of approximately 10×10^6 m^3 per month, discharges at this station exceed the summed discharge contributed by the dams and upstream

Crocodile ..../17

Crocodile River. This excess reflects the contribution of surface run-off to the river below the dams and station A2M19A.

- The above situation is reversed during the dry winter months, the deficit in discharge gauged at A2M25A being attributed to abstractions of river water upstream of this station, losses due to evapotranspiration, seepage losses in the riverbed, and the inaccurate gauging of low flows at both stations A2M25A and A2M19A. Figure 5 represents a double-mass curve of river discharge, and clearly reflects the change in the discharge regime of the river following the construction of the surface reservoirs.

2.3.2 Correlation of rainfall with river discharge:

Figure 6 and 7 represent an attempt at the correlation of rainfall with river discharge (station A2M25A). Rainfall stations 549/130 (Vaalkop) and 588/385 (Leeupoort) were used in the analysis, the rainfall data for the hydrological years 1960/61 to 1979/80 being expressed as an index of the long-term yearly mean, thereby obtaining a so-called "index of wetness" I_W.

Figure 6 represents the correlation with discharge as obtained for rainfall station 549/130 alone while figure 7 represents the correlation of discharge with the average combined rainfall of stations 549/130 and 588/385.

It is evident that a reasonable correlation exists for the pre-1970/71 period for both sets of data, the correlation being described by an exponential function of the form

$$y = ae^{bx}$$

where y = the annual discharge at station A2M25A (hydrological year) in million m^3,

and x = the index of wetness for the same period.

DOUBLE-MASS CURVE OF RIVER-DISCHARGE.

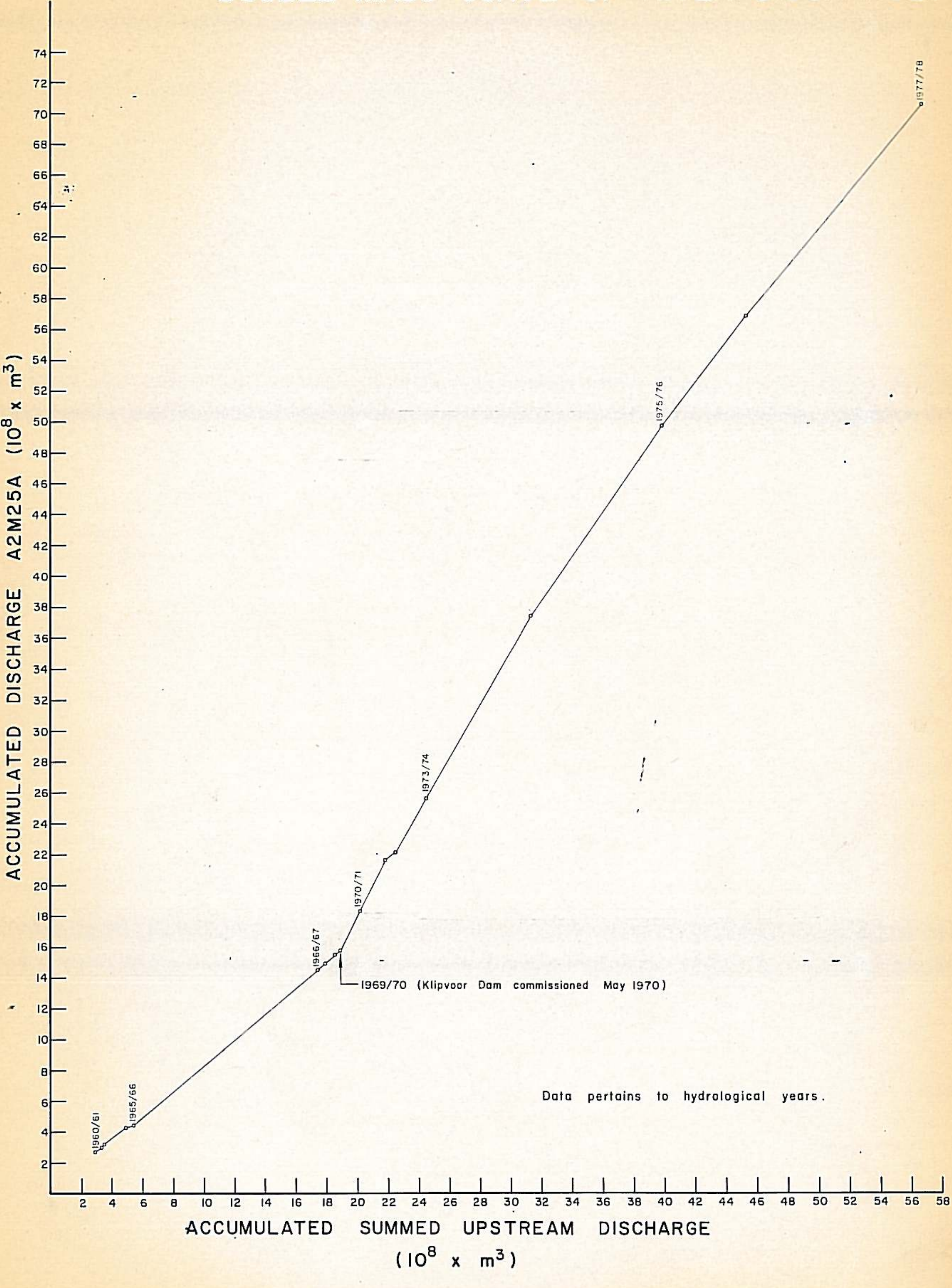


FIGURE 5.

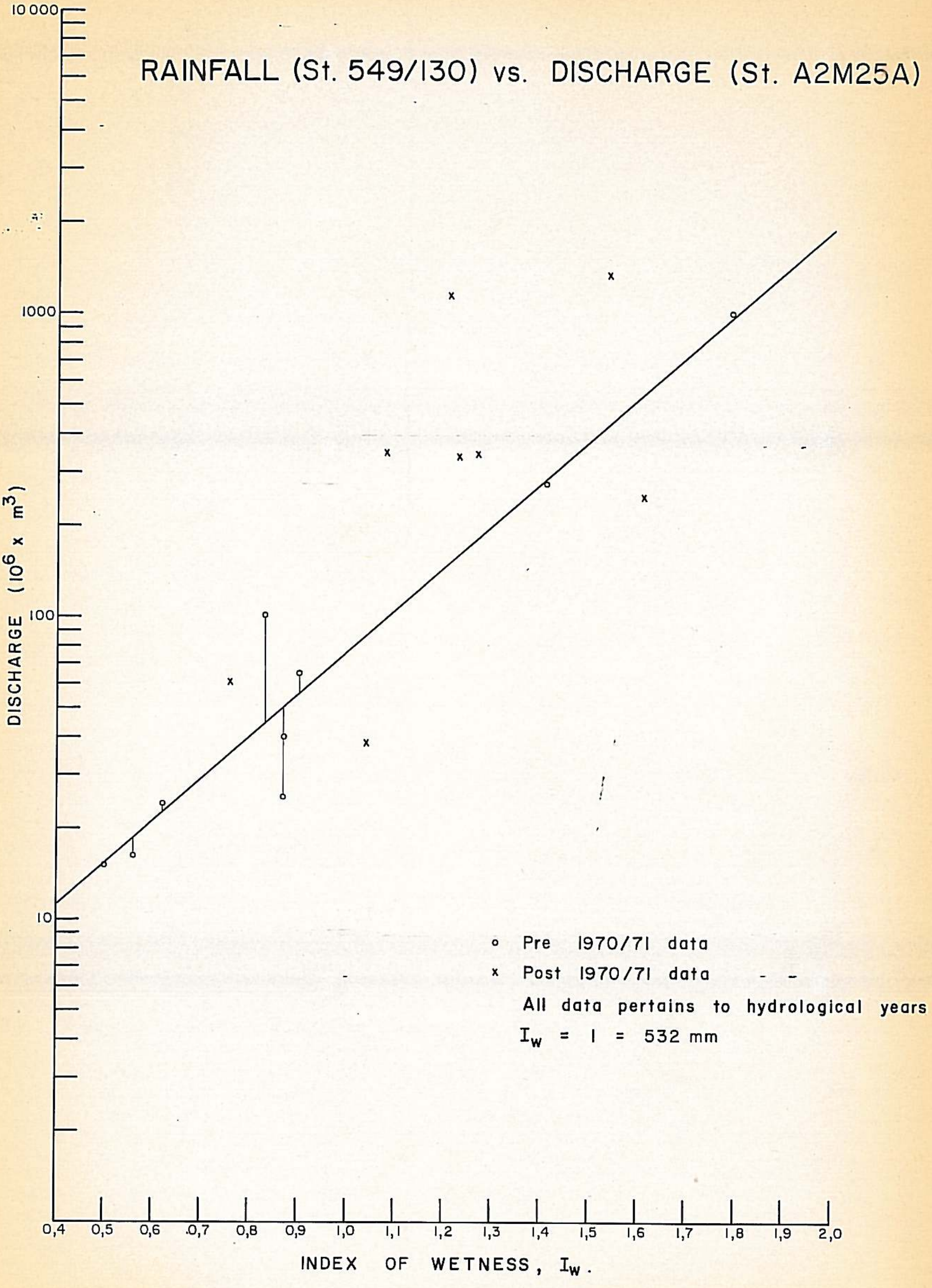

RAINFALL (St. 549/130) vs. DISCHARGE (St. A2M25A)
10 000
1000
100
10
DISCHARGE (10^6 x m^3)
0,4
0,5
0,6
0,7
0,8
0,9
1,0
1,1
1,2
1,3
1,4
1,5
1,6
1,7
1,8
1,9
2,0
INDEX OF WETNESS, I_W.
○ Pre 1970/71 data
x Post 1970/71 data
All data pertains to hydrological years
I_W = 1 = 532 mm

FIGURE 6.

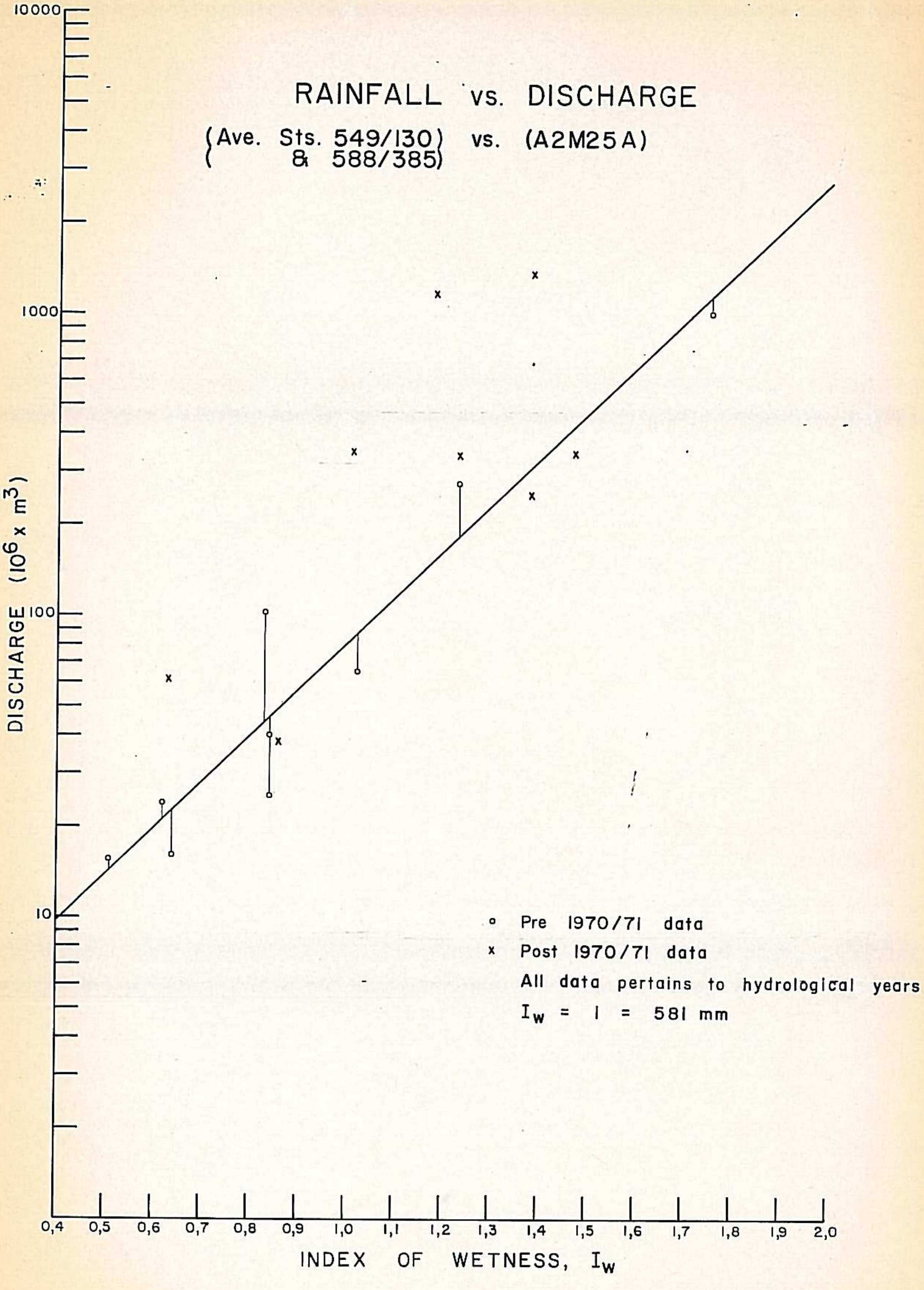

RAINFALL vs. DISCHARGE
(Ave. Sts. 549/130 & 588/385) vs. (A2M25A)
DISCHARGE (10^6 x m^3)
10000
1000
100
10
0,4
0,5
0,6
0,7
0,8
0,9
1,0
1,1
1,2
1,3
1,4
1,5
1,6
1,7
1,8
1,9
2,0
INDEX OF WETNESS, I_W
o Pre 1970/71 data
x Post 1970/71 data
All data pertains to hydrological years
I_W = 1 = 581 mm

FIGURE 7.

This function yields the equation $y = 3.05e^{(3.22x)}$ with a coefficient of determination (r^2) = 0.92 for figure 6, and similarly $y = 2.35e^{(3.54x)}$, for which r^2 = 0.91, for figure 7.

The correlation for the post-1970/71 period is weak for both sets of data, once more highlighting the important influence of the dams on river discharge, and thus negating any attempt at determining the direct influence of rainfall on river discharge for this latter period.

2.3.3 Analysis of base-flow:

An analysis of base-flow has been made for two periods as presented in Figure 8-1 and 8-2. These periods have been chosen for their completeness of data, and entail one period representative of discharge prior to the commissioning of the dams (Fig. 8-1), and one period representative of discharge subsequent thereto (Fig. 8-2).

The method of analysis used is that of Meyboom (1961), also described in Butler (1957). This method entails the graphical separation of base-flow on stream hydrographs by plotting the logarithm of discharge (ordinate) against time (abscissa). The reader is referred to the above mentioned references for further details of this method. Suffice it to say that the method enables a calculation of the total potential groundwater discharge (Q_{t_p}) and the actual groundwater discharge (Q) for a given base-flow recession to be made.

The governing equations yielding the above components are:

$$Q_{t_p} = \frac{K_1 \; K_2}{2.3} \qquad \text{and} \qquad Q = \left[\frac{-K_1 \; K_2 /2.3}{10^{t/K_2}} \right]_{t_1}^{t_2}$$

where K_1 = groundwater discharge at the beginning of the base-flow recession in m³/day,

K_2 = time increment corresponding to one log cycle change in discharge,

$t_1 = t_o = 0$

t_2 = time increment (since t_1) preceding the following recharge period.

2.3.3.1 Discussion ..../22

2.3.3.1 Discussion and results:

Period; October 1966 - January 1970 (Fig (8-1)

The daily discharge hydrograph presented in Figure 8-1 reflects the large fluctuations in streamflow at station A2M25A during this period of record. The base-flow recession curves have been constructed as straight lines connecting successive points of minimum stream discharge (after Meyboom, 1961), the upward deviations from this line being seen as increases in direct run-off produced by rainfall. Although the method of construction of the base-flow recessions is subjective, the results obtained from the analysis thereof are taken to be indicative of the natural flow regime of the river at A2M25A during this period.

It is noted that the preceding period of 19 months (March 1965 to mid-October 1966) witnessed zero daily average discharge at A2M25A. Consequently, discharge related to the onset of the first subsequent "wet period" (October / November 1966) shows wild fluctuations, the daily average flow reverting to values of below 0.1 cumecs within days of discharges in excess of 10 cumecs. This observation is attributed to large flow-losses through recharge of the dry sandy riverbed, saturating the latter, and enabling subsequent high discharges to create influent conditions whereby aquifer-recharge takes place. Hereafter, the general components of streamflow ie. direct run-off, interflow (originating as bank storage) and base-flow are manifested in the declining segments of the stream hydrograph. It would seem from Figure 8-1 that direct run-off and interflow plays the most important role in the discharge regime of the upstream portion of the study area.

The very low flows witnessed in February and September / October 1969 are attributed to abstractions of river-water upstream of A2M25A, the river providing the main source of water for irrigation purposes before 1970/71.

Analysis .../23

Analysis of the base-flow recession curves yielded the following results:

For recession 1:

$Q_{t_p} = 2.29 \times 10^6$ m³ $K_1 = 0.2$m³/s
$K_2 = 305$ days

$Q = 1.02 \times 10^6$ m³ $t_1 = 0$
$t_2 = 78$ days

For recession 2:

$Q_{t_p} = 1.26 \times 10^6$ m³ for $K_1 = 0.13$ m³/s
$K_2 = 257$ days

$Q = 0.65 \times 10^6$ m³ for $t_1 = 0$
$t_2 = 81$ days

From the above, it is clear that the baseflow component of river discharge at station A2M25A is negligible. Furthermore it would seem that aquifer-recharge during this period is non-existent for discharges below at least 10 cumecs (0,86 million m³/day), as is brought out by the fact that the remaining potential groundwater discharge for recession 1 ($Q_{t_p} - Q = 1.27 \times 10^6$ m³) exceeds the total potential groundwater discharge for recession 2 ($Q_{t_p} = 1.26 \times 10^6$ m³).

Period; October 1977 - August 1980 (Fig. 8-2):

The stablising influence of the upstream reservoirs on streamflow is immediately evident from Figure 8-2, discharge at A2M25A being sustained at an average of 1,5 cumecs for the period July to Ocober 1979. Let it therefore immediately be stated that the base-flow recession curves for Figure 8-2 are

not ..../24

not seen as a true reflection of base-flow conditions for the post-1970/71 period, but rather as an indication of the nominal discharge of the river as influenced by the dams.

Analysis of the "quasi-baseflow" recession curve yielded the following result:

$$Q_{t_p} = 41.83 \times 10^6 \text{ m}^3 \quad \text{for } K_1 = 1.7 \text{ m}^3/\text{s}$$
$$K_2 = 655 \text{ days}$$

$$Q = 33.48 \times 10^6 \text{ m}^3 \quad \text{for } t_1 = 0$$
$$t_2 = 459 \text{ days}$$

It is realised that many important factors influencing river-discharge have been neglected in the above analyses. Furthermore, the analyses are derived for that portion of the study area that least well reflects the general geohydrological conditions in the study area, ie. the portion upstream of station A2M25A. Discharge at this station is subject to the influence of a complexity of factors upstream of the study area, and the results obtained cannot, therefore, be seen to accurately reflect the contribution of base-flow to river discharge for that portion of the study area downstream of A2M25A. The construction of a river gauging station at the lower extremity of the study area is imperative if an accurate estimation of this component is to be obtained. Such a station would also serve to determine the magnitude of surface run-off below station A2M25A.

3. GEOHYDROLOGY:

3.1 INTRODUCTION:

The alluvial deposits of the Crocodile River constitute the primary aquifer in the study area, and although varying greatly in areal extent

and ..../25

and thickness, nontheless exhibit a fairly uniform character.

The relatively dense and clay-rich loamy soil forming the overburden in the valley accounts for the semi-confined to semi-unconfined nature of the aquifer. The average thickness of this overburden varies between 6 and 9 metres, below which the aquiferous sands, gravels and coarser riverine deposits are to be found. The depth to bedrock seldom exceeds 16 metres, the zone of weathering of the bedrock appearing to be minimal (in the order of 2 metres).

3.2 EXTENT, OCCURRENCE and NATURE of the ALLUVIAL AQUIFER:

Four distinct sub-areas, and bearing a relationship to the geology of the area, can be delineated (Fig. 9). At this point it is pertinent to mention the difficulty of delineating the physical boundary of the alluvial aquifer, as the uniform and homogeneous overburden masks the transition from alluvium to the more natural soil-cover present in the valley. It was therefore deemed realistic to regard the geologically mappable outcrop of bedrock as forming this boundary. In addition, information gained from past and present drilling programmes was used in order to better define the lateral extent of the aquifer where possible:

3.2.1 Sub-area A:

The zone extending from Nooitgedacht 22JQ in the south, to the Hardekoolbult 548/Haakdoornbult 542 KQ boundary. The lateral extent of the alluvium in this area is limited by extensive outcrops of dolomite and quartzite, and attains an average width of approximately 500 m on both the left and right banks.

This area is further characterised by the very shallow depth to bedrock along portions of the river banks, examples being B.R.G.M. auger drillings KL9 (9m), BL23(4m) and HD1(1,5m), and an outcrop of dolomite visible in a gully some 100 m from the river on the farm Karoobult 144 JQ. Depths to bedrock nearer the expected average are witnessed in boreholes NG 23(16m) on the riverbank,

and ...../26

FIG. 8-1 (Ghp 5699)

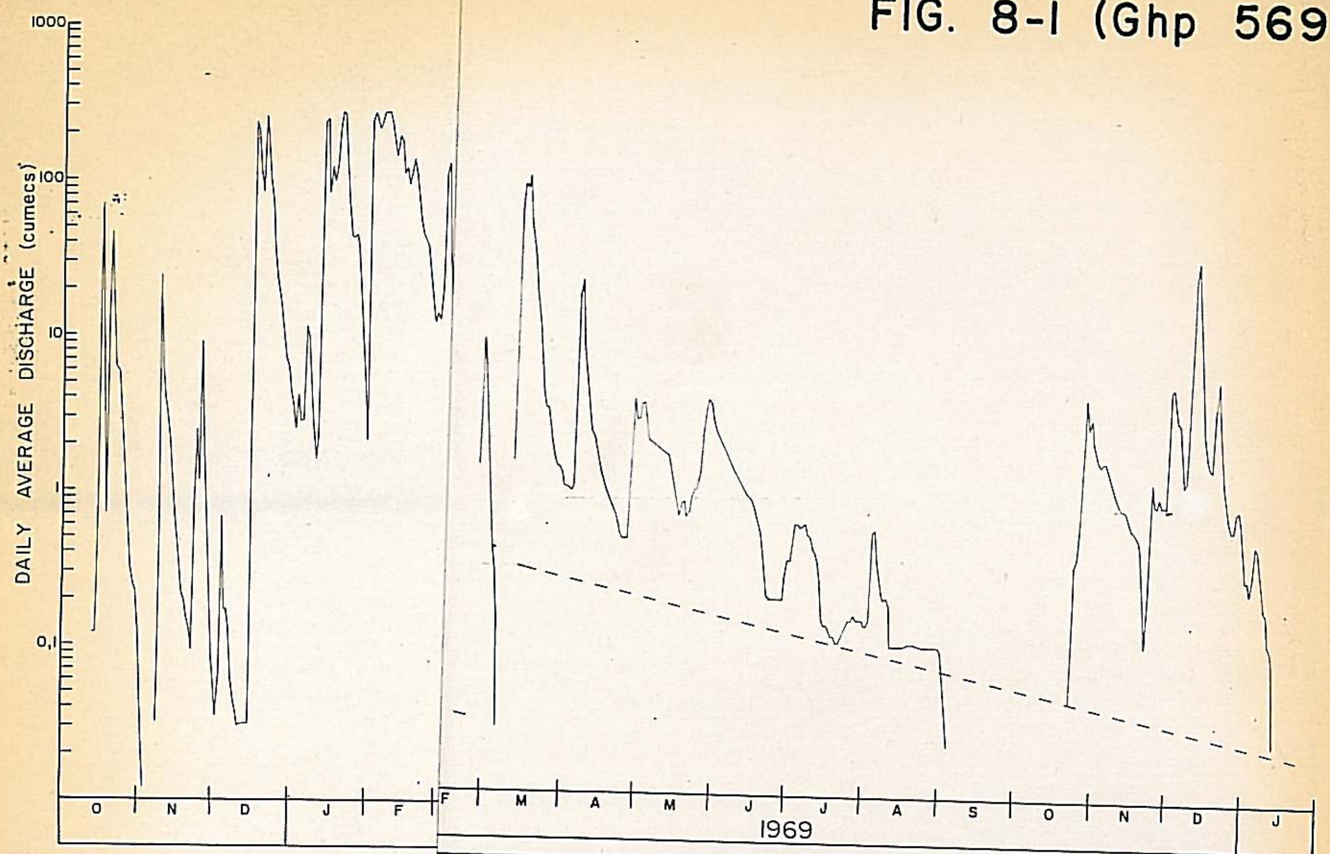
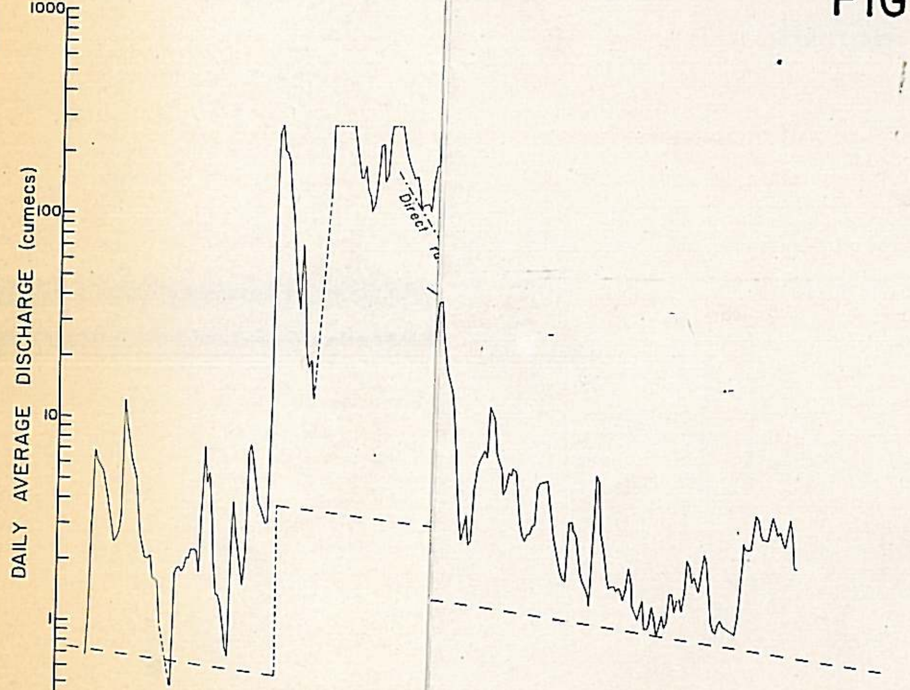
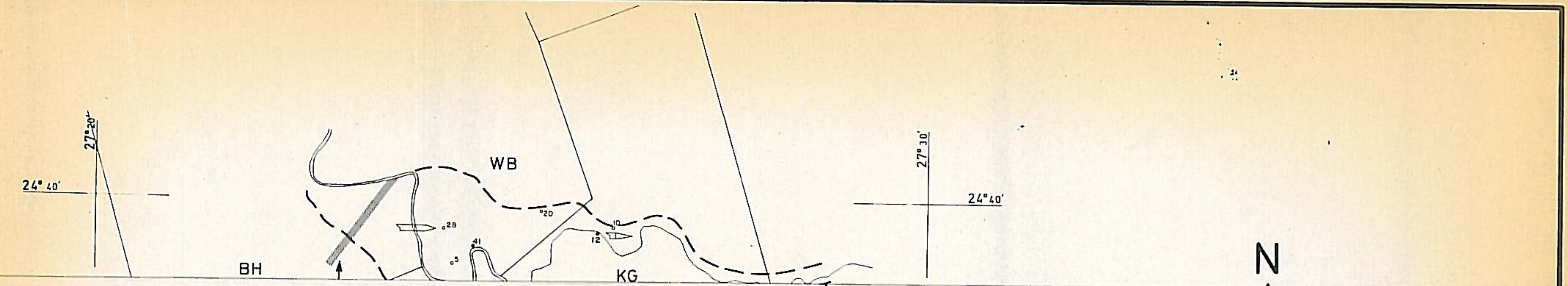


FIG. 8-2 (Ghp 5700)





GENERAL GEOHYDROLOGICAL AND HYDROCHEMISTRY LOCATION MAP.

LEGEND

Lateral extent of the alluvium, alternatively the limit of bedrock outcrop.

Major producing well-fields.

o29 Location and number of boreholes sampled for hydrochemical analysis.

•31 Location and number of long-term observation wells.

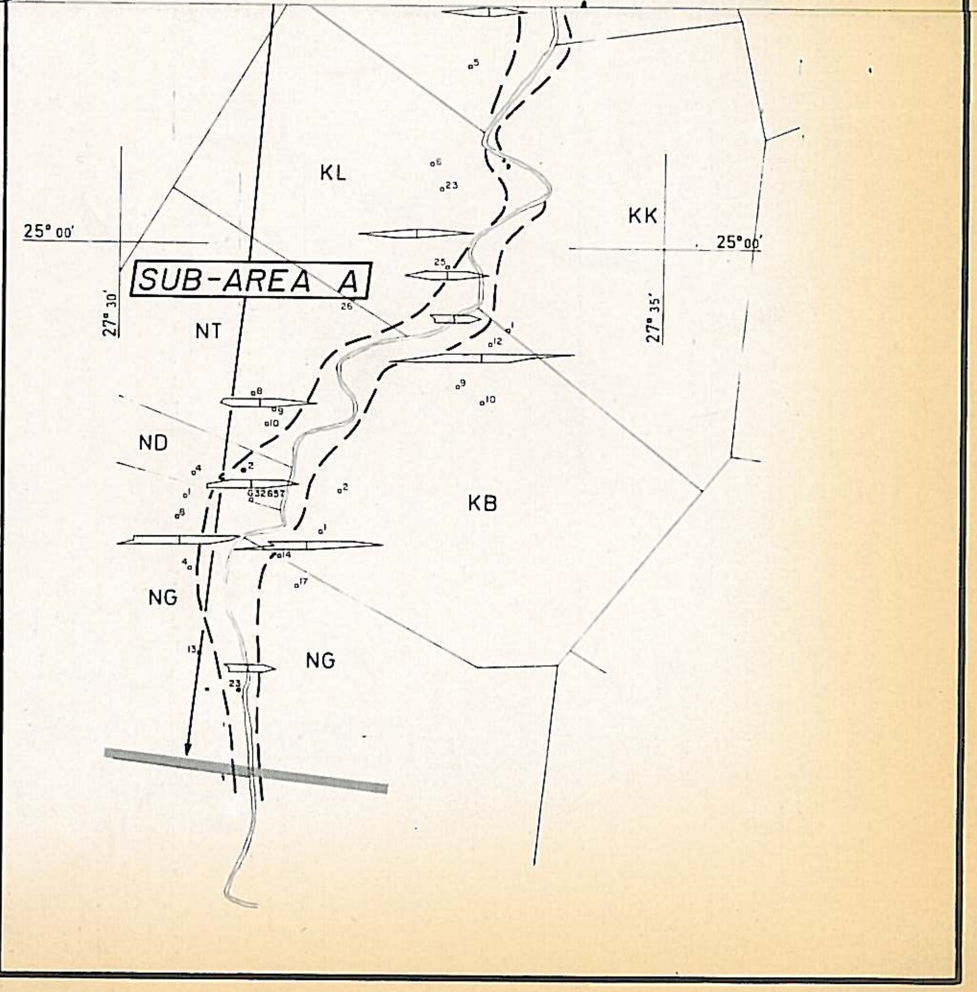
x15 Location and number of Amandelbult Mine (J.C.I.) exploration drillings.

Na+K, Ca, Mg | Cl, HCO3, SO4 Break-down of Stiff diagrams.

Stiff diagram.

4 3 2 1 | 1 2 3 4 Scale of Stiff diagrams, in milliequivalents per litre.

0 1000 2000 3000 4000 5000 6000 metres



Div. Geohydrology

FIG. 9 (Ghp 5701)

and G32653 (16m), G32654 (13m) and G32657 (13m) all located some 200 - 400 m distant from the river. High-yielding boreholes in the area are few, and are generally limited to those sunk in dolomite, for example ND2 (18ℓ/s) and NG 15 (20ℓ/s). Exploration boreholes G32657 on the farm Nooitgedacht 135 is taken to represent the nature of the alluvial aquifer in this portion of the area, and reveals the fact that the aquifer is rather poorly developed in this vicinity. It is seen that a 9m thick overburden of clayey soil overlies the 4m thick water bearing horizon in this borehole.

The presence of the fault traversing the northern portion of this zone seems to have no geohydrological significance. Exploration boreholes G32653 (dolomite)and G32654 (granite) straddle the location of the fault on the farm Buffelskraal 544, but yielded very little water, the blow-yield of G32653 being estimated at 0.4 ℓ/s . Borehole G32654 was practically dry.

3.2.2 Sub-area B:

The zone extending from the Hardekoolbult/Haakdoornbult boundary, to the northern boundary of Kromdraai 424/KQ. In this area, the aquifer is especially well-developed along the left bank, relating to the large cut-off meanders located on the farms Liverpool (LP) and Olifantskop (OK). The alluvial aquifer is weakly developed along the right bank except on the farm Rietfontein (RF).

The area is further characterised by numerous high-yielding boreholes (+18ℓ/s) tapping the alluvium. Boreholes BL 9 (21ℓ/s), BL 10 (19ℓ/s) and BL 11 (15ℓ/s) on the farm Buffelskraal would seem to tap groundwater related to the presence of the fault, the latter also having a marked influence on the groundwater-levels on this farm (see the piezometric map for May 1980, Figure 12)

The aquifer generally is characterised by a thinner overlying clay layer than elsewhere, examples being exploration boreholes G32649 (3m), OK 40 (5m), RF 45 (4m), G32646 (3m) and G 32651 (3m). Borehole G32652, located some 1700m from the river on the farm Kromdraai, is a notable exception, 10m of very clayey material being intersected above a 2m thick water-bearing horizon consisting of very coarse gravels. This borehole is thus seen to indicate the lateral extent of the alluvial aquifer on this farm.

3.2.3 Sub-area C:

The zone extending from the northern boundary of Kromdraai to the farm Wachteenbietjesdraai 350 KQ in the extreme north. The southern portion of this area (on the left bank Middledrift 379 KQ and Elandskuil 378 KQ, on the right bank Grootkuil 376 KQ) is characterised by the relatively narrow alluvial deposits (see Figure 3). Outcrops of gabbro occur over extensive areas, being visible especially close to the river on the northern portion of Middledrift and southern portion of Elandskuil. Information gained from mine exploration boreholes in this area yielded valuable information concerning the nature and extent of the aquifer. This information was kindly obtained from the Chief Geologist of the Amandelbult Mine (J.C.I.), and is presented in Table 2.

The alluvial aquifer widens out considerably on the right bank north of Grootkuil (GK) and numerous very high-yielding boreholes (+20ℓ/s) are in evidence. This portion of the aquifer underlies the farms Haakdoorndrift 373 (HA) and 374 (HT) KQ, and represents the most productive and heavily exploited aquifer in the study area. The aquifer, including the overlying surface material and underlying zone of decomposed bedrock, attains thicknesses of up to 30m (see Table 2).

The greater part of the left bank further than 300 m from the river is underlain by very shallow bedrock (mainly gabbro and norite), generally less than 9 m below the surface. The overburden consists mainly of decomposed bedrock and an associated clay material. Nearer the river, depths to bedrock increase up to 20 m, and large-yielding boreholes such as HT 78 (15ℓ/s) and HT 81 (15ℓ/s) tap the alluvial deposits present close to the river.

TABLE 2 ..../28

TABLE 2. Information gained from the Amandelbult Mine (JCI) exploration drillings on the farms Haakdoorndrift 374, Elandskuil 378 and Grootkuil 376 KQ.

Drilling No.	Depth in metres	Geological Description
HT1	0 - 5	Overburden and rubble
HT2	0 - 9	-do-
HT3	0 - 15	-do-
HT5	0 - 20	-do-
HT7	0 - 16	-do-
HT11	0 - 16	-do-
HT12	0 - 24	-do-
HT13	0 - 22	-do-
HT14	0 - 27	-do-
	27 - 31	Weathered gabbro
HT15	0 - 24	Overburden, rubble and heavily decomposed gabbro
	24 - 30	Weathered gabbro
EK9	0 - 2	Black turf
EK15	0 - 6	Speckled norite
GK1	0 - 27	Decomposed gabbro
GK3	0 - 9	Overburden and rubble

Note: The geological descriptions are necessarily brief due to the sensitive nature of the information. The location of these drillings are detailed in Fig. 9

3.2.4 Sub-area..../29

3.2.4 Sub-area D:

The zone along the strike of the fault on the farm Grootkuil 376 KQ. The presence of riverine deposits in this zone (exploration borehole G32650) would seem to indicate that this was once the course of the Crocodile River, now forming a buried fossil river-bed of some considerable geohydrological potential. Numerous high-yielding boreholes are located in this zone.

Borehole G32650 revealed an aquiferous horizon consisting of coarse quartzitic gravels and rounded pebbles and boulders (some of the latter greater than 15 cm in diameter) at a depth of 34 m, and some 4 m thick.

The overlying material consists of finer quartzitic gravels intercalated with more sandy horizons. A weathered zone some 14 m thick consisting of fault debris and containing a small percentage of chert-like nodules, underlies the water-bearing horizon. Rather fresh norite was struck at 52 m, indicating the true fault zone to lie a small distance to the east of this borehole.

The location of boreholes tapping groundwater in this zone indicate the breadth of the zone to be less than 100 m wide. Attempts by farmers to find notable groundwater supplies either side of this zone have proved unsuccessfull.

3.3 THE NATURE OF THE RIVER CHANNEL:

Eight sites in the river-bed were selected for investigation, their selection primarily being dictated by accessibility and the availability of work-space. Nonetheless, it is felt that the selected sites provide a good representation of the nature of the river-bed through the study area.

A Cobra-drill was used to drill profiles across the river-bed at

each ..../30

each site, the results of these drillings being schematically illustrated in Figure 10. The depth of penetration achieved by the drill was limited to the depth of a very dense and compact clay horizon prevalent in the river-bed, and which the drill found impossible to penetrate. A sampling tube was used to obtain relatively undisturbed samples each metre as drilling progressed. This information is tabulated in Table 3.

The investigation revealed the presence of an impermeable clay layer at depths varying from 2 m to 8 m below the surface of the river-bed, being overlain by unconsolidated and saturated coarse quartzitic sands and gravels. The absence of the clay layer in profile 8 is a notable exception. Indications are that this clay layer is underlain by still more sands and gravels. Evidence for this is the fact that the clay was penetrated by well-points sunk by farmers in the river-bed during the draught of the mid-1960's, and sufficient water was withdrawn from these sands and gravels to support some of the agriculture in the area during this period.

None of the exploration drillings revealed the presence of impermeable clay lenses within the water-bearing horizon of the aquifer adjacent to the river. It would therefore seem as if the clay layer occurs as an almost continuous horizon in and along the river-bed, forming "tongues" laterally into the adjacent and older alluvial deposits, and pinching out with distance away from the river.

It is observed that the river-banks are mainly composed of a rich loamy soil of a semi-pervious nature in that they exhibit a reasonably high clay content and are well consolidated. Furthermore, the banks are densely vegetated with phreatophytes along their entire length, and vary considerably in height.

On the basis of the above information, it is suggested that the river be regarded as only partly penetrating the aquifer, and serving as a semi-pervious boundary.

TABLE 3 ...../31

TABLE 3. Results of the Cobra-drilling programme (see Fig. 10)

Profile No.	Co-ordinate (lat.) and location.	Drilling No.	Depth in metres	Lithology
1	24°43'25'' Haakdoorndrift 374 KQ.	A	0 - 5,2 5,2	Coarse, sandy, quartzitic gravel Light-brown, very slightly sandy clay
		B	0 - 6,3 6,3	Coarse, sandy quartzitic gravel Coarse gravel in a very clayey matrix
2	24°44'35'' Elandskuil 378 KQ.	A	0 - 6 6	Coarse sand and quartzitic gravel Very dense and compact, grey-coloured clay
		B	0 - 6 6	Coarse sand and quartzitic gravel Very dense and compact, grey-coloured clay
3	24°47'35'' Middeldrift 379 KQ.	A	0 - 5 5	Coarse quartzitic sand and gravel Brown-coloured dense and very compact clay
4	24°49'03'' Kromdraai 424 KQ.	A	0 - 7,3 7,3	Coarse quartzitic gravel Very dense and compact clay
5	24°50'55'' Kromdraai 424 KQ.	A	0 - 4,5 4,5	Coarse gravel and small rounded pebbles Dense and compact clay
		B	0 - 5	Coarse gravel and small rounded pebbles in a slightly clayey matrix
		C	0 - 6	Coarse gravel and small rounded pebbles in a very slightly clayey matrix

Table contd. overleaf

TABLE 3 contd.

Profile No.	Co-ordinate (lat.) and location	Drilling No.	Depth in metres	Lithology
6	24°52'10"	A	0 - 1,9	Very fine, sandy gravel
	Olifantskop		1,9	Dense slightly sandyish clay
	425 KQ	B	0 - 1,9	Very fine, sandy gravel
			1,9	Very dense and compact clay
		C	0 - 2,3	Very fine, sandy gravel
			2,3	Compact, sandyish clay
7	24°53'22"	A	0 - 4,6	Fine quartzitic gravel
	Liverpool		4,6	Dense, compact grey-coloured clay
	543 KQ.	B	0 - 4,2	Fine-grained quartzitic gravel
			4,2	Dense, compact grey-coloured clay
		C	0 - 7,5	Coarse quartzitic gravel
			7,5-7,7	Coarse gravel in a clay matrix
			7,7	Dense, compact grey-coloured clay
8	24°55'00"	A	0 - 7,6	Coarse quartzitic gravel, slightly clayey at 7,6 metres
	Buffels-kraal 544 KQ	B	0 - 8,6	Coarse quartzitic gravel; very coarse with pebbles at 8,6 metres
		C	0 - 8,5	Coarse quartzitic gravel; very coarse with pebbles at 8,5 metres
		D	0 - 8,5	Coarse quartzitic gravel; very coarse with pebbles at 8,5 metres

3.4 PIEZOMETRY ...../33

3.4 PIEZOMETRY:

Figures 11 and 12 represent piezometric maps of the study area. Figure 11 has been reconstructed from B.R.G.M. data, and reflects the groundwater-level, as measured in 110 boreholes, during the period January / February 1976. Similarly, Figure 12 represents groundwater-levels in the study area for May 1980, utilising data obtained from 196 boreholes over a period of four days (Annex I). This map is regarded as reliably reflecting the natural groundwater-level in the study area, the abstraction of groundwater for irrigational purposes reaching a minimum during this period.

It is evident that a marked similarity exists between the piezometric maps, the general groundwater-level contours exhibiting much the same configuration throughout the study area for both periods of time. A study of these maps suggests that the groundwater contours resolve into four distinct sub-areas analogous to those described in Section 3.2. These zones differ from each other in the general pattern exhibited by the groundwater contours in each.

Figure 13 represents a groundwater-level change map constructed from Figures 11 and 12, and clearly reveals zones of decline and rise in the groundwater-level established in the four-year period of January / February 1976 to May 1980. This Figure is discussed in conjunction with the piezometric maps in the following sub-sections. Without attempting to infer too much from this map, it is noticed that the zone of least change in groundwater-level (the zero contour) approximates the course of the river, indicating that the groundwater-level in close proximity thereto is maintained by flow in the river. The deviation of the zero contour in some localities is attributed to two factors, namely:

i) the presence of relatively large and productive well-fields, and / or

ii) the influence of river-stage on the piezometric head in the semi-confined parts of the aquifer.

These ..../34

These two factors, where relevant, are discussed below:

3.4.1 Sub-area A:

The groundwater-levels in this zone are generally higher than the level of the river-bed and are seen to reflect the semi-confined nature of the aquifer. Although the configuration of the piezometric contours indicate the river to appear effluent this is very much doubted under the prevalent confined conditions and rather gentle groundwater gradient. This observation is supported by the fact that although this zone is a contributery source to baseflow in the river above station A2M25A, the baseflow component of river discharge at this station is seen to be minimal (Section 2.3.3.1).

It is evident from Figure 13 that a notable cone-shaped zone of decline in the groundwater-level has been established on the farms Nooitgedacht 135 (ND) and 136 (NT), a decline of some 4 m being witnessed in the vicinity of boreholes ND 1 (15 ℓ/s) and ND2 (18 ℓ/s). These two boreholes are located on the outer extremity of the alluvial aquifer and very close to outcrops of dolomite. It is seen that a large portion of this zone extends into the dolomite to the west, and has realised a steepening of the groundwater gradient in this direction.

Here it must be noted that the water-levels in boreholes ND1 and G32657, as presented in Figure 12, were measured in September 1980 (see Annex I), and as such are representative of water-levels during a period of continuous abstraction. On the basis of available information concerning the nature of the dolomite (Section 2.2.1) and the alluvial aquifer (Section 3.2.1) in this zone, it is concluded that recharge from both the dolomite and the river is slow. The rate of recharge is not rapid enough to balance the abstraction during such a period but is inevitable during extented periods of minimal abstraction such as from mid-April to mid-June of each year.

3.4.2 Sub-area .../35

3.4.2 Sub-area B:

A study of the piezometric maps reveals a marked similarity in the attitude of the piezometric surface in this area for both periods of time. The configuration of the groundwater-level contours indicate the river to appear influent along the left bank and, with the axception of Rietfontein (RF), effluent along the right bank. These conditions are in accordance with the geology of this zone, the aquifer being weakly developed along the right bank in the presence of very shallow granitic bedrock, and extensive along the left bank (Section 3.2.2 and Figure 3)

The presence of the fault on the farm Buffelskraal (BL) exerts a marked influence on the groundwater-levels along its strike in the northern portion of this farm (southern portion of the subare). A sharp gradient away from the river is evident in this locality on Figure 12, and the fact that Figure 13 reveals a positive change in groundwater-levels along this zone further substantiates the view that notable recharge from the river occurs in this portion of the sub-area. This observation is not as evident northwards along the strike of the fault. The piezometric contours on the farms Olifantskop (OK), Liverpool (LP) and Kromdraai (KD) indicate relatively gentle gradients away from the river, with large areas assuming a near horizontal piezometric surface. Conditions in the central portion of Rietfontein (RF) are seen to be similar.

Figure 13 further reveals the presence of various other zones of rise or decline within the sub-area. The most notable of these is the extensive zone of decline encompassing the farm Liverpool (LP). The decline of some 4 m in groundwater-level evident near the northern boundary of this farm is ascribed to the presence of the intensely productive well-field at this locality (see Figure 9). Various other boreholes and smaller well-fields contribute towards the general decline in groundwater-level witnessed on this farm. Groundwater-levels on the farm Olifants-

W. TVL.

GROUNDWATER - LEVEL
CHANGE MAP,
JANUARY/FEBRUARY 1976 to MAY 1980.

LEGEND

Contours representing the change in the groundwater - level, contour interval = one metre.

▨ Decline in groundwater-level greater than one metre.

▨ Rise in groundwater-level greater than one metre.

0 1000 2000 3000 4000 5000 6000 metres

Div. Geohydrology

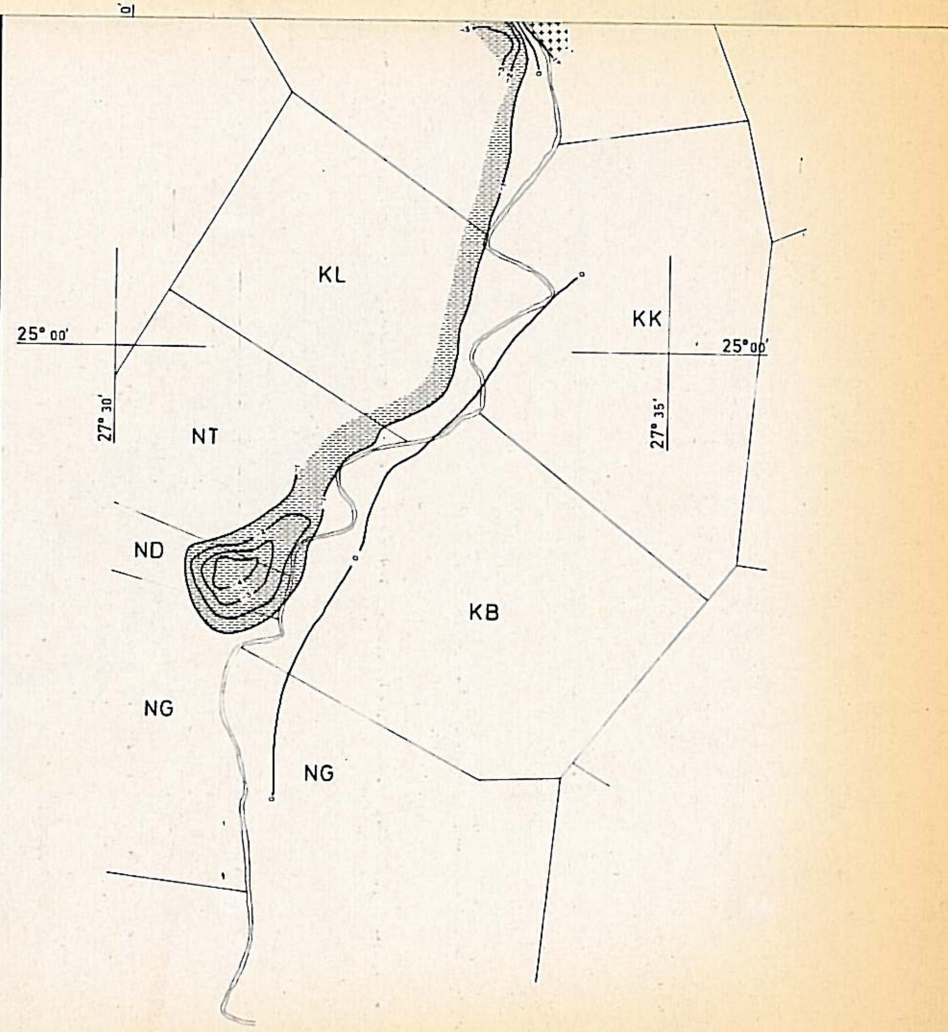


FIG. 13 (Ghp 5705)

kop are seen to be little changed, despite the presence of a large well-field (Figure 9) in this locality. In fact, a zone of rise in groundwater-level has been established on the southern portion of this farm outside the alluvial aquifer, and is considered to be a possible zone of limited recharge to the aquifer in this locality.

Considering the farm Kromdraai, it is noticed that the piezometric contours have been displaced further away from the river, the 910 m - contour now occupying a greater portion of this farm than in 1976. Nonetheless, the change in groundwater-level is seen to be minimal, reflecting the stabilising influence of recharge from the river. Conditions on the farm Rietfontein show little change from that in 1976.

3.4.3 Sub-area C:

The attitude of the piezometric surface in this area is the reverse of that in sub-area B, revealing a distinct gradient towards the river along the greater part of the left bank, and generally influent conditions along the right bank.

A notable feature of this sub-area is the configuration of the groundwater-level contours on the farms Middeldrift (MD), Elandskuil (EK), Aapieskraal (AK) and Grootkuil (GK). The contours parallel the course of the river on these farms, manifesting a distinct groundwater gradient from west to east. The higher groundwater-levels along the left bank are seen to reflect the geohydrological nature of this zone in that very shallow bedrock (gabbroic) is overlain by a decomposed and very clayey overburden. Figure 13 reveals the presence of potential recharge from the west but this is to be doubted for the reason that little groundwater potential exists in the norites and gabbros in this vicinity. This observation is substantiated by the fact that those few boreholes that do exist outside the alluvial aquifer are either weak (gene-

rally ..../37

rally less than 3 ℓ/s) or abandoned.

Two prominent zones of decline in groundwater-level are evident on the farms Aapieskraal, Grootkuil and a portion of Haakdoorndrift 374 (HT). The aquifer in these zones is more confined in nature the clay overburden attaining thicknesses of up to 8 m (borehole GK 39). The absence of well-fields or high-yielding boreholes in these zones rules out the large-scale abstraction of groundwater as a cause of the decline in water-levels. A more logical explanation would seem to be the influence of river-stage on the piezometric head in the more confined aquifer, a lower riverwater-level resulting in a lowering of the piezometric head and, thus groundwater-levels, in the aquifer. This observation should be confirmed by the careful monitoring of future changes in groundwater-levels at specific localities in response to notable changes in riverstage.

The piezometric surface in the extensive alluvial deposits on the farm Haakdoorndrift 374 (HT) indicates a gentle gradient away from the river, with little change in groundwater-levels in this zone in evidence (Figure 13). The large and productive well-field located on this farm (see Figure 9), rather than dewatering the aquifer, is regarded to considerably encourage recharge from the river in this locality. The prominent groundwater "mound" evident on the farm Haakdoorndrift 373 (HA) and a portion of Klipgat (KG) (Figure 13) most probably reflects past recharge of the aquifer which, at present, remains unexploited. It is expected that this situation will be reversed with the advent of abstraction from the large new well-field on Haakdoorndrift 373 (HA) (see Figure 9).

3.4.4 Sub-area D:

This zone is characterised by the trough-like configuration of the groundwater contours formed as a result of the relatively large abstractions from the well-field tapping the fossil river-bed associated with the fault (Section 3.2.4) in this zone. It would appear, from Figure 13, that the present rate of abstraction has

not ...../38

not, as yet caused a decline in groundwater-levels in this zone and that recharge from out of the granite to the east is highly probable.

3.5 WATER-LEVEL OBSERVATIONS:

The period of record of water-level observations extends only as far back as mid-1976. Nonetheless, valuable information has been acquired with respect to the general behaviour of the groundwater-level during this period, and the observation boreholes are seen to reliably reflect the reponse of the aquifer to flow conditions in the river. The locations of the observation boreholes are plotted on Figure 9, and the data obtained from periodical observations is presented in Annex II. Figures 14, 15 and 16 represent borehole hydrographs for wells in close proximity to the river (less than 200 m), an intermediate distance (300 - 700 m) and far from the river (greater than 800 m) respectively. Geologic profiles of thirteen of the fifteen wells subject to periodical water-level observations since 1976 are presented in Figure 17.

It is immediately evident that the wells depicted in Figure 14 show the greatest sensitivity to flow conditions in the river, realising marked rises in groundwater-level in response to the peak discharges of May 1976, March 1977. February 1978 (488 million m³) and February 1980 (99.5 million m³). The most important of the aforementioned discharges is that of February 1978, which produced flooding of large areas adjoining the river, and consequently the submersing of many of the observation boreholes.

The direct result of this flood was to drastically raise groundwater levels over most of the study area, this rise being witnessed in boreholes further than 800 m from the river (Figure 16). In comparison, the other periods of relatively high discharge realised only a slight influence on groundwater-levels, producing rises of less than 2 m in boreholes located close to the river, and even less in those some distance away. A notable exception is the rise of some 2m of the water-level in borehole RF 46 (Figure 16) in response to the discharges of May 1976 and February 1980. This phenomenon is attributed to the proximity of the fault realising a geohydrological connection between the aquifer and the river at this locality.

GEOLOGIC PROFILES OF BOREHOLES SUBJECT TO PERIODICAL WATER-LEVEL MEASUREMENTS.

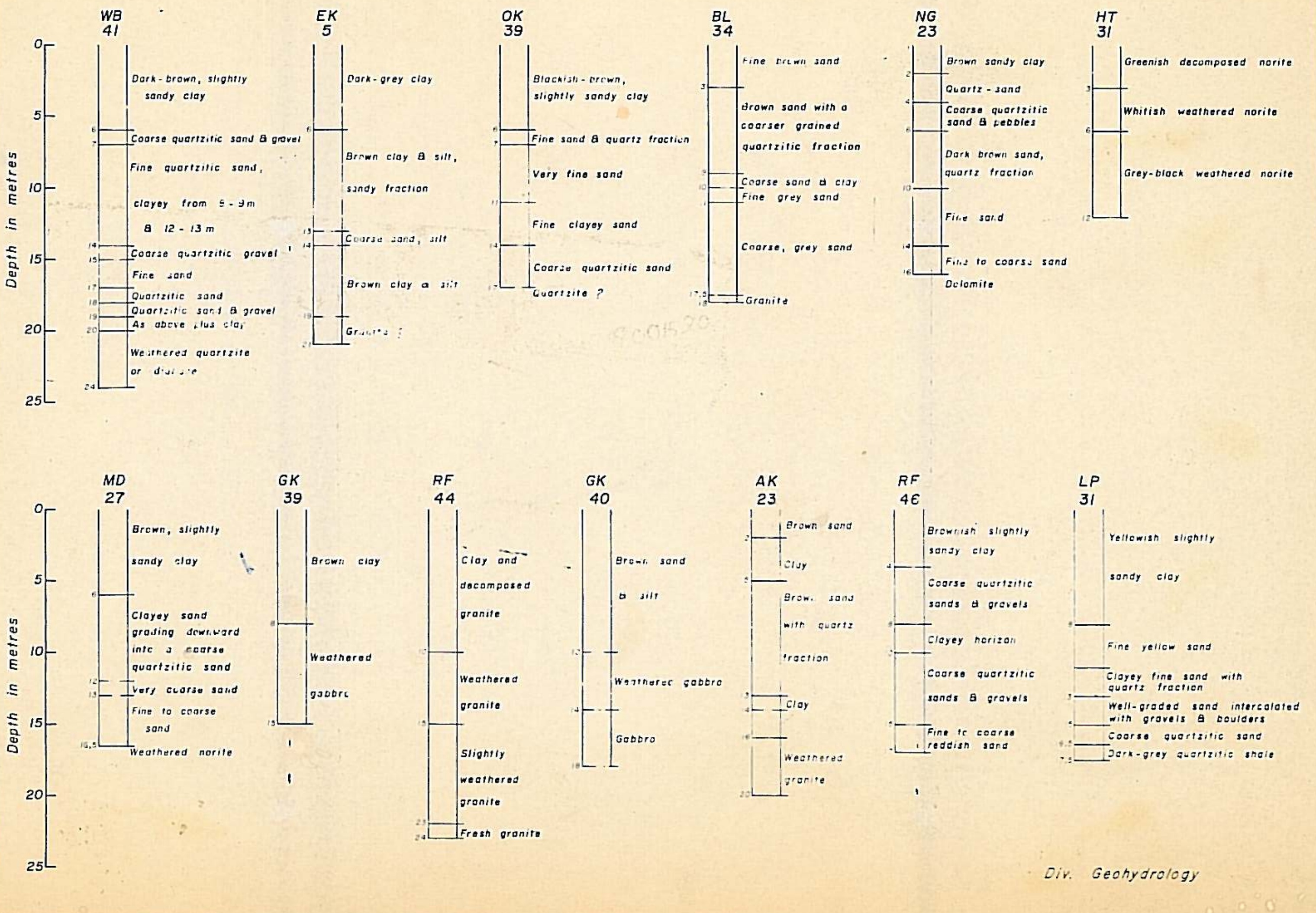


FIGURE 17.

140
140
160

The irregular fluctuations of the water-level evident in boreholes MD 27 (Figure 15) and LP 31 (Figure 16), both located within well-fields, is attributed to the influence of abstraction from the nearby production boreholes. It is observed that the drawdowns obtained in these well-fields during periods of obstraction seldom exceeds 3 m, and that subsequent recovery of the groundwater-levels is reasonably swift. A further interesting observation is the fact that the water-levels in most of the observation boreholes decline exponentially in the period following the February 1978 flood, assumming the form of recession - curves in the absence of notable recharge during this period. Although the slightly higher river-discharges are manifested as corresponding small peaks in the hydrographs, this effect is soon dissipated (within a month), and is not seen to result in a lasting increase of the general groundwater-level.

The hydrograph of borehole MD 28 (Figure 16) differs markedly from the rest, witnessing a general rise of some 2 m in water-level since mid-1977. This borehole is located some 1200 m away from the river and penetrates the gabbroic bedrock, and is therefore seen to reflect the behaviour of the groundwater-level outside the river-aquifer regime in this vicinity.

3.6 AQUIFER-RESPONSE TO FLOODING:

The response of the aquifer to the flood of January / February 1978, as monitored by the automatic water-level recorder installed on borehole OK 39 (station A2N068) on the farm Olifantskop, is graphically illustrated in Figure 18. The recorder is located approximately 85 m from the river and some 8 km downstream from surface gauging station A2M25A. In order to draw a more direct comparison between the river-stage at station A2M25A and the water-level in borehole OK 39, the river-stage as monitored at A2M25A has been expressed as a height above the approximate elevation of the river-bed opposite the borehole. It is accepted that some discrepancy will exist as a result of the difference in cross-sectional area of the river channel at these two points. Nonetheless, a tight relationship between groundwater-levels and river-stage is observed.

Calculations ..../41

Calculations based on hydrological data available for the flow characteristics at station A2M25A yielded rough estimates of the flow velocity for discharges of varying magnitude (Table 4). It is accepted that daily average discharges in excess of 200 cumecs realise a minimum flow velocity of 1.7 m/s. Peak discharges in this range are thus expected to arrive some 80 min. later at a point 8 km downstream from station A2M25A. This time lag is regarded as negligible on the time scale depicted in Figure 18, and as such will be disregarded as having any influence on the time lag evident in the response of the aquifer to peak discharges and related river-stages.

The response of the aquifer to each of the three main periods of extremely high discharge evident in Figure 18 is discussed below.

i) The period 3 - 4 January:

The daily average flow on these two days was in excess of 250 and 272 cumecs respectively, and realised a rise of approximately 4 m in river-stage. The groundwater-level prior to this period was some 1.5 m below river-stage, and is seen to start to rise some 8 hrs. after the onset of the peak discharge. The continuing response is gradual, manifesting a rise of approximately 0.8 m over a period of about 8 days, and with a period of close on 7 days separating the peaks in river-stage and groundwater-level.

A pumping test performed by B.R.G.M. on borehole OK 39 yielded values of 130 m^2/day and 1.6 x 10^{-2} for the transmissivity (T) and storativity (S) of the aquifer respectively. The saturated thickness of the aquifer is 11 m (from B.R.G.M. data). These values yield a value of ± 12 m/day for the permeability (k) of the aquifer. If the distance of the borehole from the river (85 m) is divided by the permeability of the aquifer (12 m/day), a travel time of 7 days is obtained for the propagation of a flood wave through the aquifer over this distance. This value agrees well with that observed in Figure 18.

TABLE 4 ..../42

TABLE 4. Estimated average flow velocity of discharges of varying magnitude at station A2M25A, as obtained from flow gauging records (Division of Hydrology).

Discharge (Q) in m³/s	Average flow velocity in m/s
0,25	0,45
2,61	0,80
3,82	1,16
4,05	1,23
102,00	1,32
136,00	1,38
169,00	1,69
207,00	1,69

ii) The period 25 January to 3 February:

The daily average flow in this period was far in excess of 276 cumecs, and resulted in extensive flooding of areas adjacent to the river. The peak discharge occurred on the 29th January, at which time the borehole was submerged and direct vertical recharge of the aquifer took place. The preceding period of 8 days witnessed a sharp rise in groundwater-level of 1.4 m in the face of a continuous discharge in excess of 276 cumecs.

A study of the recorder chart for the period of direct inflow reveals that the borehole was submerged for some 20 hrs., with the peak of the flood standing ± 0.5 m above the collar of the borehole. This constitutes a rise of over 6 m in groundwater-level. The small peak evident on the decending limb of the hydrograph following the flood-peak can be correlated with an increase in river-stage resulting from the contributive discharge of the Pienaars River after having been delayed by the Klipvoor Dam. The resulting rise of ± 10 cm in groundwater-level, and the change in form of the groundwater recession curve, indicates that additional recharge of the aquifer took place.

iii) The period 18 - 23 February:

A daily average flow in excess of 276 cumecs is once again witnessed, the peak occurring on the 20th February. The rapid rise of 2.1 m in groundwater-level took place over a period of 2.75 days, with approximately 5 hours separating the river-stage and groundwater-level peaks. No flooding of the borehole occurred. The shape of the recession curve during the period of 17 days following this peak shows a marked similarity to that following the previous peak. The influence of the high discharge which occurred on the 11th March would seem to have no real effect on the

general ..../44

general trend of this recession curve, indicating the aquifer to be fully saturated.

3.6.1 Determination of the ratio S/T:

It is evident that additional information concerning the aquifer parameters may be obtained from analyses of the propagation of flood waves through the alluvial aquifer resulting from an adrupt change in river-stage (Oakes, 1980). An analytic solution to this problem is provided in Huisamen (1972, p.39) and Walton (1970, p 179), and is based on the theory that the propagation of a train of sinusoidal waves through the aquifer, in response to correlative changes in river-stage, is exhibited as sinusoidal fluctuations of the water-level in a borehole. The greater the distance of the well from the river, the smaller the amplitude of the transmitted wave and the greater the time lag.

The formula relating a sudden change in river-stage to the change in water-level in a borehole can be written nondimensionally as

$$s = s_d \, W(u_h) \qquad (3.1)$$

where

$$u_h = x \, (S/4Tt)^{\frac{1}{2}} \qquad (3.2)$$

s = change in water-level in the well (metres)
s_d = adrupt change in river stage (metres)
x = distance of the well from the river (metres)
t = time after the adrupt change in river stage (days)
T = transmissivity of the aquifer (m²/day)
S = storage coefficient (dimensionless)

and $W(u_h)$ is read as the "well function for nonleaky artesian aquifers with a drain having an adrupt change in stage". Values for $W(u_h)$ are presented in Walton (Table 3,11, pg. 181) and Huisamen (Table 2.1, pgs. 42 - 47).

The determination of the ratio S/T for each of the time periods depicted in Figure 18 yielded the following tabulated values.

TABLE 5 Determination of the ratio S/T

Period	Time (t) in days	Change in g/w level(s) in metres	Change in river-stage (s_d) in metres	$W(u_h)$	u_h	S/T
1	1.6	0.20	3.60	0.0556	1.36	1.6×10^{-3}
2	3.1	0.98	5.04	0.1944	0.92	1.5×10^{-3}
3	1.5	0.42	0.94	0.4468	0.84	2.0×10^{-4}
4	1.6	0.14	1.36	0.1029	1.15	1.2×10^{-3}
5	2.0	0.80	4.32	0.1852	0.94	1.0×10^{-3}
6	2.2	0.32	1.76	0.1818	0.945	1.1×10^{-3}

3.6.2 Application of the ratio S/T:

It can be appreciated that the ratio S/T provides a usefull tool for determining either the transmissivity or the storativity of an aquifer should one of these values be known. The results listed in Table 5 yield an average value for S/T of 1.1×10^{-3} for the aquifer in this locality.

An analysis of the aquifer test data for borehole OK 39 yielded an average value for $T = 57 m^2/day$. Substition of this value into the ratio for S/T yields a value for S of 6.3×10^{-2}. This value is smaller than that obtained for the specific yield (S_y) of the aquifer (1.4×10^{-1} from the same aquifer test) but compares favourably with those obtained from the other aquifer tests (see Section 3.7).

The discrepancy noted above should be sought in the analysis of the aquifer test data. The transmissivity value so obtained is seen to be reliable, but doubt is expressed concerning the S_y-value obtained. It is possible that the aquifer test was not of long enough duration for the effects of delayed gravity drainage to have dissipated in the observation well and this has lead to the erroneous determination of the specific yield (S_y) of the aquifer in this locality.

It is unfortinate that no other data similar to that presented above is available for other localities in the study area, and serious consideration should be given to the determining of aquifer diffusivity values (the ratio T/S) for other portions of the aquifer in the same manner as described above.

3.7 AQUIFER TESTS:

A total of three constant-discharge aquifer tests of long duration were performed in the study area. The following boreholes were used as production wells in the execution of these tests:

G 32647 (observation well G 32646)
G 32648 (" " G 32649)
G 32655 (" " G 32656)

The location of these test-sites, presented in Figure 9 was primarily dictated by the need for additional geohydrological information concerning the nature of the aquifer in these specific localities. In addition to the above, the following aquifer tests performed by B.R.G.M. in 1976 were re-analysed:

OK 39 (observation well OK 40)
and LP 31 (observation well LP 32)

A detailed discussion of the methods used in analysing the aquifer test data contained in this report is to be found in Kruseman and de Ridder (1976). The method of Neuman is discussed in a paper presented in Vol. II, No. 2 of the Water Resources Research journal April 1975 (see references). The data obtained during the tests, together with the analysis thereof following various methods, is presented in Annex III.

3.7.1 Discussions .../47

3.7.1 Discussions and results:

It is observed that all three aquifer tests were performed on boreholes which fully penetrated the alluvium. A single fully penetrating observation borehole was made use of in each case. The absence of unequipped private boreholes in close proximity to each test, and which could have been used as additional observation wells, is unfortunate.

It was further observed that the yields obtained during pumping never realised the apparent potential yield of the boreholes as witnessed during the drilling operations ie. the blow yields. Attempts at conducting step-drawdown tests were unsuccessfull, mainly due to the fact that the water-level in the pumped wells fluctuated continuously, with the result that no single set of drawdown-data could be related to a specific discharge increment. It thus proved impossible to determine well-efficiencies for the pumped boreholes.

Despite the fact that the relatively low yields that were obtained realised only small drawdowns in the observation wells, the resulting data proved to be interpretable, and valuable information concerning the hydraulic properties of the aquifer was obtained.

Aquifer test on G 32647: (Annex III, Graphs 1.1 - 1.6)

The bi-log time-drawdown curves obtained for observation borehole G 32646 indicate the presence of possible delayed yield phenomena, and were accordingly analysed following the methods of Neuman (Graph 1.3) and Boulton (Graph 1.4). The results are seen to be in close agreement, the following average values for the hydraulic parameters being obtained:

Transmissivity ..../48

Transmissivity (T) = 311 m²/day
Elastic storage coëff (S) = 4.4×10^{-3}
Specific yield (S_y) = 3.8×10^{-2}

The late drawdown data on the semi-log time-drawdown curves seem to indicate the approach of steady-state flow conditions. The results obtained from the analysis of these curves (Graphs 1.1 and 1.2) closely approach those given above:

T = 352 m²/day
S = 4.4×10^{-3}

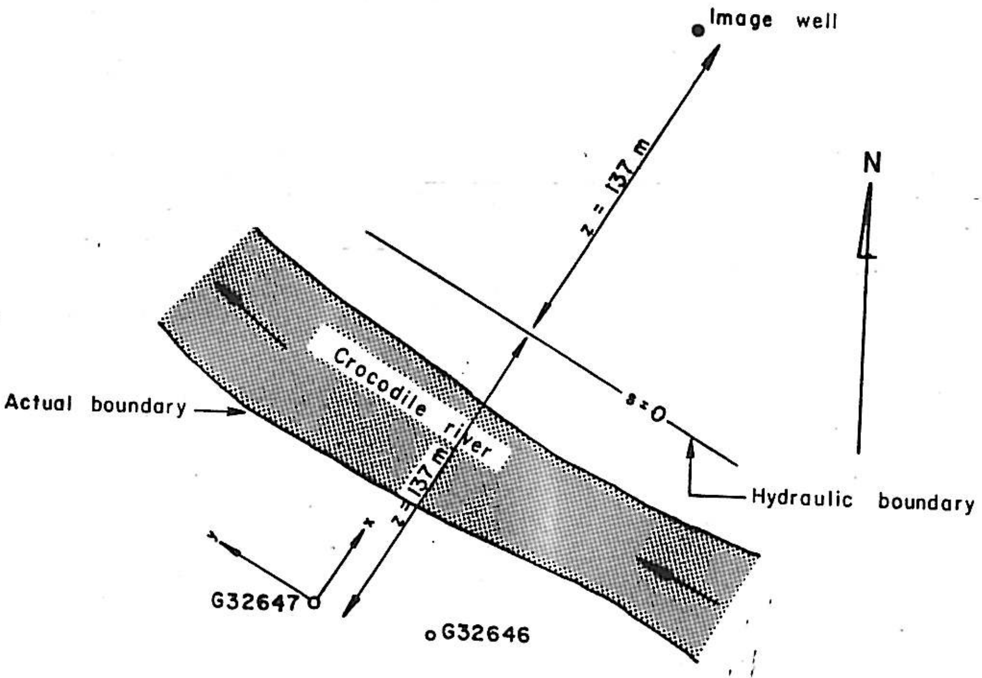
The inflection point method of Hantush (Graph 1.2) affords a check on the correctness of the analysis (Kruseman and de Ridder, 1976, p.86). Application of this procedure to graph 1.2, and taking time (t) = 20 min, yield a theorectical drawdown value of 0.12 m , which agrees exactly with that observed on the graph. This corroboration implies that the surmised steady-state drawdown has been accurately extrapolated from the graph.

Graph 1.5 explores the further possibility that the observed apparent delayed yield phenomenon is, in fact, the effect of recharge from the river. According to Kruseman and de Ridder (1976, p 120), the Hantush image method takes into account the effect of one recharge boundary "when the effective line of recharge does not correspond with the bank or the streamline of the river ....", as a result of partial penetration effects of the recharging boundary, or an entrance resistance at the boundary contact. From Section 3.3 it is evident that both these factors are in existance in this instance. The analysis yielded the following results:

T = .../49

$T = 361\ \text{m}^2/\text{day}$
$S = 4.0 \times 10^{-3}$
$\text{Ƶ} = 137\ \text{m}$

where Ƶ = the distance between the real discharging well (G 32647) and the hydraulic boundary (effective line of recharge).



Scale approx. 1 : 3000

Figure 19: Schematic illustration of the application of the Hantush image method as applied to the aquifer test performed on borehole G32647.

The above results highlight the difficulty in distinguishing which effect manifests itself on the time drawdown curves ie. the effect of delayed gravity drainage, or the effect of river recharge, or both. Both possibilities fit the available data and

information ..../50

information excellently, are both equally applicable, and yield results which are in close agreement. Nonetheless, the following conclusions concerning the nature of the alluvial aquifer in this locality can be drawn:

i) the river acts as a recharge boundary, the influence of this recharge outweighing the effect of delayed gravity drainage from out of the semi-previous overlying layer;

ii) the aquifer undergoes a transition from semi-unconfined to unconfined conditions with pumping;

iii) the aquifer possesses a transmissivity in the order of 355 m²/day, an elastic storage coefficient (early time storativity) of 4.4×10^{-3} and a specific yield (S_y) of 3.8×10^{-2}.

Aquifer test on G 32648 : (Annex III, Graph 2.1 - 2.3)

The time-drawdown data obtained from this test is observed to reflect the effect of leakage from the semi-previous covering layer, and was analysed following the methods of Cooper-Jacob, Walton and Hantush (inflection point). The latter two methods yielded similar values for the hydraulic parameters of the aquifer, and were thus accepted as being the more accurate. The following average values were obtained:

$$T = 607 \text{ m}^2/\text{day}$$
$$S = 6.5 \times 10^{-2}$$

This storage coefficient indicates the aquifer to be unconfined rather than semi-confined in this locality. An average leakage factor ( ) of 58m, and a hydraulic resistance of the semi-previous layer of 5.6 days, is obtained.

The ..../51

The analysis of graph 2.1 was checked for accuracy, and yielded a drawdown value of 0.015 m at time (t) = 40 min. This value is in close agreement with that observed on the graph.

Aquifer test on G 32655: (Annex III, Graph 3.1 - 3.3)

The data obtained from this test proved difficult to interpret, and the results obtained should be accepted with caution. Both the bi-log and semi-log plot of the time-drawdown data reflect the presence of a barrier boundary. The effect of this boundary manifests itself on the drawdown data some 220 min. after the start of the test. It is postulated that this boundary reflects the changes in thickness and hydrogeologic properties related to the "outer" boundary of the alluvial aquifer.

As mentioned above, the time-drawdown graphs are seen to resolve themselves into two portions ie. one portion (segment) indicative of drawdown prior to the effect of the barrier boundary being felt, and a second segment subsequent thereto. Each of these segments has been analysed separately following the same methods, the analysis of the earlier portions of each graph yielding the following average values for the hydraulic parameters:

$T = 4454 \text{ m}^2/\text{day}$

$S = 3.9 \times 10^{-4}$

The validity of these results is highly questionable, and will not be considered further.

The analysis of the later portions of each graph yielded more acceptable results, these being:

$T = 1073 \text{ m}^2/\text{day}$

$S = 10^{-2}$

The ...../52

The analysis of the recovery data for borehole G 32655 yielded a transmissivity of 613 m²/day, which is in close agreement with the average of 688 m²/day obtained from the re-analysis of the B.R.G.M. aquifer test performed on borehole LP 31, located some 220 m distant (Figure 9).

Taking into consideration the coarse nature of the alluvium in this locality (evident from the drilling logs of boreholes G 32655 and G 32656, Annex IV), the average transmissivity of 843 m²/day obtained from the analyses of the latter portions of the time-drawdown graphs and the recovery graph appears to be a much more acceptable value. The storage coefficient value of 10^{-2}, indicating unconfined conditions, is also acceptable.

Re-analysis of B.R.G.M. aquifer test on borehole LP 31 (Annex III) Graphs 4.1 - 4.6)

The re-analysis of the data obtained from this aquifer test confirmed the transmissivity value obtained by B.R.G.M., and resolved the somewhat contradictory storativity value obtained.

The time-drawdown data has been re-analysed following the method of Neuman (both the bi-log and semi-log methods), Cooper-Jacob, Chow and Theis. Of these, only the method of Neuman considers the effect of delayed gravity drainage. The results obtained show a remarkable agreement, yielding the following average values for the hydraulic parameters:

$$T = 688 \text{ m}^2/\text{day}$$
$$S = 6.9 \times 10^{-3}$$
$$S_y = 1.1 \times 10^{-2}$$

It is thus evident that the aquifer in this vicinity undergoes

a transition ..../53

a transition from semi-unconfined to fully phreatic conditions with pumping. This observation is supported by the fact that the groundwater-level in the well-field surrounding these boreholes recovers rapidly following an extended period of abstraction (see Fig. 16 and Section 3.5).

The method of Neuman affords a calculation of both the horizontal (K_r) and vertical (K_z) permeability, as well as the specific storage (S_s) of the aquifer. The following average values were obtained:

K_r = 75.8 m/day
K_z = 0.35 m/day
S_s = 7.5×10^{-4} m^{-1}

Re-analysis of B.R.G.M. aquifer test on borehole OK 39: (Annex III, Graphs 5.1 - 5.3)

The results obtained from the re-analysis of this data following the methods of Boulton and Neuman, again considering the effect of delayed gravity drainage, are not in agreement with those obtained by B.R.G.M..

An average transmissivity value of 57 m^2/day as opposed to the 130 m^2/day of B.R.G.M. , is arrived at. The drilling logs of boreholes OK 39 and OK 40 (B.R.G.M., Appendix 3) indicate the aquifer to consist of a fine sand, with some gravel, in this locality. This explains the low transmissivity of the aquifer and also the extremely low yield of borehole OK 39 (1 ℓ/s). Furthermore, the horizontal permeability of the aquifer is a low 5.7 m/day (graph 5.2).

The average elastic storage coefficient (Neuman = S, Boulton = S_A)

of 6.7 ....../54

of 6.7×10^{-3} for the aquifer in this locality once more indicates an initially semi-unconfined aquifer which, with pumping becomes phreatic with an average specific yield (S_y) of 1.7×10^{-1}.

4. HYDROCHEMISTRY:

A total of 122 groundwater samples and 5 river water samples were collected throughout the study area. The samples were analysed at the Hydrological Research Institute, and the results thereof are presented in Annex IV. The sampling points are indicated in Figure 9. The main objects of this investigation can be summarised as follows:

i) to identify those areas adjoining the river which avail over groundwater supplies similar in composition to that of the river;

ii) to investigate the difference in the composition of groundwaters from various geological environments in the study area, and ascertain their relationship to the alluvial groundwater in the valley.

The results of all the analyses have been plotted on Piper tri-linear diagrams (Figs. 20.1 - 20.5) in an attempt at determining the essential chemical character of the various groundwaters according to the relative concentrations of their chemical constituents. The correlative methods of both Schoëller (Figs. 21.1 - 21.11) and Stiff (Fig. 9) have been applied in the graphical presentation of the data.

4.1 DISCUSSION and RESULTS:

It is immediately evident from the Piper diagrams that the majority of the samples exhibit a mixed cation composition (ie. there is no dominant single major cation), with bicarbonate as the dominant anion present. These waters are deemed to be fresh and of recent origin. This observation is substantiated by the fact that 65% of the samples

have ...../55

Figure 21.9 represents groundwaters from wells located on the farm Rietfontein. These samples are singularly exceptional in the fact that they all reveal a relatively low sulfate concentration for the groundwater in this locality. These waters are further characterized by relatively high concentrations of sodium and chloride. This farm is partially underlain by granite, and it is possible that the weathering of the sodium-rich plagioclase feldspars in these granites is the cause of the relatively high sodium content of these groundwaters. The cause of the relatively high concentrations of chloride in some of these samples should be sought in the fact that these samples represent stagnant groundwater (Johnson, 1975 p.4). This possibility is corroborated by the fact that the piezometric surface in this locality maintains a constant height of some 912 metres a.m.s.l., and with virtually no gradient evident in any direction. Other factors contributing towards this phenomenon are thought to be:

i) the fact that groundwater-levels in this locality are shallow, on average 6 metres below the surface;
ii) the area is intensely cultivated;
iii) drainage through the clay-rich and loamy soil overburden is poor;
iv) the area is prone to flooding when the river overflows its banks (during periods of extremely high river-discharge).

Figure 21.9 further reflects the close resemblance of the composition of the groundwater sample obtained from borehole RF 46, to that of the river, and would seem to corroborate the observation made in Section 3.5, namely that the aquifer in the vicinity of the borehole is hydraulically connected to the river.

Figure ....../57

have a total dissolved solids (TDS) count of less than 1000 mg/ℓ. Furthermore, only 18% of the samples have a TDS count greater than 1500 mg/ℓ, and it is observed that the majority of the latter samples represent groundwater from boreholes tapping the various bedrock aquifers.

A second general observation to be made, and which is especially evident from the Schoëller diagrams, is the fact that the average river water sample exhibits a lower calcium concentration than that of the alluvial groundwaters. This phenomenon is possibly the result of precipitation of calcium carbonate ($CaCO_3$) in the upstream reservoirs in which the river water is impounded.

Figures 21.1 - 21.6 illustrate the close correlation between those samples obtained from boreholes tapping the alluvial aquifer, and the average composition of river water. The major anomolous factor evident from these graphs is the low sulfate content of some of the alluvial groundwaters eg. HA23 and WB5 (Fig. 21.4), HT123 and HT133 (Fig. 21.5) and OK40 and DF17 (Fig. 21.6). This is thought to be the result of possible sulfate reduction by bacteriological action (Hem, 1970 p. 165).

Figure 21.7 represents the composition of groundwaters obtained from wells tapping the dolomitic bedrock in the southern portion (sub-area A) of the study area. These waters are relatively high in calcium and low in sodium, with bicarbonate as the predominant major anion present. Figure 21.8 reveals the difference in composition between the alluvial groundwater obtained from boreholes OK9, OK42 and OK44, and groundwater obtained from boreholes tapping the quartzites and shales flanking the alluvial deposits on the farm Olifantskop. The latter waters reveal a predominance of magnesium over calcium, with sodium the dominant major cation , and chloride the dominant major anion, present.

Figure 21.9 ..../56

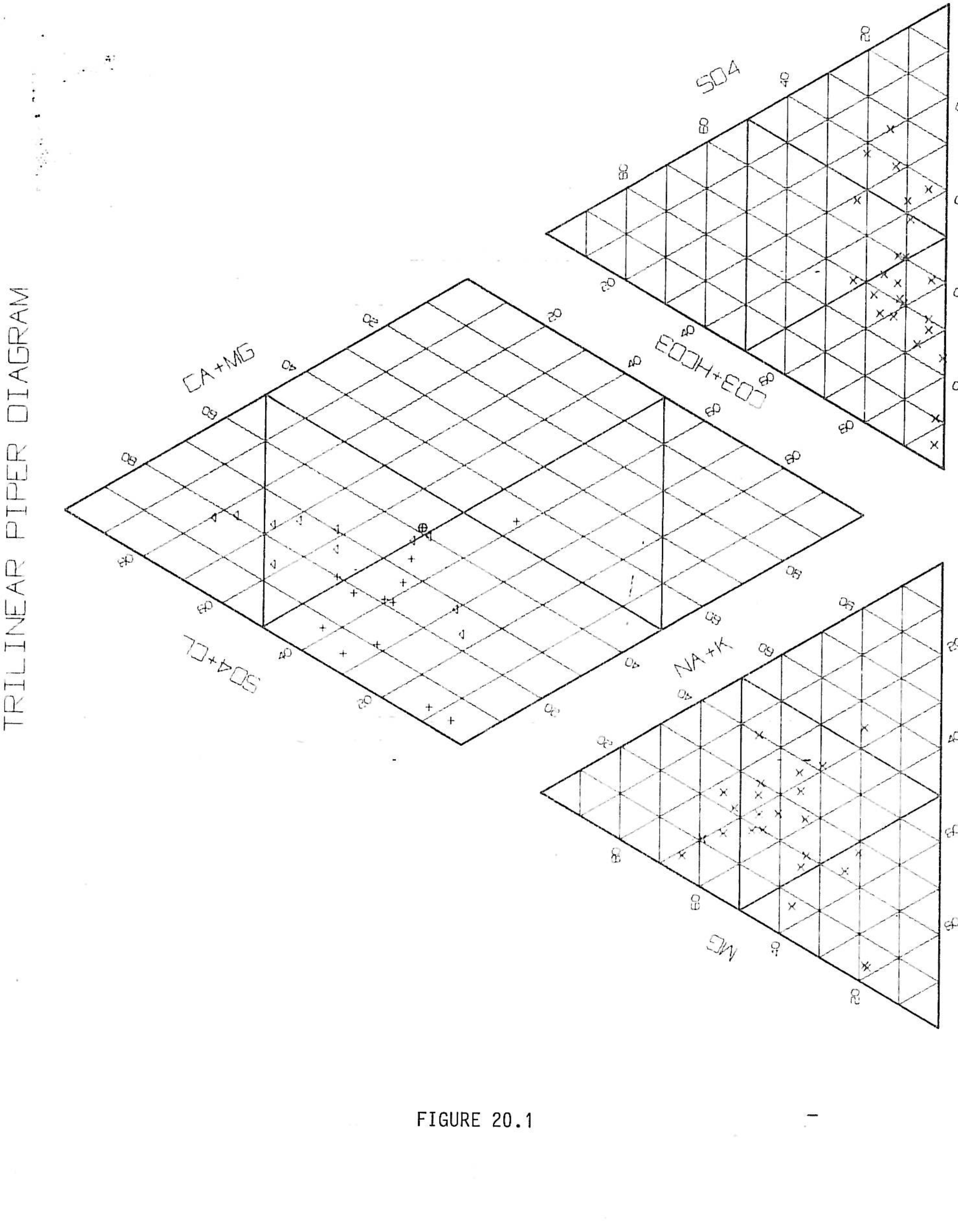

TRILINEAR PIPER DIAGRAM
CA+MG
SO4+CL
CO3+HCO3
NA+K
SO4
CL
CA
MG
20
40
60
80

FIGURE 20.1

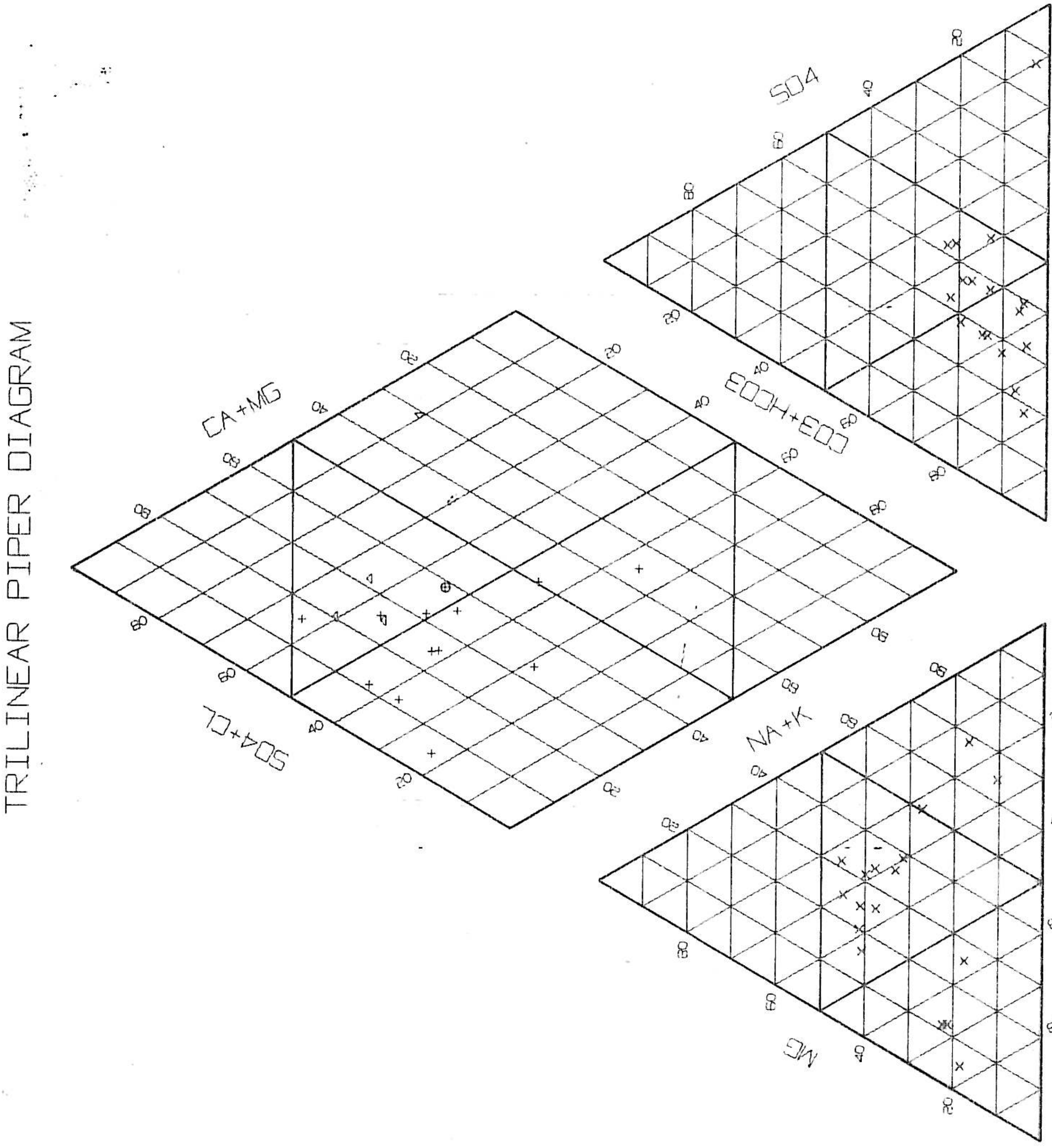

TRILINEAR PIPER DIAGRAM
CA+MG
SO4+CL
CO3+HCO3
SO4
CL
NA+K
CA
MG
20
40
60
80

FIGURE 20.2

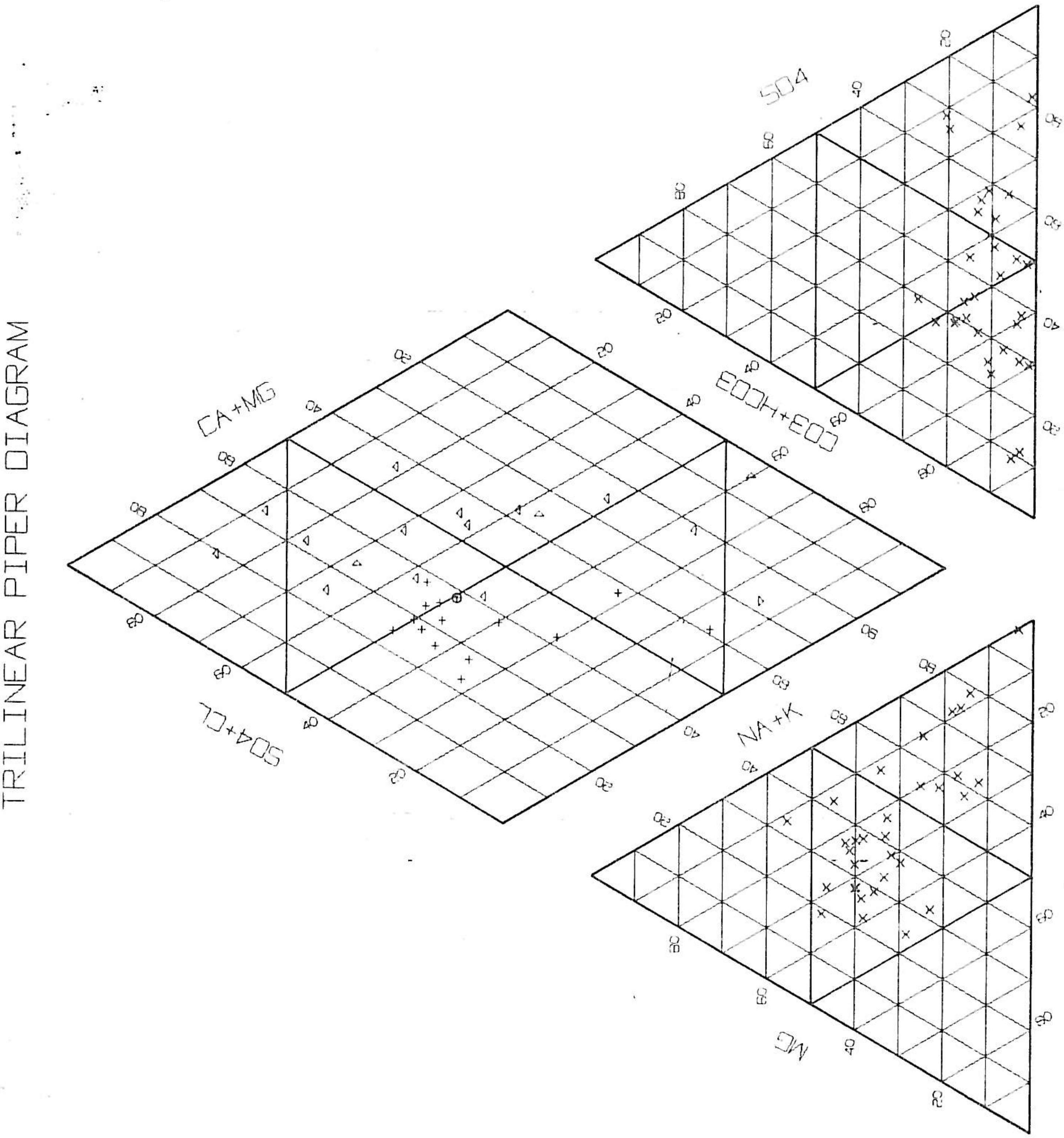

TRILINEAR PIPER DIAGRAM
CA+MG
SO4+CL
CO3+HCO3
NA+K
SO4
CL
CA
MG
20
40
60
80

FIGURE 20.3

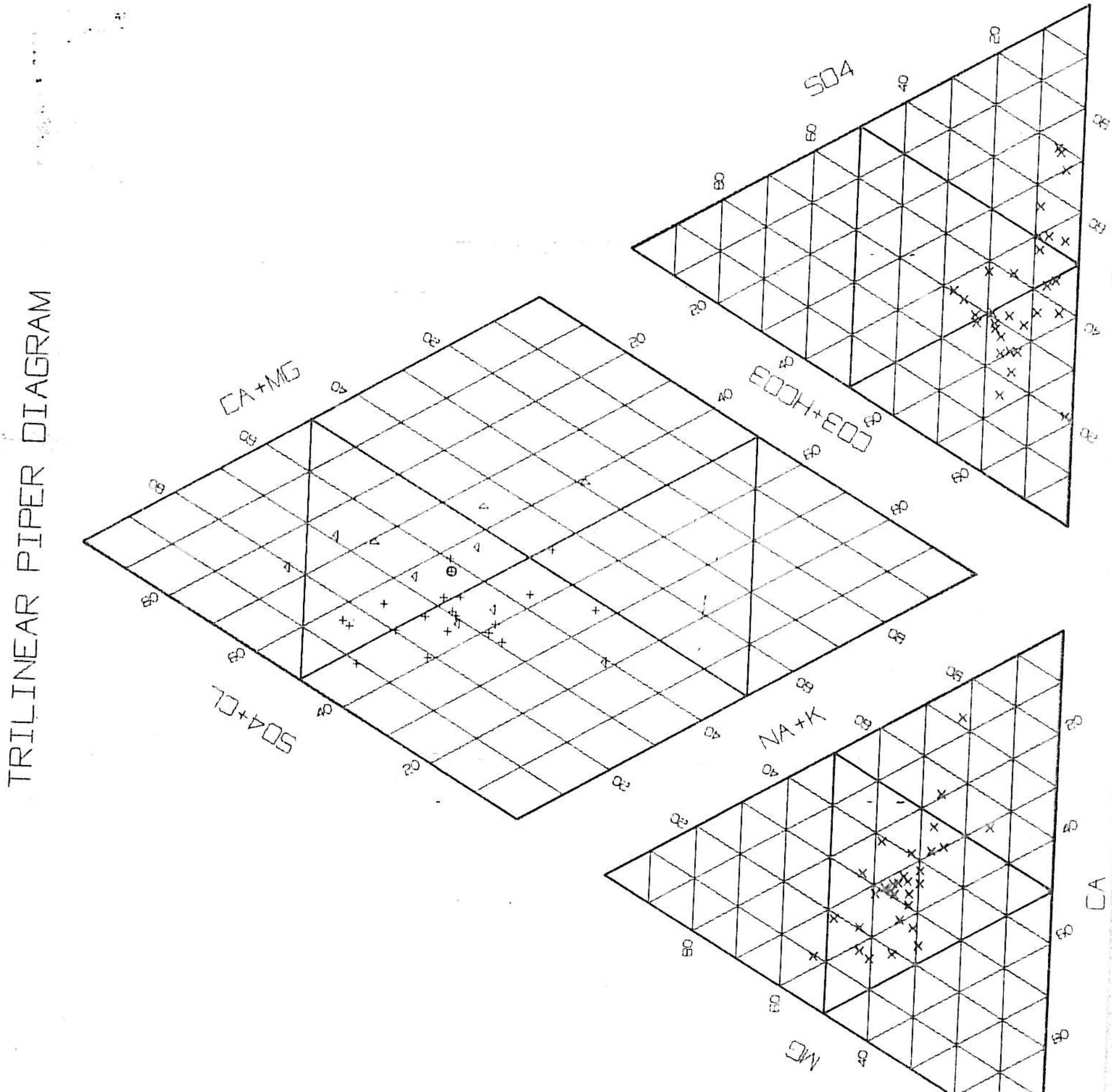

TRILINEAR PIPER DIAGRAM
CA+MG
SO4+CL
CO3+HCO3
NA+K
SO4
CL
CA
MG
20
40
60
80

FIGURE 20.4

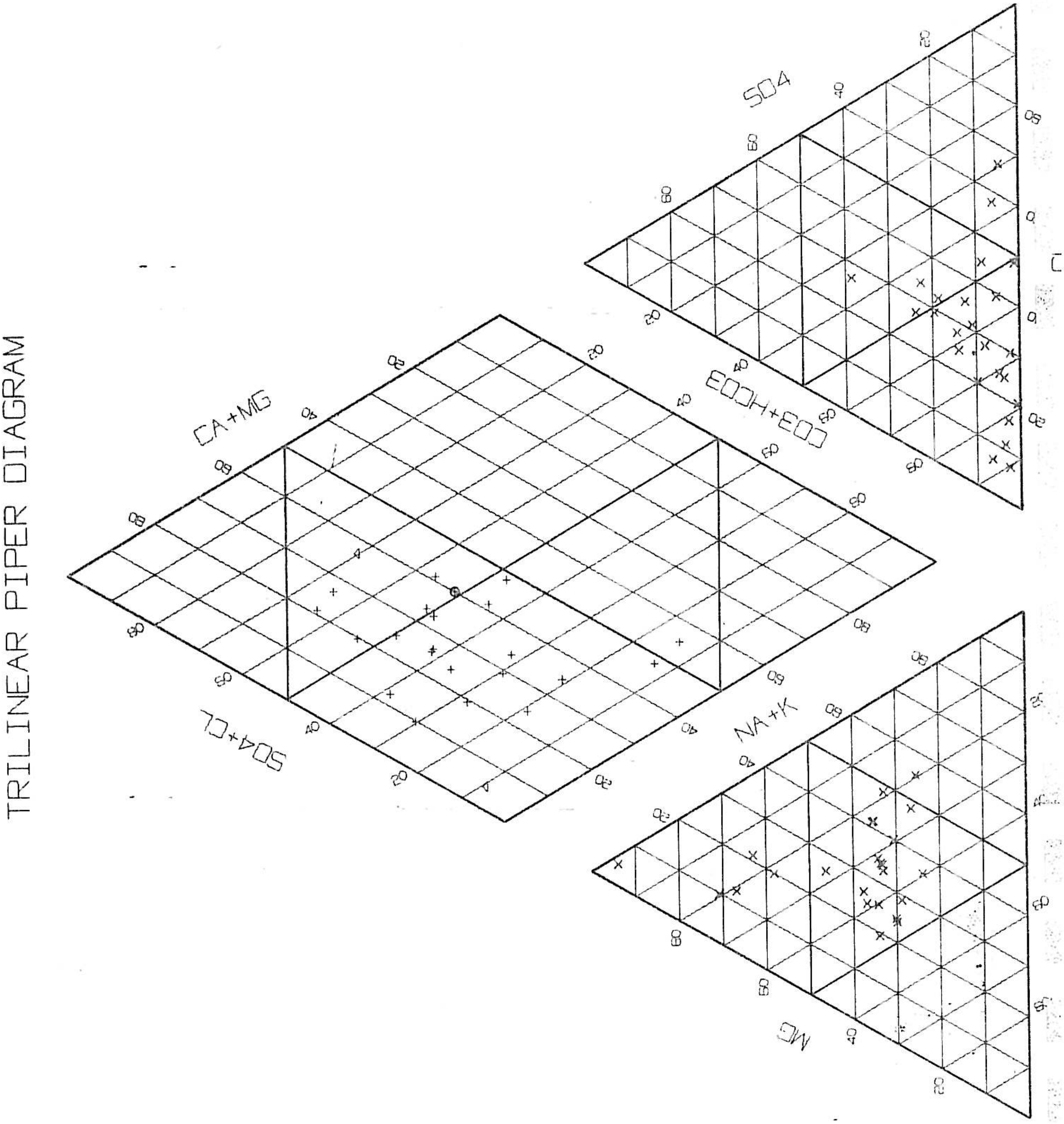

TRILINEAR PIPER DIAGRAM
CA+MG
SO4+CL
CO3+HCO3
NA+K
MG
SO4
CL
20
40
60
80

FIGURE 20.5

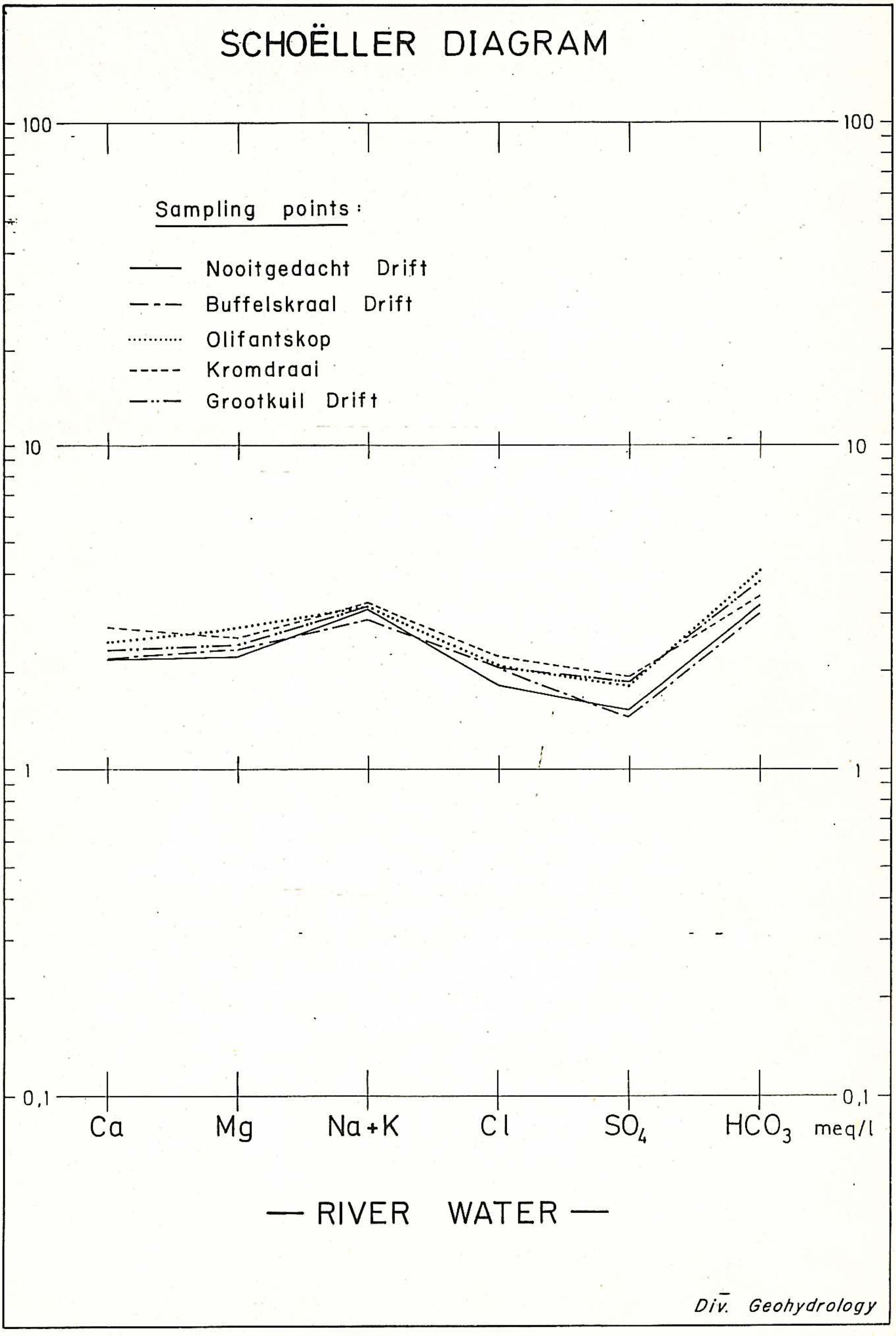

SCHOËLLER DIAGRAM
Sampling points:
Nooitgedacht Drift
Buffelskraal Drift
Olifantskop
Kromdraai
Grootkuil Drift
100
10
1
0,1
Ca
Mg
Na+K
Cl
SO4
HCO3
meq/l
— RIVER WATER —
Div. Geohydrology

FIGURE 21.1

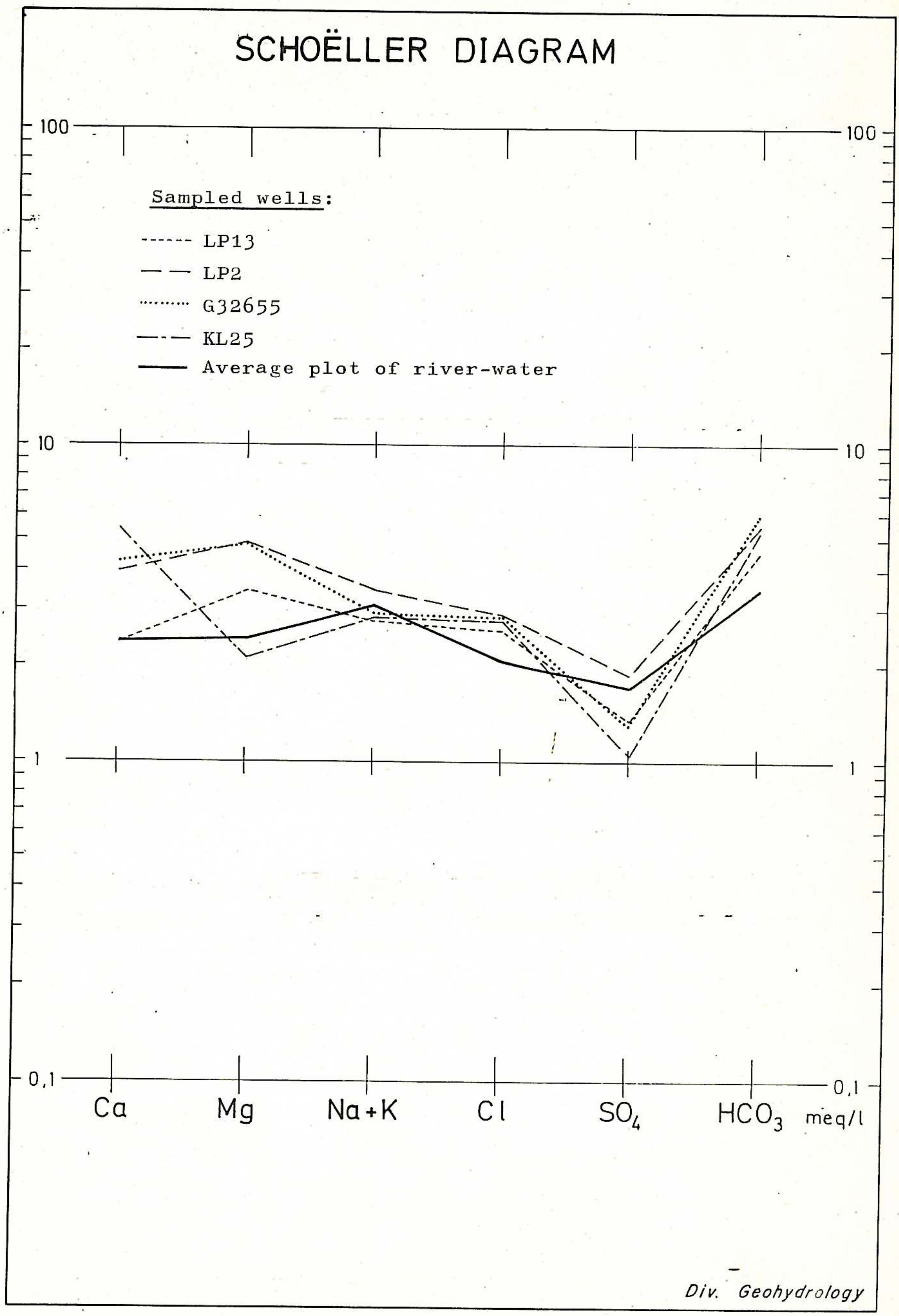

SCHOËLLER DIAGRAM
100
10
1
0,1
Sampled wells:
LP13
LP2
G32655
KL25
Average plot of river-water
Ca
Mg
Na+K
Cl
SO_4
HCO_3
meq/l
Div. Geohydrology

FIGURE 21.2

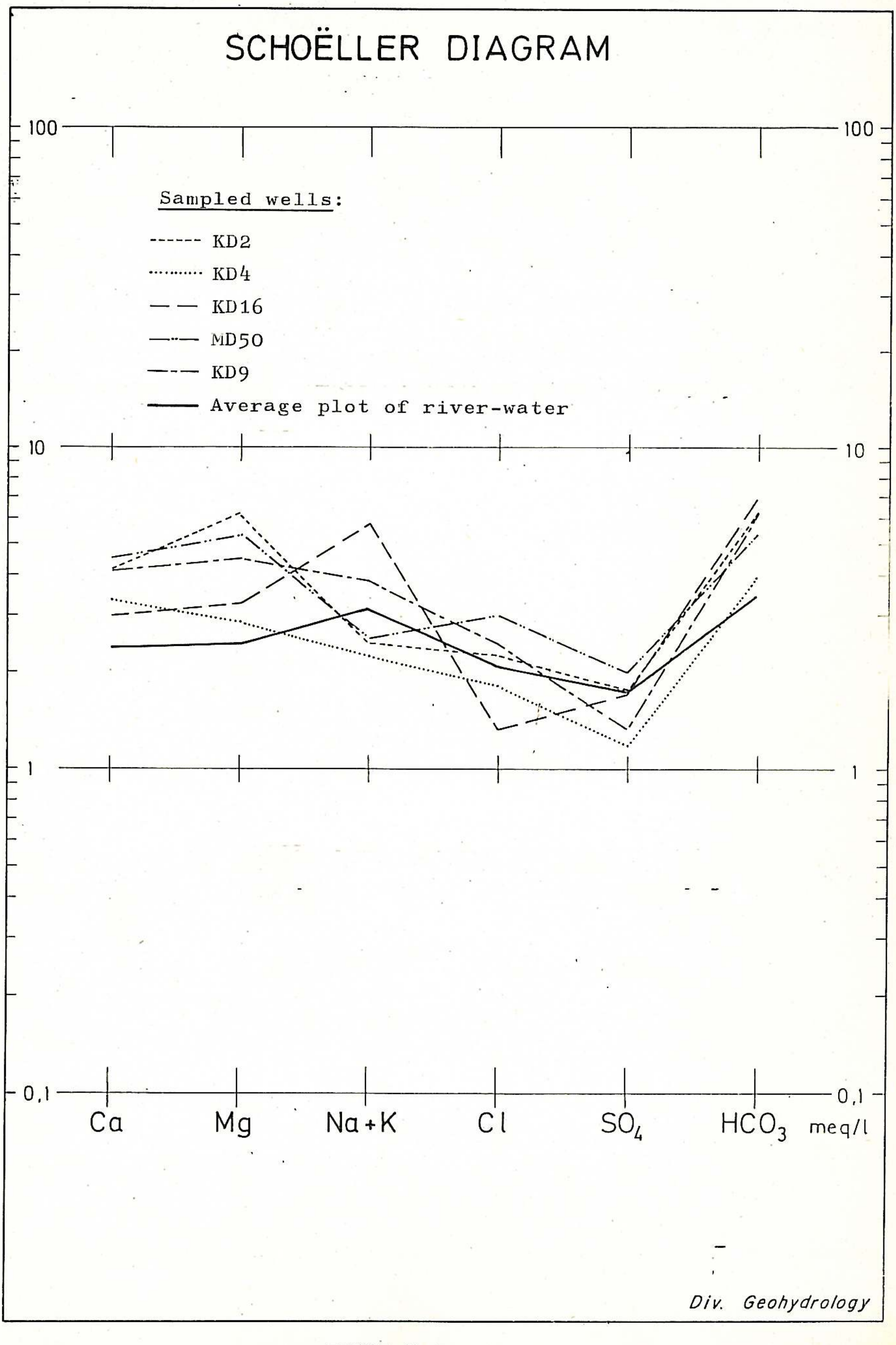

SCHOËLLER DIAGRAM
100
10
1
0,1
Sampled wells:
KD2
KD4
KD16
MD50
KD9
Average plot of river-water
Ca
Mg
Na+K
Cl
SO_4
HCO_3
meq/l
Div. Geohydrology

FIGURE 21.3

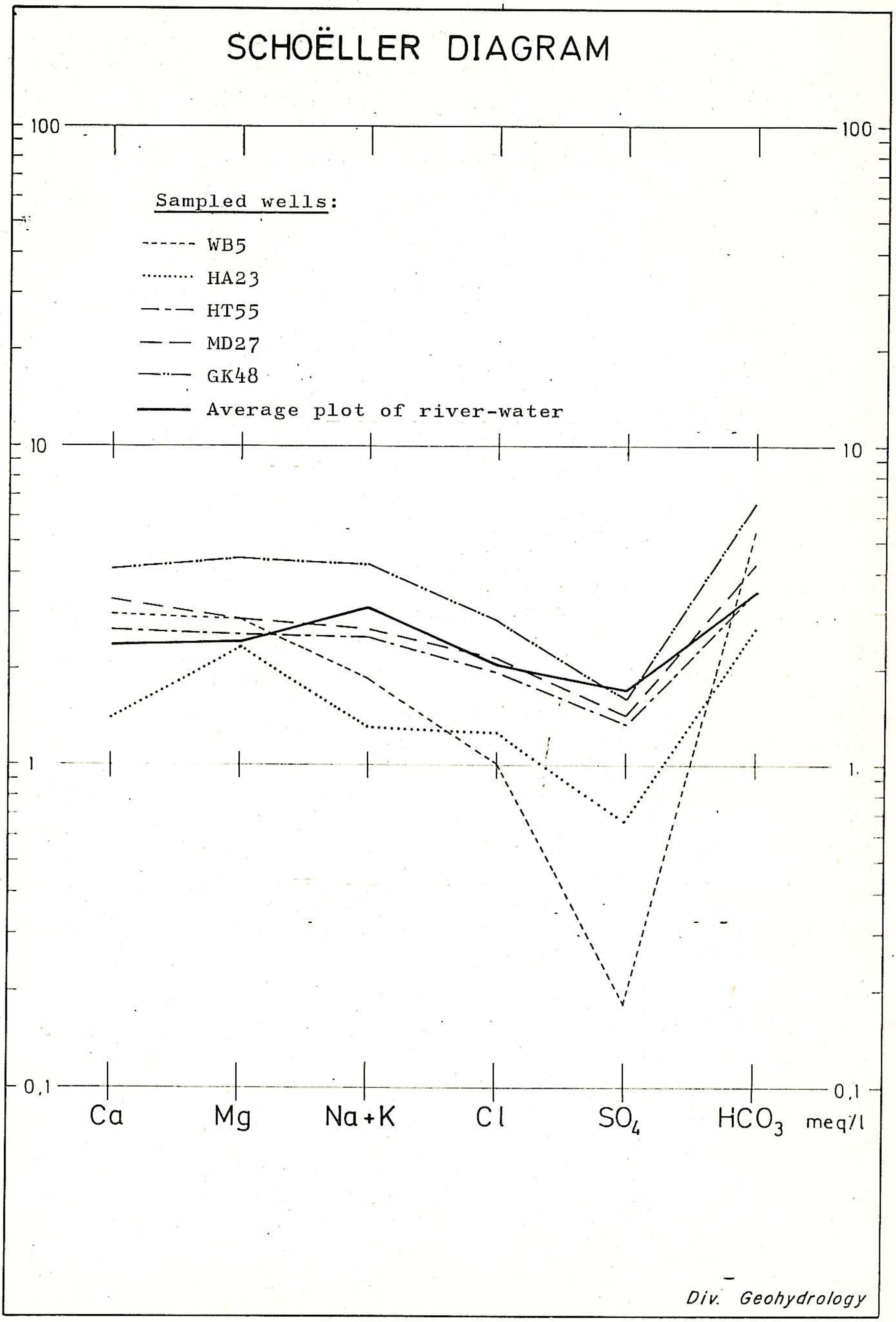

SCHOËLLER DIAGRAM
100
10
1
0,1
Sampled wells:
WB5
HA23
HT55
MD27
GK48
Average plot of river-water
Ca
Mg
Na+K
Cl
SO4
HCO3
meq/l
Div. Geohydrology

FIGURE 21.4

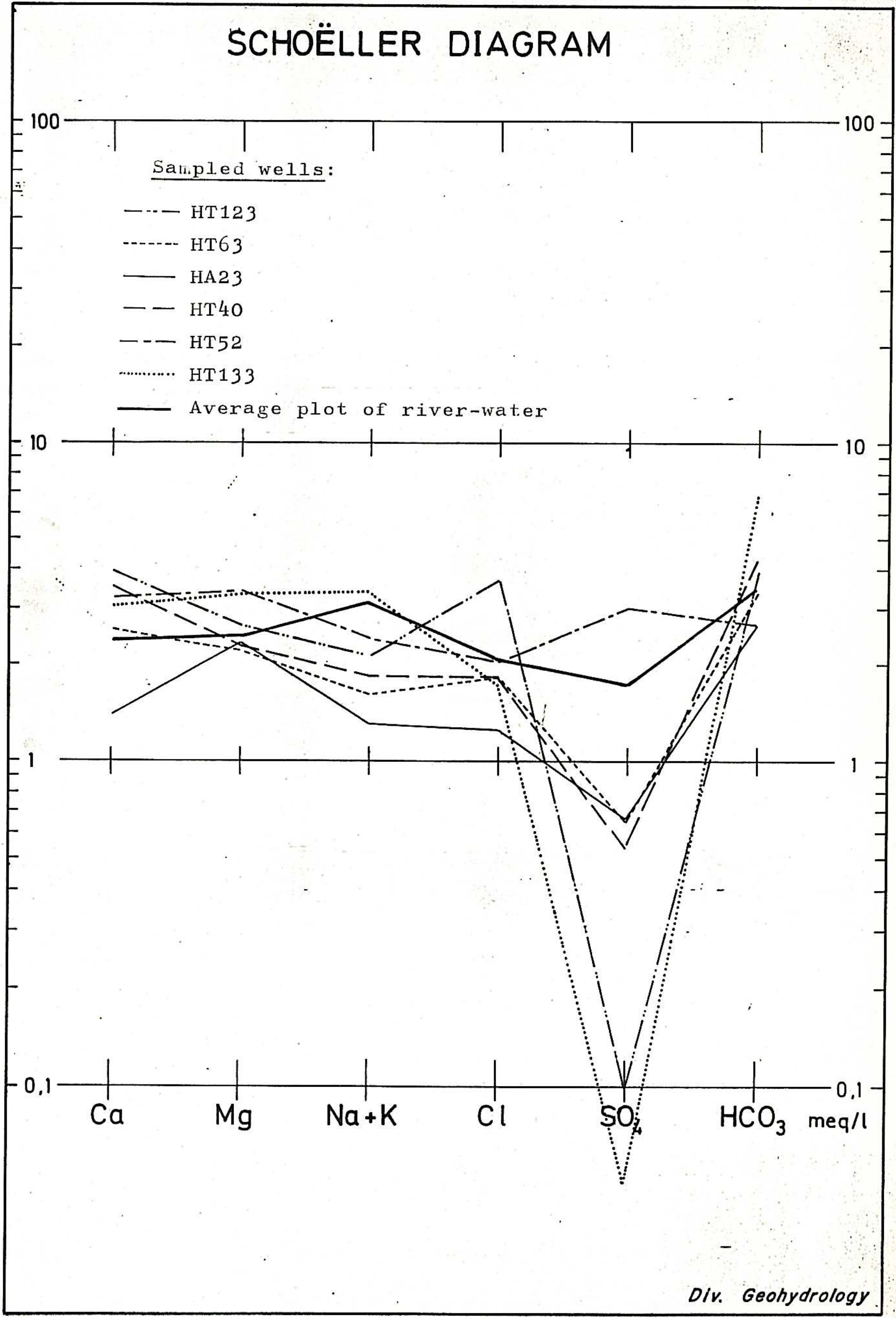

SCHOËLLER DIAGRAM
Sampled wells:
HT123
HT63
HA23
HT40
HT52
HT133
Average plot of river-water
100
10
1
0,1
Ca
Mg
Na+K
Cl
SO_4
HCO_3
meq/l
Div. Geohydrology

FIGURE 21.5

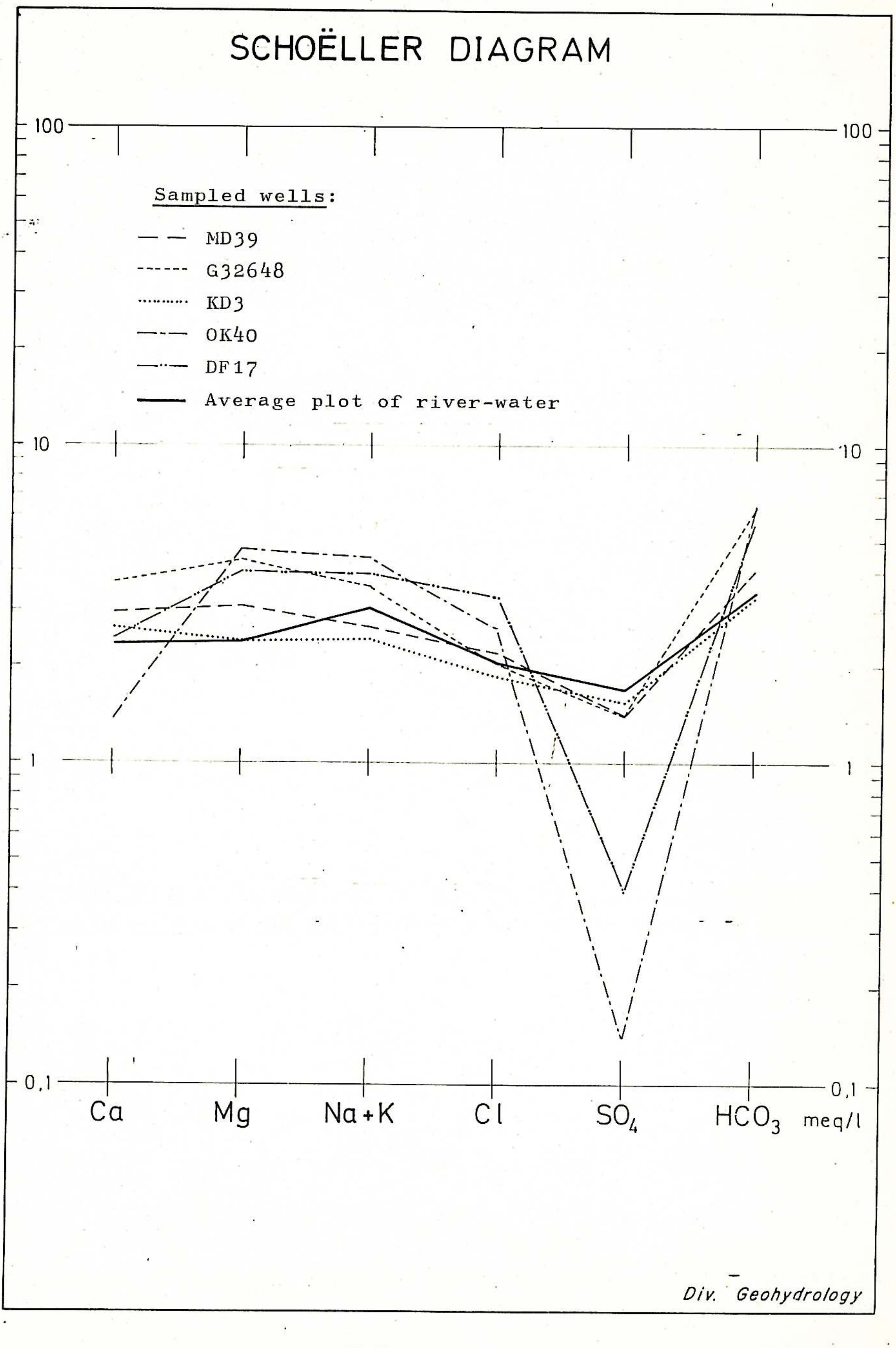

SCHOËLLER DIAGRAM
100
10
1
0,1
Sampled wells:
MD39
G32648
KD3
OK40
DF17
Average plot of river-water
Ca
Mg
Na+K
Cl
SO4
HCO3
meq/l
Div. Geohydrology

FIGURE 21.6

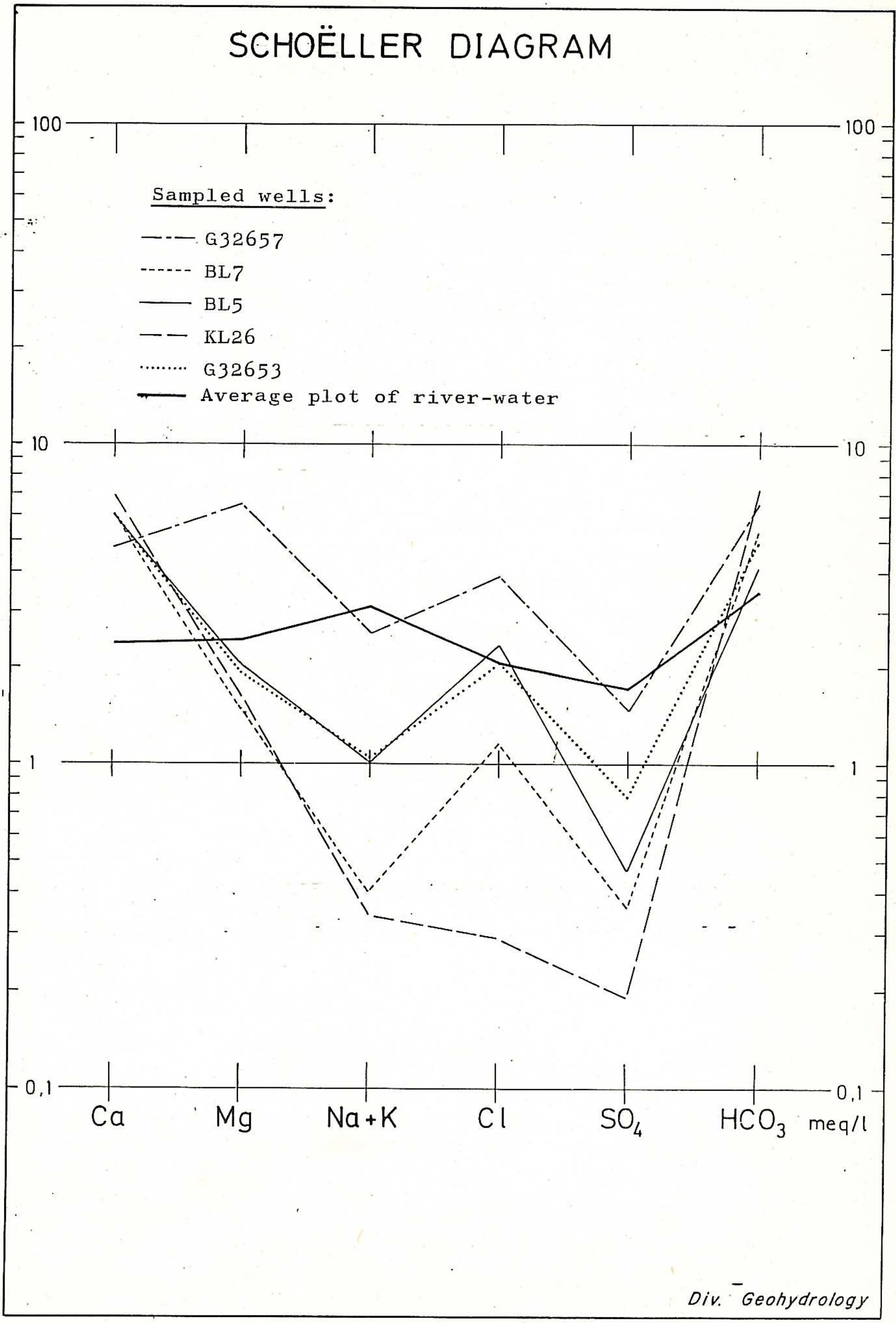

SCHOËLLER DIAGRAM
Sampled wells:
G32657
BL7
BL5
KL26
G32653
Average plot of river-water
100
10
1
0,1
Ca
Mg
Na+K
Cl
SO_4
HCO_3
meq/l
Div. Geohydrology

FIGURE 21.7

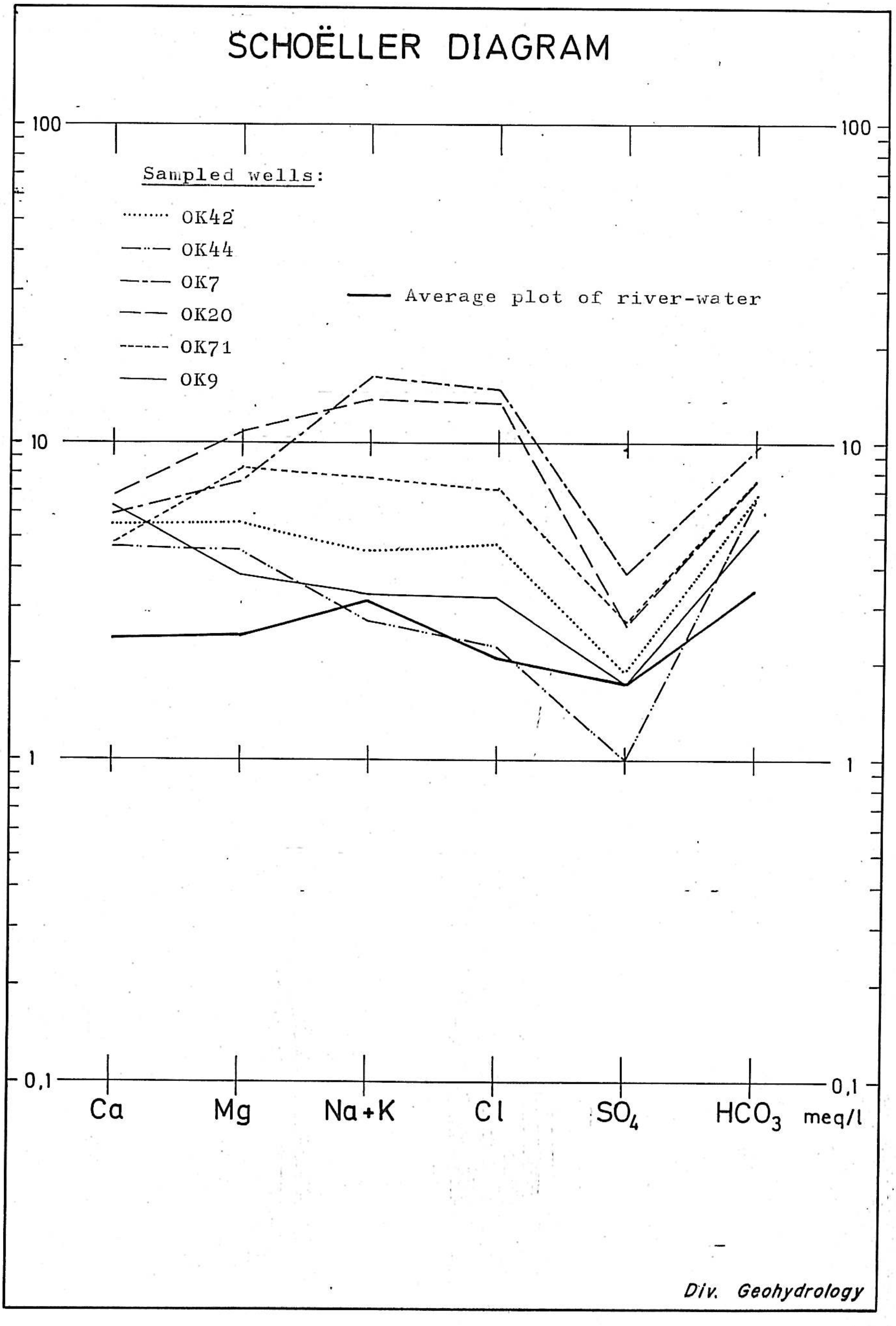

SCHOËLLER DIAGRAM
100
10
1
0,1
Sampled wells:
OK42
OK44
OK7
OK20
OK71
OK9
Average plot of river-water
Ca
Mg
Na+K
Cl
SO4
HCO3
meq/l
Div. Geohydrology

FIGURE 21.8

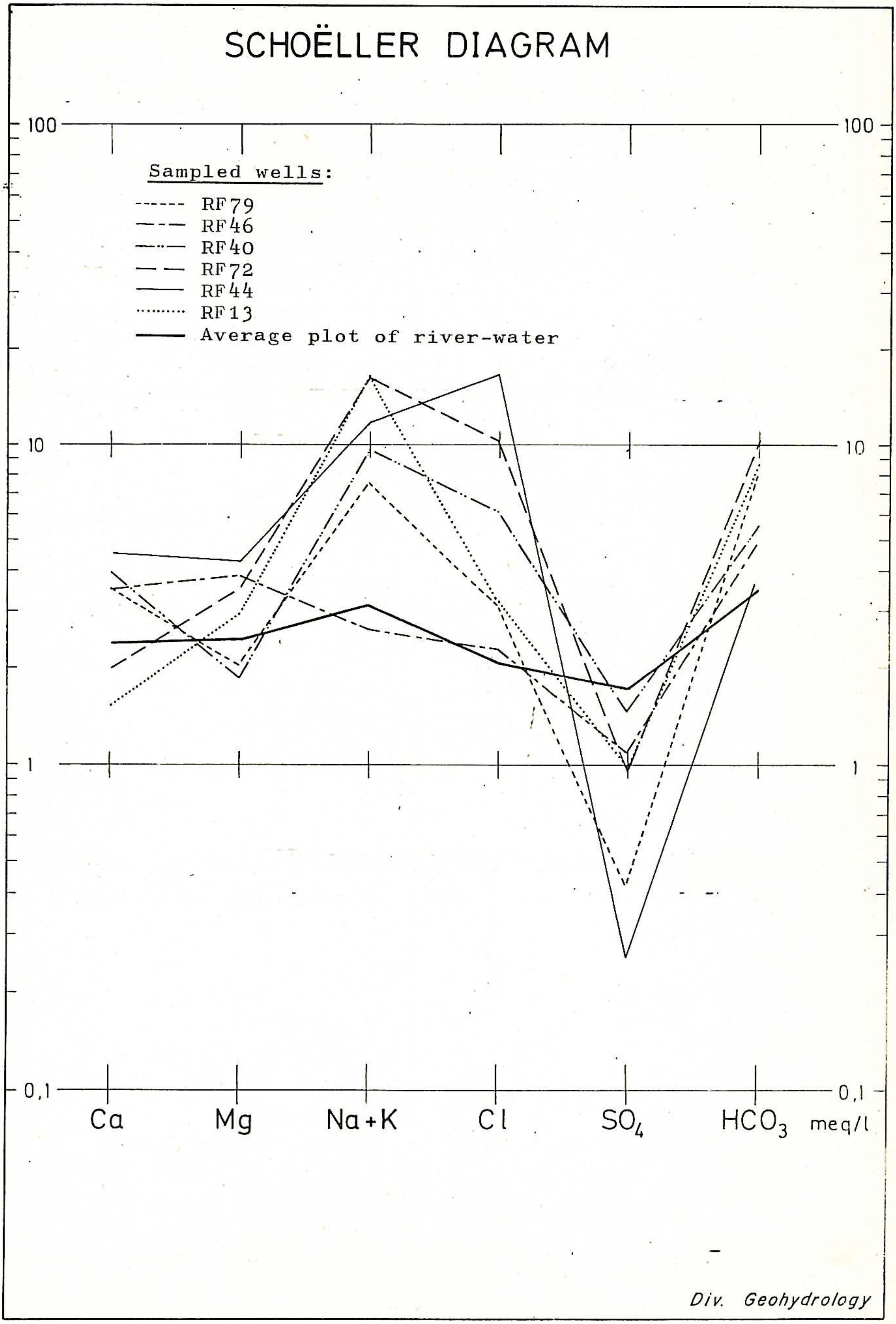

SCHOËLLER DIAGRAM
Sampled wells:
RF79
RF46
RF40
RF72
RF44
RF13
Average plot of river-water
100
10
1
0,1
100
10
1
0,1
Ca
Mg
Na+K
Cl
SO4
HCO3
meq/l
Div. Geohydrology

FIGURE 21.9

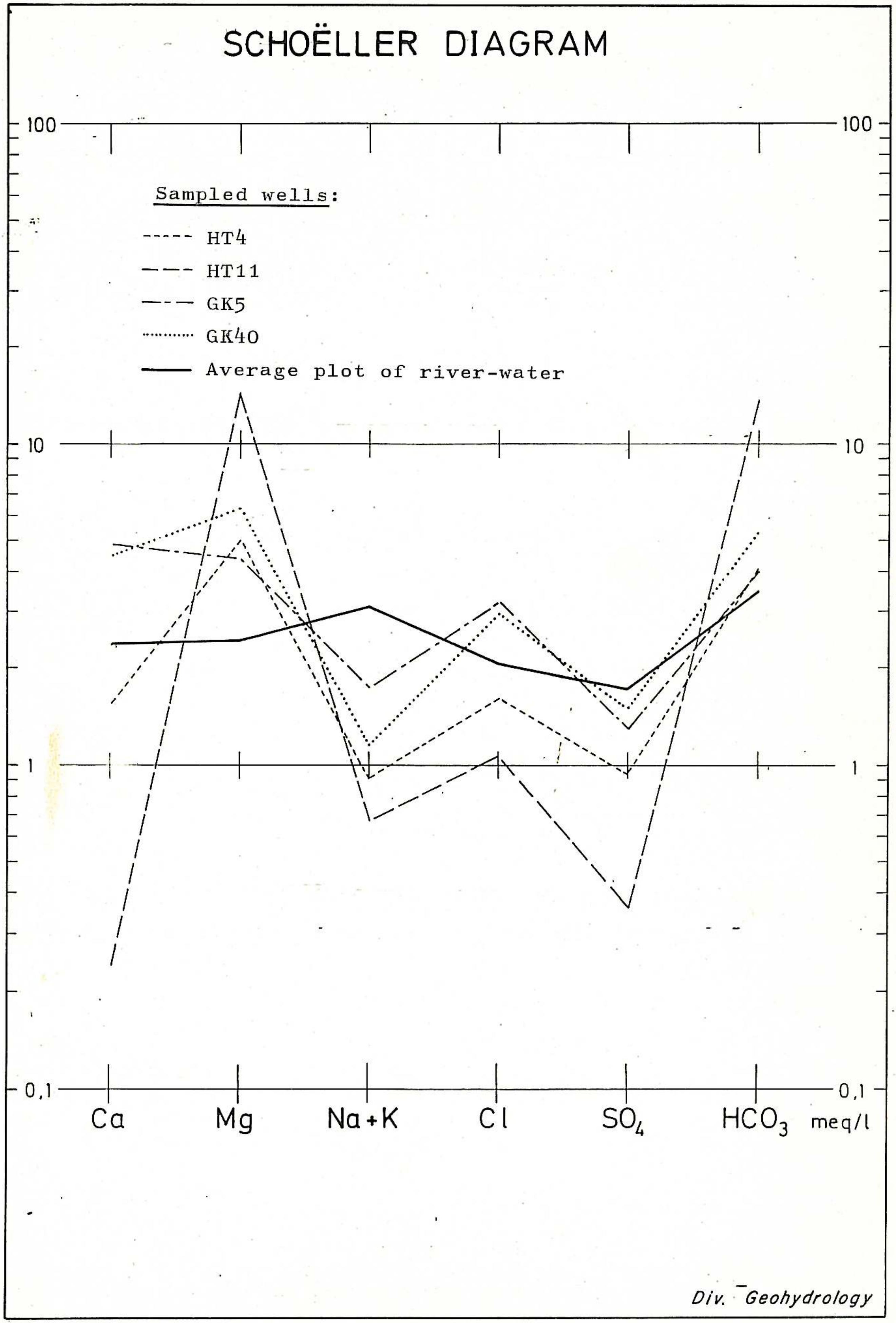

SCHOËLLER DIAGRAM
Sampled wells:
HT4
HT11
GK5
GK40
Average plot of river-water
100
10
1
0,1
100
10
1
0,1
Ca
Mg
Na+K
Cl
SO_4
HCO_3
meq/l
Div. Geohydrology

FIGURE 21.10

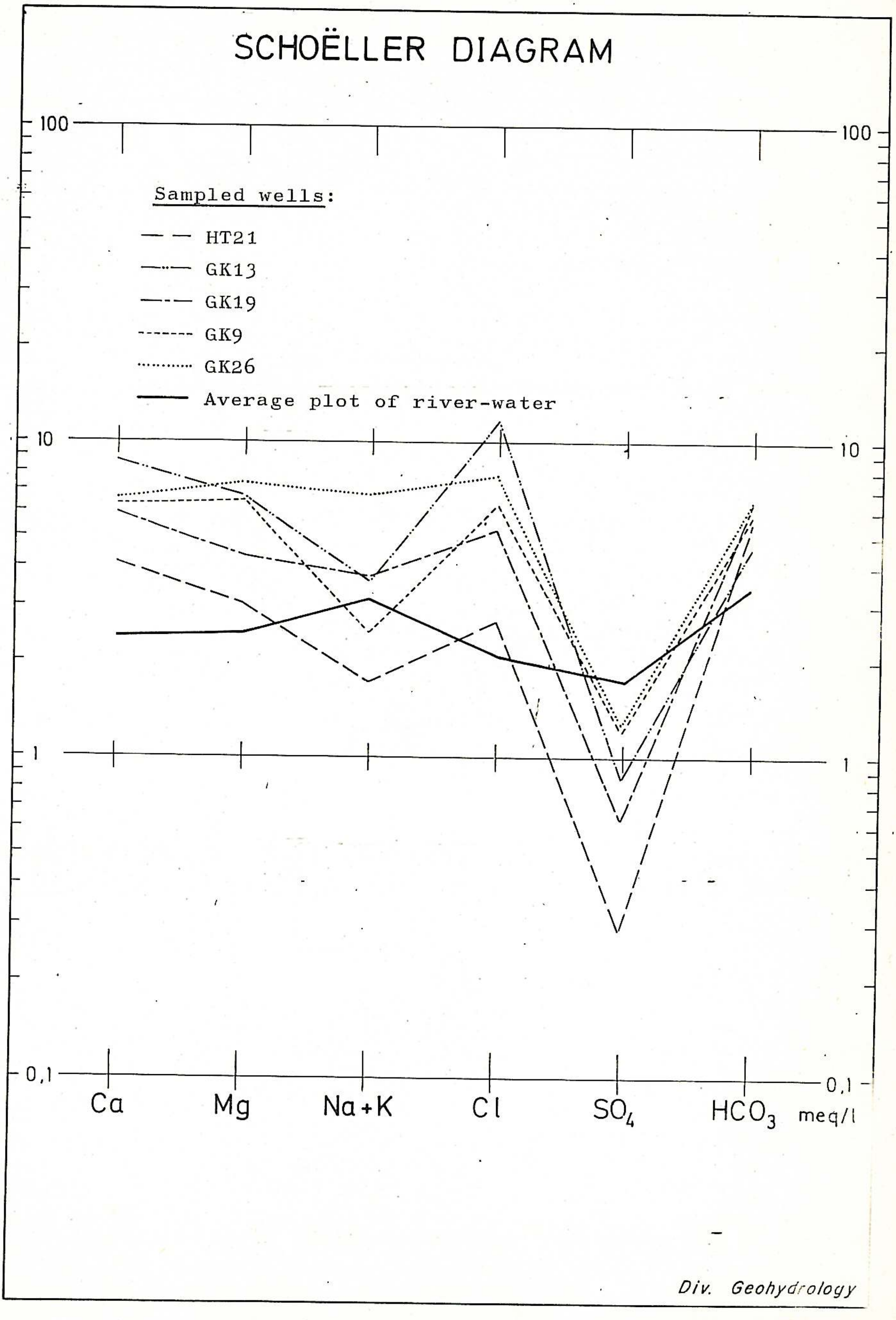

SCHOËLLER DIAGRAM
Sampled wells:
HT21
GK13
GK19
GK9
GK26
Average plot of river-water
100
10
1
0,1
100
10
1
0,1
Ca
Mg
Na+K
Cl
SO_4
HCO_3
meq/l
Div. Geohydrology

FIGURE 21.11

- Figure 21.10 represents groundwaters from wells tapping the gabbroic bedrock underlying sub-area C (Fig. 9) of the study area, and reveal little similarity to the average plot of river water. Magnesium is seen to be the major cation present in these groundwaters. Figure 21.11 represents groundwaters from sub-area D, and once again there is little resemblance to the average composition of river water.

The application of Stiff diagrams in Figure 9 illustrates clearly the variation in groundwater chemistry in the study area, and further illustrates the resemblance between river water and alluvial groundwater in the valley.

5. EVALUATION OF THE GROUNDWATER POTENTIAL OF THE STUDY AREA:

An evaluation of the groundwater potential of, and reserves in, the study area, and based on all the geohydrological information available, can be made. The large areal extent of the study area dictates that such an evaluation be generalized. In this regard, the area has already been divided into sub-areas (Section 3.2), and it follows that the above-mentioned evaluation be made accordingly. The location of these sub-areas is detailed in Figure 9.

5.1 SUB-AREA A:

A feature of this sub-area is the fact that the zone of direct river - aquifer interaction closely approximates the zone of alluvial cover, the latter encompassing an area of approximately 15,2 km² (15200000 m²). The nature of the aquifer in this sub-area can be summarised as follows:

Ave. depth to bedrock = 13 m
" saturated thickness of the aquifer = 5 m
" storativity (S) = $4{,}4 \times 10^{-3}$

The average storage capacity of the alluvial aquifer in this sub-area is thus calculated at $\underline{0,33 \times 10^6 \text{ m}^3}$. This value may seem small, but it must be borne in mind that the few high-yielding boreholes in this area tap groundwater from the underlying dolomitic aquifer, and not from the alluvium as such.

5.2 SUB-AREA B:

The alluvial deposits in this sub-area cover a total area of some 29,6 km² (29600000 m²). Three zones within this sub-area can be identified, each zone exhibiting slightly different hydraulic parameters for the aquifer from the other. The location of these zones is detailed in Folder 1. An evaluation of the geohydrological potential of each of these zones follows.

Zone 1:

area = 6050000 m²
ave. depth to bedrock = 16 m
" saturated thickness of the aquifer = 9 m
" storativity (S_y) = $1,1 \times 10^{-2}$

The average storage capacity of the aquifer in this zone thus approximates $\underline{0,599 \times 10^6 \text{ m}^3}$.

Zone 2:

area = 3320000 m²
ave. depth to bedrock = 16 m
" saturated thickness of the aquifer = 9 m
" storativity (S_y) = 10^{-1}

The average storage capacity of the aquifer in this zone thus approximates $\underline{2,988 \times 10^6 \text{ m}^3}$.

Zone 3:

area = 3700000 m²

ave. ..../59

ave. depth to bedrock = 16 m
" saturated thickness of the aquifer = 9 m
" storativity (S_y) = $6,5 \times 10^{-2}$

The average storage capacity of the aquifer in this zone thus approximates $\underline{2,165 \times 10^6 \text{ m}^3}$.

Remainder of the sub-area:

area = 16530000 m^2
ave. depth to bedrock = 13 m
" saturated thickness of the aquifer = 6 m
" storativity (S_y) = $4,4 \times 10^{-2}$

The average storage capacity of the aquifer in this zone thus approximates $\underline{4,364 \times 10^6 \text{ m}^3}$.

The above values yield a total storage capacity for the aquifer in sub-area B of $\underline{10,12 \times 10^6 \text{ m}^3}$.

5.3 SUB-AREA C:

The alluvial deposits in this su-area cover an area of some 29,5 km^2 (29500000 m^2). It is observed that the average saturated thickness of the alluvium in a zone encompassing the farms Haakdoorndrift 374, Haakdoorndrift 373 and Klipgat 348 KQ, is 20 m. This zone, therefor, is evaluated seperately.

Zone 1:

area = 9000000 m^2
ave. depth to bedrock = 26 m
" saturated thickness of the aquifer = 20 m
" storativity (S_y) = $5,2 \times 10^{-2}$

The average storage capacity of the aquifer in this zone thus approximates $\underline{9,36 \times 10^6 \text{ m}^3}$.

Remainder ..../60

Remainder of the sub-area:

area = 20500000 m²
ave. depth to bedrock = 18 m
" saturated thickness of the aquifer = 10 m
" storativity (S_y) = $5,2 \times 10^{-2}$

The average storage capacity of the aquifer in this zone thus approximates $\underline{10,66 \times 10^6 \text{ m}^3}$.

The above values yield a total storage capacity for the aquifer in sub-area C of $\underline{20,02 \times 10^6 \text{ m}^3}$.

5.4 SUB-AREA D:

area = 3190000 m²
ave. saturated thickness of the aquifer = 10 m
" storativity (S_y) = $4,0 \times 10^{-2}$

The average storage capacity of the aquifer in this sub-area thus approximates $\underline{1,28 \times 10^6 \text{ m}^3}$.

5.5 DISCUSSION:

It follows from the above evaluation that the groundwater reserves in the study area total some $31,75 \times 10^6$ m^3, of which about 95% ($30,14 \times 10^6$ m^3) occurs in sub-areas B and C. This observation is in keeping with the finding that the aquifer attains it's greatest extent in these two areas. Furthermore, it is seen that these areas support the most productive well-fields in the study area.

The evaluation, as set out above, is deemed reliable within the constraints imposed by the necessity of assuming average hydraulic parameters for the aquifer in various localities.

6. ...../77

6. MANAGEMENT OF THE RIVER/AQUIFER SYSTEM:

There can be no doubt that the optimal use of agricultural water in the study area, derived both from surface and groundwater reservoirs, should be based on a sound management policy. The undoubted viability of the conjunctive use of the groundwater/surface water system, as well as the determination of the most efficient management policy for such an integrated use scheme, can best be investigated with mathematical simulation models. Such a study would entail a detailed and intensive study far beyond the scope of this report, and would have to consider a multitude of factors including physical, social, legal and economic considerations. Suffice to say that the present investigation has provided a more complete knowledge of the river/aquifer inter-relationship, and of the aquifer itself.

It is apparent that the ideal and most optimal management policy should lie somewhere between the following two extreme options.

Option 1:

To maintain flow in the river through the study area with controlled releases of water from the surface reservoirs while groundwater resources are utilised simultaneously. This option, in fact, represents the present status quo, and it is felt that this policy does not exploit the groundwater potential of the area to the full. Such a policy merely serves to maintain the aquifer, which can be regarded as a natural reservoir, at near full capacity at the expense of impounded surface water resources.

Option 2:

To suspend releases from the surface reservoirs destined for consumption by irrigators in the study area, and encourage the greater utilisation of groundwater accordingly. This option, in effect, would imply the mining of groundwater in the study area. Such a policy would represent a controlled dewatering of the aquifer over a limited period of time, with the storage made available by lowered water levels being recharged from the river with discharges generated by the upstream reservoirs.

6.1 DISCUSSION:

The implementation of a conjunctive use system necessitates the identification of possible physical, legal and economic constraints imposed thereon. In this regard, the present investigation has aided in identifying the following geohydrological constraints.

i) The spatial pattern of those areas exhibiting significant groundwater potential for exploitation is irregular, whereas the distribution of surface water "users" is uniform throughout the study area. It is thus not uncommon to find that an area availing over relatively large and exploitable (if not already exploited) groundwater resources adjoins an area within which the potential for groundwater exploitation is poor. Where such an area is located opposite, or even downstream, from the former, it becomes necessary to maintain flow in the river to meet the demand of scheduled irrigators in such areas.

Example: large portions of the farms Liverpool and Olifantskop (on the left bank) avail over significant and exploited groundwater reserves, while the exploitable groundwater resources on the farms Haakdoornbult and Doornfontein (on the right bank opposite) are minimal in comparison, and irrigators on these farms rely almost entirely on river water for irrigation.

ii) Irrigation boreholes tapping the alluvial aquifer occur in clusters, with no regard to the optimal spacing of wells. As a result, local drawdowns in the aquifer are increased both in rate and magnitude. It can further be appreciated that such a situation does not lend itself to the optimal, judicious and economic exploitation of the groundwater resources present in the alluvial aquifer.

iii) Due consideration must be given to the quality of groundwater within certain portions of the alluvial aquifer, notably the zone on the farm Rietfontein (see Section 4.1 p. 56, and Fig. 21.9). Even though the groundwater reserves on this farm represent a viably exploitable resource, the high concentrations of sodium and chloride in these waters limits their suitability for irrigation.

7. DISCUSSION AND CONCLUSIONS:

Groundwater reserves in the area total some 32×10^6 m³. The present rate of abstraction is calculated at approx. 25×10^6 m³ per annum. Continued development and uncontrolled exploitation of groundwater has been curtailed by having the area proclaimed a subterranean water control area (Proclamation no. 208 of 23 rd October 1981).

The specific yield of the aquifer ranges between 5% and 10%. Major recharge coincides with extensive flooding of the alluvial plain. The semi-pervious nature of the river banks, together with an impermeable clay layer at varying depths below the surface of the river bed limits recharge during periods of low flow (minimum observed flow since 1970 is 2×10^6 m³ per month).

In the absence of recharge, those areas supporting large and productive well-fields (see Fig. 9) such as on the farms Kaaldraai and Olifantskop in Sub-area B and Haakdoorndrift 374 in Sub-area C will witness a drop

in ..../80

in groundwater level of 2 to 3 m over one dry season, with the narrow zone comprising Sub-area D witnessing an even greater decline (up to 4 or 5 m). Considering the unconfined nature of the alluvial aquifer, these changes should spread slowly as gravity drainage takes place, with the remainder of the aquifer experiencing a decline of less than 1 m. It is appropriate to mention the value a computer simulation of the stream/aquifer system would provide in predicting areal changes in groundwater level in response to abstraction without recharge.

Aspects that are deemed important if a true evaluation of the river/aquifer system is to be made, and on which available information is either non-existent, insufficient or unreliable are:

i) the accurate determination of ney surface in-and-outflow of the study area (see Section 2.3.3.1 p 24),

ii) the accurate determination of net surface and groundwater usage for irrigation, and

iii) the extension of the network of water level monitoring wells particularly in those localities where groundwater abstraction is significant and yet no water level data is available.

In regard of the first aspect mentioned above, it is recommended that absolute priority be given to the construction of a flow gauging station at the downstream extremity of the study area. Two possible sites, both indicated on Folder 1 , present themselves for this purpose. These sites are ideally situated, and are further characterised by the presence of quartzite ridges, outcrops of which appear in the river bed, and intersecting the river.

The second aspect is catered for in the fact that each productive irrigation borehole is to be equipped with a flow meter, and that the abstraction of river water is to some extent controlled by the limitation of pump capacities according to scheduling.

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In addition to the extension of the water level monitoring network, it is envisaged that an intensive groundwater level measuring programme be carried out in the study area in May 1982. This programme will be similar to that described in this report, the latter enabling the construction of the piezometric map for May 1980. It is thereby hoped to construct a similar map for May 1982, to be compared with that of May 1980, and hence gain further insight into the behaviour of the aquifer.

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ANNEX I : Groundwaterlevel Measurements, MAY 1980

Bh. No.	Date	Collar elev. (m)	Depth to W.L. (m)	W.L. elev. (m)	Reference point and/or remarks
WB 5	21/5/80	908,12	6,48	901,64	Height of casing
WB 6	"	908,42	6,93	901,49	Outlet of turbine
WB 7	"	907,45	5,89	901,56	" " "
WB 18	20/5/80	907,79	7,04	900,75	Height of casing
WB 24	"	909,27	11,40	897,87	Height of cement base
WB 25	21/5/80	912,61	16,47	896,14	Height of casing
WB 28	"	907,33	5,68	901,65	" " "
WB 29	"	908,15	9,19	898,96	" " "
WB 20	20/5/80	908,48	11,07	897,41	" " "
KG 12	22/5/80	910,53	5,29	905,30	" " "
HA 5	21/5/80	911,91	14,29	897,62	" " "
HA 12	20/5/80	912,77	15,46	897,31	" " "
HA 20	"	910,46	12,35	898,11	Height of cement base
HA 21	"	912,49	12,06	900,43	" " " "
HT 2	20/5/80	933,65	29,44	904,21	Height of casing
HT 6	"	911,38	14,18	897,20	" " "
HT 11	"	920,65	13,73	906,92	" " "
HT 12	"	916,95	10,23	906,72	" " "
HT 21	"	919,40	19,99	899,41	" " "
HT 22	"	920,56	21,25	899,31	" " "
HT 30	"	912,09	6,82	905,27	" " "
HT 31	"	912,96	6,33	906,63	" " "
HT 37	"	916,83	17,14	899,70	" " "
HT 38	"	915,49	15,69	899,80	" " "
HT 39	"	915,64	15,98	899,66	" " "
HT 52	"	910,98	6,94	904,04	" " "
HT 56	"	911,79	9,27	902,52	" " "
HT 62	"	911,66	6,88	904,78	" " "
HT 81	"	913,49	8,19	905,30	" " "
HT 51	"	910,38	9,16	901,22	" " "
HT 93	"	913,90	12,15	901,75	Metal base of turbine
HT 96	"	909,68	6,44	903,24	Height of casing
HT 99	"	915,91	14,85	901,06	Metal base of turbine
HT 123	"	911,06	9,16	901,90	Height of casing
HT 133	6/12/80	911,31	9,36	901,95	" " "
HA 22	"	908,57	6,39	902,18	" " "
HA 23	"	907,76	6,29	901,47	" " "
EK 1	20/5/80	925,32	12,09	912,23	" " "
EK 5	"	913,52	5,56	907,96	" " "
EK 4	"	921,63	8,67	912,96	Height of cement base
EK 9	"	912,48	4,58	907,90	Height of casing
EK 20	"	926,33	11,70	914,63	" " "

ANNEX I contd.

Bh. No.	Date	Collar elev. (m)	Depth to W.L. (m)	W.L. elev. (m)	Reference point and/or remarks
KD 2	20/5/80	921,84	11,36	910,48	Stone rim of well
KD 3	"	919,52	7,73	911,79	" " " "
KD 4	"	917,56	7,49	910,07	Hole in casing
KD 5	"	918,22	8,16	910,06	Height of cement base
KD 8	"	920,78	10,76	910,02	Stone rim of well
KD 10	"	920,67	10,61	910,06	" " " "
KD 11	"	920,62	10,50	910,12	" " " "
KD 16	"	918,35	8,22	910,13	" " " "
KD 23	"	921,35	10,43	910,92	Height of cement base
KD 24	"	920,90	9,79	911,11	" " " "
KD 29	"	917,29	6,88	910,41	Height of casing
KD 36	"	921,56	11,09	910,47	Height of cement base
KD 37	"	921,52	11,12	910,40	Stone rim of well
KD 39	"	921,12	10,92	910,20	Height of casing
RF 1	22/5/80	921,92	8,91	913,01	" " "
RF 3	23/5/80	921,74	8,70	913,04	" " "
RF 4	"	926,27	13,39	912,88	Height of cement base
RF 8	22/5/80	925,11	12,90	912,21	" " " "
RF 12	"	924,03	12,03	912,00	Height of casing
RF 15	"	924,40	12,30	912,10	" " "
RF 16	"	924,40	12,50	911,90	Stone rim of well
RF 17	"	924,56	12,76	911,80	" " " "
RF 10	"	925,07	12,63	912,44	Height of cement base
RF 28	23/5/80	928,98	15,24	913,74	" " " "
RF 31	22/5/80	925,34	13,59	911,75	" " " "
RF 41	"	921,89	3,76	918,13	" " " "
RF 44	23/5/80	924,19	8,69	915,50	Height of casing
RF 46	22/5/80	923,32	10,49	912,83	" " "
RF 47	"	928,51	12,39	916,12	Hole in casing
RF 61	"	925.20	12,91	912,29	Height of casing
RF 62	"	925,10	12,78	912,32	Height of cement base
RF 63	"	925,29	12,86	912,43	" " " "
RF 64	23/5/80	925,53	11,76	913,77	" " " "
RF 70	22/5/80	919,00	12,39	912,61	" " " "
RF 71	"	918,95	6,41	912,54	" " " "
RF 72	"	------	-----	------	
RF 73	"	------	-----	------	
RF 74	"	919,56	7,03	912,53	Height of casing
RF 75	"	920,08	7,72	912,36	Height of cement base
RF 79	"	926,56	21,72	904,84	Height of casing
RF 80	23/5/80	920,58	8,42	912,16	" " "

ANNEX I contd.

Bh. No.	Date	Collar elev. (m)	Depth to W.L. (m)	W.L. elev. (m)	Reference point and/or remarks
OK 4	20/5/80	923,21	9,23	913,98	Height of cement base
OK 6	"	927,85	14,15	913,70	" " " "
OK 7	"	926,25	11,32	914,13	" " " "
OK 8	"	921,51	7,03	914,48	" " " "
OK 9	"	923,26	8,34	914,92	" " " "
OK 10	"	922,90	8,66	914,24	Height of casing
OK 13	"	922,13	7,78	914,35	" " "
OK 14	"	921,96	7,92	914,04	" " "
OK 16	"	922,45	8,12	914,33	Height of cement base
OK 22	"	924,96	8,11	916,85	" " " "
OK 24	"	930,62	15,68	914,93	" " " "
OK 28	"	922,86	8,42	914,34	Height of casing
OK 35	"	923,57	9,22	914,35	Hole in casing
OK 40	"	923,36	8,33	915,03	Height of casing
OK 41	"	923,19	8,88	914,31	Height of cement base
OK 43	"	923,20	8,65	914,55	Groundlevel
OK 44	"	920,75	6,59	914,16	Height of casing
OK 50	"	928,42	16,40	912,02	" " "
OK 51	"	922,64	8,32	914,32	Height of cement base
OK 52	"	922,78	8,49	914,29	Groundlevel
OK 53	"	924,65	12,79	911,86	Height of cement base
OK 71	"	929,46	14,33	915,13	" " " "
DF 1	23/5/80	924,93	5,97	918,96	Height of cement base
DF 8	"	923,92	8,19	915,73	Height of metal base
DF 16	"	922,54	6,31	916,23	Height of casing
DF 18	"	922,70	6,42	916,28	" " "
DF 21	"	927,92	8,81	919,11	" " "
DF 22	"	935,52	16,00	919,52	Height of cement base
DF 24	"	926,85	9,67	917,18	" " " "
DF 30	"	922,40	3,60	918,80	Height of casing (hole blocked, mud?)
LP 15	20/5/80	925,56	12,88	912,68	Height of cement base
LP 26	"	926,05	12,05	914,00	Height of casing
LP 27	"	926,88	12,79	914,09	Height of cement base
LP 30	"	926,30	12,39	913,91	Height of metal base of turbine
LP 31	"	925,38	8,00	917,38	Height of casing
LP 32	"	925,65	8,18	917,47	" " "
LP 45	"	929,05	11,86	917,19	" " "
HD 2	22/5/80	931,78	8,14	923,64	" " "
HD 3	"	932,93	9,43	923,50	" " "
HD 5	"	932,53	12,48	920,05	" " "
HD 10	"	936,86	10,17	926,69	" " "

2427CD 310

ANNEX I contd.

	Bh. No.	Date	Collar elev. (m)	Depth to W.L. (m)	W.L. elev. (m)	Reference point and/or remarks
2427CB231	GK 4	21/5/80	922,08	22,87	899,21	Height of casing
CD340	GK 9	22/5/80	915,69	10,11	905,58	Height of cement base
	GK 20	21/5/80	927,93	29,29	898,64	" " " "
	GK 28	22/5/80	928,23	23,93	904,30	" " " "
	GK 24	21/5/80	926,31	27,17	899,14	" " " "
	GK 39	22/5/80	916,53	7,73	908,80	Height of casing
	GK 40	"	916,10	6,28	909,82	Hole in casing
	GK 43	"	929,03	29,81	899,22	Height of casing
	GK 45	21/5/80	926,86	28,01	898,85	" " "
	GK 47	"	915,26	7,00	908,26	" " "
	GK 48	"	916,29	7,95	908,34	" " "
	GK 60	"	923,71	24,53	899,18	" " "
	GK 61	"	926,80	27,99	898,81	" " "
	GK 62	"	926,77	27,83	898,94	" " "
	MD 1	"	916,53	6,46	916,53	Height of cement base
	MD 3	"	916,26	6,15	910,11	" " "
	MD 10	"	918,54	8,19	910,35	" " "
	MD 12	"	918,29	7,72	910,57	" " "
	MD 17	"	918,86	7,70	911,16	Height of casing
	MD 19	"	919,00	8,23	910,77	Height of cement base
	MD 20	"	928,31	14,07	914,24	" " "
	MD 21	"	919,53	9,36	909,17	Stone rim of well
CD 354	MD 22	"	918,91	8,72	910,19	Height of casing
	MD 27	"	917,32	7,23	910,09	" " "
	MD 28	"	924,27	10,66	913,61	" " "
	MD 33	"	913,74	7,45	906,29	" " "
	MD 34	"	917,08	7,02	910,06	" " "
	MD 37	"	917,56	7,69	909,87	" " "
	MD 38	"	917,35	6,50	910,85	Height of cement base
	MD 40	"	919,77	7,88	911,89	Height of casing
	MD 41	"	920,22	8,37	911,85	" " "
	MD 42	"	918,74	3,01	915,73	Height of cement base
2427CD359	MD 50	"	917,86	7,68	910,18	Height of casing
	KG 4	"	910,94	6,73	904,21	Groundlevel
	KG 15	"	908,85	6,37	902,48	Height of casing
	KG 16	"	907,35	5,57	901,78	" " "
	AK 9	22/5/80	919,43	10,10	909,33	Height of cement base
	AK 19	"	919,91	10,64	909,27	" " "
	AK 20	"	916,98	7,69	909,29	" " "
	AK 22	"	916,91	7,62	909,29	Metal base of turbine
	AK 23	"	919,72	11,09	908,63	Height of cement base
	AK 28	"	916,28	7,76	908,52	Height of casing
	AK 40	"	920,09	10,96	909,13	" " "

ANNEX I contd.

	Bh. No.	Date	Collar elev. (m)	Depth to W.L. (m)	W.L. elev. (m)	Reference point and/or remarks
2427DC 100	BL 13	20/5/80	929,62	13,26	916,36	Height of cement base
DC 101	BL 20	"	939,19	12,21	926,98	Height of casing
102	BL 26	"	932,52	3,62	928,90	" " "
103	BL 33	"	932,10	12,46	919,64	Height of cement base
104	HB 1	22/5/80	942,67	10,03	932,64	" " " "
105	HB 4	"	932,67	4,82	927,85	" " " "
106	HB 5	"	930,69	1,66	929,03	Height of casing. Obstruction in bhole.
107	KL 4	21/5/80	941,72	12,90	928,82	" " "
	KL 12	"	935,58	8,59	926,99	Height of cement base
	KL 13	"	936,01	8,99	927,02	" " " "
	KL 21	"	941,22	11,72	929,50	Height of casing
	KL 22	"	938,90	13,50	925,40	" " "
DC108	KL 23	"	940,61	13,27	927,34	" " "
	NT 8	"	949,95	15,76	934,19	" " "
	NT 9	"	942,39	7,79	934,60	" " "
	NT 10	"	943,78	7,23	936,56	" " "
	NT 12	"	942,34	7,70	934,64	" " "
	ND 1	"	944,18	17,80	926,38	Height of cement base
	ND 4	"	951,96	19,97	931,99	Height of casing
	KB 1	"	948,29	16,90	931,39	" " "
	KB 6	"	937,93	9,29	928,64	Height of cement base
	KB 14	"	939,93	9,78	930,15	Height of casing
	NG 11	"	956,53	25,77	930,76	" " "
	NG 23	"	936,75	6,00	930,75	" " "
2427CD20	G32652		917,11	7,46	909,65	" " "
CD9	G32653		932,05	8,74	923,31	" " "
CD6	G32654		931,10	8,20	922,90	" " "
	G32655		928,51	9,26	919,25	" " "
2527 BA 1	G32657		936,88	9,04	927,84	" " "

SPOT-HEIGHTS IN THE RIVERBED ALONG THE COURSE OF THE RIVER

Location	Elevation	Remarks
Nooitgedacht Drift	931m	Position at the level of borehole NG 23
Haakdoornbult	923m	" " " " " " HD 3
Koedoeskop Bridge	917m	Position immediately upstream of the bridge
Olifantskop	916m	Position at a level midway between boreholes DF 8 & 16
Olifantskop	915m	Position at the level of borehole OK 10
Kromdraai	912m	" " " " " " MD 22
Middeldrift	910m	" " " " " " MD 37
Grootkuil Drift	906m	Position immediately downstream of the drift
Haakdoorndrift	905m	Position at the level of borehole HT 81
Wachteenbietjesdraai	898m	" " " " " " WB 24

ANNEX II : Periodical Waterlevel Measurements.

Bh. No.	Year	MONTH											
		Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
WB 41 Col. elev.=908,07 (m.a.m.s.l.)	1976	----	----	----	----	----	----	6,03	6,07	----	6,23	6,05	----
	1977	6,99	6,04	5,30	6,10	6,42	6,67	6,78	6,74	6,95	6,97	7,36	7,15
	1978	fl.	fl.	4,24	5,10	5,70	6,00	6,27	6,67	6,60	6,70	6,86	7,05
	1979	7,05	7,12	7,18	7,25	7,28	7,25	7,30	7,30	7,38	7,33	7,15	----
	1980	6,66	5,98	6,77	7,10	7,22	7,17	6,23	7,31	7,30	7,38	7,18	----
	1981	7,08	6,16										
EK 5 Col. elev.=913,52 (m.a.m.s.l.)	1976	----	----	----	----	----	----	----	----	----	----	----	----
	1977	----	----	----	5,52	5,77	5,88	5,95	5,85	5,82	5,79	5,77	5,75
	1978	fl.	fl.	3,54	3,94	4,25	4,56	4,90	4,89	4,89	4,93	4,99	5,14
	1979	5,09	4,17	6,15	5,20	5,18	5,41	5,62	5,56	5,61	5,65	5,61	----
	1980	5,43	5,23	5,64	5,51	5,60	5,62	5,72	5,79	5,75	5,37	5,64	----
	1981	5,53	5,21										
OK 39 Col. elev.=923,01 (m.a.m.s.l.)	1976	----	----	----	----	----	5,53	5,99	6,41	6,82	6,73	6,93	----
	1977	7,67	7,05	6,58	6,99	7,33	7,48	7,57	7,75	7,98	8,10	8,28	8,66
	1978	7,07	0,72	3,60	4,67	5,45	9,85	6,25	6,56	6,87	7,28	7,56	7,78
	1979	7,80	7,93	8,04	8,20	8,45	8,27	8,27	8,29	8,32	8,38	8,36	----
	1980	----	7,71	8,08	8,29	8,33	8,32	8,36	8,43	8,57	8,67	8,58	----
	1981	8,61	7,74										
BL 34 Col. elev.=927,19 (m.a.m.s.l.)	1976	----	----	----	----	----	5,28	5,72	5,72	----	5,91	5,87	----
	1977	6,11	5,64	4,75	5,34	5,77	5,99	6,09	6,15	6,15	6,74	6,18	6,10
	1978	1,30	0,37	4,48	5,17	5,50	5,78	5,76	6,04	5,90	5,95	6,14	6,12
	1979	5,86	5,85	6,48	6,26	5,39	6,20	6,15	6,10	6,12	6,13	6,02	----
	1980	5,57	4,91	5,82	6,04	6,15	6,03	6,11	6,13	6,10	6,20	5,48	----
	1981	6,03	5,31										
NG 23 Col. elev.=936,75 (m.a.m.s.l.)	1976	----	----	----	----	----	4,87	5,22	5,60	5,78	5,93	5,25	----
	1977	----	5,37	4,76	5,14	5,14	5,68	5,81	5,94	6,00	6,02	6,00	5,32
	1978	2,39	0,35	4,06	4,64	4,78	5,00	5,20	5,64	----	5,82	5,84	5,83
	1979	5,68	4,97	5,17	6,10	6,04	6,40	6,45	6,07	6,10	6,13	5,94	----
	1980	5,44	4,98	4,98	5,92	6,22	----	6,01	6,11	6,15	6,15	5,20	----
	1981	5,82											

Values represent depth to waterlevel (in metres) below collar elevation.

fl. = borehole underwater as a result of flooding.

---- = no waterlevel measurement taken.

ANNEX II contd.

Bh. No.	Year	MONTH											
		Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
KG 12 Col. elev.=910,53 (m.a.m.s.l.)	1976	----	----	----	----	----	3,42	3,61	3,66	3,74	3,82	3,80	----
	1977	4,16	3,53	----	3,59	3,77	3,97	3,88	3,75	4,00	4,06	4,36	4,05
	1978	fl.	fl.	3,80	3,86	4,35	3,08	3,29	2,90	2,50	2,85	4,12	4,38
	1979	4,64	4,37	4,49	4,82	4,82	4,84	4,89	5,65	5,67	5,77	5,96	----
	1980	4,77	4,63	4,98	4,50	5,35	5,54	6,60	5,78	6,02	6,46	7,23	----
	1981	5,03	5,18										
HT 31 Col. elev.=912,96 (m.a.m.s.l.)	1976	----	----	----	----	----	----	5,64	5,72	6,03	5,87	5,95	----
	1977	6,13	6,09	6,04	6,01	6,11	6,20	6,34	6,37	6,42	6,49	6,50	6,60
	1978	fl.	fl.	4,25	5,20	5,70	2,40	5,58	5,60	5,60	5,87	5,98	6,18
	1979	6,17	6,07	6,75	6,77	6,76	6,89	6,89	6,35	----	6,47	6,24	----
	1980	----	----	6,72	6m28	6,35	6,33	6,47	6,59	6,62	6,71	6,70	----
	1981	6,57	6,39										
MD 27 Col. elev.=917,32 (m.a.m.s.l.)	1976	----	----	----	----	----	----	5,99	----	----	----	8,07	----
	1977	8,08	7,80	6,70	6,61	6,94	7,05	6,27	8,48	10,22	9,95	8,26	8,26
	1978	fl.	fl.	3,12	5,35	5,60	6,30	8,86	9,70	9,81	7,00	7,50	9,75
	1979	8,30	8,17	10,35	10,37	10,62	10,62	10,70	8,81	10,63	8,88	----	----
	1980	----	----	9,22	7,42	7,25	7,40	10,14	11,01	10,81	9,22	7,83	----
	1981	9,20	7,12										
GK 39 Col. elev.=916,53 (m.a.m.s.l.)	1976	----	----	----	----	----	----	----	----	----	----	----	----
	1977	----	----	----	6,71	7,12	7,37	7,47	7,44	7,70	7,57	7,00	8,55
	1978	fl.	fl.	4,54	4,63	5,20	6,38	6,77	6,78	7,18	7,13	7,25	7,56
	1979	7,35	7,74	8,47	8,45	8,43	8,43	8,46	7,50	----	7,53	7,58	----
	1980	7,35	----	7,61	7,60	----	----	----	8,15	10,20	----	7,86	----
	1981	7,88	7,68										
RF 44 Col. elev.=924,19 (m.a.m.s.l.)	1976	----	----	----	----	----	4,26	5,44	6,08	6,62	6,71	6,92	----
	1977	7,42	6,73	5,54	5,58	6,32	6,74	7,16	7,10	7,59	7,68	7,84	7,97
	1978	3,12	2,98	3,41	4,20	5,19	5,82	5,97	6,07	6,59	6,86	7,00	9,50
	1979	7,66	8,79	10,84	8,67	8,79	8,83	8,81	8,36	8,35	8,58	8,57	----
	1980	8,40	8,22	8,51	8,58	8,65	8,70	8,75	8,88	8,91	9,03	8,93	----
	1981	8,44	8,11										

Values represent depth to waterlevel (in metres) below collar elevation.

fl. = borehole underwater as a result of flooding.

---- = no waterlevel measurement taken.

ANNEX II contd.

Bh. No.	Year	MONTH											
		Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
HT 30 Col. elev.=912,09 (m.a.m.s.l.)	1977	----	----	----	7,90	7,98	7,01	8,05	8,04	7,48	8,23	8,35	8,40
	1978	fl.	fl.	4,30	6,38	6,94	3,10	7,12	6,15	7,06	7,17	8,22	7,35
	1979	7,19	6,34	7,64	7,62	7,70	7,68	7,73	7,20	----	7,33	7,18	----
	1980	----	----	7,52	6,65	6,89	7,00	6,97	6,93	6,91	6,98	7,08	----
	1981	6,92	6,35										
MD 28 Col.elev.=924,27 (m.a.m.s.l.)	1977	----	----	----	----	12,03	12,21	11,64	11,60	11,63	11,52	11,28	11,25
	1978	10,86	10,72	10,38	10,00	11,10	10,00	9,92	10,10	11,07	10,25	10,21	10,23
	1979	10,00	9,15	9,33	9,73	10,21	10,24	10,37	9,85	10,15	9,95	10,36	----
	1980	10,24	10,15	10,21	10,37	10,72	10,75	10,59	10,48	10,39	10,35	10,62	----
	1981	10,05	10,07										
GK 40 Col. elev.=916,10 (m.a.m.s.l.)	1977	----	----	----	6,50	6,94	7,16	7,37	7,50	7,63	7,75	7,80	7,74
	1978	fl.	1,47	2,99	3,77	4,90	4,60	5,67	5,77	5,87	5,89	6,23	6,49
	1979	5,62	5,71	6,35	6,54	6,74	7,83	7,84	6,42	6,30	6,67	6,71	----
	1980	6,34	5,32	6,65	6,06	6,24	6,48	6,65	6,15	7,10	6,52	6,72	---
	1981	----	----										
AK 23 Col. elev.=919,72 (m.a.m.s.l.)	1977	----	----	----	5,13	6,69	7,58	8,24	8,65	8,98	10,08	9,35	9,63
	1978	1,61	2,54	2,07	3,11	4,70	5,55	6,30	6,34	7,60	7,61	7,97	8,48
	1979	8,78	9,00	9,89	9,95	10,17	9,84	10,11	10,10	10,23	10,33	10.38	----
	1980	10,58	10,58	10,87	10,83	12,63	----	28,17	10,34	8,10	28,16	10,33	----
	1981	10,33	28,20										
RF 46 Col. elev.=923,32 (m.a.m.s.l.)	1976	----	----	----	----	----	8,16	7,91	9,58	10,32	10,16	10,12	----
	1977	10,33	9,65	9,43	9,36	9,27	8,59	10,24	10,60	11,17	15,16	10,93	11,06
	1978	8,78	6,50	13,48	7,58	7,67	8,09	8,20	10,07	7,58	9,97	10,90	11,55
	1979	11,47	11,36	11,48	11,17	11,18	11,27	11,30	10,60	----	10,78	10,74	----
	1980	10,56	8,34	8,59	11,00	10,53	10,53	10,88	10,96	11,07	11,24	10,91	----
	1981	10,57	10,15										
LP 31 Col. elev.=925,38 (m.a.m.s.l.)	1976	----	----	----	----	----	4,65	6,77	8,36	8,73	7,98	6,56	----
	1977	8,78	7,15	6,30	6,71	6,14	7,53	7,15	8,70	10,46	9,26	8,89	7,55
	1978	fl.	1,25	2,35	3,23	3,85	4,59	4,35	4,40	8,40	8,64	8,26	7,74
	1979	6,72	4,07	9,00	8,94	8,85	7,38	----	9.43	----	9,76	8,33	----
	1980	----	7,97	8,23	9,99	8,03	7,95	10,05	10,40	10,18	9,79	----	----
	1981	8,30	7,10										

Values represent deph to waterlevel (in metres) below collar elevation.

fl. = borehole underwater as a result of flooding.

---- = no waterlevel measurement taken.

ANNEX III.1

BOREHOLE G32647 (pumped well).

Drawdown Data		Recovery Data		
Time t (min)	Drawdown s (m)	Time t" (min)	t/t"	Res. drawdown s" (m)
1	5,01	1	4051	-2,05
2	5,52	2	2026	-1,42
4	5,04	3	1351	-1,12
6	5,04	4	1014	-0,78
8	5,04	5	811	-0,43
15	5,47	6	676	-0,22
30	5,40	7	580	-0,09
50	5,47	8	507	0,05
240	3,75	10	406	0,18
4050	4,22	12	339	0,20
	Stop	17	239	0,22
		21	194	0,215
		28	146	0,21
		35	117	0,20
		45	91	0,195
		50	82	0,19
		90	46	0,16
		120	35	0,145
		290	15	0,085

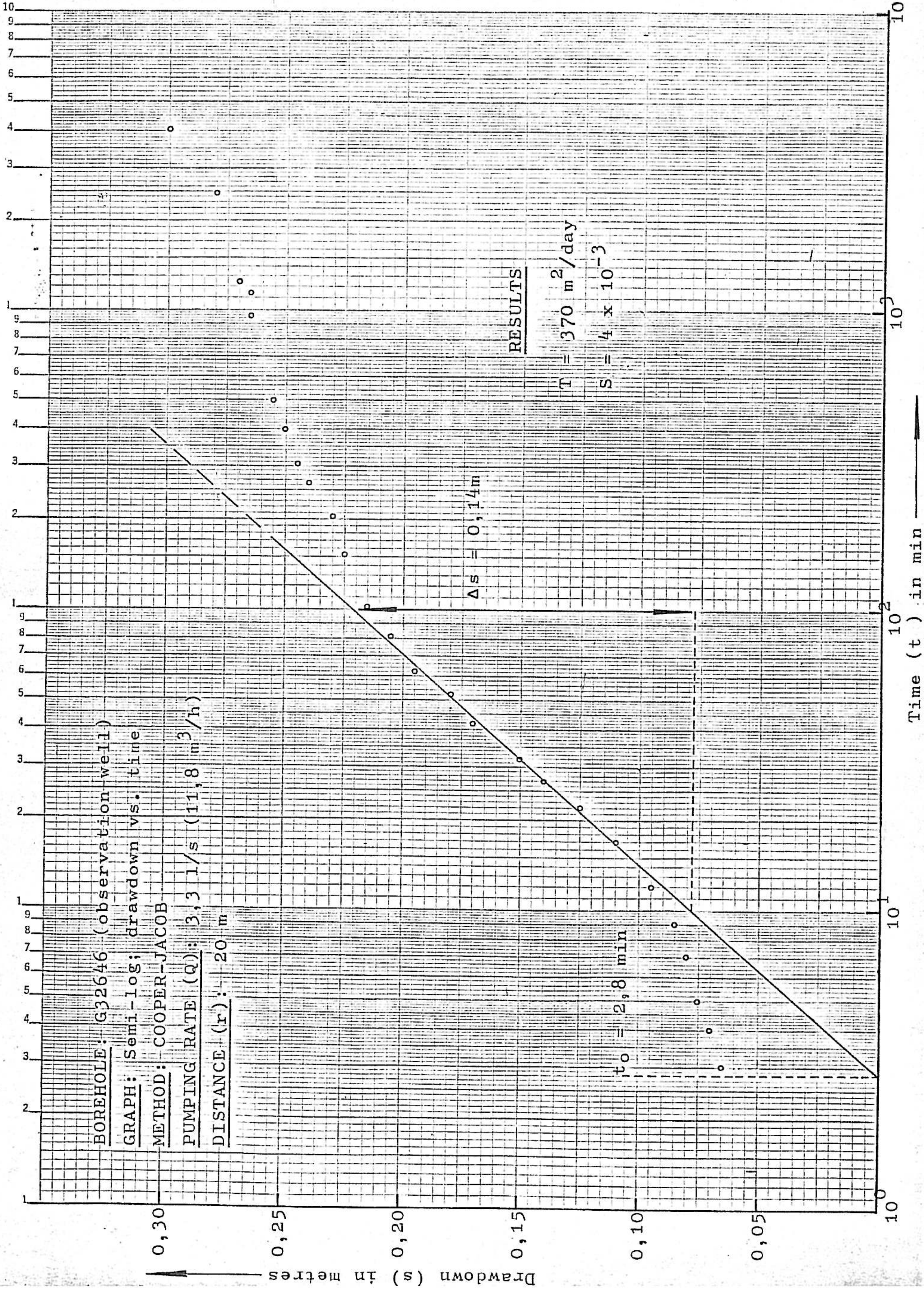
ANNEX III.1 contd.

BOREHOLE G32646 (observation well).

Drawdown Data		Recovery Data		
Time t (min)	Drawdown s (m)	Time t" (min)	t/t"	Res. drawdown s" (m)
3	0,065	1	4051	0,26
4	0,07	2	2026	0,25
5	0,075	3	1351	0,24
7	0,08	5	811	0,225
9	0,085	7	580	0,215
12	0,095	10	406	0,21
17	0,11	15	271	0,20
22	0,125	20	204	0,195
27	0,14	25	163	0,185
32	0,15	30	136	0,17
42	0,17	40	102	0,15
52	0,18	50	82	0,14
62	0,195	60	69	0,13
82	0,205	80	52	0,12
102	0,215	100	42	0,12
152	0,225	120	35	0,11
202	0,23	150	28	0,10
266	0,24	280	15	0,08
302	0,245			
400	0,25			
500	0,255			
960	0,265			
1140	0,265			
1230	0,27			
2480	0,28			
4050	0,30			
	Stop			

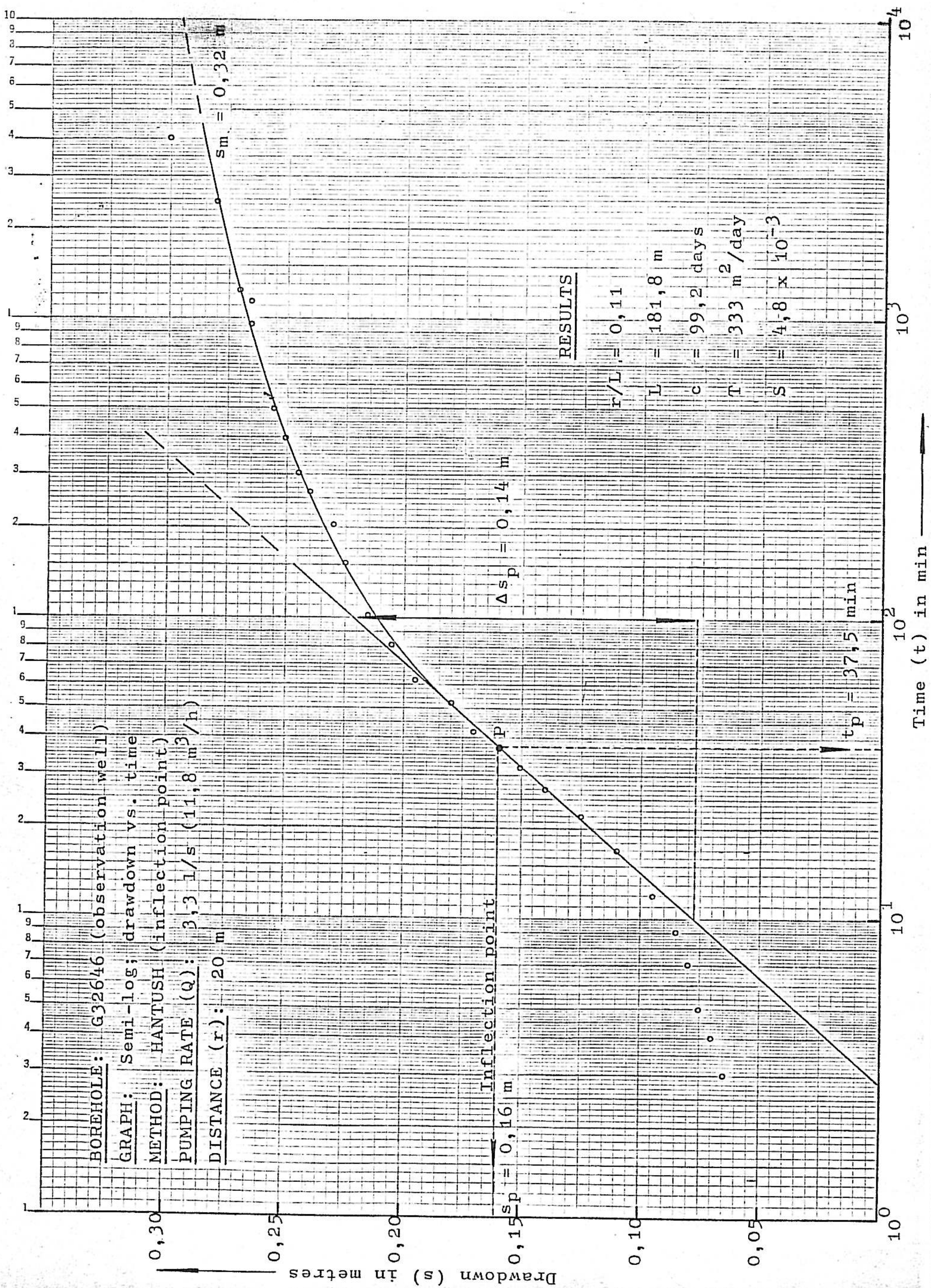
ANNEX III.1 contd.

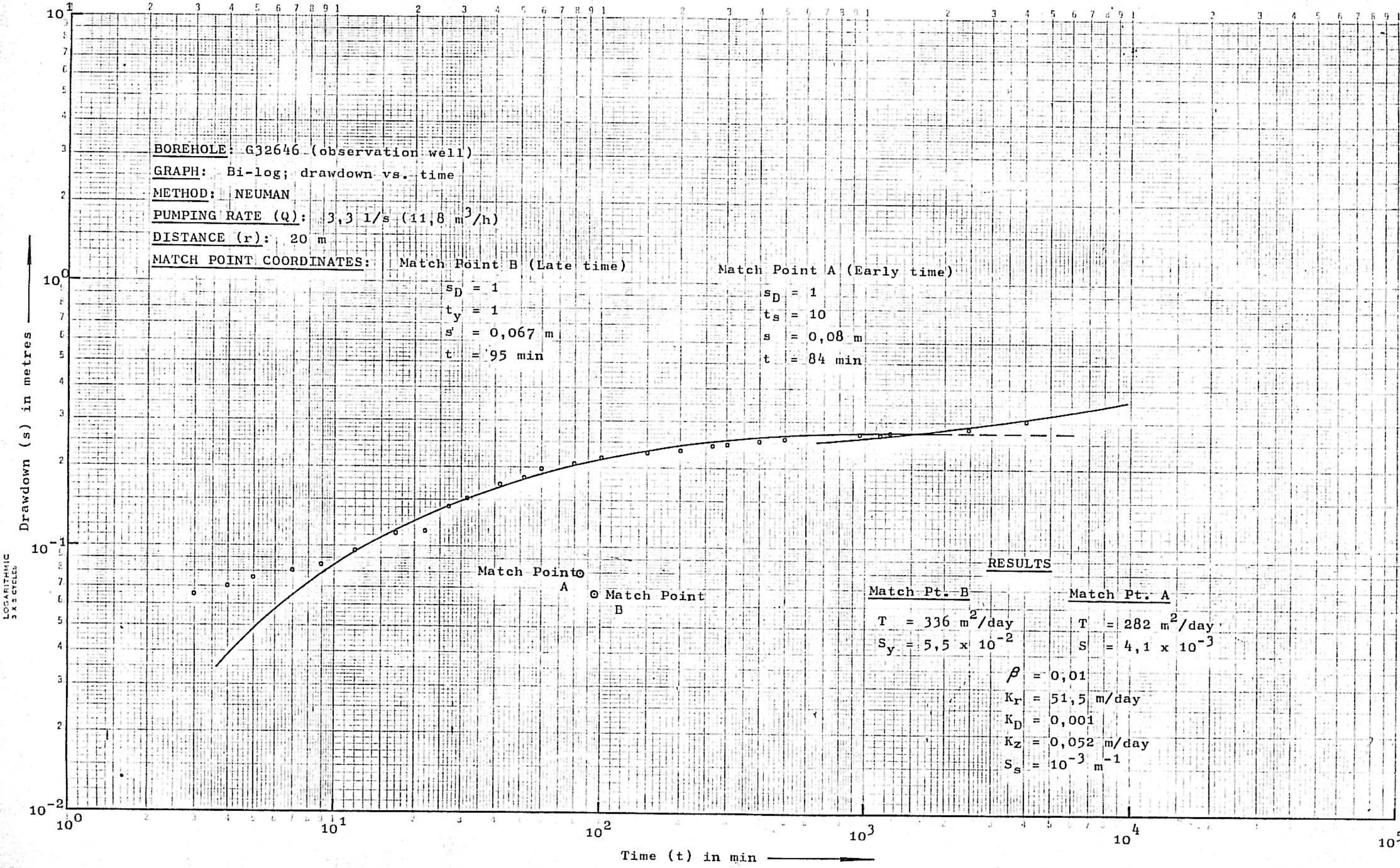
GRAPH 1.1



ANNEX III.1 contd.

GRAPH 1.2





BOREHOLE: G32646 (observation well)

GRAPH: Bi-log; drawdown vs. time

METHOD: NEUMAN

PUMPING RATE (Q): 3,3 l/s (11,8 m^3/h)

DISTANCE (r): 20 m

MATCH POINT COORDINATES:

Match Point B (Late time)

$s_D = 1$
$t_y = 1$
$s' = 0,067$ m
$t = 95$ min

Match Point A (Early time)

$s_D = 1$
$t_s = 10$
$s = 0,08$ m
$t = 84$ min

RESULTS

Match Pt. B

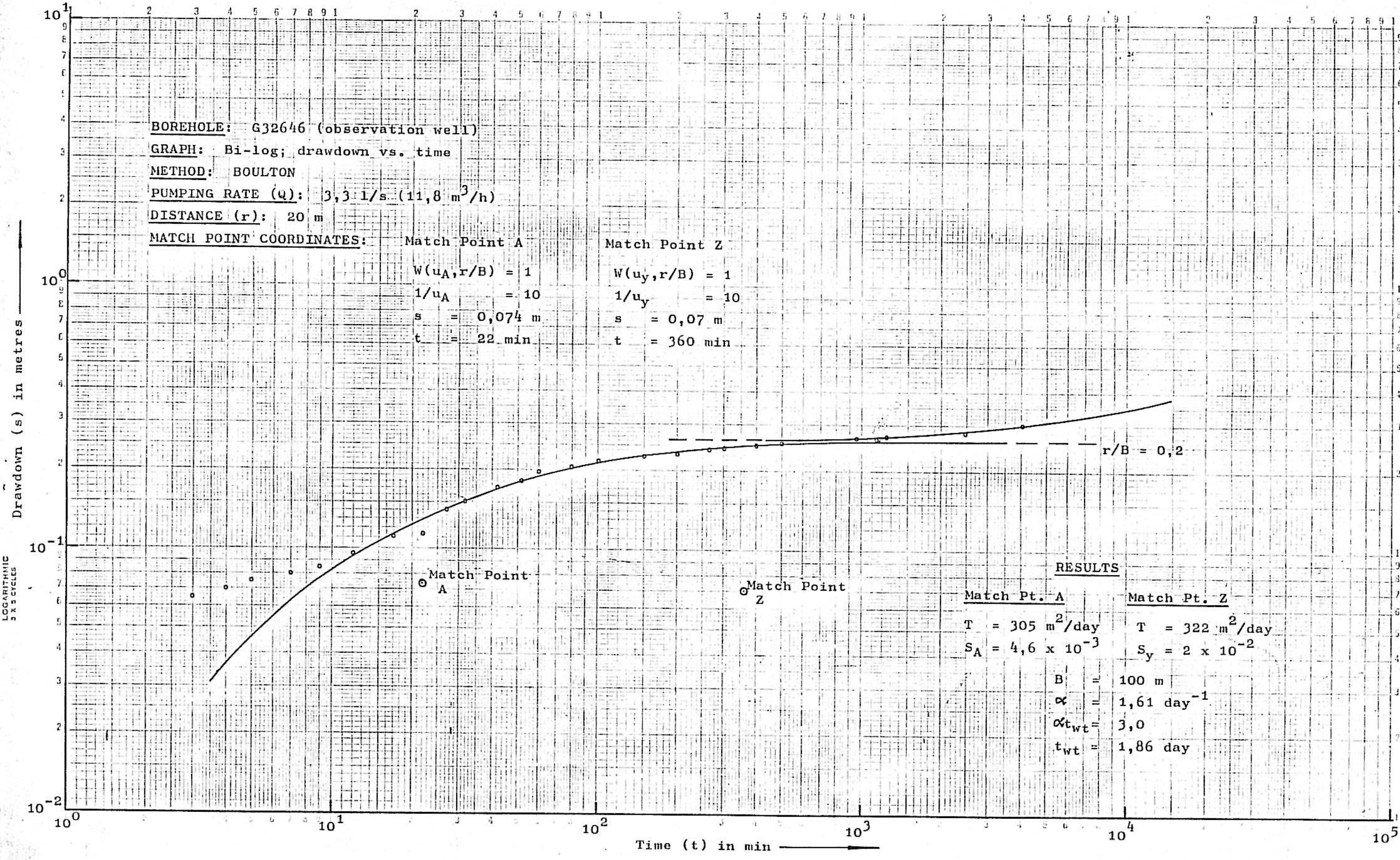
$T = 336\ m^2/day$
$S_y = 5,5 \times 10^{-2}$

Match Pt. A

$T = 282\ m^2/day$
$S = 4,1 \times 10^{-3}$

$\beta = 0,01$
$K_r = 51,5$ m/day
$K_D = 0,001$
$K_z = 0,052$ m/day
$S_s = 10^{-3}\ m^{-1}$

GRAPH 1.4



BOREHOLE: G32646 (observation well)

GRAPH: Bi-log; drawdown vs. time

METHOD: BOULTON

PUMPING RATE (Q): 3,3 l/s (11,8 m^3/h)

DISTANCE (r): 20 m

MATCH POINT COORDINATES:

Match Point A	Match Point Z
$W(u_A, r/B) = 1$	$W(u_y, r/B) = 1$
$1/u_A = 10$	$1/u_y = 10$
s = 0,074 m	s = 0,07 m
t = 22 min	t = 360 min

RESULTS

Match Pt. A	Match Pt. Z
T = 305 m^2/day	T = 322 m^2/day
$S_A = 4,6 \times 10^{-3}$	$S_y = 2 \times 10^{-2}$

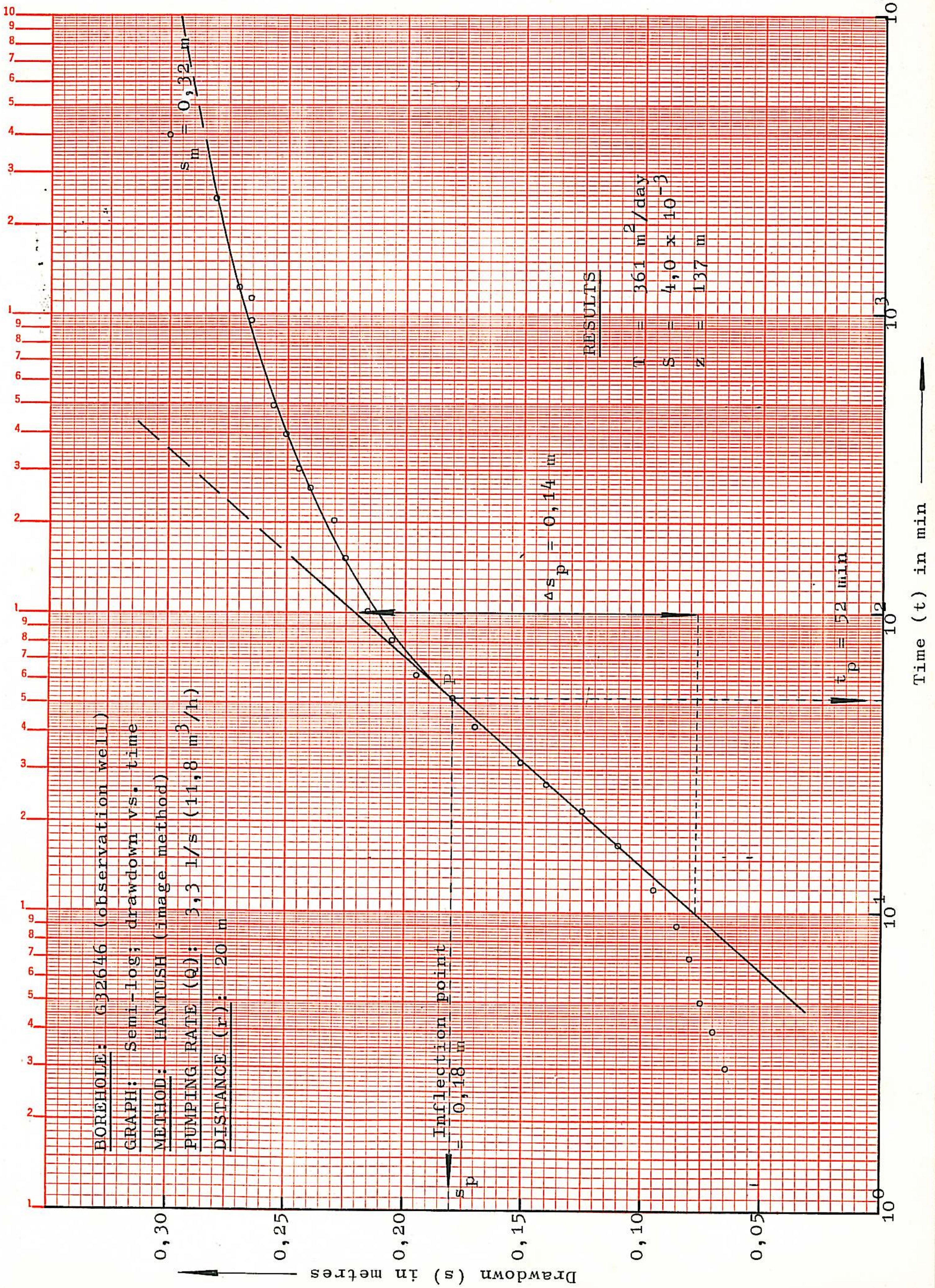
B = 100 m

α = 1,61 day^{-1}

αt_{wt} = 3,0

t_{wt} = 1,86 day

GRAPH 1.5



BOREHOLE: G32646 (observation well)

GRAPH: Semi-log; drawdown vs. time

METHOD: HANTUSH (image method)

PUMPING RATE (Q): 3,3 l/s (11,8 m^3/h)

DISTANCE (r): 20 m

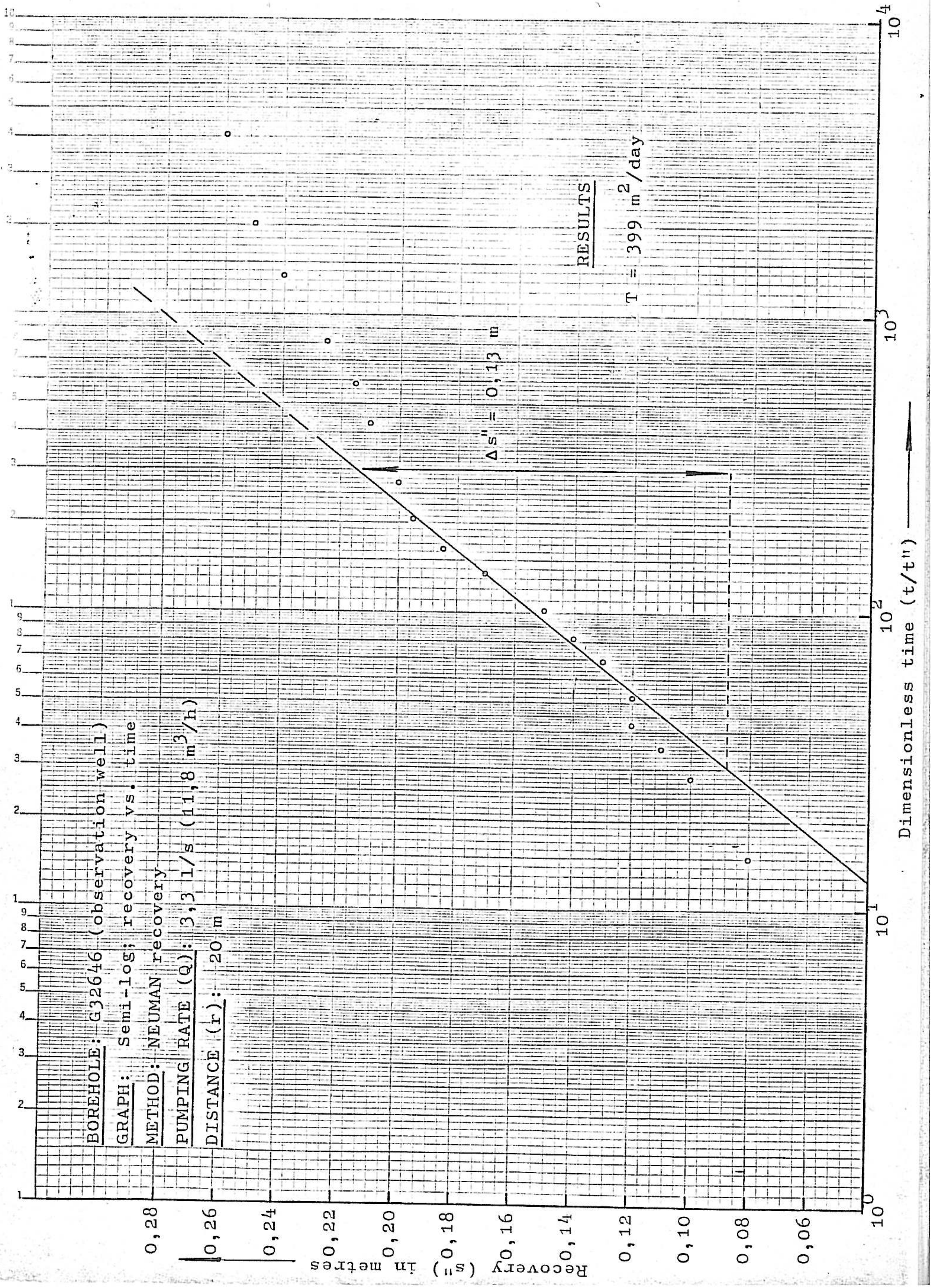
RESULTS

T = 361 m^2/day

S = 4,0 x 10^{-3}

z = 137 m

GRAPH 1.6



BOREHOLE: G32646 (observation well)

GRAPH: Semi-log; recovery vs. time

METHOD: NEUMAN recovery

PUMPING RATE (Q): 3,3 l/s (11,8 m^3/h)

DISTANCE (r): 20 m

RESULTS

$T = 399\ m^2/day$

ANNEX III.2

BOREHOLE G32648 (pumped well).

Drawdown Data

Time t (min)	Drawdown s (m)
1	0,09
3	0,12
6	2,32
8	2,30
10	2,49
17	2,63
28	2,52
45	2,66
52	2,47
71	2,62
120	2,35
185	2,73
1860	Stop

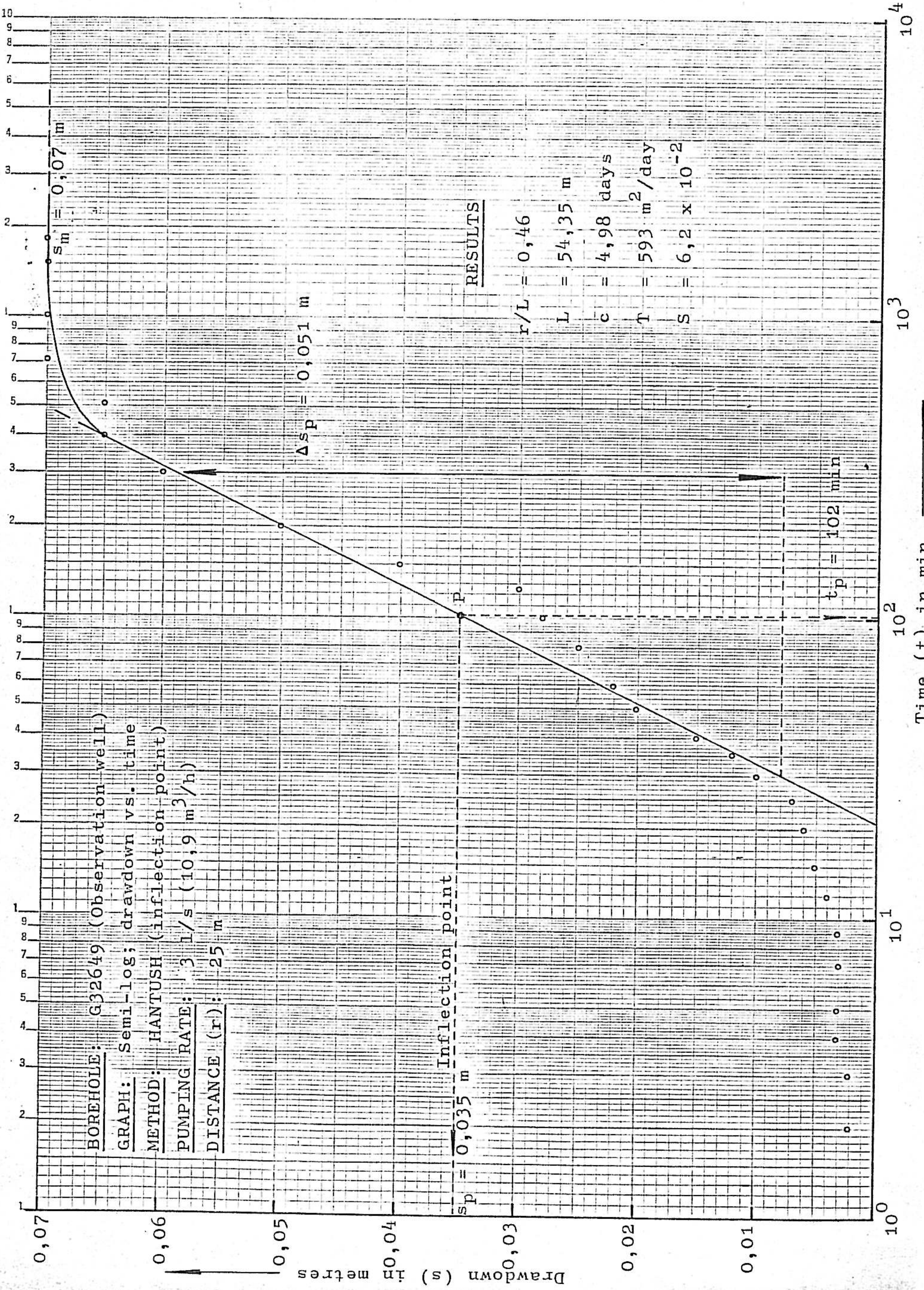
ANNEX III.2 contd.

BOREHOLE G32649 (observation well).

Drawdown Data

Time t (min)	Drawdown s (m)
1	0,000
2	0,002
3	0,002
4	0,003
5	0,003
7	0,003
9	0,003
12	0,004
15	0,005
20	0,006
25	0,007
30	0,010
35	0,012
40	0,015
50	0,020
60	0,022
80	0,025
100	0,028
125	0,030
150	0,040
200	0,050
250	0,060
300	0,060
400	0,065
510	0,065
720	0,070
1010	0,070
1510	0,070
1860	0,070
	Stop

GRAPH 2.1



BOREHOLE: G32649 (Observation well)

GRAPH: Semi log; drawdown vs. time

METHOD: HANTUSH (inflection point)

PUMPING RATE: 3 l/s (10,9 m^3/h)

DISTANCE (r): 25 m

RESULTS

$r/L = 0,46$

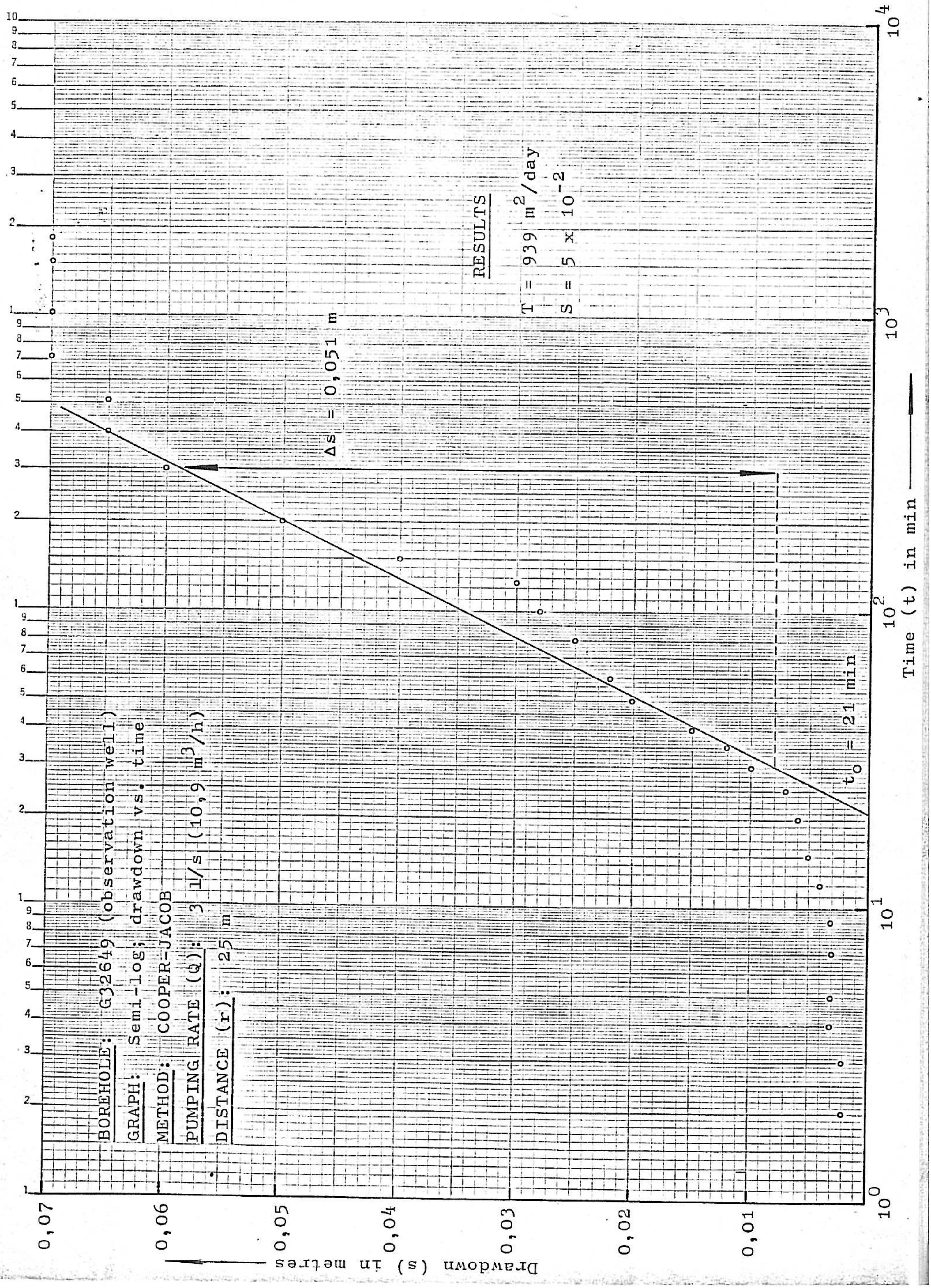
$L = 54,35$ m

$c = 4,98$ days

$T = 593$ m^2/day

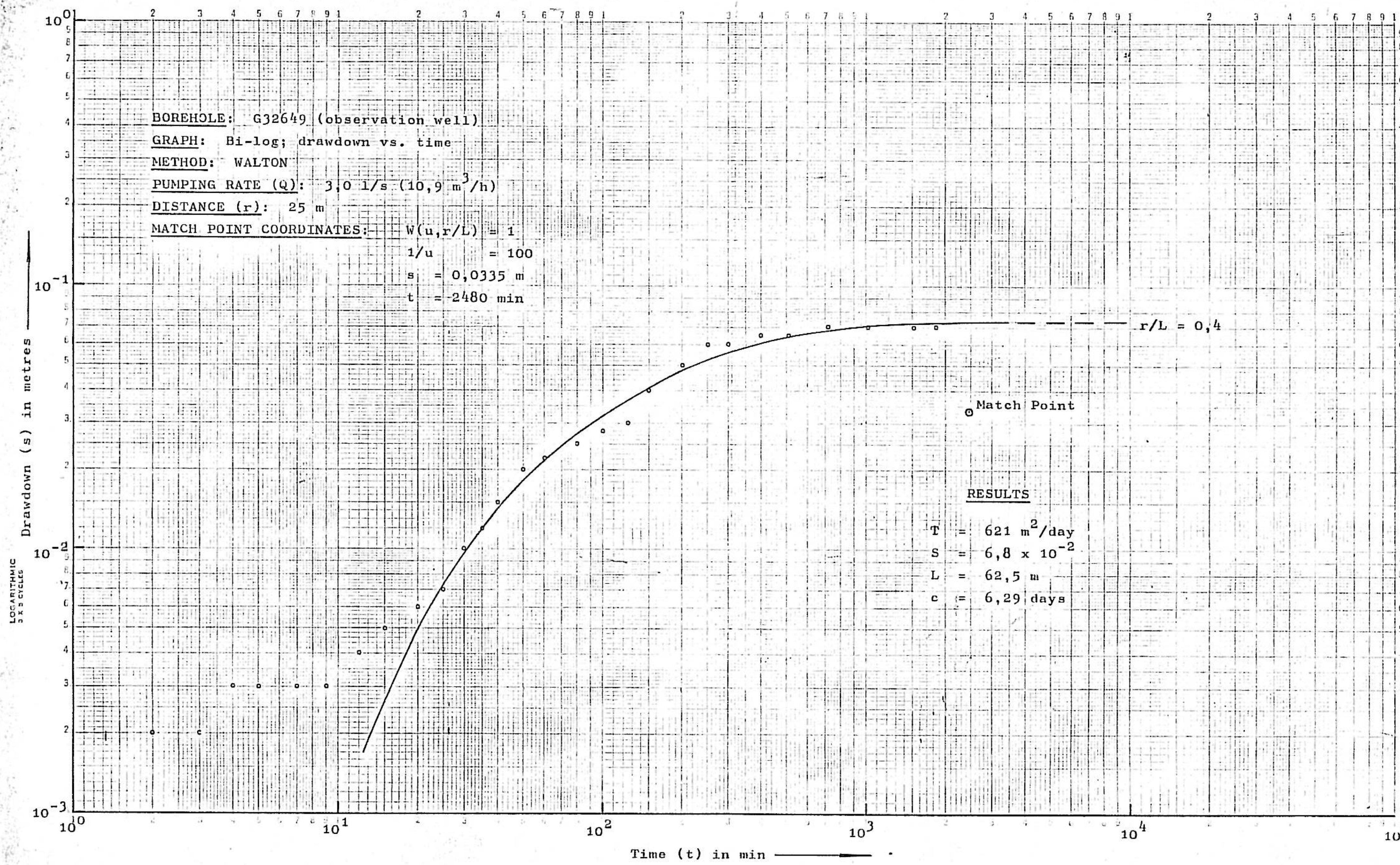
$S = 6,2 \times 10^{-2}$

GRAPH 2.2


BOREHOLE: G32649 (observation well)
GRAPH: Semi-log; drawdown vs. time
METHOD: COOPER-JACOB
PUMPING RATE (Q): 3 l/s (10,9 m^3/h)
DISTANCE (r): 25 m
RESULTS
T = 939 m^2/day
S = 5 x 10^{-2}
Δs = 0,051 m
t$_0$ = 21 min
Time (t) in min
10^0
10^1
10^2
10^3
10^4
Drawdown (s) in metres
0,07
0,06
0,05
0,04
0,03
0,02
0,01

ANNEX III.2 contd.

GRAPH 2.3



BORESHOLE: G32649 (observation well)

GRAPH: Bi-log; drawdown vs. time

METHOD: WALTON

PUMPING RATE (Q): 3,0 l/s (10,9 m^3/h)

DISTANCE (r): 25 m

MATCH POINT COORDINATES: W(u,r/L) = 1
1/u = 100
s = 0,0335 m
t = 2480 min

RESULTS

T = 621 m^2/day
S = 6,8 x 10^{-2}
L = 62,5 m
c = 6,29 days

ANNEX III.3

BOREHOLE G32655 (pumped well).

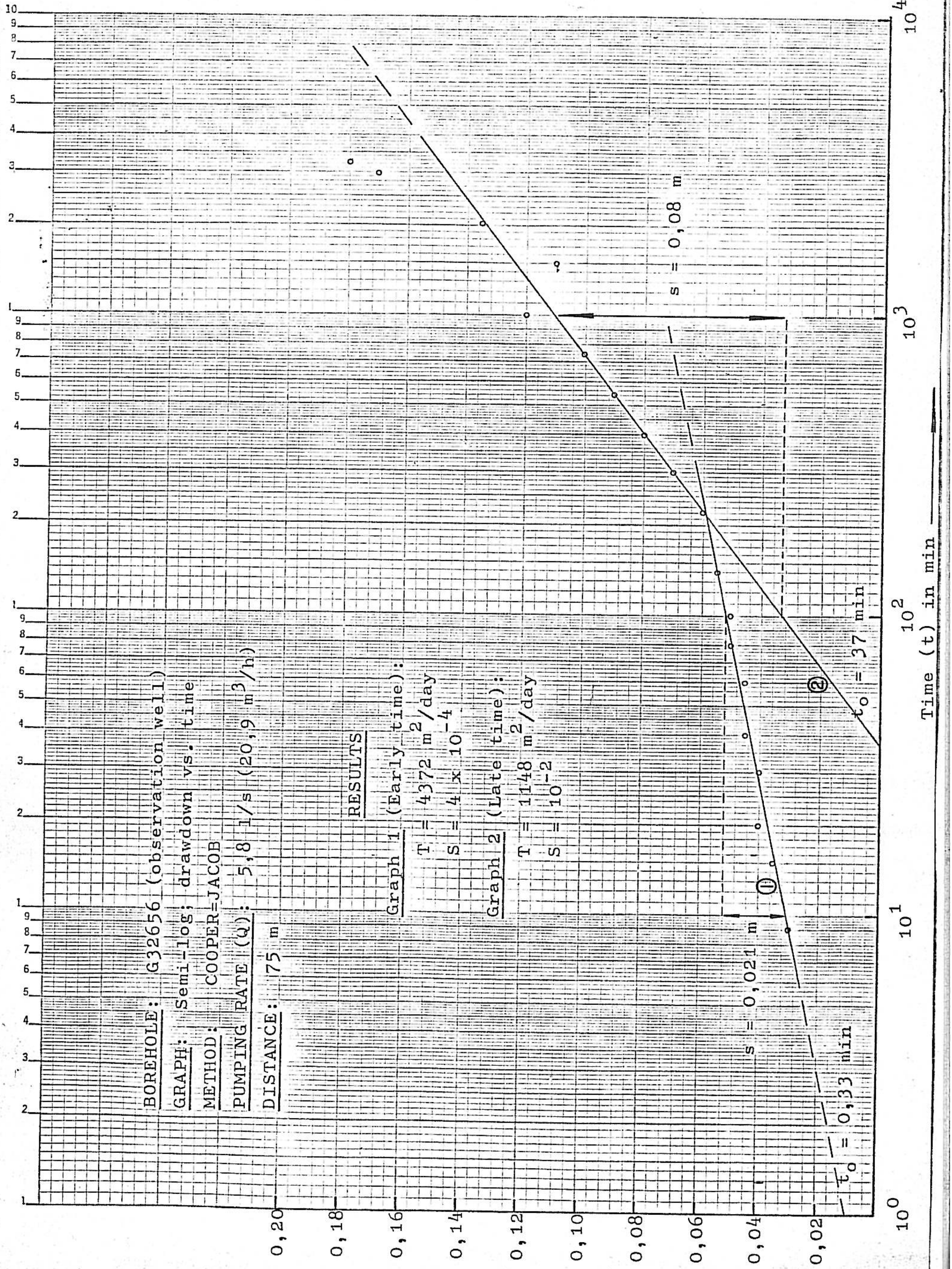
Drawdown Data		Recovery Data		
Time t (min)	Drawdown s (m)	Time t" (min)	t/t"	Res. drawdown s" (m)
5	3,39	1	3241	0,74
18	3,40	2	1621	0,62
32	3,40	3	1081	0,56
42	3,40	4	811	0,53
65	3,48	5	649	0,39
76	3,39	7	464	0,33
105	3,35	10	325	0,33
140	3,38	15	217	0,38
295	3,30	20	163	0,37
540	3,34	25	131	0,36
720	3,14	30	109	0,35
1000	3,14	40	82	0,32
1500	3,18	50	66	0,31
2360	3,24	60	55	0,30
2980	2,97	90	37	0,27
3240	Stop	100	33	0,27
		150	23	0,26
		220	16	0,23
		400	9	0,18
		620	6	0,16

ANNEX III.3 contd.

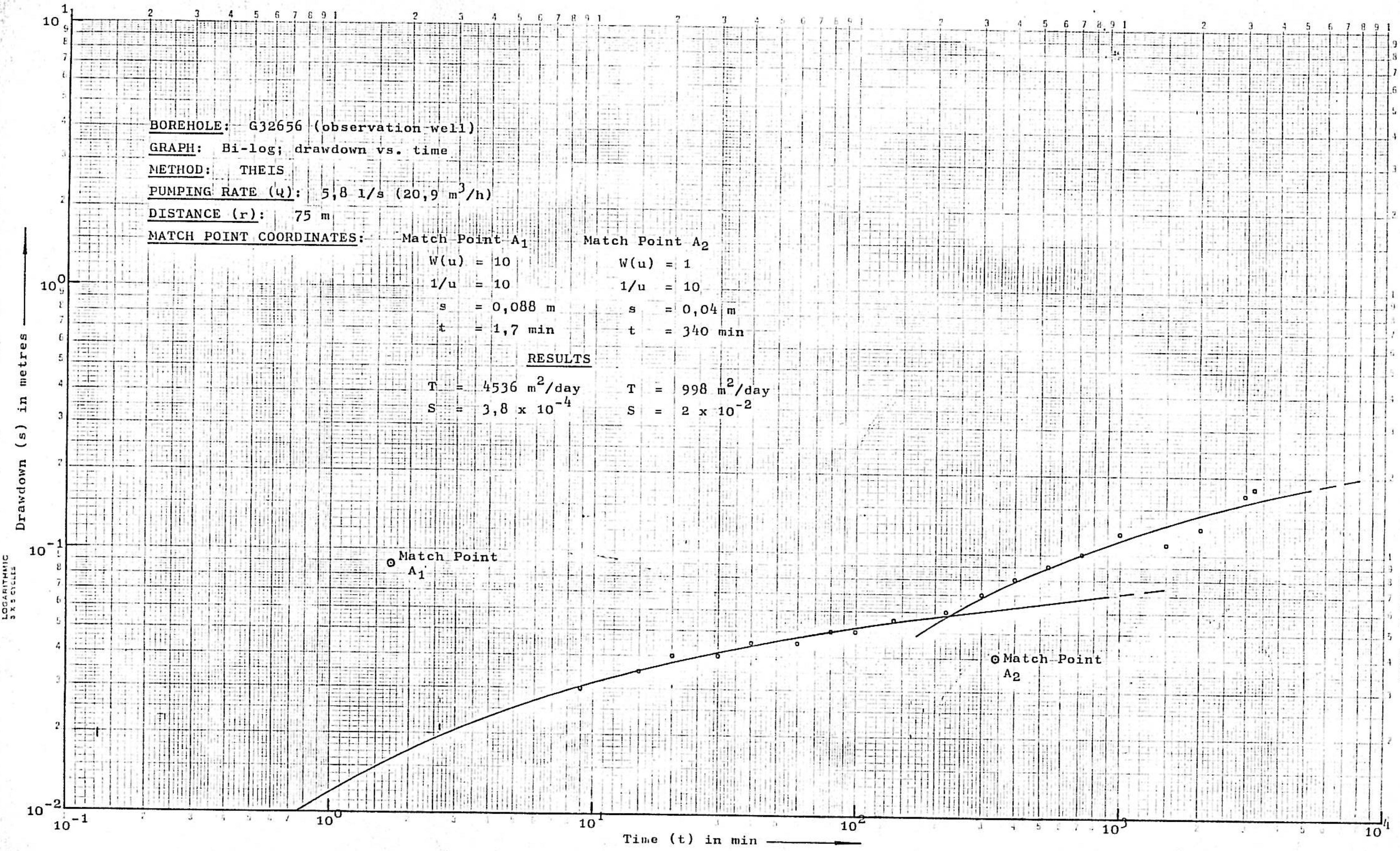
BOREHOLE G32656 (observation well).

Drawdown Data		Recovery Data		
Time t (min)	Drawdown s (m)	Time t" (min)	t/t"	Res. drawdown s" (m)
9	0,03	1	3241	0,17
15	0,035	2	1621	0,17
20	0,04	3	1081	0,14
30	0,04	5	649	0,155
40	0,045	7	464	0,15
60	0,045	10	325	0,135
80	0,05	15	217	0,13
100	0,05	20	163	0,13
140	0,055	25	131	0,145
220	0,06	30	109	0,13
300	0,07	40	82	0,13
400	0,08	50	66	0,13
540	0,09	60	55	0,125
720	0,10	80	42	0,125
1000	0,12	100	33	0,12
1500	0,11	120	28	0,12
2010	0,135	150	23	0,12
2990	0,17	220	16	0,11
3220	0,18	400	9	0,11
3240	Stop	620	6	0,08

GRAPH 3.1


BOREHOLE: G32656 (observation well)
GRAPH: Semi-log; drawdown vs. time
METHOD: COOPER-JACOB
PUMPING RATE (Q): 5,8 l/s (20,9 m^3/h)
DISTANCE: 75 m
RESULTS
Graph 1 (Early time):
T = 4372 m^2/day
S = 4 x 10^{-4}
Graph 2 (Late time):
T = 1148 m^2/day
S = 10^{-2}
s = 0,08 m
s = 0,021 m
t_o = 37 min
t_o = 0,33 min
①
②
Time (t) in min
10^0
10^1
10^2
10^3
10^4
Drawdown (s) in metres
0,20
0,18
0,16
0,14
0,12
0,10
0,08
0,06
0,04
0,02

GRAPH 3.2



BOREHOLE: G32656 (observation well)

GRAPH: Bi-log; drawdown vs. time

METHOD: THEIS

PUMPING RATE (Q): 5,8 l/s (20,9 m^3/h)

DISTANCE (r): 75 m

MATCH POINT COORDINATES:

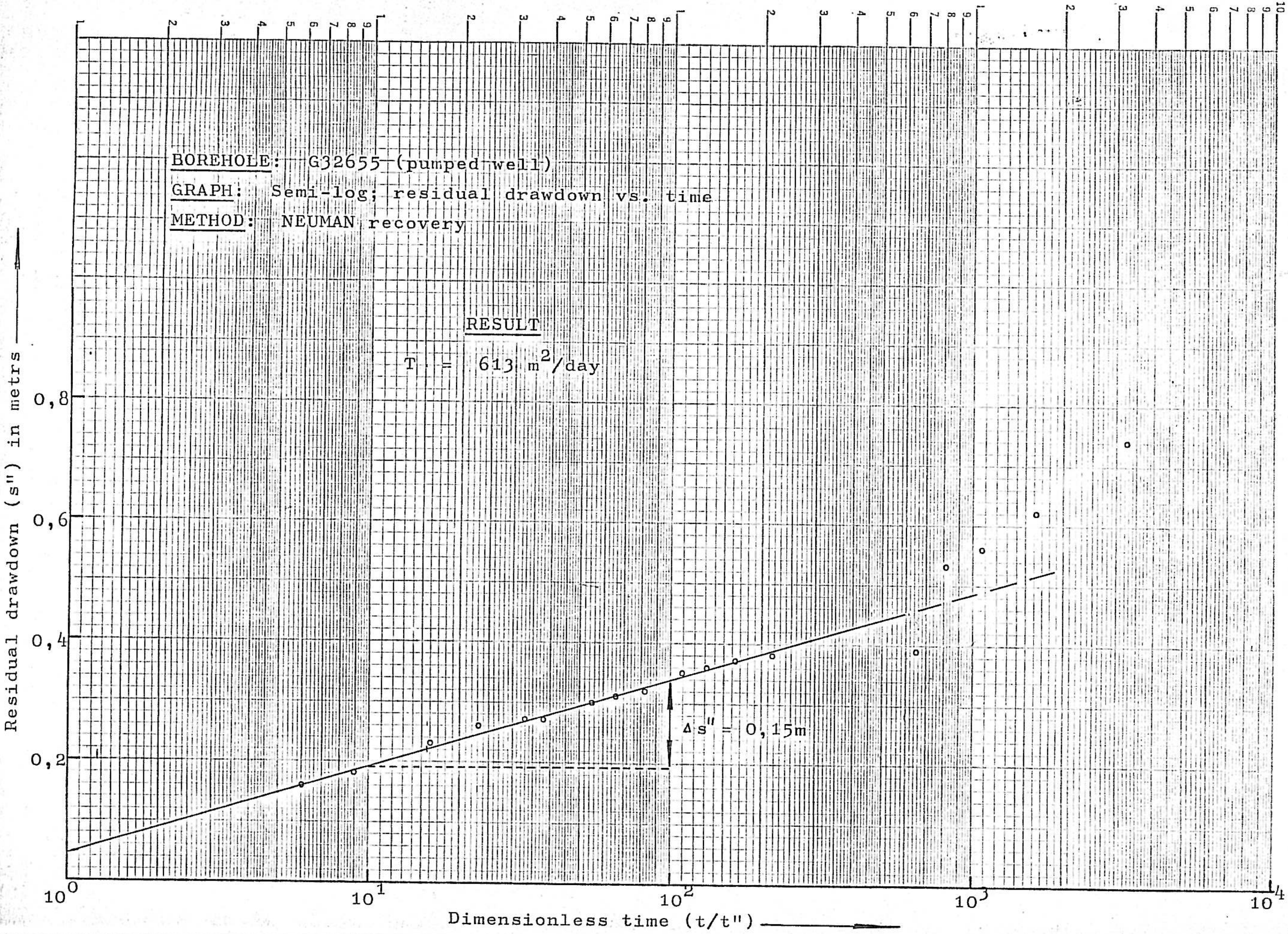
Match Point A_1	Match Point A_2
W(u) = 10	W(u) = 1
1/u = 10	1/u = 10
s = 0,088 m	s = 0,04 m
t = 1,7 min	t = 340 min

RESULTS

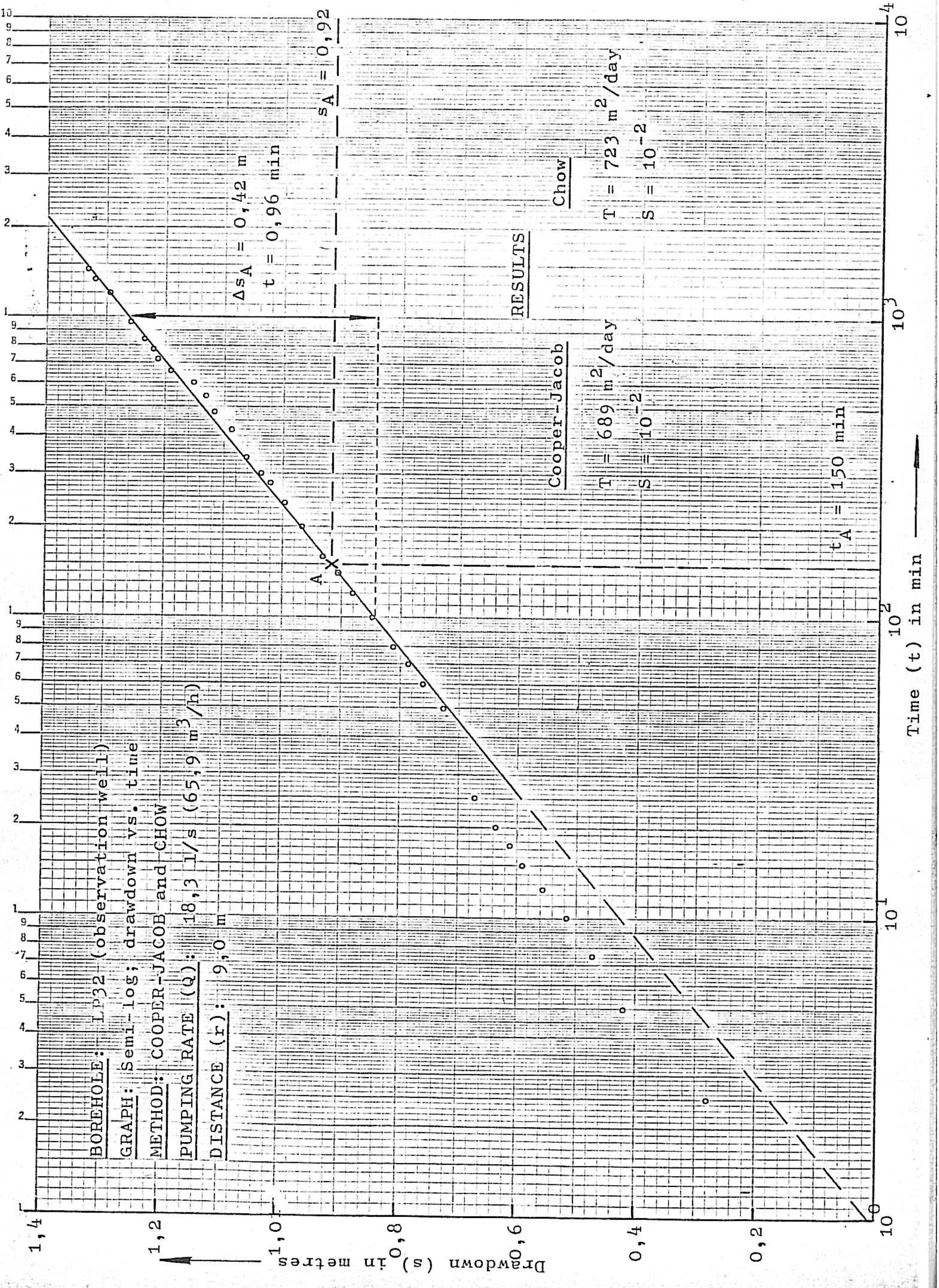
T = 4536 m^2/day	T = 998 m^2/day
S = 3,8 x 10^{-4}	S = 2 x 10^{-2}

ANNEX III.3 contd.

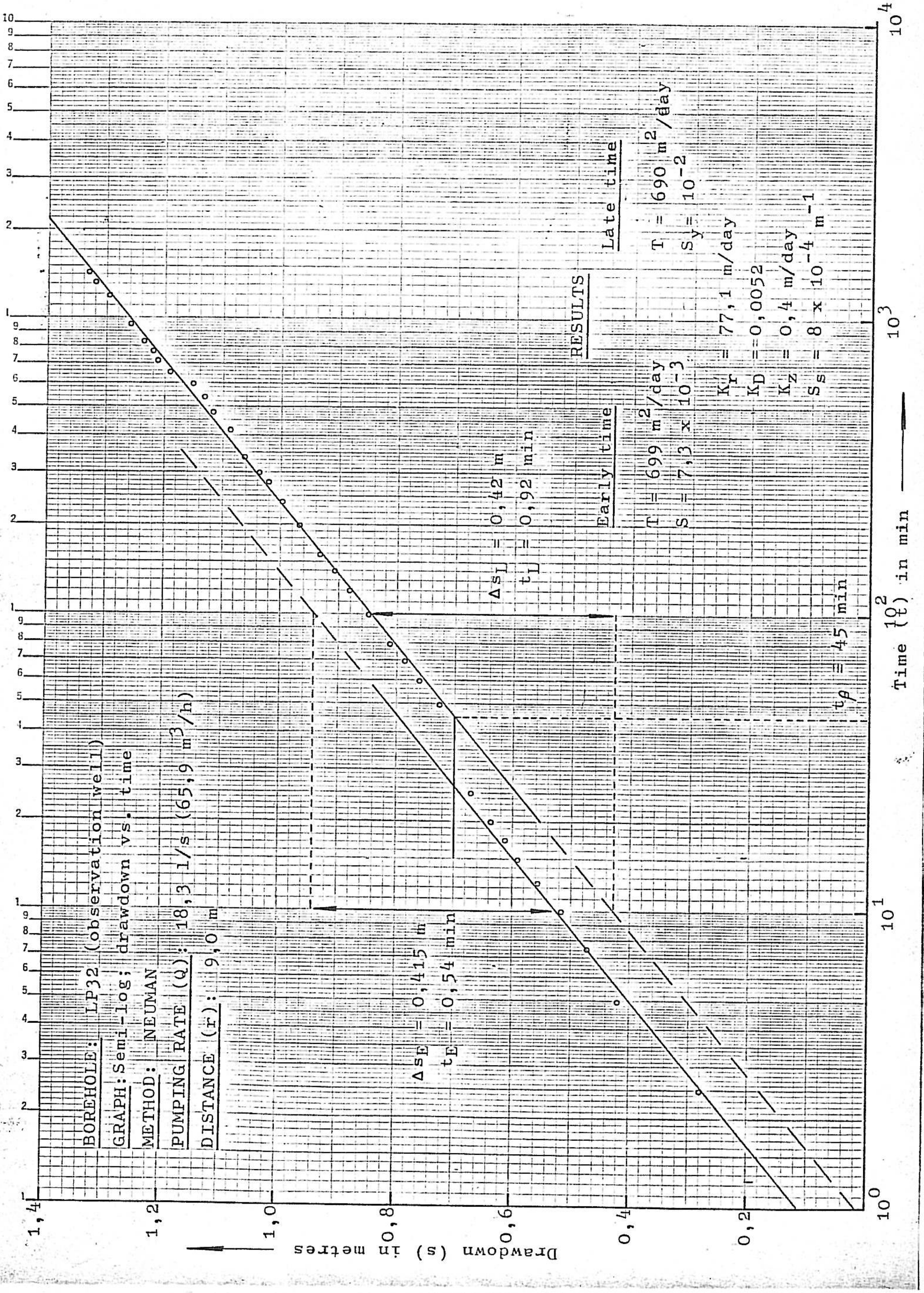
GRAPH 3.3



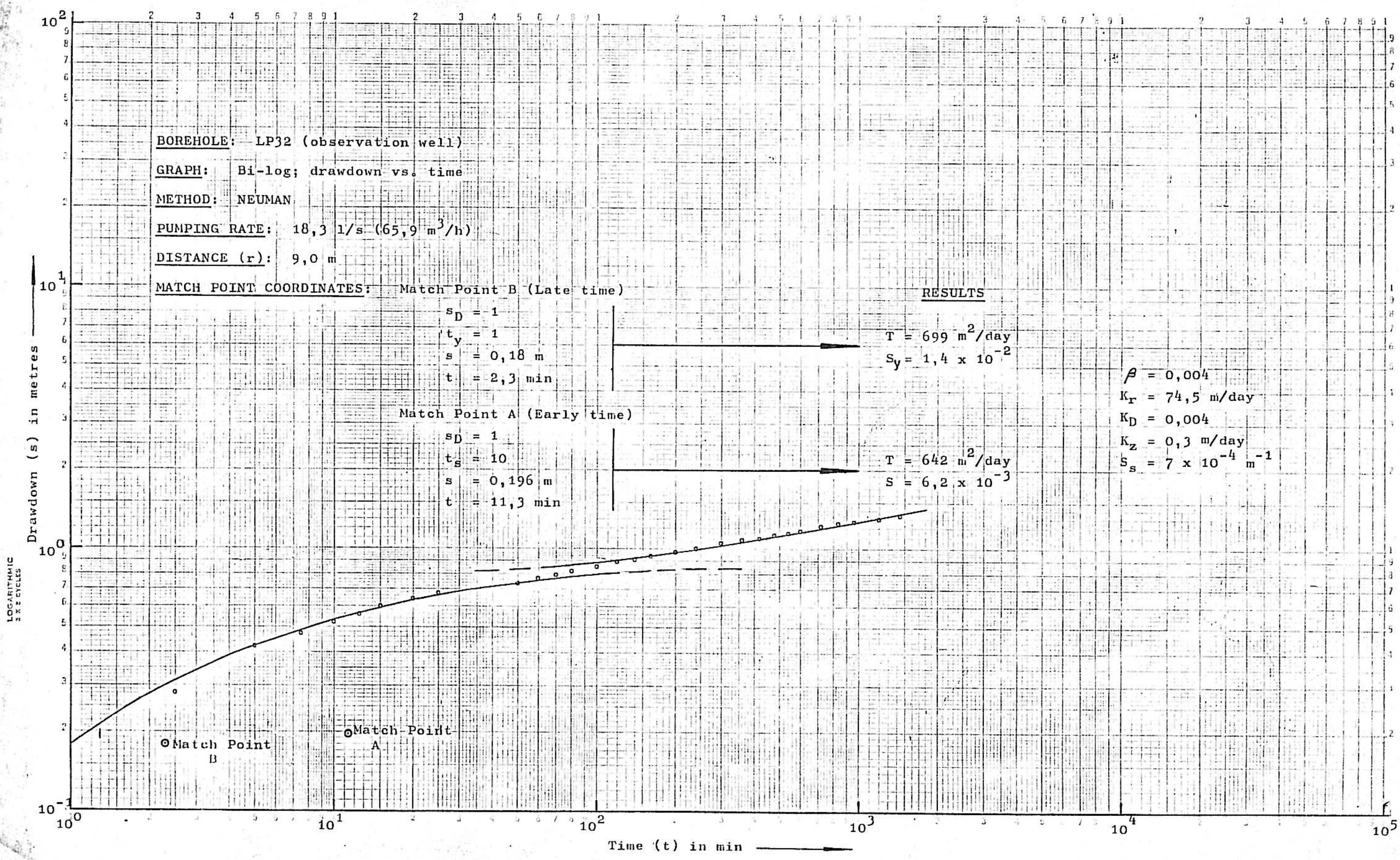
ANNEX III.4 GRAPH 4.1



GRAPH 4.2


BOREHOLE: LP32 (observation well)
GRAPH: Semi-log; drawdown vs. time
METHOD: NEUMAN
PUMPING RATE (Q): 18,3 l/s (65,9 m³/h)
DISTANCE (r): 9,0 m
Δs_E = 0,415 m
t_E = 0,54 min
Δs_L = 0,42 m
t_L = 0,92 min
t_β = 45 min
RESULTS
Early time
T = 699 m²/day
S = 7,3 x 10^{-3}
Late time
T = 690 m²/day
S_y = 10^{-2}
K_r = 77,1 m/day
K_D = 0,0052
K_z = 0,4 m/day
S_s = 8 x 10^{-4} m^{-1}
Time (t) in min
Drawdown (s) in metres
10^0
10^1
10^2
10^3
10^4
1,4
1,2
1,0
0,8
0,6
0,4
0,2

GRAPH 4.3



BOREHOLE: LP32 (observation well)

GRAPH: Bi-log; drawdown vs. time

METHOD: NEUMAN

PUMPING RATE: 18,3 l/s (65,9 m^3/h)

DISTANCE (r): 9,0 m

MATCH POINT COORDINATES: Match Point B (Late time)

$s_D = 1$
$t_y = 1$
$s = 0,18$ m
$t = 2,3$ min

Match Point A (Early time)

$s_D = 1$
$t_s = 10$
$s = 0,196$ m
$t = 11,3$ min

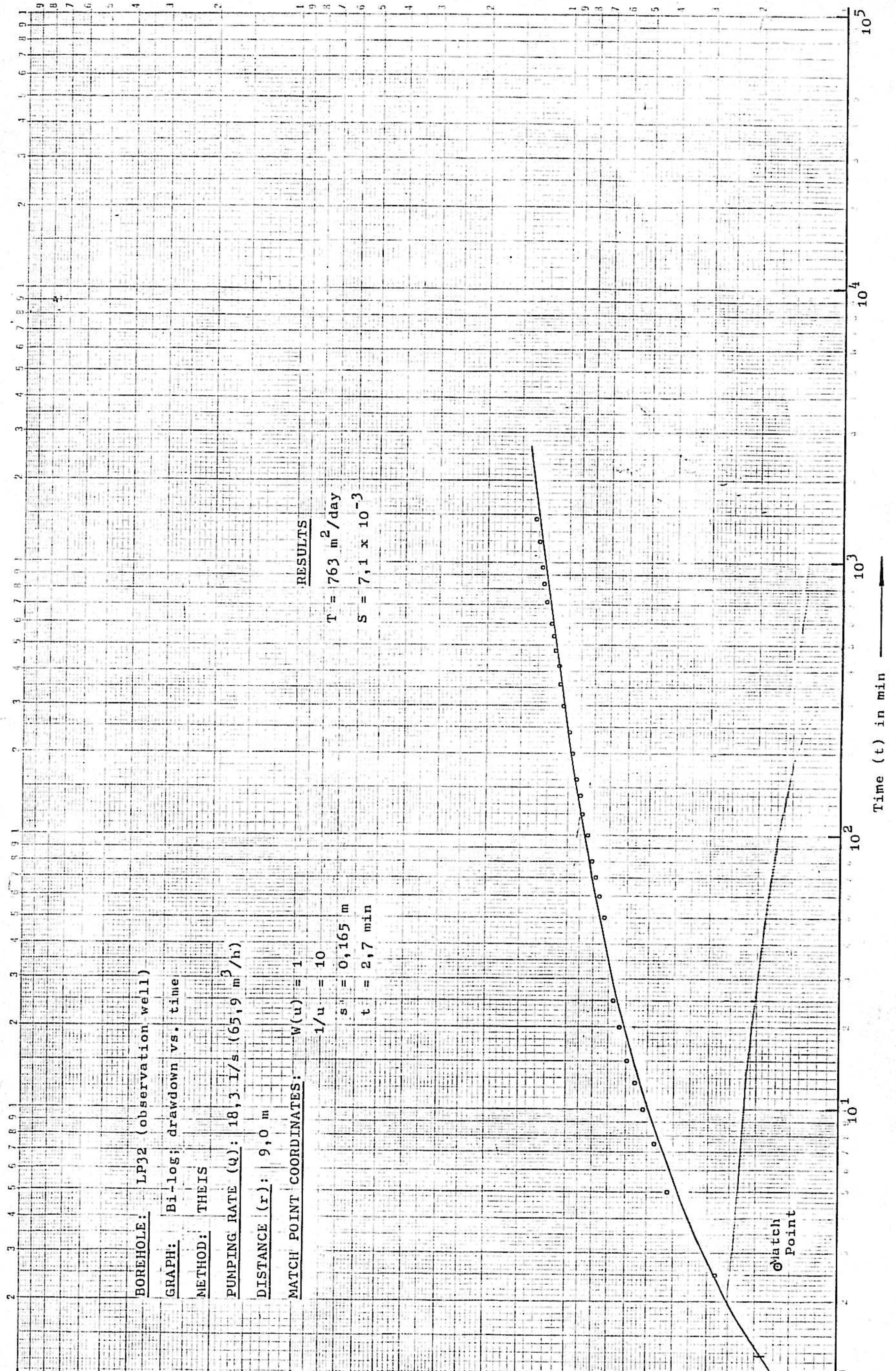
RESULTS

$T = 699\ m^2/day$
$S_y = 1,4 \times 10^{-2}$

$T = 642\ m^2/day$
$S = 6,2 \times 10^{-3}$

$\beta = 0,004$
$K_r = 74,5$ m/day
$K_D = 0,004$
$K_z = 0,3$ m/day
$S_s = 7 \times 10^{-4}\ m^{-1}$

GRAPH 4.4



BOREHOLE: LP32 (observation well)

GRAPH: Bi-log; drawdown vs. time

METHOD: THEIS

PUMPING RATE (Q): 18,3 l/s (65,9 m^3/h)

DISTANCE (r): 9,0 m

MATCH POINT COORDINATES:

W(u) = 1

1/u = 10

s = 0,165 m

t = 2,7 min

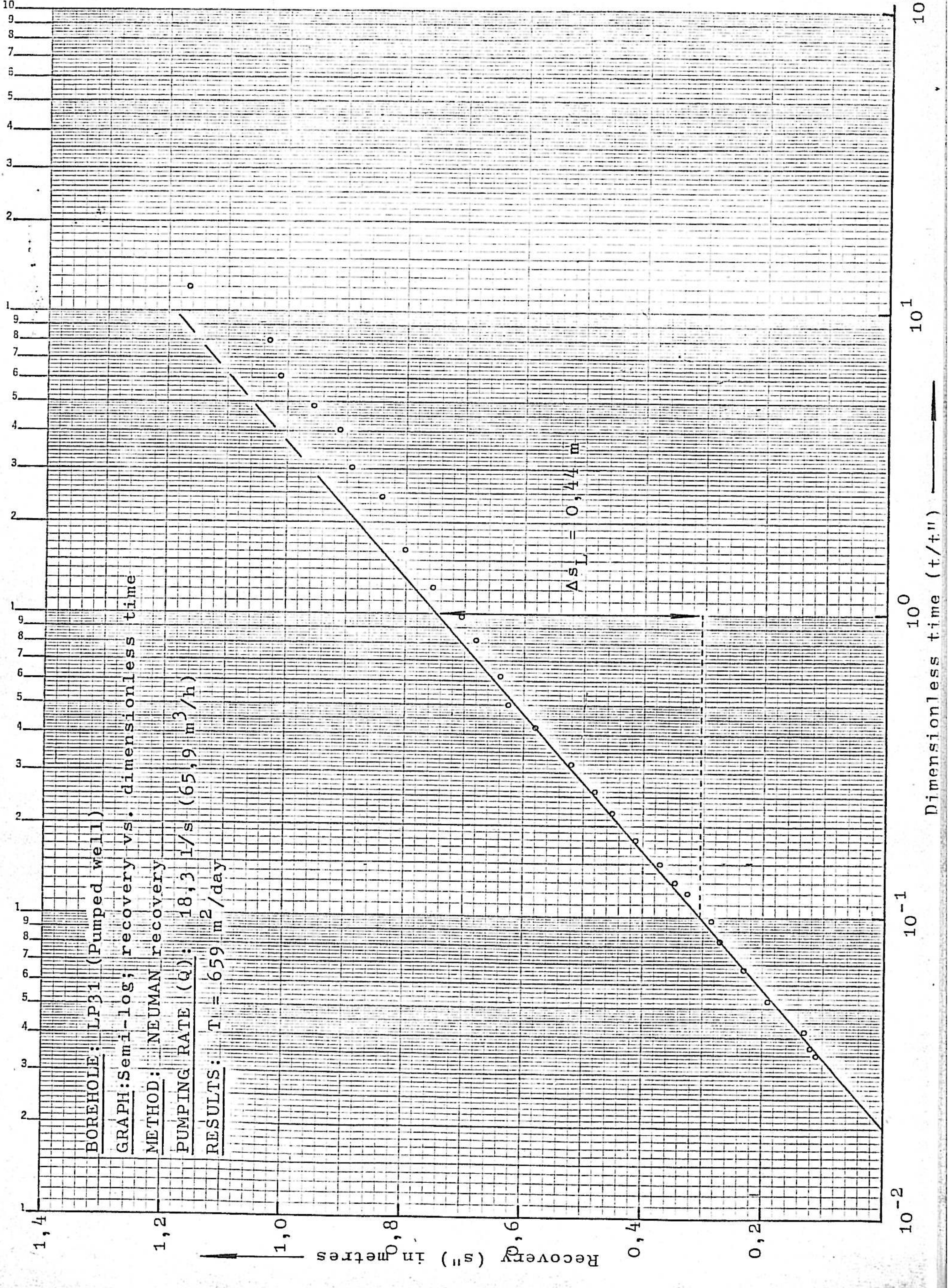
RESULTS

T = 763 m^2/day

S = 7,1 x 10^{-3}

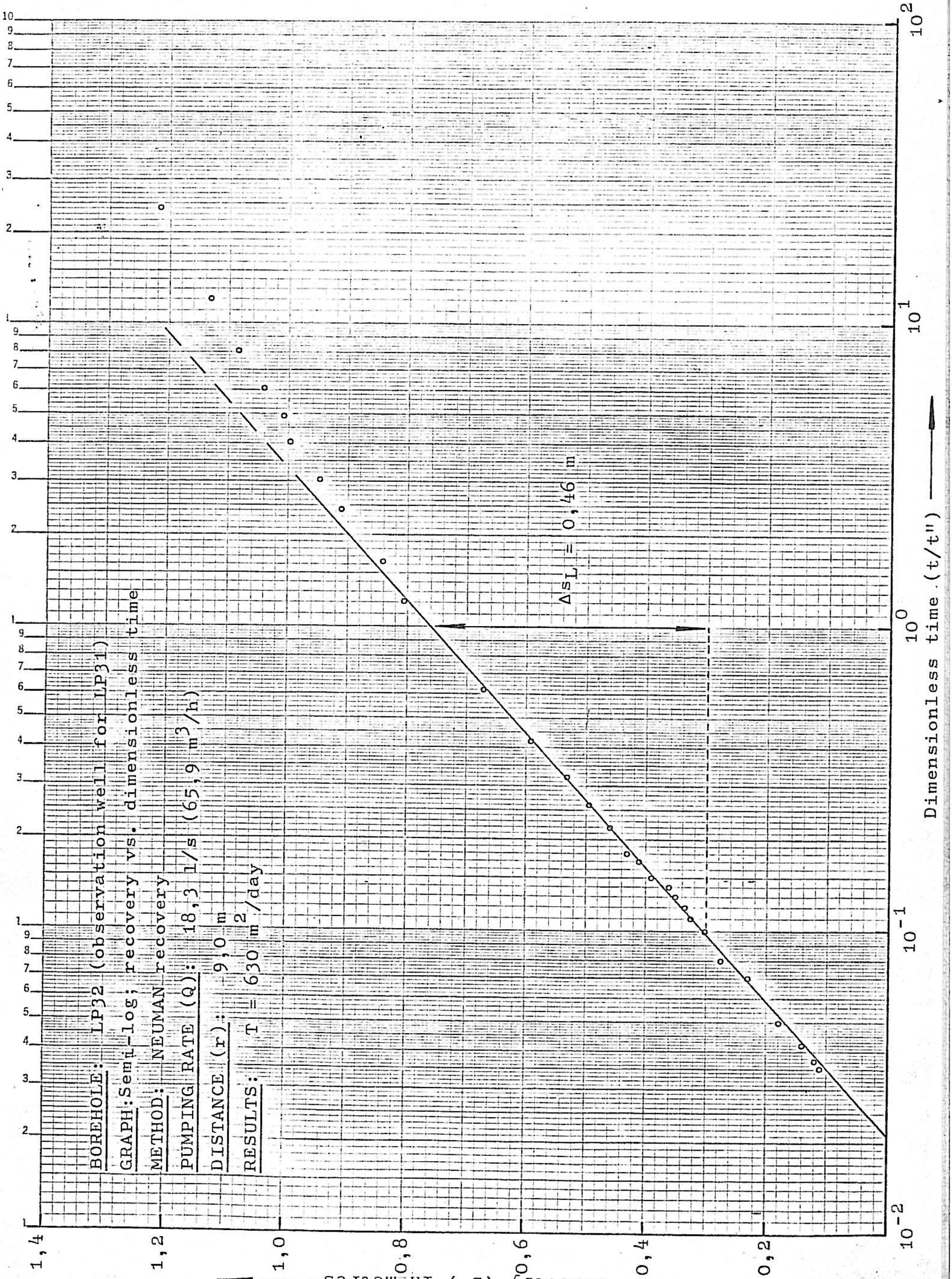
ANNEX III.4 contd.

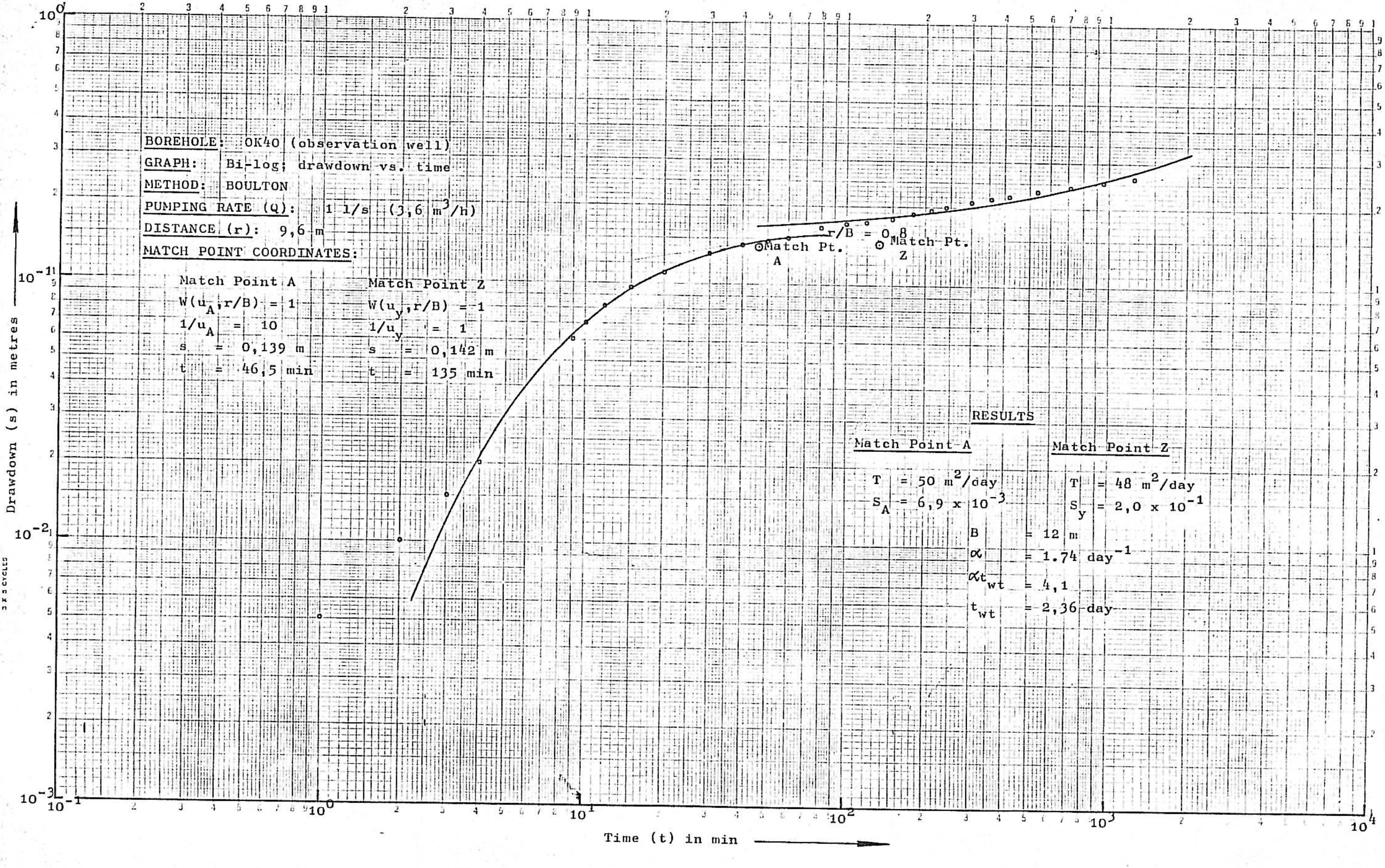
GRAPH 4.5



BOREHOLE: LP31 (Pumped well)
GRAPH: Semi-log; recovery vs. dimensionless time
METHOD: NEUMAN recovery
PUMPING RATE (Q): 18,3 l/s (65,9 m^3/h)
RESULTS: T = 659 m^2/day

GRAPH 4.6


BOREHOLE: LP32 (observation well for LP31)
GRAPH: Semi-log; recovery vs. dimensionless time
METHOD: NEUMAN recovery
PUMPING RATE (Q): 18,3 l/s (65,9 m³/h)
DISTANCE (r): 9,0 m
RESULTS: T = 630 m²/day
Δs_L = 0,46 m
Dimensionless time (t/t")
Recovery (s") in metres
10⁻²
10⁻¹
10⁰
10¹
10²
1,4
1,2
1,0
0,8
0,6
0,4
0,2



BOREHOLE: OK40 (observation well)

GRAPH: Bi-log; drawdown vs. time

METHOD: BOULTON

PUMPING RATE (Q): 1 l/s (3,6 m^3/h)

DISTANCE (r): 9,6 m

MATCH POINT COORDINATES:

Match Point A
$W(u_A, r/B) = 1$
$1/u_A = 10$
s = 0,139 m
t = 46,5 min

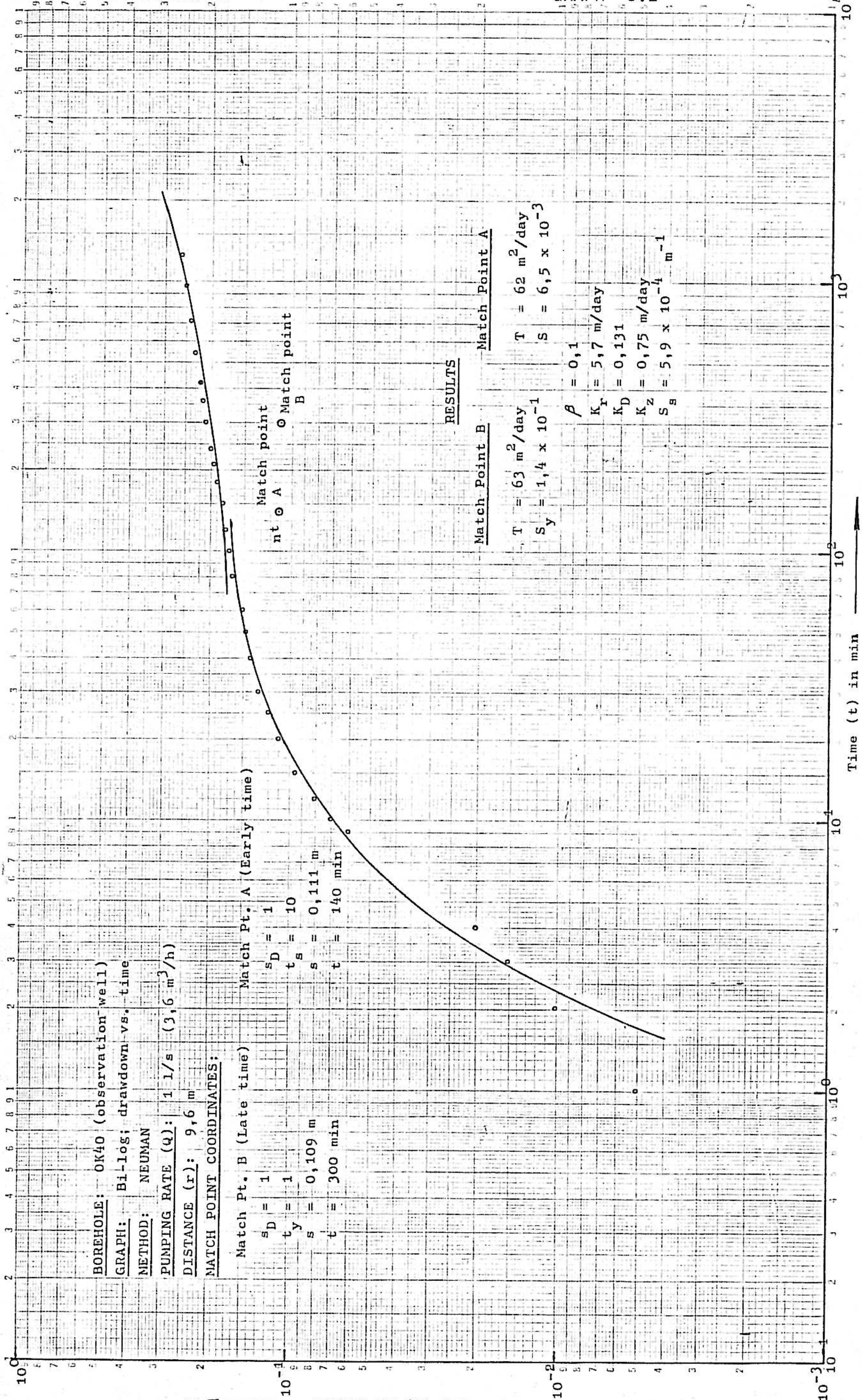
Match Point Z
$W(u_y, r/B) = 1$
$1/u_y = 1$
s = 0,142 m
t = 135 min

RESULTS

Match Point A
$T = 50\ m^2/day$
$S_A = 6,9 \times 10^{-3}$

Match Point Z
$T = 48\ m^2/day$
$S_y = 2,0 \times 10^{-1}$

B = 12 m
$\alpha = 1.74\ day^{-1}$
$\alpha t_{wt} = 4,1$
$t_{wt} = 2,36\ day$



BOREHOLE: OK40 (observation well)

GRAPH: Bi-log; drawdown vs. time

METHOD: NEUMAN

PUMPING RATE (Q): 1 l/s (3,6 m^3/h)

DISTANCE (r): 9,6 m

MATCH POINT COORDINATES:

Match Pt. B (Late time)

s_D = 1
t_y = 1
s = 0,109 m
t = 300 min

Match Pt. A (Early time)

s_D = 1
t_s = 10
s = 0,111 m
t = 140 min

Match point A

Match point B

RESULTS

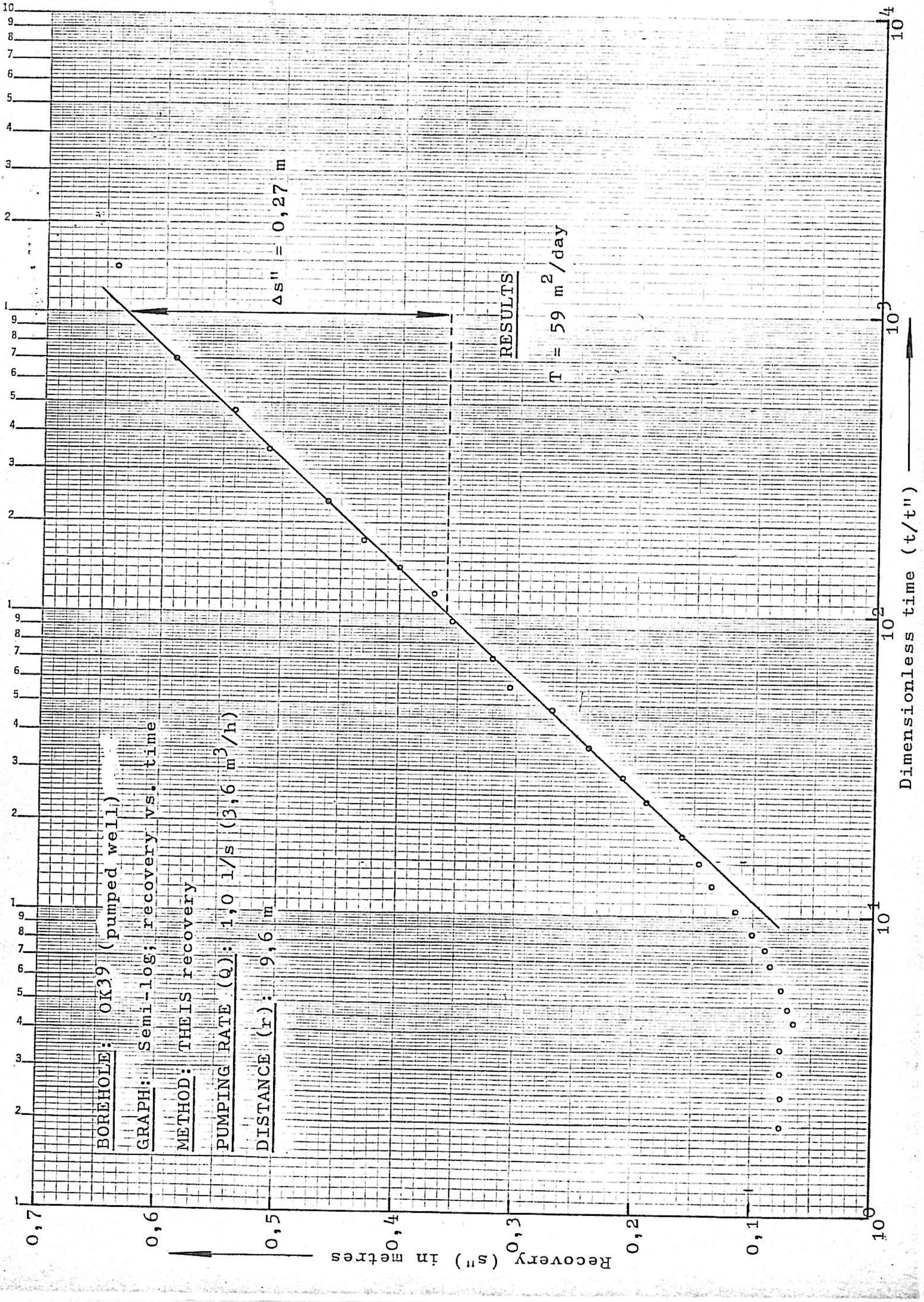
Match Point B

T = 63 m^2/day
S_y = 1,4 x 10^{-1}

Match Point A

T = 62 m^2/day
S = 6,5 x 10^{-3}

β = 0,1
K_r = 5,7 m/day
K_D = 0,131
K_z = 0,75 m/day
S_s = 5,9 x 10^{-4} m^{-1}


BOREHOLE: OK39 (pumped well)
GRAPH: Semi-log; recovery vs. time
METHOD: THEIS recovery
PUMPING RATE (Q): 1,0 l/s (3,6 m^3/h)
DISTANCE (r): 9,6 m
RESULTS
Δs" = 0,27 m
T = 59 m^2/day
Recovery (s") in metres
0,7
0,6
0,5
0,4
0,3
0,2
0,1
0
Dimensionless time (t/t")
10
10^2
10^3
10^4

ANNEX IV : Chemical Analyses

Sample Bh. No	pH	Cond mS/m	TDS mg/l	HCO$_3$		Cl		SO$_4$		Ca		Mg		Na + K	
				mg/l	meq/l	mg/l	meq/l	mg/l	meq/l	mg/l	meq/l	mg/l	meq/l	mg/l	meq/l
WB 2	7,4	72,0	479,90	194,45	3,19	72,83	2,05	58,73	1,22	49,30	2,46	30,16	2,48	59,51	2,50
WB 5	7,4	68,7	520,01	322,38	5,29	35,77	1,01	8,51	0,18	59,22	2,95	34,36	2,83	45,19	1,85
WB 20	6,4	21,8	144,55	61,37	1,01	23,20	0,65	11,49	0,24	7,54	0,38	7,99	0,66	22,49	0,97
WB 28	7,6	59,8	481,57	309,15	5,07	21,48	0,61	10,09	0,21	26,29	1,31	20,79	1,71	86,57	3,72
KG 10	7,2	34,1	278,23	166,60	2,73	4,56	0,13	9,80	0,20	17,99	0,90	11,43	0,94	39,35	1,71
KG 16	7,8	92,7	678,36	376,36	7,17	94,13	2,66	9,85	0,21	66,07	3,30	41,47	3,41	79,91	3,42
HA 3	7,4	99,2	648,15	262,29	4,30	143,63	4,05	38,05	0,79	45,63	2,28	73,61	6,05	48,75	2,06
HA 21	7,8	149,6	938,99	317,08	5,20	291,34	8,22	42,53	0,89	49,50	2,47	119,93	9,86	77,17	3,27
HA 22	7,8	99,4	668,02	309,15	5,07	126,16	3,56	24,05	0,50	47,56	2,37	43,46	3,57	97,14	4,19
HA 23	7,1	49,4	350,43	161,53	2,65	44,09	1,24	31,75	0,66	27,78	1,39	28,37	2,33	30,54	1,31
HT 4	7,6	70,1	505,71	249,46	4,09	57,12	1,61	45,18	0,94	31,53	1,57	61,48	5,06	21,78	0.92
HT 11	7,9	133,1	1119,88	824,89	13,53	37,82	1,07	17,37	0,36	4,89	0,24	175,22	14,41	16,00	0,68
HT 12	7,6	11,2	817,25	464,09	7,61	67,62	2,16	5,82	1,08	49,50	2,47	109,86	9,04	28,76	1,23
HT 14	7,8	156,8	1004,86	264,86	4,34	342,68	9,67	32,42	0,67	134,02	6,69	49,66	4,08	143,62	6,17
HT 21	7,2	84,0	3624,41	335,71	5,51	59,29	1,67	13,62	0,28	83,17	4,15	36,92	3,04	47,39	1,72
HT 39	7,4	36,1	476,27	257,15	4,22	48,67	1,37	13,53	0,28	57,07	2,85	32,61	1,94	48,44	1,95
HT 40	7,7	73,3	532,75	259,72	4,26	62,76	1,77	26,13	0,54	70,78	3,53	27,93	2,30	45,20	1,84
HT 51	6,7	40,6	253,26	95,92	1,57	42,10	1,19	39,31	0,82	18,35	0,92	16,93	1,39	37,60	1,60
HT 52	7,0	85,6	551,46	164,06	2,69	72,04	2,03	144,68	3,01	65,48	3,27	41,63	3,42	56,80	2,40
HT 55	7,5	73,3	504,12	212,05	3,48	68,55	1,93	63,69	1,32	52,79	2,63	30,91	2,54	58,56	2,50
HT 63	7,3	61,6	439,56	209,55	3,44	64,43	1,82	31,43	0,65	52,01	2,59	26,88	2,21	38,93	1,63
HT 123	7,5	85,8	555,67	241,88	3,97	132,03	3,72	4,39	0,09	78,84	3,93	32,11	2,64	51,23	2,14
HT 133	7,1	86,9	683,71	418,12	6,86	61,33	1,73	2,62	0,05	60,98	3,04	40,71	3,35	79,40	3,36
EK 4	7,6	174,0	1494,14	931,26	15,28	139,05	3,92	16,12	0,34	93,79	4,68	98,54	8,10	192,62	8,16
EK 20	7,5	78,2	562,11	240,68	3,95	74,39	2,10	83,12	1,73	53,54	2,67	32,18	2,65	64,83	2,80
GK 5	7,8	108,4	682,02	244,35	4,01	114,51	3,23	62,26	1,30	98,44	4,91	55,02	4,53	41,81	1,76
GK 9	7,7	145,5	952,79	354,55	5,82	225,22	6,35	57,51	1,20	126,84	6,33	79,22	6,52	57,60	2,44
GK 13	7,6	188,9	1129,60	177,78	4,56	416, 4	11,74	41,03	0,85	174,14	8,69	82,16	6,76	87,01	3,53
GK 19	7,8	128,6	916,16	387,38	6,35	188,98	5,33	30,42	0,63	119,77	5,98	52,80	4,34	88,51	3,71
GK 26	7,9	194,3	1276,05	455,35	7,47	315,23	8,89	60,76	1,27	132,73	6,62	90,43	7,44	157,57	6,77
GK 40	7,7	109,9	746,40	319,72	5,24	204,39	2,94	71,98	1,50	90,63	4,52	77,43	6,37	27,04	1,16
GK 48	7,8	115,1	825,47	400,16	,56	99,47	2,81	76,76	1,60	82,18	4,10	53,59	4,41	98,09	4,24

ANNEX IV contd.

Sample Bh. No	pH	Cond mS/m	TDS mg/l	HCO_3		Cl		SO_4		Ca		Mg		Na + K	
				mg/l	meq/l	mg/l	meq/l	mg/l	meq/l	mg/l	meq/l	mg/l	meq/l	mg/l	meq/l
MD 17	7,9	147,0	1079,42	381,83	6,26	157,10	4,43	197,50	4,11	98,29	4,90	49,74	4,09	171,89	7,45
MD 20	7,9	132,5	1020,42	476,44	7,82	153,29	4,32	78,94	1,64	100,83	5,03	52,50	4,32	119,30	5,17
MD 23	8,0	127,4	890,67	379,04	6,22	179,74	5,07	40,48	0,84	84,13	4,20	24,15	1,99	169,30	7,33
MD 27	7,8	80,0	573,45	256,57	4,21	76,22	2,15	68,20	1,42	65,91	3,29	43,11	2,81	62,12	2,64
MD 39	7,9	79,6	567,05	248,59	4,08	78,21	2,21	67,86	1,41	59,63	2,98	37,75	3,11	62,68	2,68
MD 50	7,8	108,0	782,33	322,32	5,29	106,62	3,01	95,56	1,99	90,59	4,52	64,40	5,30	58,43	2,52
AK 19	7,8	138,5	887,05	326,10	5,35	210,63	5,94	19,11	0,40	132,21	6,60	51,22	4,21	83,05	3,40
AK 23	7,7	107,4	817,17	384,38	6,3-	144,70	4,08	21,14	0,44	67,30	3,36	38,47	3,16	118,35	4,93
KD 2	7,9	108,0	799,13	377,44	6,19	79,80	2,25	84,03	1,75	83,19	4,15	75,97	6,25	57,06	2,45
KD 3	7,7	72,0	495,42	201,69	3,31	66,37	1,87	73,73	1,54	53,60	2,67	29,45	2,42	57,53	2,44
KD 4	7,8	76,0	550,25	241,84	3,97	64,02	1,81	56,87	1,18	66,84	3,33	35,02	2,88	51,84	2,22
KD 9	7,9	108,0	792,45	378,71	6,21	86,19	2,43	63,63	1,32	82,34	4,11	54,71	4,50	89,39	3,86
KD 16	7,7	108,0	843,41	419,01	6,87	46,90	1,32	81,10	1,69	59,75	2,98	39,75	3,27	133,27	5,77
KD 23	7,9	332,8	2119,81	594,33	9,75	736,31	20,77	58,02	1,21	228,20	11,39	147,22	12,11	295,32	12,66
KD 24	8,0	157,0	1092,02	477,57	7,83	160,92	4,54	59,90	1,25	115,93	5,78	87,55	7,20	120,27	5,19
KD 26	7,9	143,0	977,07	334,23	5,48	159,96	4,51	125,63	2,62	87,04	4,34	60,79	5,00	150,04	6,32
KD 27	7,9	282,9	1718,07	412,55	6,77	655,13	18,48	73,49	1,53	162,79	8,12	160,06	13,17	220,59	9,49
KD 30	7,9	320,0	2197,49	684,38	11,23	639,75	18,05	142,58	2,97	134,18	6,69	109,17	8,98	439,00	19,04
G 32648	7,9	100,8	775,01	389,35	6,39	72,67	2,05	67,63	1,41	74,64	3,72	53,52	4,40	83,71	3,61
G 32652	8,1	300,8	2155,76	780,89	12,81	564,56	15,93	142,02	2,96	43,04	2,15	84,02	6,91	526,44	22,83
RF 13	2,7	185,4	1190,24	524,30	8,60	113,64	3,20	47,46	0,99	30,49	1,52	36,15	2,97	376,12	16,36
RF 22	7,9	285,2	1940,56	656,79	10,77	554,56	15,36	127,10	2,65	74,46	3,72	126,98	10,45	373,42	16,21
RF 31	7,8	236,7	1353,05	286,43	4,69	560,67	15,81	37,04	0,77	205,49	10,25	63,90	5,25	168,92	7,26
RF 40	7,7	152,9	1008,41	333,82	5,48	216,02	6,09	69,94	1,46	79,54	3,97	22,73	1,87	221,85	9,58
RF 44	7,4	219,8	1242,49	219,04	3,59	590,20	16,64	11,84	0,25	90,59	4,52	52,17	4,29	265,10	11,48
RF 46	7,6	93,0	631,93	293,40	4,81	81,36	2,29	52,29	1,09	70,00	3,49	46,85	3,85	61,03	2,63
RF 72	7,9	214,0	1521,81	632,19	10,37	365,53	10,31	46,02	0,96	39,95	1,99	43,13	3,55	372,58	16,19
RF 76	8,1	338,9	2367,49	881,97	14,47	554,98	15,65	153,00	3,19	75,09	3,75	108,80	8,95	535,04	23,24
RF 79	7,8	118,0	911,81	480,29	7,88	110,28	3,11	19,98	0,42	70,59	3,52	24,73	2,03	174,92	7,59
RF 80	7,8	277,7	2038,33	988,30	16,21	350,83	9,89	43,34	0,90	1,85	0,09	10,49	0,86	592,07	25,63
DF 8	7,7	140,3	913,30	375,40	6,16	181,63	5,12	48,90	1,02	98,43	4,91	60,10	4,94	112,80	4,87

ANNEX IV contd.

Sample Bh. No	pH	Cond mS/m	TDS mg/l	HCO$_3$		Cl		SO$_4$		Ca		Mg		Ma + K	
				Mg/l	meq/l	mg/l	meq/l	mg/l	meq/l	mg/l	meq/l	mg/l	meq/l	mg/l	meq/l
G 32654	6,9	66,5	396,47	131,43	2,16	88,22	2,49	59,52	1,24	54,98	2,74	31,57	2,60	26,16	1,03
G 32655	7,9	107,9	767,46	359,09	5,89	101,39	2,86	62,99	1,31	85,73	4,28	58,68	4,83	68,52	2,93
HB 1	7,6	127,5	832,17	29,40	4,76	124,17	3,50	100,06	2,08	150,28	7,50	28,55	2,35	82,28	3,44
HB 4	7,2	53,2	396,27	196,65	3,23	47,59	1,34	11,30	0,24	27,52	1,37	6,90	0,57	81,64	3,52
KL 6	7,7	94,0	735,97	485,38	7,96	29,34	0,83	10,33	0,22	162,10	8,09	23,87	1,96	10,47	0,42
KL 23	7,4	115,2	788,73	385,38	6,32	149,58	4,22	18,74	0,39	138,73	6,92	56,02	4,61	22,62	0,91
KL 25	7,5	94,8	687,08	320,52	5,26	97,81	2,76	50,24	1,05	108,51	5,41	25,68	2,11	65,05	2,81
KL 26	7,9	78,1	637,58	438,97	7,20	10,29	0,29	8,96	0,19	138,78	6,93	19,51	1,60	8,30	0,34
KK 1	7,5	170,3	1074,53	367,67	6,03	293,02	8,27	75,25	1,57	116,47	5,81	122,90	10,11	63,28	2,68
NT 8	7,8	94,3	695,03	328,70	5,39	78,07	2,20	55,86	1,16	119,02	5,94	31,72	2,61	55,23	2,35
NT 9	7,8	126,7	1011,16	554,22	9,09	96,10	2,71	44,46	0,93	110,09	5,49	59,16	4,87	92,63	3,98
NT 10	7,9	122,7	819,02	419,26	6,88	99,23	2,82	93,46	1,95	69,88	3,49	31,42	2,58	170,46	7,35
ND 1	7,6	307,8	1888,24	355,84	5,84	666,14	18,79	205,35	4,28	325,02	16,22	142,73	11,74	134,39	5,69
ND 2	7,3	126,7	836,30	336,85	5,53	150,04	4,23	66,59	1,39	126,07	6,29	55,23	4,54	64,10	2,71
ND 4	7,7	117,0	842,49	366,85	6,02	109,66	3,09	97,95	2,04	82,23	4,10	54,92	4,52	99,74	4,29
G 32657	7,8	125,8	872,89	394,17	6,47	137,30	3,87	69,63	1,45	95,56	4,77	79,42	6,53	60,49	2,58
KB 1	7,7	184,5	1122,58	396,33	6,50	352,30	9,94	38,83	0,81	88,79	4,43	96,73	7,96	123,24	5,28
KB 2	8,0	202,3	1365,58	582,17	9,55	202,67	5,72	141,63	2,95	60,81	3,03	116,04	9,55	194,92	8,37
KB 9	7,8	297,1	1774,99	366,74	6,02	536,49	15,13	261,97	5,45	230,82	11,52	175,38	14,43	153,88	6,52
KB 10	7,9	146,2	948,14	535,92	8,79	141,34	3,99	26,74	0,56	99,11	4,95	124,70	10,26	16,86	0,70
KB 12	7,5	222,2	1332,30	354,01	5,81	405,60	11,44	125,55	2,61	147,09	7,34	128,27	10,55	124,04	5,33
KB 14	7,8	161,5	1298,91	809,93	13,29	141,74	4,00	5,05	0,11	88,42	4,41	128,98	10,61	105,87	4,51
NG 1	7,9	181,6	1225,06	456,95	7,50	304,18	8,58	77,35	1,61	133,48	6,66	97,38	8,01	118,34	5,02
NG 4	7,7	190,4	1245,26	348,40	5,72	292,59	8,25	199,40	4,15	114,55	5,72	115,82	9,53	132,77	5,67
NG 8	7,8	153,5	1080,13	451,22	7,40	210,15	5,93	72,77	1,52	94,01	4,69	73,21	6,02	147,51	6,30
NG 13	7,8	130,8	895,34	431,68	7,08	116,10	2,25	60,79	1,27	79;59	3,97	91,59	7,53	73,34	3,10
NG 17	7,8	131,9	934,18	528,47	8,67	116,27	3,28	26,44	0,55	86,39	4,31	104,26	8,58	36,46	1,54

ANNEX IV. contd.

RIVER WATER ANALYSES

Location	pH	Cond mS/m	TDS mg/l	HCO_3		Cl		SO_4		Ca		Mg		Na + K	
				mg/l	meq/l	mg/l	meq/l	mg/l	meq/l	mg/l	meq/l	mg/l	meq/l	mg/l	meq/l
Nooitgedacht drift	7,3	71,4	482,55	191,78	3,15	64,44	1,82	72,93	1,52	43,57	2,17	26,97	2,22	74,88	3,09
Buffelskraal drift	7,1	70,6	472,04	182,06	2,99	72,06	2,03	68,61	1,43	43,89	2,19	28,24	2,32	68,39	2,86
Olifantskop	7,4	79,4	571,00	245,86	4,03	73,70	2,08	86,48	1,80	49,12	2,45	31,85	2,62	75,26	3,13
Kromdraai	7,4	58,0	548,37	206,62	3,39	78,21	2,21	92,41	1,92	54,50	2,72	3,60	2,52	77,66	3,23
Grootkuil drift	7,4	77,9	547,77	228,17	3,74	72,67	2,05	87,79	1,83	46,32	2,31	29,23	2,40	76,34	3,16