Technical Report Gh 3655

THE CAPE FLATS GROUNDWATER DEVELOPMENT PILOT ABSTRACTION SCHEME

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by

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ABSTRACT

The Cape Flats Groundwater Development Pilot Abstraction Scheme was established in Mitchells Plain in the period 1983-85 by the Department of Water Affairs in co-operation with the Municipality of Cape Town. The objectives of the Scheme were to test the aquifer under concentrated stress conditions in an urban environment in respect of yield and aquifer response and to monitor the quality of the water and the effect of water extraction on the environment.

A mean annual yield of 4130 Ml was produced from ten production boreholes in the period May 1985 to April 1988 under suboptimal operating conditions but favourable recharge conditions. A rather limited regional watertable decline was generated. Seawater intrusion and ground subsidence did not occur. The groundwater produced in bulk supply is potable (median TDS= 640 mg/l). Polluted water was induced from the nearby Sewage Works maturation ponds. A yield of 6000 Ml per year can be achieved under optimal operating efficiency and under above-average recharge conditions. The exploitation limit under more stringent hydrogeological conditions and the effect of urban development on the water balance could not be determined numerically because of the failure to construct a valid and reliable groundwater flow model for the test area.

The availability of a wider and denser network of data points and more reliable and site specific hydraulic parameters is a minimum requirement for developing a numerical aquifer flow model with management capabilities. The Scheme contributed little to better define the exploitation potential of the Cape Flats aquifer, but confirmed that recharge of the primary aquifers in the SW-Cape varies between 15% and

35% of the annual precipitation. Hydrogeologically there is scope for extending the pilot wellfield in a north-westerly direction to an output of 10000 Ml/year.

The Scheme has demonstrated that limited facilities can produce considerable volumes of groundwater from a primary aquifer and that groundwater development and exploitation is not a straightforward enterprise in an urban setting. Most of the Scheme's findings are neither unique nor original. The final judgement is that too much time and money was spent to buy a bit more certainty.

SAMEVATTING

Die Kaapse Vlakte Loodspompskema is deur die Departement van Waterwese in samewerking met die Munisipaliteit van Kaapstad tussen 1983 en 1985 in Mitchells Plain tot stand gebring. Die oogmerke van die Skema was om vas te stel hoe die waterdraer in 'n stadsgebied met betrekking tot lewering en watertafelgedrag sou reageer onder gekonsentreerde onttrekkingsdruk, en om in die proses die watergehalte en die invloed van onttrekking op grondstabiliteit te moniteer.

'n Gemiddelde jaarlikse lewering van 4130 Ml is in die periode Mei 1985 tot April 1988 uit tien produksieboorgate onder suboptimale bedryfstoestande verkry. Die beperkte regionale watertafelaftrekking wat bewerkstellig is, kan gedeeltelik aan gunstige aanvullingstoestande toegeskryf word. Nóg seewaterindringing nóg grondversakking het voorgekom. In gehomogeniseerde vorm voldoen die grondwater aan die vereistes vir drinkwatergebruik. Besoedelde water lek uit die belugtingsdamme van die Mitchells Plain Suiweringswerke en vorm 'n bedreiging vir die grondwater bron. Die boorgatveld kan onder meer doeltreffende bedryfsomstandighede en onder bogemiddelde aanvullingstoestande sowat 6000 Ml per jaar lewer. Die ontginningslimiet onder moeiliker hidrogeologiese omstandighede en die invloed van stedelike ontwikkeling op die waterbalanskomponente kon nie numeries bepaal word , omdat pogings om 'n geldige en betroubare grondwatervloeimodel op te stel, nie suksesvol was nie.
Baie meer waarnemingspunte en meer betroubare en toepaslike hidrouliese parameters is die minimumvereistes vir die daarstelling van 'n wiskundige vloeimodel wat vir bronbestuur aangewend kan word.
Die ontginningspotensiaal van die waterdraer kon nie nader bepaal word aan die hand van inligting verkry uit die Skema nie. Bevestiging is nogtans verkry dat die natuurlike aanvulling van die primêre waterdraers in die Suidwes-Kaap tussen 15% en 35% van die totale jaarlikse neerslag beloop.

Vanuit ´n hidrogeologiese oogpunt lyk uitbreiding van die produksieveld in noordwestelike rigting heeltemaal moontlik. Minstens 10000 Ml per jaar behoort ontgin te kan word in ´n gebied rondom die Suiweringswerke.

Hoewel sekere insiggewende inligting deur die Skema verkry is, is die mees kwellende vrae soos waar en hoeveel grondwater globaal uit die waterdraer ontgin kan word, nog nie opgelos nie. Indien grootskaalse onttrekking in die Kaapse Vlakte nie stapsgewys aangepak word, sal die antwoorde ook nooit verkry word nie.

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1 INTRODUCTION

1.1 BACKGROUND

The Cape Flats aquifer was explored and studied from several angles by a number of research organizations between 1966 and 1980. Most work was sponsored by the Water Research Commission and the Department of Water Affairs and was guided by a Working Group composed of members of the above-mentioned organizations, the Municipality of Cape Town and the Cape Provincial Administration.

At its last meeting on 18 November 1980, the Working Group expressed the opinion that knowledge and understanding of the aquifer was sufficient to take on the actual development of a water supply from the aquifer. The pilot abstraction scheme proposed by Gerber (1980) consisting of 27 production boreholes yielding 10000 Ml per annum between Weltevreden Road, Mitchells Plain and the Kuils River marshes was recommended for implementation (Figure 1). It appointed a Sub-committee to propose a concrete development programme.

Convening on 18 March 1981, the Sub-committee concluded that the Gerber scheme was impracticable. The City Engineer´s Department adviced that the Cape Town City Council would not be willing to fund neither partially nor wholly, a supply scheme based on a resource which, in its opinion, was not only unproven but would in any event add very little to Cape Town´s total water supply resources. Faced by this standpoint of the major stakeholder, the Sub-committee could but adopt a minimum solution: to scale down the Gerber wellfield and to locate it in a section of the aquifer that would require a minimum of outlay expenditure, but at the same give some scientific indications as to the potential of the aquifer, or so it was hoped, and the behaviour of the aquifer under concentrated stress conditions. Since no party was willing to accept the financial implications of feeding the groundwater production into the water supply network, it was decided to pump to waste.

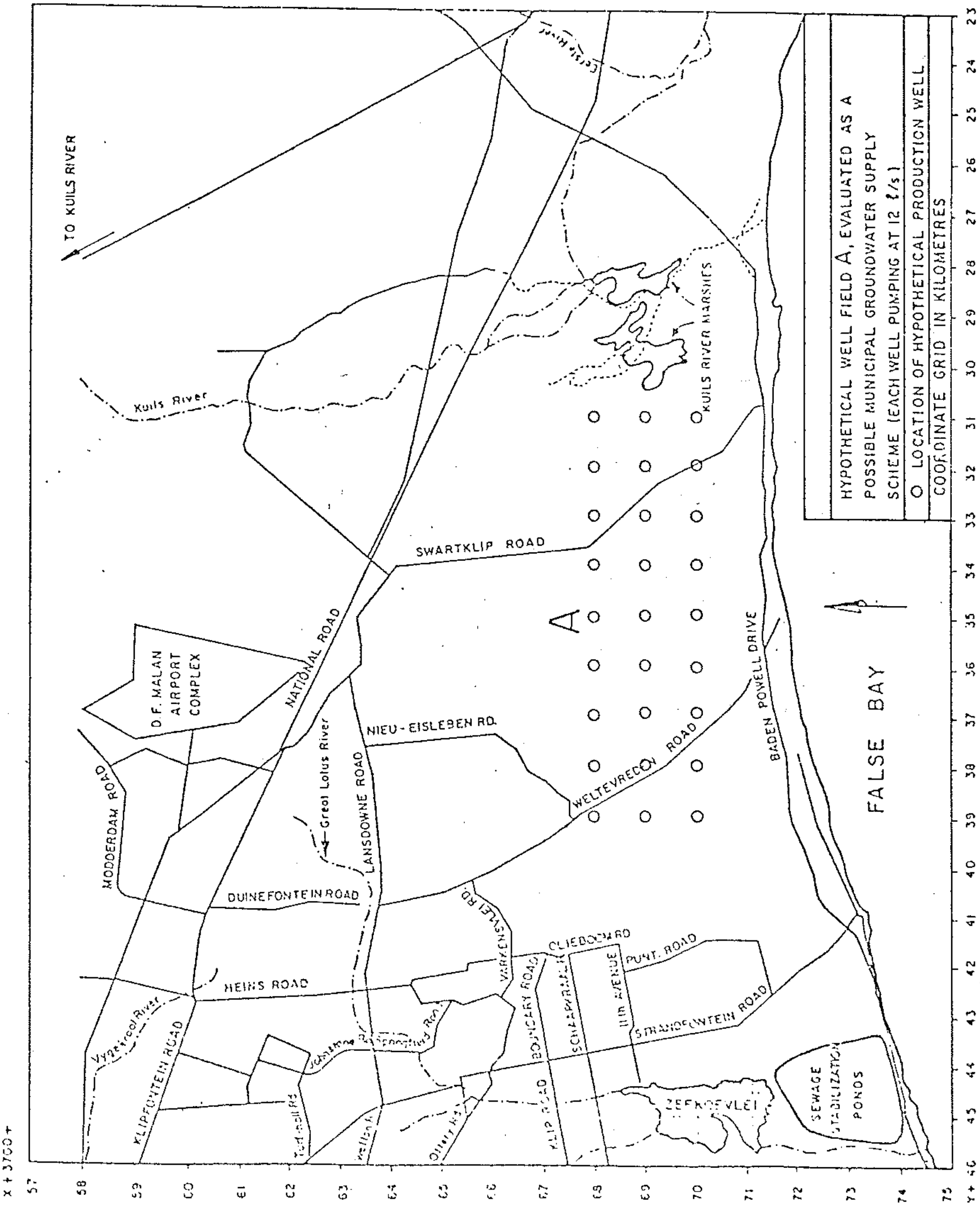

Figure 1: Hypothetical well field A, evaluated as a possible municipal groundwater supply scheme (*after*: Gerber, 1980)

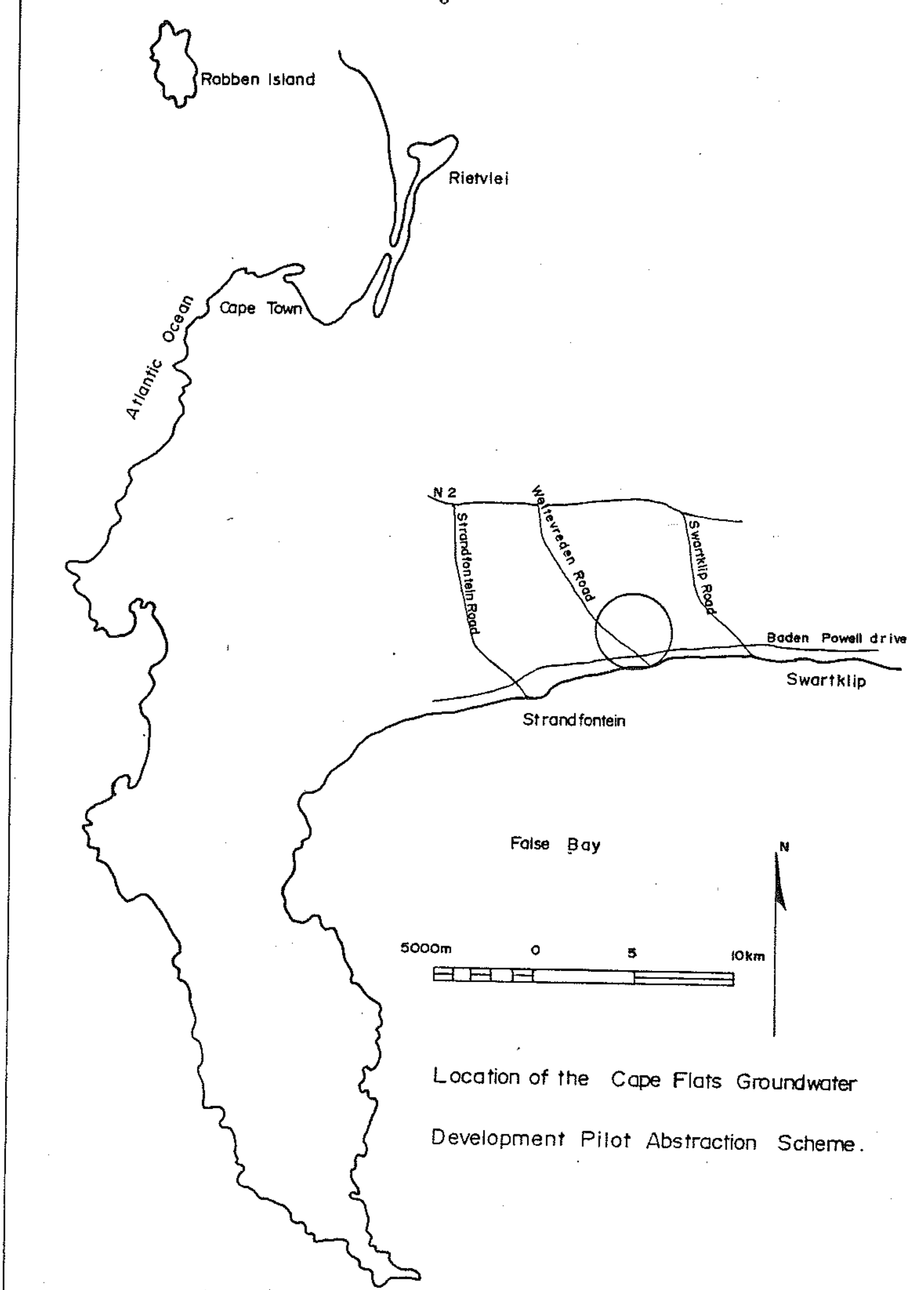

Figure 2: Location of the Cape Flats Groundwater Development Pilot

The section of the aquifer chosen for the pilot abstraction scheme is centered on Weltevreden Road, Mitchells Plain and situated north-east of the Mitchells Plain Sewage Treatment Works (The Sewage Works)(Figure 2). It coincides with the zone of high aquifer transmissivity identified by Gerber (1980) (Figure 3). Although the choice had the drawback of largely preselecting production borehole sites and necessitating special construction and security measures, the saving in cost to be had from the proximity of existing power and stormwater networks, was rather overwhelming. In addition there were a number of scientifically-inspired advantages:

(1) proximity to the coast to study possible seawater intrusion;
(2) proximity to the Philippi agricultural area to the north-west to study possible interference between the two abstraction zones;
(3) the aquifer would be tested under the "unnatural urban conditions" of reduced infiltration and evapotranspiration; and
(4) the possible contamination of the aquifer from man-made sources, in casu the Sewage Works, could be studied.

1.2 OBJECTIVES AND RESPONSIBILITIES

The primary objectives of the pilot scheme known as the Cape Flats Groundwater Development Pilot Abstraction Scheme were spelled out in the Memorandum of Agreement between the Department and the Municipality of Cape Town:

(1) to test the model simulation of the borehole field in respect of yield and aquifer response;

(2) to monitor the quality of the water; and

(3) to monitor the effect of the water extraction on the environment.

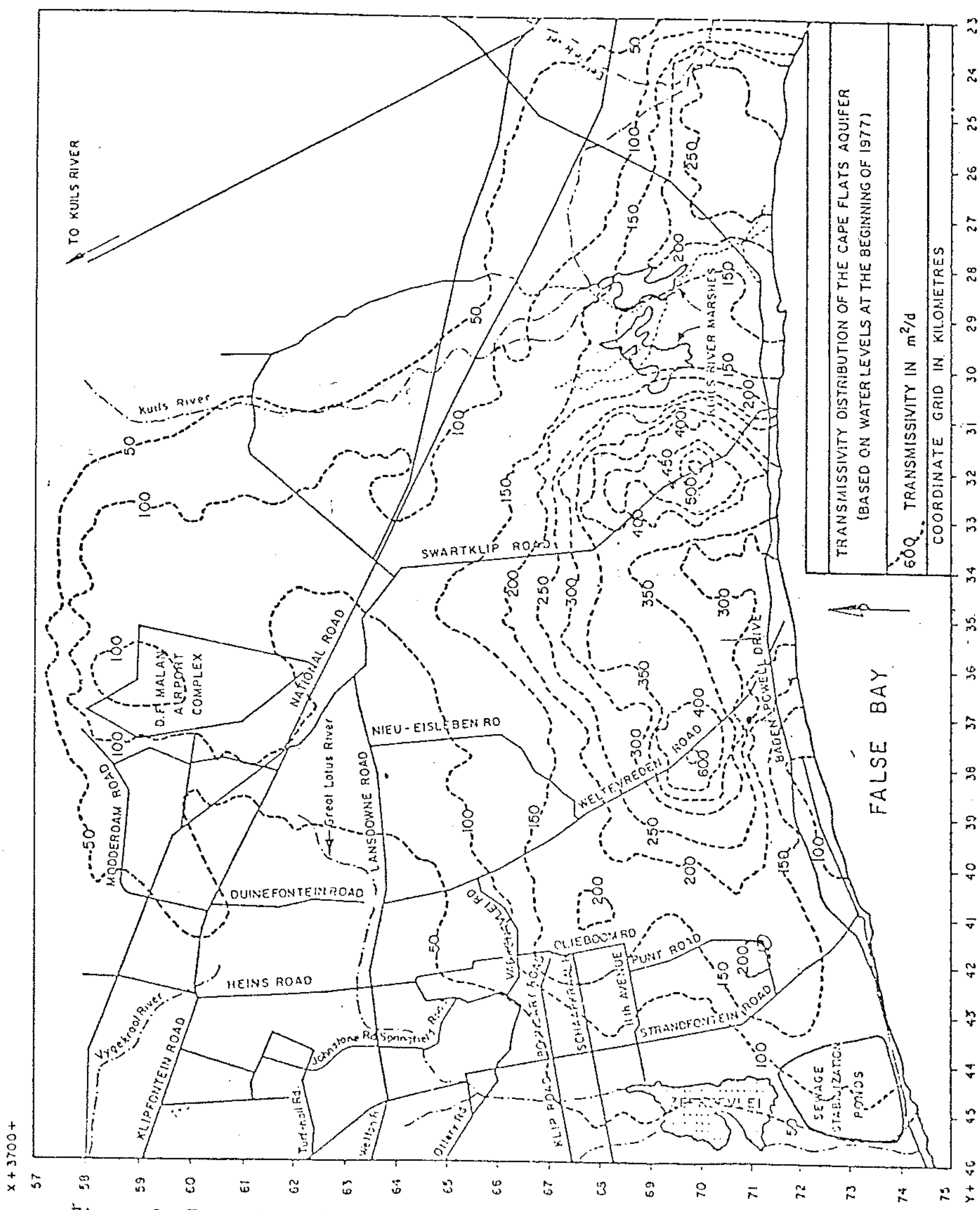

Figure 3: Transmissivity distribution of the Cape Flats aquifer
(after: Gerber, 1980)

The model simulation referred to is the Gerber finite difference model of the aquifer (Gerber, 1980). It must be mentioned that at the inception of the Mitchells Plain scheme, the Directorate Geohydrology undertook to run the Gerber model using the scheme's proposed design criteria prior to the development of the wellfield. The exercise apparently never materialised for reasons unknown to the writer.

The third objective entailed the determination of:

(1) possible ground settlement or compaction due to dewatering of geological formation, and
(2) possible lowering of the groundwater table and reduction of borehole yields in the Philippi farming area upgradient and to the north-west of the Scheme site.

The Memorandum of Agreement indemnified the Municipality against claims for damages arising from environmental issues.

The Department provided funds and assumed overall responsibility for the development and installation costs of the Scheme and for the analysis and processing of all records of the test run.
The installation (preparation of tender documents, installation of pumps, ancillary works and equipment, electricity and other connections, etc.) as well as the operation and maintenance of the Scheme was carried out by the Municipality. The Municipality financed the running of the Scheme, the collection of waterlevel data and water samples at the production boreholes and the analysis of pumped water for certain chemical compounds.

The Agreement took effect on the 29th of December 1983 and expired on the 30th of April 1988 after an extension of 28 months beyond the original dates was agreed upon by both parties.

1.3 HISTORY OF EVENTS

The major milestones and events in the history of the Cape Flats Groundwater Development Pilot Abstraction Scheme are listed cronologically in table 1.
Close on nine years have lapsed since the idea of a pilot abstraction scheme was first mooted in the Working Group meeting of November 1980 and the completion of this, the final report. It seems an inordinate length of time considering that the wellfield was in operation for slightly less than three years.

Three lengthly periods of real or perceived inactivity occurred:

(1) between the inception of the scheme and the development of the wellfield;
(2) between the signing of the working agreement between the Department and the Municipality of Cape Town and the installation of the pumping and ancillary gear; and
(3) between the termination of pumping and the completion of the report.

Some delays were inevitable, others not.

Table 1: Some major milestones and events in the history of the Cape Flats Groundwater Development Pilot Abstraction Scheme

DATE	ACTION / EVENT
18/11/80	Working Group for the Cape Flats aquifer recommends the development of a water supply from the Cape Flats aquifer.
18/03/81	A Sub-committee of the Working Group discusses the recommendation and proposes a pilot scheme centred on Mitchells Plain.
19/07/82	Drilling of four geophysical calibration boreholes by the Sub-directorate Drilling Services (SD:DS) started.
02/02/83	Wellfield drilling and testing programme by Aarwater (Pty)Ltd.

Table 1: continued

	started.
06/04/83	Wellfield drilling and testing programme is completed.
05/83	Calibration borehole G32963 converted to production borehole by SD:DS.
07/83	SD:DS replaces defunct production borehole G32980 by G32990.
29/12/83	Memorandum of Agreement covering the development, installation and operation of the Scheme between the Department and the Municipality of Cape Town is signed.
07/84	Contract for the supply and installation of test pumps awarded to Andrag P. & Sons (Pty) Ltd.
01/85	Installation of submersible pumps and ancillary equipment by the contractor started.
03/85	Three observation boreholes destroyed through vandalism are re-established by SD:DS.
04/85	Design and levelling of the Ground Settlement Control Grid by the Subdirectorate Surveys.
20/05/85	First production borehole is switched on.
27/06/85	Tenth and last production borehole is switched on.
13/08/85	Resposibilities for water quality sampling, analysis and monitoring are split between HRI (DWA), DWT (CSIR) and Cape Town Municipality.
12/86	Temporary shutdown of production borehole G32963 due to screen problems.
03/02/88	Early shutdown of production borehole G32979 on account of urban development activities.
30/04/88	Pumping of the pilot scheme terminated.
06/88	Data processing and analysis by Directorate Geohydrology.
05/89	Report by the HRI on the groundwater quality aspects of the pilot run is completed.
09/89	Compilation of the final report by the Directorate Geohydrology is completed.

2 WELLFIELD DEVELOPMENT PROGRAMME

2.1 LOCATION AND LAYOUT OF THE WELLFIELD

The location of the Pilot Scheme site within the Cape Flats aquifer was predetermined by the Sub-committee's decision to opt for "a concentrated stress test of the aquifer" which would involve a minimal expenditure on wellfield infrastructure (power supply, discharge pipeline). The eastern half of the high transmissivity zone centred on Weltevreden Road in the western part of Mitchells Plain and about 2 km north of False Bay was then the only suitable site (Gerber, 1980)(Figure 3). The western half of the zone is occupied by the municipal sewage works and could not be considered. The actual positions of the production boreholes (Figure 4) within the high transmissivity zone were determined by the Municipality on grounds of availability of open space and the closeness of power supply and stormwater drains. Most boreholes were kept in "safe places" like municipal yards and nature reserves.

The positions of the observation boreholes (Figure 4) were determined by:

(1) their purpose:
- to monitor the vertical and lateral extent of watertable drawdown due to abstraction, with specific interest targeted in the direction of the Philippi agricultural zone to the north-west and the sea towards the south.
- to monitor regional water quality variations.

(2) practicalities: availability of open space in the built-up area and easy accessibility in the dune terrain.

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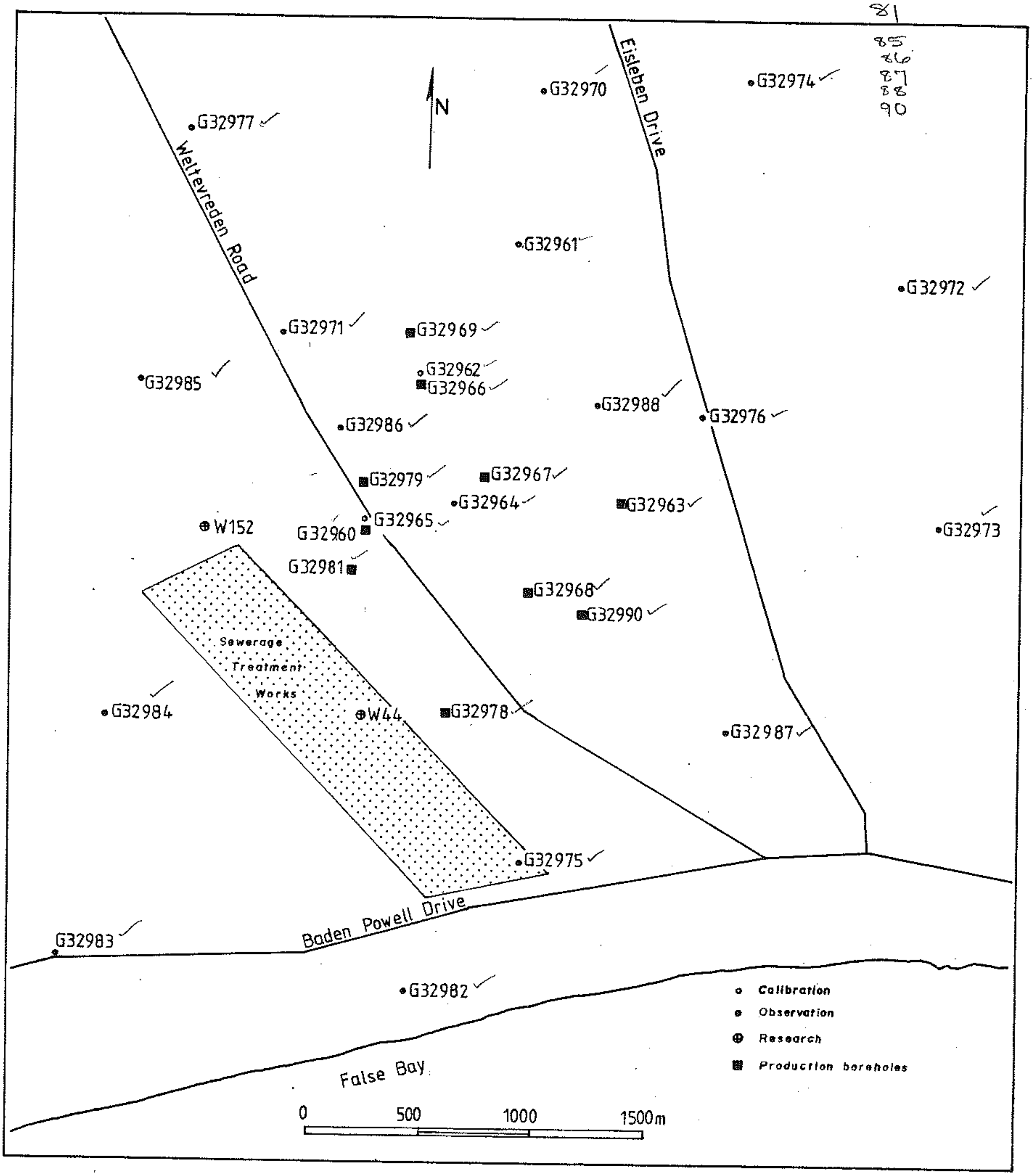


Figure 4: Location of the production and observation boreholes

2.2 DRILLING PROGRAMME

2.2.1 Percussion drilling

The Subdirectorate Drilling Services established four calibration boreholes during the second half of 1982 using two cable tool rigs. The boreholes were drilled to solid bedrock and lined with 250 mm diameter steel casing. Their positions are shown on Figure 4.

These four boreholes were drilled to facilitate the interpretation of the geophysical borehole logs run in open mud-drilled boreholes. Rotary mud drilling was used for the first time and it was considered prudent to obtain characteristic geophysical prints for the different local lithologies with the view of correct screen positioning. For this reason the first two production boreholes (G32965 and G32966) were drilled right next to calibration boreholes G32960 and G32962 respectively. The latter two boreholes did not play any further operational role.
Borehole G32961 was subsequently converted into an observation borehole and G32963 was equipped for production purposes. Equipment and other relevant borehole details are contained in tables 2 and 3.

2.2.2 Mud rotary drilling

Aarwater (Pty) Ltd was awarded the contract to establish " 5 or more high yield, large diameter boreholes and 10 or more normal diameter observation boreholes on the Cape Flats in and near Mitchells Plain ". The assignment was completed almost on schedule between the 2^{nd} of February and the 4^{th} of April 1983.
The contractor drilled and equipped eight production boreholes and sixteen observation boreholes. A rotary drilling unit with organic mud circulation was used throughout. Well development was achieved by high-velocity waterjetting, airlifting or a combination of both and lasted until the boreholes were sandfree.

	BOREHOLE NUMBER G	DRILLING DEPTH (m)	COLLAR ELEVATION (m)a.m.s.l.	CASING PVC TYPE	CASING INTERVAL from - to	SCREEN TYPE	SCREEN INTERVAL from - to	GRAVELPACK TYPE	GRAVELPACK INTERVAL from - to	CO-ORDINATES X	CO-ORDINATES Y	ESTABLISHMENT COST (R)
3418BA 1	32963	36.0	19.336	200 mmOD	0 - 9	200 mmOD perf	9 - 23			69901,90	36368,40	
					23 - 26	PVC+bidim U34						
BA20	32965	33.0	19.884	250 mmOD	0 - 20	Johnson no 30	20 - 23	7/16	17 - 26	70076,60	37458,60	12,664.51
					26 - 33	Johnson no 40	23 - 26					
BA 18	32966	28.0	24.460	250 mmOD	0 - 13,5	Johnson no 30	13,5-16,5	7/16	11 - 20	69383,90	37284,70	10,474.89
					13,5- 26,1	Johnson no 40	16,5-19,5					
3418 BA 37	32967	32.0	23.768	250 mmOD	0 - 17	Johnson no 20	17 - 26	16/30	15 - 26	69820,00	36984,80	13,190.68
					26 - 32							
BA 17	32968	35.6	21.871	250 mmOD	0 - 20	Johnson no 20	20 - 23	16/30	18 -22,5	70252,00	36760,40	13,708.72
					29 - 35,6	Johnson no 30	23 - 26	7/16	22,5- 29			
						Johnson no 40	26 - 29					
3418BA 7	32969	39.0	26.015	250 mmOD	0 - 16	Johnson no 20	16 - 19	16/30	14 - 19	69131,20	37361,40	13,833.62
					19 - 31	Johnson no 30	31 - 37	7/16	30 - 37			
BA 39	32978	41.0	18.624	250 mmOD	0 - 14,5	Johnson no 30	14,5-20,5	7/16	12 - 25	70836,60	37062,30	15,474.69
					20,5- 28	Johnson no 20	28 - 31	16/30	25 - 31			
					31 - 41							
246	32979	35.1	21.977	250 mmOD	0 - 21	Johnson no 30	21 - 24	7/16	18 - 27	69877,20	37527,80	13,217.43
					30 - 35	Johnson no 40	24 - 30	4/7	27 - 32			
3418 BA 32	32981	37.8	21.929	250 mmOD	0 - 20,5	Johnson no 30	20,5-26,5	7/16	18 -29,	70178,00	37640,10	13,002.22
				250 mmOD	29,5- 36,1	Johnson no 40	26,5-29,5					
BA 34	32990	36.0	20.605	200 mmOD	0 - 12	200 mmOD perf	12 - 30			70369,50	36538,10	
					30 - 36	PVC+bidim U34						

REMARKS! JOHNSON SCREENS: 200 mm OD PIPESIZE STAINLESS STEEL
PVC CASING: CLASS 12

TABLE 2: DRILLING, BOREHOLE AND CONSTRUCTION DETAILS: PRODUCTION BOREHOLES

	BOREHOLE NUMBER G	DRILLING DEPTH (m)	COLLAR ELEVATION (m)a.m.s.l.	CASING PVC TYPE	CASING INTERVAL from - to	SCREEN PVC TYPE	SCREEN INTERVAL from - to	GRAVELPACK TYPE	GRAVELPACK INTERVAL from - to	CO-ORDINATES X	CO-ORDINATES Y	ESTABLISH-MENT COST (R)
3418BA 2	32961	40.0	27.610	160 mmOD	0 - 12	160 mmOD perf	12 - 18			68573,20	37062,70	
				class 9	18 - 30	+bidim U34						
BA 35	32964	33.6	21.040	110 mmID	0 - 23	0,5mm Johnson	23 - 26	16/30	21 - 26	70042,20	37066,40	3,163.73
				class 9	26 - 32	100 mmID						
BA 4	32970	39.0	27.076	160 mmOD	0 - 18	160 mmOD perf	18 - 21			68096,80	36808,50	3,333.21
				class 9	21 - 27	+bidim U34						
BA 25	32971	24.0	25.649	110 mmID	0 - 14,9	0,5mm Johnson	14,9-17,9	16/30	13 -18,5	69266,60	38038,38	2,616.46
				class 9	17,9 - 24	100 mmID						
BA 9	32972	33.0	25.319	110 mmID	0 - 17,5	0,5mm Johnson	17,5-20,5	16/30	15 - 21	68874,80	35222,80	3,153.58
				class 9	20,5 - 32,7	100 mmID						
BA 76	32973	26.5	21.433	110 mmID	0 - 18	0,5mm Johnson	18 - 21	7/16	16 - 21	69929,50	34997,70	2,628.30
				class 9	21 - 26,5	100 mmID						
BA 5	32974	28.0	27.450	110 mmID	0 - 18	0,5mm Johnson	18 - 21	16/30	16 - 21	67999,30	35943,60	2,715.07
				class 9	21 - 27	100 mmID						
BA 71	32975	28.0	27.622	110 mmID	0 - 13	0,5mm Johnson	13 - 16	16/30	10 - 16	71462,69	36700,58	2,812.95
				class 9	16 - 28	100 mmID						
BA 69	32976	26.0	26.009	160 mmOD	0 - 17	160 mmOD perf	17 - 20			69510,50	36017,40	2,780.95
				class 9	20 - 26	+bidim U34						
BA 68	32977	30.0	30.700	110 mmID	0 - 12	0,5mm Johnson	12 - 15	7/16	10 - 16	68310,79	38423,68	2,818.86
				class 9	15 - 21	100 mmID						
3418BA 11	32982	24.0	5.750	110 mmID	0 - 9	0,5mm Johnson	9 - 12	7/16	7 - 14	71974,46	37245,21	2,476.62
				class 9	12 - 24	100 mmID						
3418BA 72	32983	42.0	21.923	110 mmID	0 - 30	0,5mm Johnson	30 - 33	7/16	28 - 34	71816,42	38825,52	3,611.07
				class 9	33 - 42	100 mmID						
31	32984	39.0	26.965	110 mmID	0 - 30	0,5mm Johnson	30 - 33	16/30	28 -33,5	71027,87	38523,89	3,164.64
				class 9	33 - 39	100 mmID						
14	32985	36.0	25.544	110 mmID	0 - 24	0,5mm Johnson	24 - 27	16/30	22 - 28	69452,06	38564,76	3,182.32
				class 9	27 - 36	100 mmID						
3418BA 12	32986	30.0	24.816	110 mmID	0 - 21	0,5mm Johnson	21 - 24	16/30	19 - 25	69621,77	37726,41	2,855.67
				class 9	24 - 30	100 mmID						
13	32987	39.0	29.164	160 mmOD	0 - 30	160 mmOD perf	30 - 33			70860,70	35876,60	3,430.12
				class 9	33 - 39	+bidim U34						
25	32988	30.0	23.267	110 mmID	0 - 21	0,5mm Johnson	21 - 24	16/30	19 - 25	69474,20	36490,20	2,855.67
				class 9	24 - 30	100 mmID						

TABLE 3 : DRILLING, BOREHOLE AND CONSTRUCTION DETAILS: OBSERVATION BOREHOLES

The first attempt at site G32979 was unsuccessful and resulted in the loss of well screens. The upshot of this event was that the available length of the required well screen type was insufficient to establish a tenth production borehole.
Shortly after completion of the drilling programme production borehole G32980 was found to produce unacceptable amounts of sand during testing. A replacement borehole (G32990) was subsequently established by the Subdirectorate Drilling Services. Borehole G32980 was equipped for observation purposes.
The full complement of 10 production boreholes was reached by converting calibration borehole G32963 into a production facility.

In the period between wellfield development and wellfield switch-on observation boreholes G32970, G32976 and G32987 were destroyed through vandalism and had to be replaced by the Subdirectorate Drilling Services during the first quarter of 1985.

All relevant drilling, borehole and equipment details are listed in tables 2 and 3.

2.3 TESTING PROGRAMME

2.3.1 <u>General</u>

Upon completion each production borehole was subjected to two production type tests. Step drawdown tests were performed to determine the efficiency of the boreholes and the optimal abstraction rates for the subsequent constant discharge rate tests. The aim of the latter tests was to determine the optimal long-term pumping rates and associated maximum anticipated drawdowns, parameters in turn needed to determine wellfield equipment specifications, pump settings, pump intake depths and automatic shutdown depths.
Aarwater (Pty) Ltd subcontracted Groundwater Practitioners (Pty) Ltd to carry out the tests on the eight production boreholes established by them. Borehole G32963 was tested by the Subdirectorate Drilling Services, while borehole G32990 was not tested due to lack of time.

A 100 mm monopump discharged the groundwater to a nearby stormwater culvert.

2.3.2 Step drawdown tests

Table 4 lists the yields and accumulative (1-hour) specific drawdowns for each step as well as the pump intake depths for the nine step drawdown tests. The test data were interpreted with the Bierschenk and Wilson method (Clark, 1977), but only five tests produced satisfactory straight-line fits for specific drawdown versus yield and therefore well efficiencies. The formation and well loss portions of the drawdowns that were calculated (Table 5), are of questionable value in view of the very nature of the local aquifer system which varies from semi-unconfined to semi-confined.

2.3.3 Constant discharge rate tests

The production boreholes were pumped for 24 hours on average, except G32965 which was pumped for 48 hours. The pumping periods were followed by recovery periods of the same duration. Pumpintake depths, abstraction rates and maximum drawdowns are given in table 6 below.

Although the constant discharge rate tests were not aimed at obtaining hydraulic parameters for this particular section of the Cape Flats aquifer - in which case test site monitor boreholes would have been required -, an attempt was nevertheless made to extract the maximum amount of hydrogeological information from the tests.

Table 4: Step drawdown test data I: yields and specific drawdowns

Borehole Number	Pump-intake (m) below collar		Step I	Step II	Step III	Step IV	Step V	Step VI
G32963	?	Q (Kl/d)	487.6	712.3	888.3	1045.4	1293.4	-
		Σs (m)	2.45	3.49	4.35	5.03	6.30	
G32965	18	Q (Kl/d)	483.8	704.2	893.7	1283.0	1845.5	-
		Σs (m)	3.35	4.78	6.14	8.68	12.60	
G32966	24	Q (Kl/d)	490.7	621.2	1005.6	1128.3	1367.7	-
		Σs (m)	3.55	4.61	7.34	8.31	10.60	
G32967	27	Q (Kl/d)	537.1	757.3	1010.0	1539.2	2290.4	2970.7
		Σs (m)	2.45	3.48	4.48	6.61	9.47	12.84
G32968	30	Q (Kl/d)	508.9	775.4	1111.9	1810.1	3168.2	-
		Σs (m)	1.87	2.23	3.71	6.50	11.04	
G32969	24	Q (Kl/d)	365.0	509.7	657.5	792.2	1005.6	-
		Σs (m)	4.00	5.84	7.87	10.52	14.75	
G32978	33	Q (Kl/d)	529.6	788.8	1111.9	1539.6	2270.6	3116.4
		Σs (m)	1.94	2.93	4.16	5.8	8.64	13.66
G32979	18	Q (Kl/d)	478.2	688.6	1061.8	1473.1	2185.0	-
		Σs (m)	2.02	2.90	4.54	6.31	9.55	
G32981	33	Q (Kl/d)	533.9	766.3	1057.9	1508.5	2290.4	3665.0
		Σs (m)	2.86	4.13	5.7	7.91	11.61	15.42

Q = Yield

Σs = sum of specific drawdowns for a time period of 60 minutes

Table 5: Step drawdown test data: borehole efficiencies

Borehole Number	Step	Q (Kl/d))	Σs/Q (d/m²)	B (d/m²)	BQ (m)	C (d²/m⁵)	CQ² (m)	Efficiency (%)
G32965	1	483.8	.00692		3.3		.0014	99.95
	2	704.2	.00679		4.8		.0030	99.93
	3	893.7	.00687	.00679	6.1	6.0E-9	.0048	99.90
	4	1283.0	.00680		8.7		.0098	99.88
	5	1845.5	.00680		12.5		.0200	99.83
G32966	1	490.7	.00723		3.4		.1700	99.48
	2	621.2	.00742		4.4		.2800	99.36
	3	1005.6	.00730	.00707	7.1	7.5E-7	.7600	98.94
	4	1128.3	.00736		7.9		.9500	98.81
	5	1367.7	.00775		9.6		1.4000	98.56
G32967	1	537.1	.00456		2.2		.0280	98.70
	2	757.3	.00513		3.1		.0570	98.15
	3	1010.0	.00495		4.1		.1000	97.59
	4	1539.2	.00462	.00410	6.3	1.0E-7	.2300	96.38
	5	2290.4	.00434		9.3		.5200	94.71
	6	2970.7	.00441		12.1		.8800	93.24
G32969	1	365.0	.01100		3.7		.0720	99.99
	2	509.7	.01130		5.2		.1400	99.98
	3	657.5	.01160	.01020	6.7	5.4E-6	.2300	99.98
	4	792.2	.01280		8.1		.3300	99.99
	5	1005.6	.01400		10.2		.5400	99.99
G32979	1	478.2	.00422		2.0		.0210	98.96
	2	688.6	.00422		2.8		.0450	98.42
	3	1061.8	.00428	.00420	4.4	9.5E-8	.1100	97.56
	4	1473.1	.00428		6.2		.2000	96.88
	5	2185.0	.00437		9.1		.4500	95.29

Table 6: Constant discharge rate test data

Borehole Number	Depth of pumpintake (m) below collar	Yield l/s	Yield Kl/d	RWL (m)	Maximum drawdown (m) below collar
G32963	20	13.7	1187	3.94	5.83
G32965	18	20.1	1735	4.25	12.28
G32966	24	12.9	1115	5.71	8.83
G32967	27	22.9	1980	7.28	8.78
G32968	30	32.8	2838	7.36	10.28
G32969	24	10.2	879	6.12	12.52
G32978	33	22.5	2023	5.90	7.78
G32979	18	25.8	2231	4.77	9.77
G32981	33	14.0	1187	5.29	11.88
Total		174.9	15176		

The drawdown-time (s/t) plots of all tests display rather similar characteristics: only a few minutes after the start of pumping (recovery) the waterlevel in the production boreholes reached its maximum (minimum) depth and kept fluctuating about that level for the remainder of the test duration. This phenomenon indicates that vertical leakage is an important component of flow, at least in the very early (<48 hours) stage of pumping, in this portion of the Cape Flats aquifer.

The test data were therefore interpreted with the Walton and Hantush methods for unsteady state flow in a semi-confined aquifer. The resultant transmissivity and hydraulic conductivity values are given in table 7.

The s/t-plots could also be matched with the early time portion of the Boulton standard curves, which implies semi-unconfined to unconfined aquifer conditions with delayed yield effect. The tests were simply of insufficient duration to induce and observe the end of gravitational drainage, if at all applicable.

Table 7: Hydraulic parameters derived from the constant discharge rate tests.

Borehole Number	Interpretation method	Transmissivity (m^2/day)	Aquifer Thickness (m)	Hydraulic Conductivity (m/day)
G32963	Hantush	133.8	32	4.2
G32965	Walton	116.0	28	4.1
G32966	Walton	76.5	19	4.0
G32967	Walton	106.5	21	5.1
	Hantush	127.5		6.1
G32968	Walton	117.6	27	4.3
	Hantush	174.3		6.4
G32969	Walton	27.8	19	1.4
	Hantush	21.6		1.1
G32978	Walton	203.8	32	6.3
	Hantush	134.5		4.2
G32979	Walton	84.5	32	2.6
	Hantush	115.6		3.6

The interpretation of the pumping test results was altogether difficult because of the immediate onset of leakage or delayed yield. Not enough data points were available to either select a Walton curve with great accuracy or to draw an acceptable straight line in case of the Hantush method.
With no observation boreholes in the immediate vicinity of the production boreholes no values for aquifer storativity and no leakage factors could be derived.

2.4 DISCUSSION

Although the wellfield development programme achieved the objectives in terms of the minimum required groundwater output rate (10000 Kl/day), it is argued that an even better result would have been achieved if the location of the ten production boreholes had not been left entirely to administrative preference and practical considerations, but had instead been based on the results of small diameter exploratory boreholes drilled at 15 to 20 prospective production sites in a first phase of the development programme. Such process would have yielded three major advantages:

* selection of the best production sites on geohydrological grounds and, simultaneously, a reduction of the "chance" element.

  As it happened, consistent pressure existed to equip indiscriminately every borehole drilled, irrespective of the geohydrological merits, for fear of running out of available production sites before reaching the required yield quota, and for fear of running up drilling and plant movement expenditure in the search of that elusive better site.
  In retrospect, sites G32966 and G32969 would probably not have qualified for production if the exploratory approach had been followed.

* the well screen order would have been based on site-specific requirements, instead of on an expected screen type distribution calculated from the sedimentological particulars of four calibration boreholes.
  The nett result of the unforeseen heavy requirement for Johnson no 20 screen and the loss of screens at site G32979 was that only eight Johnson-equipped boreholes could be established by the contractor, because insufficient length of the required types of screens were left.

* the exploration boreholes could subsequently have served as either long-term wellfield monitor boreholes or as observation

boreholes in conventional aquifer tests. As will be explained in chapter 5, site-specific hydraulic parameters would have been more than useful in the aquifer modelling process.

From a technical side the wellfield development operations ran smoothly and have not been surpassed in terms of speed and end product quality by any other rotary mud drilling campaign undertaken ever since in other areas of the Western Cape coastal plain. The problems experienced with the emplacement of gravelpacks and weak PVC-stainless couplings were subsequently solved to satisfaction elsewhere.
Another lesson learned from the pilot scheme experience is that adequate protection of boreholes against vandalism in an urban environment should be part of the borehole establishment process.

3 GEOHYDROLOGICAL DESCRIPTION OF THE SCHEME SECTION OF THE CAPE FLATS AQUIFER

3.1 GEOLOGY

Enclosure 1 illustrates the distribution of the different lithological units recognized in the Pilot Scheme area. The differentiation is based on a sedimentological study of both undisturbed and disturbed (rotary mud) samples. Sedimentological features such as grain size, mud, silt and lime content, roundness of sand grains, sorting and the presence of shell fragments, organic matter and calcrete nodules were considered to obtain detailed geological logs of each borehole. Geophysical logs were used to adjust the depth of the different lithological units for drilling lag at each site and to help correlate the units laterally.

Although a lithostratigraphic classification of the Cenozoic lithologies encountered was not entirely successful due to the mixed nature of the samples, most lithostratigraphic units proposed by Rogers (1982) for the Cape Flats were recognized: (from top to bottom, young to old)

BREDASDORP FORMATION	
Witzand Member	shelly, calcareous sand
Langebaan Limestone Member	calcrete and very calcareous sand
Springfontyn Member	clean quartzose sand
VARSWATER FORMATION	
Calcareous Sand Member(CSM)	shelly, calcareous sand
Shelly Gravel Member(SGM)	shelly gravel and sand
ELANDSFONTYN FORMATION	clayey,silty, angular sand & gravel

The Cenozoic sequence is underlain by Malmesbury metasediments in the Mitchells Plain area as evidenced by earlier exploratory drilling (Gerber, 1976) and greyish-white weathering clay in a number of Scheme boreholes. Most boreholes penetrated onto bedrock, drilling generally being halted as soon as penetration speed fell off drastically and grey clay inclusions appeared in the samples. The bedrock elevation map (Figure 5) is therefore considered reliable.

The distribution of the Cenozoic sediments is shown in Figure 6.

3.2 PROPERTIES AND DISTRIBUTION OF THE CENOZOIC LITHOSTRATIGRAPHIC UNITS

3.2.1 Bredasdorp Formation

3.2.1.1 Witzand Member

This unit which consists of very fine to very coarse calcareous sands, is easily recognized by the presence of abundant small shells and shell fragments. Witzand sands are absent

(1) in the centre of the wellfield area (G32969,G32986,G32968), except as a small strip of dunes stretching from just west of G32969 to just west of G32968
(2) in the north-eastern corner of the Pilot Scheme area (G32974), and
(3) towards the north-west (G32977).

3.2.1.2 Langebaan Limestone Member

Locally also called the Wolfgat Member, it consists of calcrete and very fine to fine calcareous sand. Its occurrence is restricted to boreholes G32970 (10m), G32972 (2m) and G32974 (15 m).

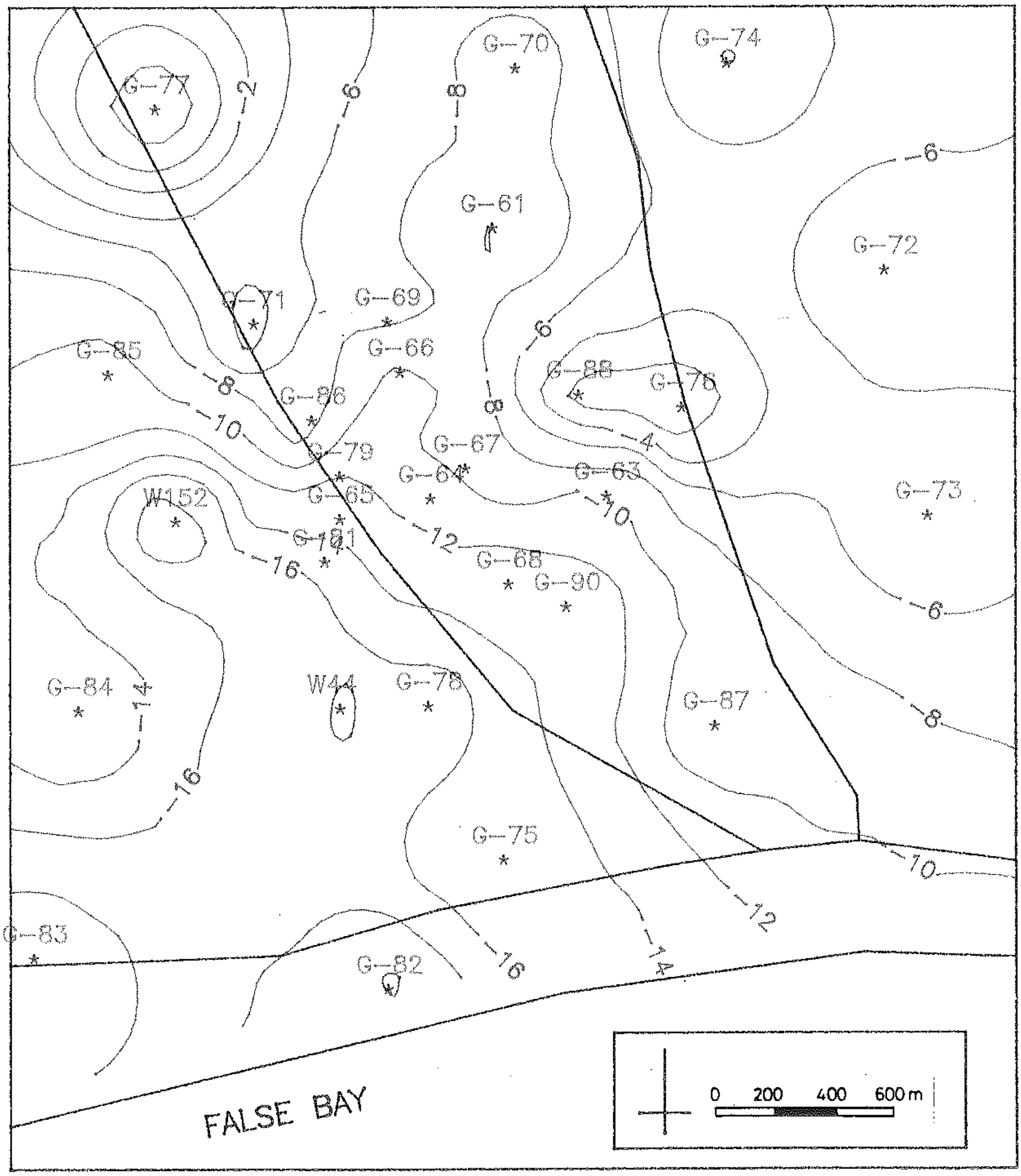


Figure 5: Contour map of the bedrock elevation

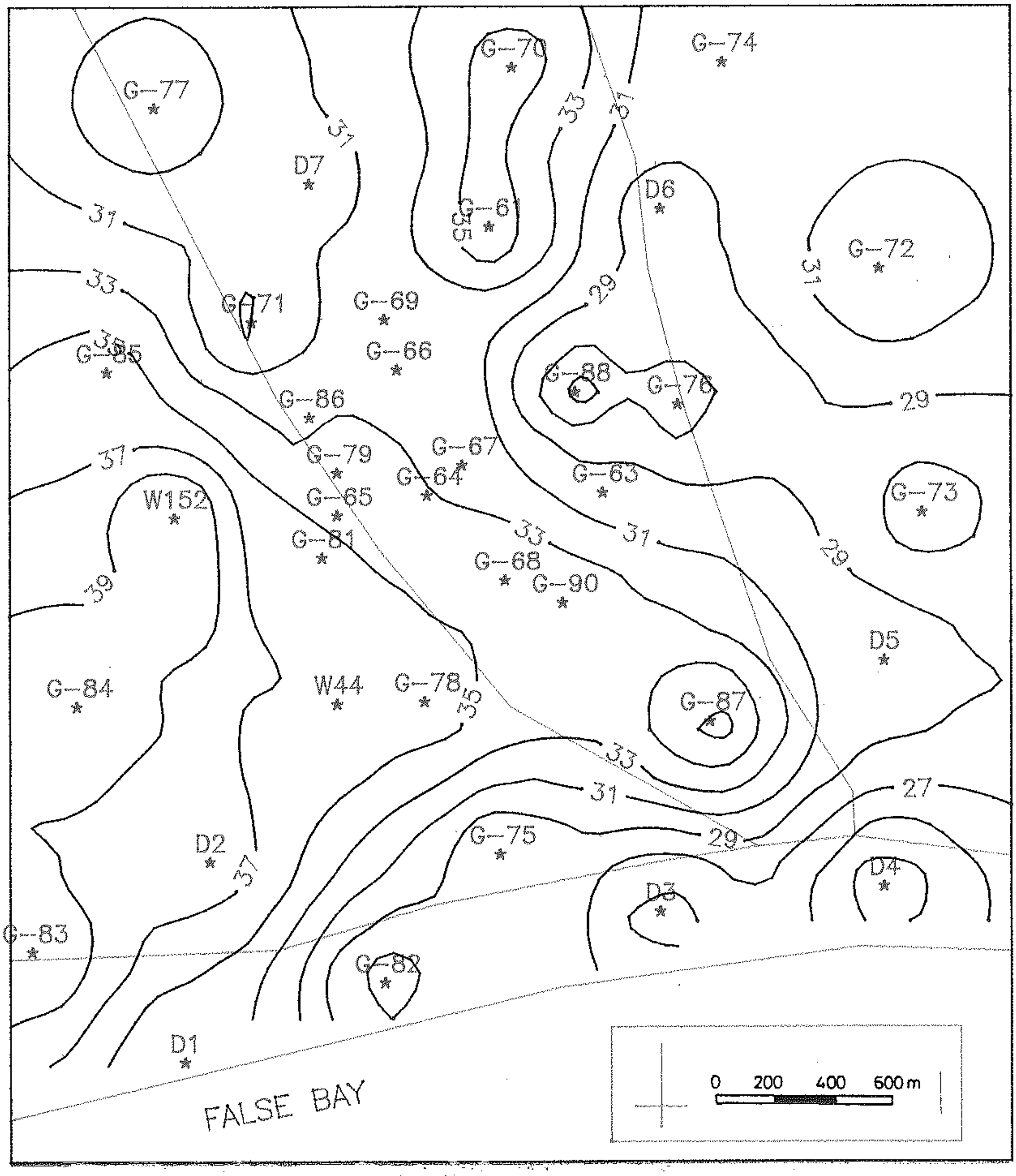


Figure 6: Contour map of the Cenozoic deposits

3.2.1.3 Springfontyn (Philippi) Member

The distribution of the well sorted and rounded, fine to medium grained quartzose Springfontyn sands is shown on Figure 7. Grain size often increases with depth and thin calcareous clay and peat lenses may locally be present. The formation is relatively uniform and free of inclusions.
Comparison of the isopachyte maps of the Witzand and Springfontyn sands reveals that, with the exception of the far eastern part of the Scheme Area, the formations complement each other: wherever Springfontyn deposits are prominent, Witzand sands are relatively insignificant and vice versa. Both formations are contemporary and of aeolian origin, but the Springfontyn formation is nothing more than a decalcified facies of the Witzand formation. Decalcification took place through the action of groundwater where surface and subsurface permeabilities were relatively high and thus condusive to recharge and quick subsurface throughflow of young, agressive groundwaters.

3.2.2 Varswater Formation

3.2.2.1 Calcareous Sand Member

This is a marine deposit made up of very fine to medium, often silty sand that contains plenty of small shells and shell fragments. The thickest layers were found along the sea and towards the east of the study area. Table 8 lists the thicknesses of the different formations, the entire Cenozoic sequence and the aquifer at the different borehole sites.

3.2.2.2 Shelly Gravel Member

The shell content of SGM deposits can be as high as 70% and the shells and shell fragments are heavily weathered. Thicknesses of 16 and 13 m were found in boreholes G32975 and G32987 respectively. The coarse sediments are interbedded with or grade gradually into finer very shelly sands. The distribution of the Varswater sediments is shown in Figure 8.

3.2.3 Elandsfontyn Formation

Angular, fine to coarse clayey sands recovered from boreholes G32960 (4 m), G32970 (7 m), G32972 (3 m) and G32974 (7 m) were identified as fluviatile Elandsfontyn sediments. Peat and peaty clay layers are characteristic of this formation. The patchy, inland occurrence of these sediments of Miocene age (Rogers, 1982) indicates that the bulk of these terrestrial deposits may have been removed by subsequent marine transgressions.

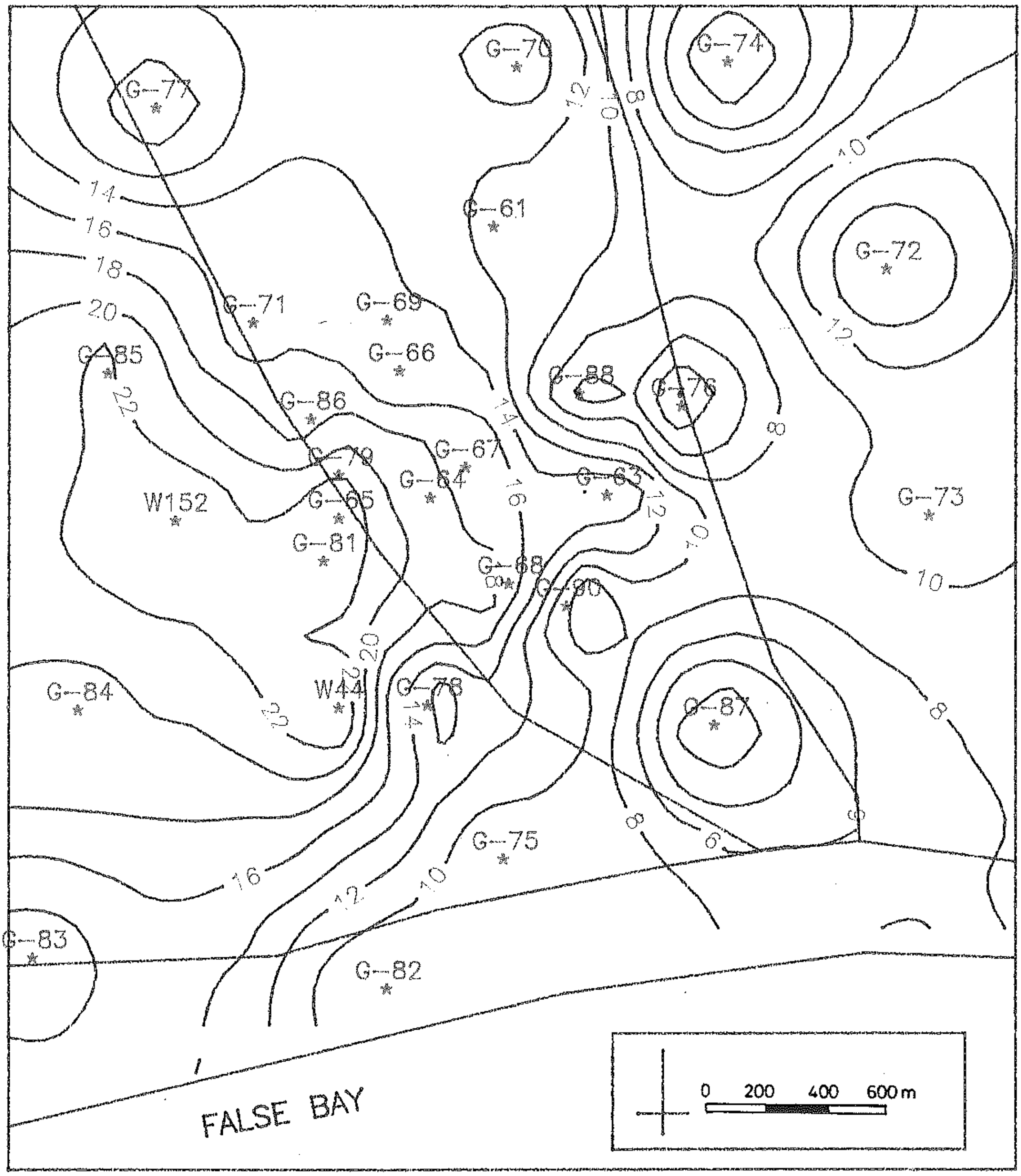


Figure 7: Contour map of the Springfontyn Member sands

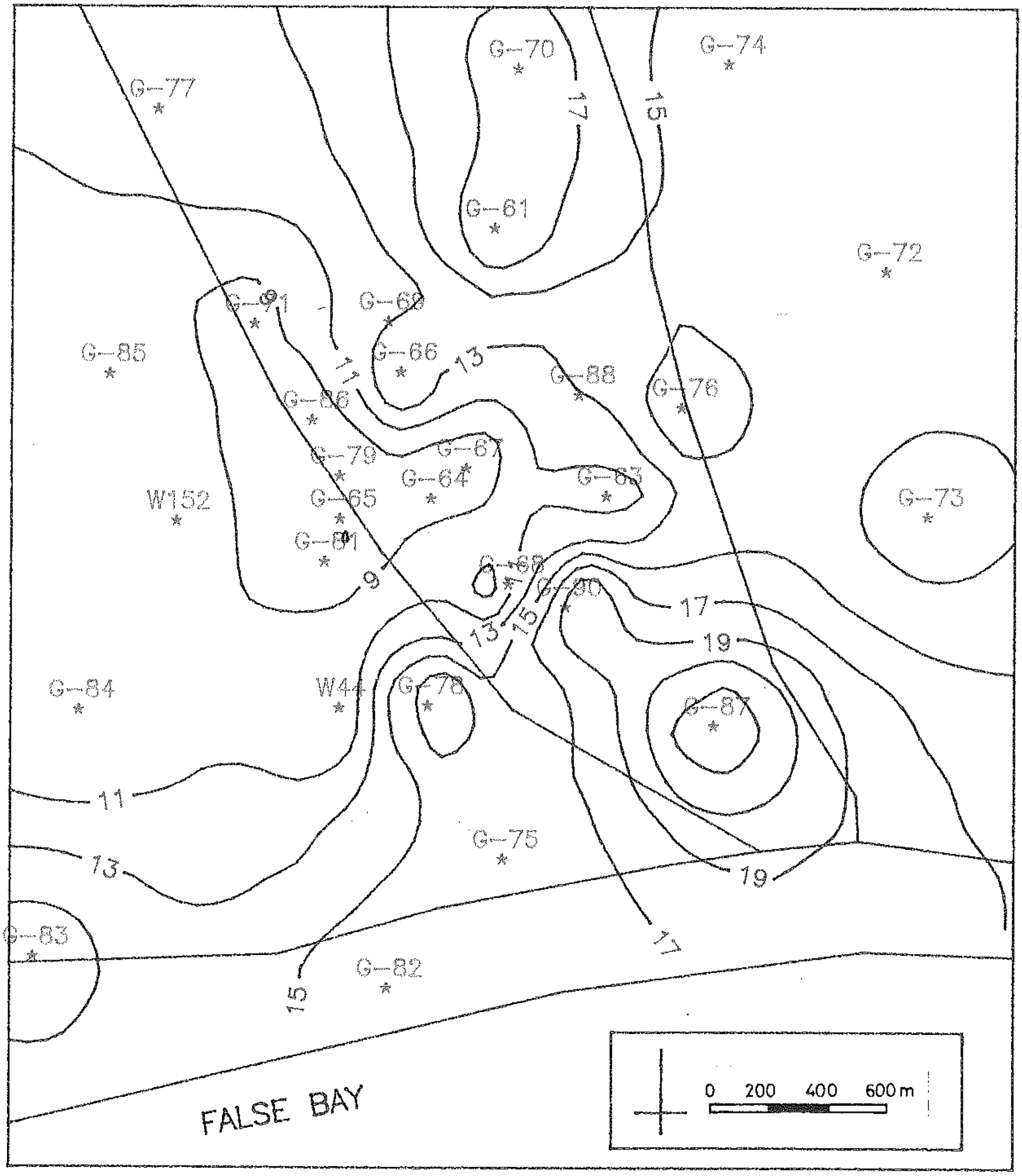


Figure 8: Contour map of the Varswater Formation

BOREHOLE NUMBER	WITZAND MEMBER (m)	WOLFGATSPRINGFON MEMBER (m)	MEMBER (m)	CSM MEMBER (m)	SGMELANDSFON MEMBER (m)	FORMATION (m)	CENOZOIC SEQUENCE (m)	SATURATED THICKNESS (m)	AQUIFER THICKNESS (m)	BEDROCK ELEVATION (m)a.m.s.l.
G32960	7	0	19	0	5	4	35	30.8	21.8	-15.2
G32961	18	0	0	8	11	0	37	30.4	19.4	-9.4
G32962	5	0	15	9	8	0	37	31.3	23.3	-12.5
G32963	9	0	12	4	5	0	30	26.1	21.1	-10.6
G32964	0	0	22	0	11	0	33	29.1	29.1	-12.0
G32965	6	0	20	0	7	0	33	28.8	21.8	-13.1
(*)G32966	0	0	8	18	2	0	28	22.3	20.3	-3.3
G32967	16	0	9	0	7	0	32	24.7	17.7	-8.2
G32968	15	0	13	3	5	0	36	28.7	23.7	-14.1
G32969	1	0	19	6	12	0	38	31.9	19.9	-12.0
G32970	8	10	0	0	10	8	36	32.3	10.0	-8.9
G32971	0	0	20	4	4	0	28	23.4	14.4	-2.4
G32972	18	2	0	7	3	3	32	27.6	22.6	-6.7
G32973	14	0	0	10	2	0	26	21.4	19.4	-4.6
G32974	0	15	0	6	0	7	28	25.8	18.8	-.9
G32975	6	0	5	0	16	0	27	24.0	24.0	.6
G32976	0	0	9	11	6	0	26	18.3	18.3	.0
G32977	0	0	15	4	8	0	27	20.6	16.6	3.7
G32978	8	0	8	11	9	0	36	30.1	21.1	-17.4
G32979	0	0	11	16	8	0	35	30.3	24.3	-13.0
G32980	0	0	11	16	8	0	35	28.1	20.1	-14.4
G32981	10	0	19	3	6	0	38	32.7	26.7	-16.1
G32982	4	0	6	0	14	0	24	21.9	11.9	-18.3
G32983	10	0	15	14	2	0	41	28.6	22.6	-19.1
(*)G32984	11	0	16	12	0	0	39	28.5	28.5	-12.0
G32985	6	0	20	4	6	0	36	32.7	22.7	-10.5
G32986	4	0	19	1	6	0	30	24.7	14.7	-5.2
G32987	12	0	0	13	14	0	39	24.0	22.0	-9.8
G32988	2	0	9	11	8	0	30	24.9	18.9	-6.7

(*) borehole not drilled to bedrock

Table 8: Thicknesses of the lithostratigraphic units, saturated sequence and aquifer, and the bedrock elevation at the data points

3.3 GEOHYDROLOGICAL SIGNIFICANCE OF THE LITHOSTRATIGRAPHIC UNITS

3.3.1 Bredasdorp Formation

The sediments of the Bredasdorp Formation, more specifically the sands of the Witzand and Springfontyn Members, are by far the most important from a production point of view: the sands range in size from fine to coarse and are generally well sorted and rounded. These characteristics translate in an above-average hydraulic conductivity for this component of the aquifer. Hydraulic conductivities in the range of 30-40 m/d were calculated by means of Hazen's formula for clean Bredasdorp sand samples recovered from calibration boreholes G32960, G32962 and G32963. Wessels and Greeff (1980) obtained k-values in the 15-50 m/d range for this type of deposits in the eastern portion of the Cape Flats aquifer.

Closer examination however reveals that the Witzand and Springfontyn formations do possess a degree of heterogeneity and anisotropy due to vertical and lateral grain size gradation and the occurrence of sandy clay and clayey sand lenses. As a result, anisotropic groundwater flow conditions and/or a vertical flow component (leakage, delayed yield) occur to a more or lesser extent in most places where this formation is pumped. Put otherwise, where the aquifer is formed by Witzand and Springfontyn sediments, it is generally unconfined to semi-unconfined. Wherever calcareous clay and calcrete layers of the Wolfgat Formation dominate as the superficial sediments, the Bredasdorp aquifer is semi-confined in nature. The Wolfgat sediments therefore act as an aquitard. This hydraulic model is similar to the one arrived at by Gerber (1976).

The "Weltevreden Road" high transmissivity zone pinpointed by Gerber (1980) and selected as the target area for the Scheme, coincides with the most prominent pocket of sandy Bredasdorp deposits in the study area.
The production boreholes with the thickest recorded Bredasdorp sequence tend to possess the highest yields (compare tables 2 and 8).

Figures 9 and 10 show the variation in thickness of the saturated Cenozoic sequence and the primary aquifer respectively.

Calcareous Witsand sands in the Grootwater aquifer unit along the West Coast (Timmerman, 1985a) have been correlated with the occurrence of groundwater of above-average hardness. The location of a thick layer of calcareous sand upstream the wellfield is therefore noteworthy.

3.3.2 Varswater Formation

The Varswater sediments form the major aquifer wherever the very transmissive Bredasdorp sands are relatively thin or altogether absent. In other but similar geological areas (Grootwater, Elandsfontyn) the CSM-sands form an aquifer characterized by relatively low hydraulic conductivities ($k \leq 5$ m/d)(Timmerman, 1985a; 1985b). Even the SGM deposits can have hydraulic conductivities between 6 and 23 m/d if the silt and clay content is low. In the study area however, fairly high silt and clay fractions were noticed and the k-values are therefore likely to be in the range of 1 to 10 m/day.

The net result is that a considerable thickness of Varswater sediments is required to produce economic supplies, as is the case, for instance, with boreholes G32990 (G32980) and G32978.

The Varswater sequence is the bottom aquitard wherever the dominant Bredasdorp aquifer is present.

3.3.3 Elandsfontyn Formation

The peat, clay and sandy and peaty clay of this formation play a very minor role in the hydrogeology of the study area and where present can be lumped into the Varswater aquitard.

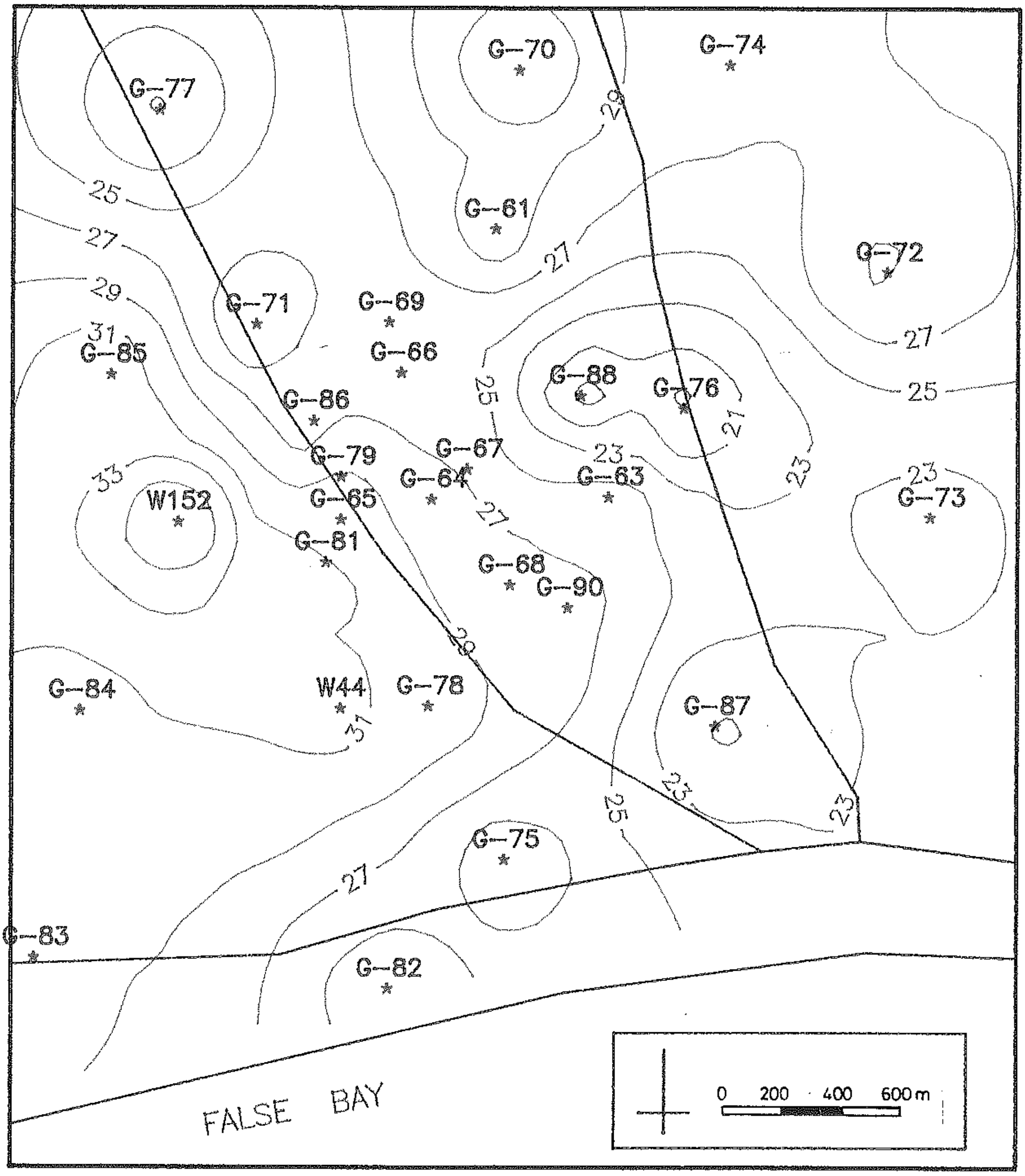


Figure 9: Contour map of the saturated Cenozoic sequence

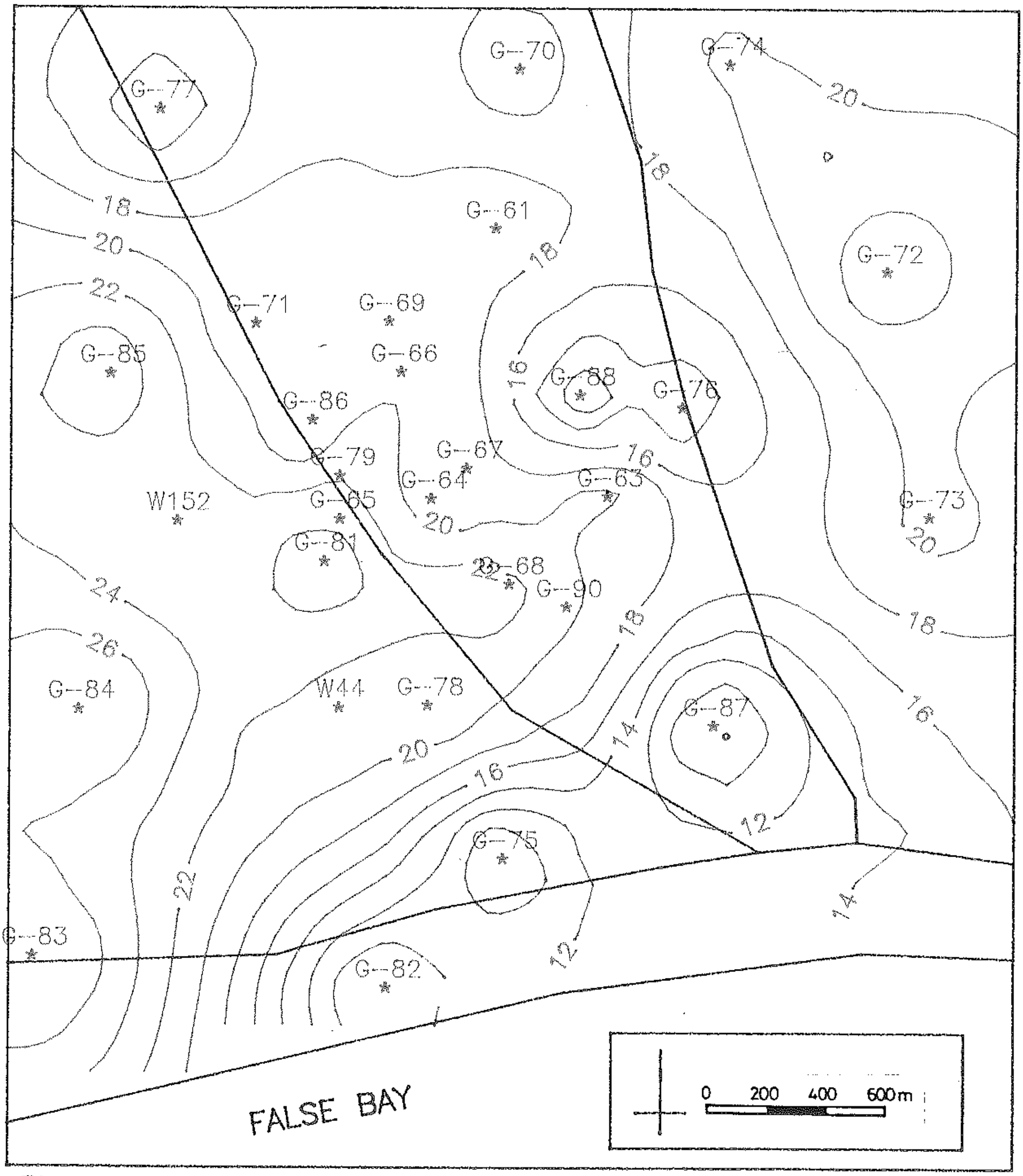


Figure 10: Contour map of the primary aquifer

3.3.4 Malmesbury Group

By virtue of the pelitic and extensively weathered nature of the Malmesbury metasediments (Geological Survey, 1984), the bedrock has up to now, here and elsewhere, generally been regarded as the impervious basement of the primary aquifer system. As such drilling and testing to study the hydrogeological properties of the Malmesbury metasediments was routinely ignored. Gerber (1976) tested the transmissivity of a Malmesbury sequence at one site and concluded that this formation could for all practical purposes be considered impermeable. Wessels & Greeff (1980) did not differ from this opinion, but allowed for the possible occurrence of transmissive, brecciated zones associated with faults, as they located a number of boreholes in their study area producing good yields and qualities out of the Malmesbury rock.

Recent work in the Atlantis (Botha, Verwey & Buys, 1988) and Elandsfontyn regions has shown that highly transmissive fracture zones sustaining yields of the order of 20 l/s occur at depths of no more than 10 - 15 m below the bottom of the Cenozoic deposits in these areas.
Tests have shown that the weathered Malmesbury zone between primary aquifer and fracture zone constitutes an aquitard through which the deeper groundwater can seep upwards whenever the watertable is drawn below the piezometric surface. It would appear however that the Malmesbury aquifer is recharged by sandwater. One argument for this hypothesis is that the hydrochemistry of both waters appears to be similar.

Whether a Malmesbury fractured aquifer occurs in the Scheme Area is conjectural, but the presence of production boreholes delivering up to 15 l/s from the Malmesbury in the Philippi Agricultural Area north-west of the Scheme Area is significant (Bertram, 1989).

3.4 PIEZOMETRY

It follows from section 3.3 that the waterlevels in some boreholes will represent atmospheric levels, others will be close to artesian pressure levels, while quite a few may reflect intermediate aquifer conditions. However, in view of the limited thicknesses of the aquifer and its components, the differential between both pressure levels can probably be measured in centimetres. One watertable/piezometric contour map (Figure 11) is therefore enclosed without fear for gross inaccuracies.
Three features stand out on the contour map:

(1) the general direction of groundwater flow is towards the sea.

(2) the watertable (piezometric) gradient is relatively steep in a 1 km strip adjoining the coastline (0,015), but flattens out rather sharply further inland (0,003). Although this feature can to an extent be seen as an expression of the topography, the hydraulic contrast between by the rather low transmissive Varswater sediments in the coastal zone and the more transmissive Bredasdorp sands in the wellfield area, i.e. a hydraulic bottleneck situation offers an additional explanation.

(3) a groundwater mound that cannot conclusively be explained. The watertable high in the vicinity of boreholes G32978 and G32975 (in box on Figure 11) could be the expression of leakage from maturation ponds further upstream.
The mound located towards the eastern boundary of the study area cannot readily be explained. It could be a local recharge phenomenon associated with a strip of thinly vegetated dunes that was kept as a greenbelt during urban development.

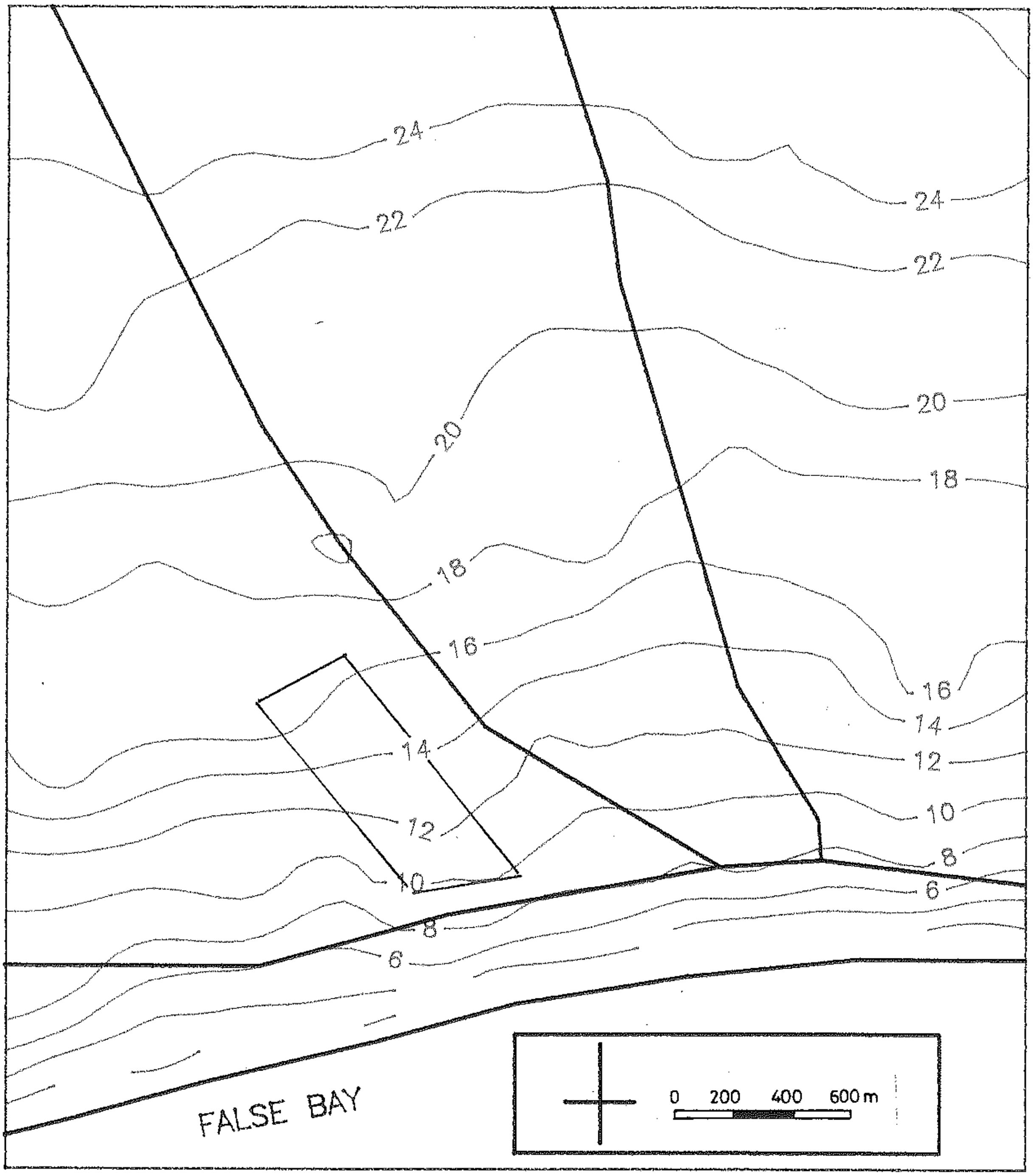


Figure 11: Watertable contour map (pre-pumping: April 1985)

3.5 GROUNDWATER QUALITY

A large number of water samples was collected during the drilling, developing and testing of the boreholes. The objectives of the sampling programme were limited to

(1) determining the general groundwater quality characteristics (EC, pH) and suitability for urban consumption;
(2) delineating the major water types prevalent in the area; and
(3) providing a base reference for hydrochemical time series built up during the test abstraction period.

A Piper diagram and the Stuyfzand (1986) classification procedure were used to discern the different groundwater types.

The total dissolved salt (TDS) content of the groundwater found in the scheme area varies between 400 and 875 mg/l, while the following range of concentrations was determined for a number of major constituents:

cations:	Ca	45 - 160 mg/l
	Mg	3 - 16 mg/l
	Na	24 - 170 mg/l
	K	1 - 6 mg/l
anions:	Cl	35 - 324 mg/l
	SO_4	12 - 169 mg/l
	HCO_3	119 - 300 mg/l

The concentrations of SO_4 and HCO_3 are relatively high. The high sulphate content could be linked to the occurrence of peaty clay and peat lenses. The reason for the high calcium bicarbonate content is obviously the calcareous nature of all but two lithological units found in the area (Springfontyn Member, Elandsfontyn Formation).

The concentrations of all major determinants fall well below the recommended limits for human consumption, except for the following:

Ca in G32977
Na in G32961 and G32976
Cl in G32976
N in G32966 and G32968

Calcium-bicarbonate is the dominant type of groundwater. A mixed-mixed and a mixed-chloride type of water occur in the eastern and northern central part of the study area. The 1:10000 scale ortho-photographs taken before urban development started in the southern Cape Flats, show that this part of the Flats was occupied by a wide interdunal area. The existence of such vlei-like area can explain the dominance of Cl, Na and K concentrations over Ca and HCO_3 content.

The application of Stuyfzand's classification system on the results of the chemical analysis also indicates that fresh, hard $CaHCO_3$ water is dominant in the study area. Based on the Cl-content (in mg/l) water samples can be classified as follows:

fresh	$Cl < 150$
fresh to brackish	$150 < Cl < 300$
brackish	$300 < Cl < 1000$

Fresh to brackish and brackish water is found in the above-mentioned interdunal area.
A further differentiation is based on the total hardness calculated in the following way:

$$\frac{Ca + Mg}{2} \quad (meq/l)$$

Hard (Ca+Mg/2 = 2 to 4) to very hard (Ca+Mg/2 = 4 to 8) groundwater is found in the Scheme area. A further subdivision of the water samples based on the proportional share of main constituents in the sum of cations and anions (meq/l) resulted in the following water types:

CaCl water
NaCl water
CaMix water
$CaHCO_3$ water

The distribution of these water types is shown on Figure 12.

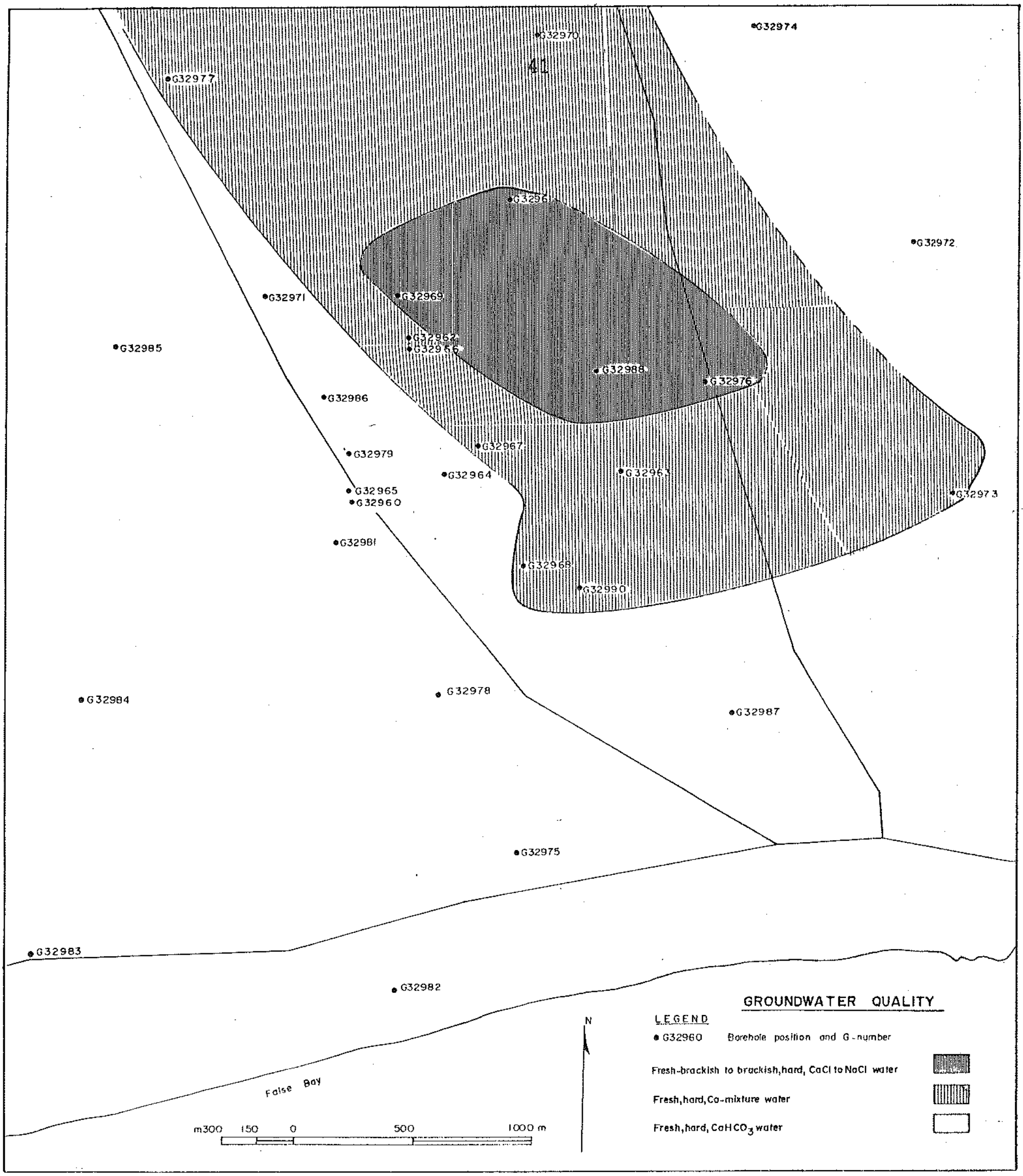


Figure 12: Distribution of groundwater types classified according to Stuyfzand (1986).

4 OPERATION OF THE PILOT ABSTRACTION SCHEME

4.1 SCHEME OPERATIONS

4.1.1 Pre-pumping Preparatory Phase

In accordance with the Agreement the Municipality assumed responsibility for the installation of the Scheme which included, inter alia,

- the preparation of tender documents for the supply and installation of the pumps, ancillary works and equipment;
- making of suitable arrangements for the provision of electricity, connections for the disposal of pumped water and generally all matters relating to the proper running and maintenance of the scheme; and
- the day-to-day operation of the scheme and recording of relevant data.

After a post-drilling interlude in the field that lasted almost a year and was needed for the conclusion of contractual arrangements, activities resumed towards the middle of 1984 with the building of underground pump housing and water disposal connections as well as the issuing of a tender for the supply and installation of pumps and ancillary equipment. It was not until well in 1985 before the contractors, Andrag P. & Sons (Pty) Ltd, began with the installation of all necessary pumping equipment. Automatic shutdown gear was installed to protect the pumps.

4.1.2 Pumping Operations

The Scheme was ready for switch-on by the middle of May 1985. Six pumps were turned on in May at two-day intervals to enable finetuning of the discharge rates and close monitoring of the waterlevels in the very early abstraction stages. The remaining production boreholes were started one month later (table 9). The water was pumped in the stormwater system.
Pumping continued, not entirely uninterrupted, for close on three years until the 30th of April 1988 at 14h00.

According to the power consumption clocks the Scheme was operative for 83,2% of the available time, individual pumps registering between 92,8% and 71,6%. Standing time occurred for a few reasons, the most important being:

* Frequent automatic shutdowns of pumps in the early weeks (finetuning) and during the first summer (influence of cyclical lowering of the regional watertable). Borehole G32981 switched off very frequently at times. Up to two weeks elapsed on some occasions before the pumps were switched on again, although standing time was usually less than one week or the agreed control and monitoring frequency.

* Political unrest in late 1985/early 1986 prevented inspections and monitoring by municipal personnel. A few pumps were standing for weeks at a time during that period.

* Borehole G32979 was out of action for four months in 1986 to repair the submersible pump and to remove the sediment from the borehole sump. Its final shutdown took place in January 1988, as urban infrastructure works required the temporary disconnection of the discharge piping.

* Borehole G32963 was switched off for more than five months in October 1986 for screen rehabilitation. A gentle but continuous yield decline for a constant waterlevel drawdown was noticed for quite some time and was attributed to clogging of the bidim wrapping with silt and lime particles.
  After acid treatment and development the borehole continued to register low discharge rates until the watermeter was replaced!

Very few pump breakdowns were recorded. Apart from borehole G32979 only two minor technical interruptions occurred (G32965, G32981).

BOREHOLE NUMBER	START DATE	START TIME	PUMP HOURS AVAILABLE	PUMP HOURS REGISTERED	% ACTION TIME	ABSTRACTION (Kl)	MEAN YIELD (Kl/HOUR)	MEAN YIELD (l/s)
G32963	24/05/85	0900	25709	18400.5	71.6%	855,600	46.5	12.9
G32965	30/05/85	0900	25566	20592.5	80.5%	945,522	45.9	12.8
G32966	22/05/85	0900	25757	22541.0	87.5%	776,351	34.4	9.6
G32967	23/06/85	0920	24989	20999.2	84.0%	1,084,045	51.6	14.3
G32968	21/06/85	0900	25037	22021.9	88.0%	1,727,539	78.4	21.8
G32969	20/05/85	0900	25805	22760.3	88.2%	1,000,125	43.9	12.2
G32978	28/05/85	0900	25613	22569.1	88.1%	1,073,545	47.6	13.2
G32979	25/06/85	0900	22680	17173.5	75.7%	1,848,950	107.7	29.9
G32981	27/06/85	1100	24891	18584.9	74.7%	1,839,225	99.0	27.5
G32990	26/05/85	0900	25661	23819.2	92.8%	710,655	29.8	8.3
TOTAL			251708	209462.1	83.2%	11,861,557	585	162
YEARS						2.9		
@ YEAR	(Kl)					4,128,087		

TABLE 9 : WELLFIELD ABSTRACTION TIMES, VOLUMES AND RATES

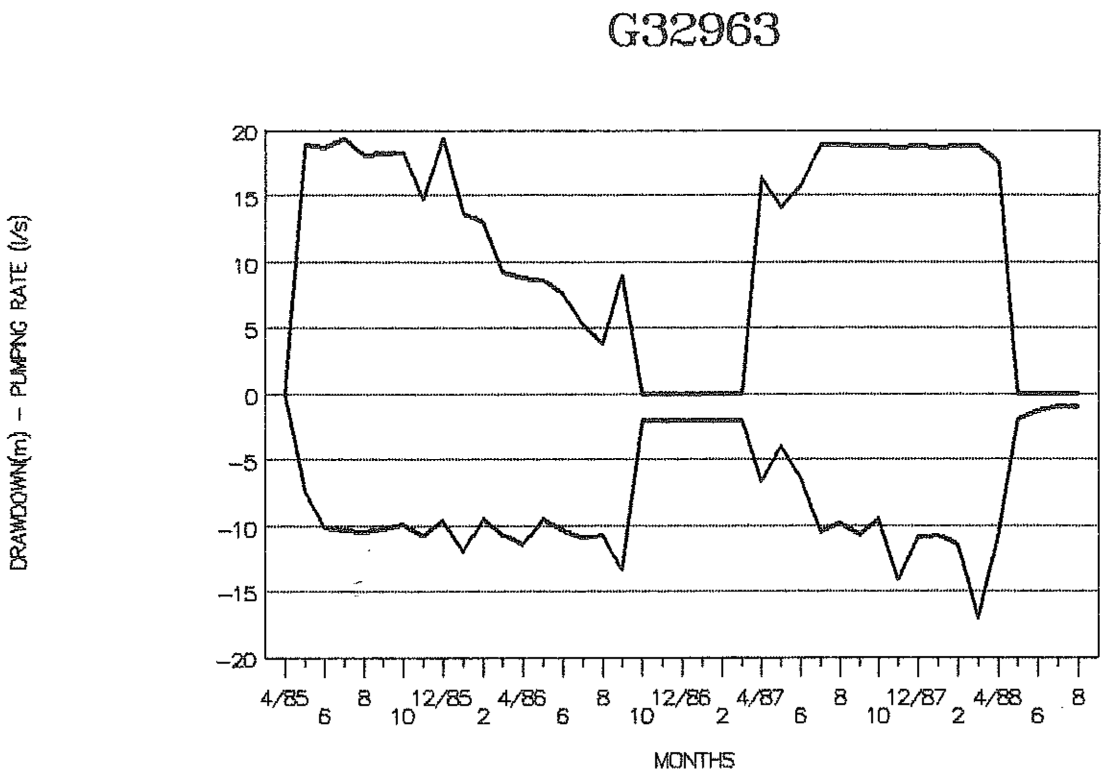
4.2 MONITORING OPERATIONS

4.2.1 Abstraction

Watermeter and power consumption meters were generally read on a weekly basis, but not according to a strict schedule. Consequently, abstraction rates rather than output volumes had to be monitored to keep a tab on the proper functioning of the Scheme. Graphs showing the mean monthly abstraction rates in conjunction with the resultant drawdown were constructed for every production borehole (Figures 13 to 17). The hiatus on the record of G32965 is caused by the fact that the meters could not be read.

About 11862 Ml of groundwater was pumped to False Bay in the period of 2,9 years. This translates into a mean abstraction rate of 162 l/s and a mean annual production of 4128 Ml (Table 9). The mean pumping rate during the 1985-86 period was only about 130 l/s, because most of the above-mentioned interruptions in production occurred in this period. The mean rate during the second half of the wellfield test was about 180 l/s.

In spite of many interruptions G32979 and G32981 were by far the most prolific boreholes (Figure 18), closely followed by G32968. Considering the favourable lithological properties at site G32990 an output rate of 20 l/s would definitely have realized with a Johnson-equipped borehole.
A more realistic loss in production occurred with G32965 (Figure 13). The combination of a gradual yield decline and a continuously rising waterlevel despite a few upward yield adjustments indicates that the pump was most likely systematically worn down by sand pumping. Under a continuous rate of 15 l/s G32965 a total output of 1200 Ml would have been achieved. Similarly, in the absence of avoidable interruptions G32963 would have produced in excess of 1000 Ml during the test period.
All this goes to argue that wellfield development mishaps and production management hiccups cost about 1500 Ml in production. It reinforces the impression gained in the latter half of the pumping period that a mean annual groundwater output of 5000 Ml from the present ten production boreholes is a distinct possibility given the hydrological conditions that prevailed during the test period.



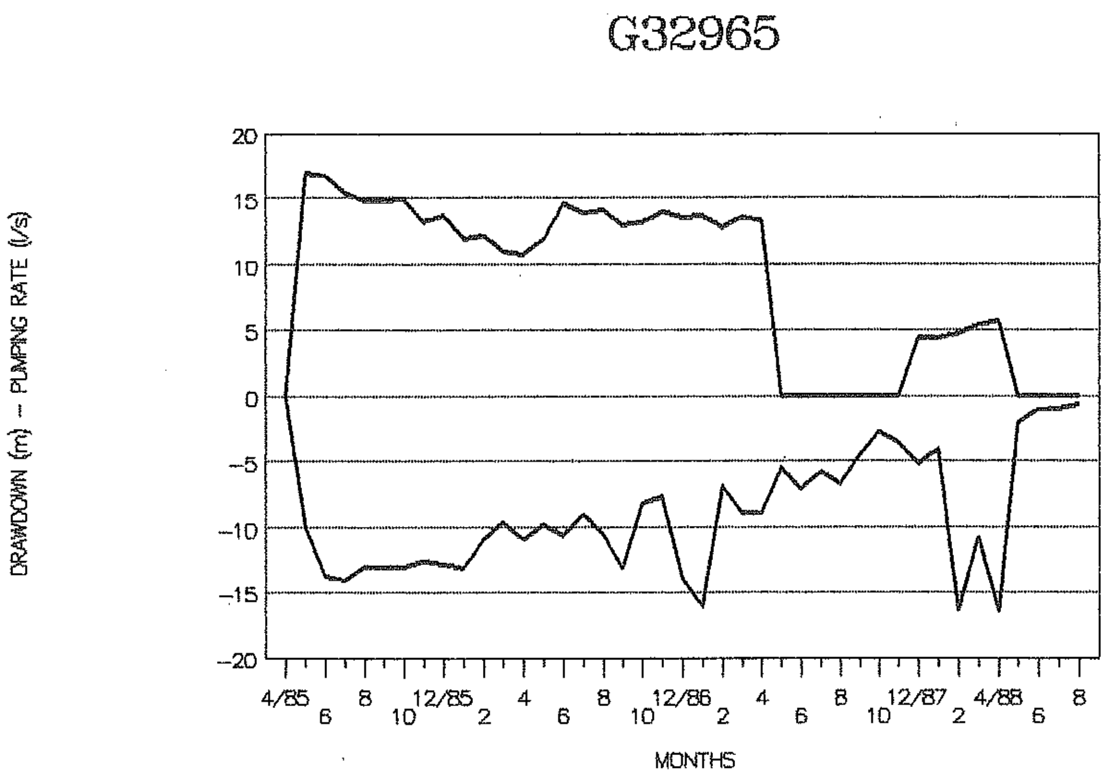
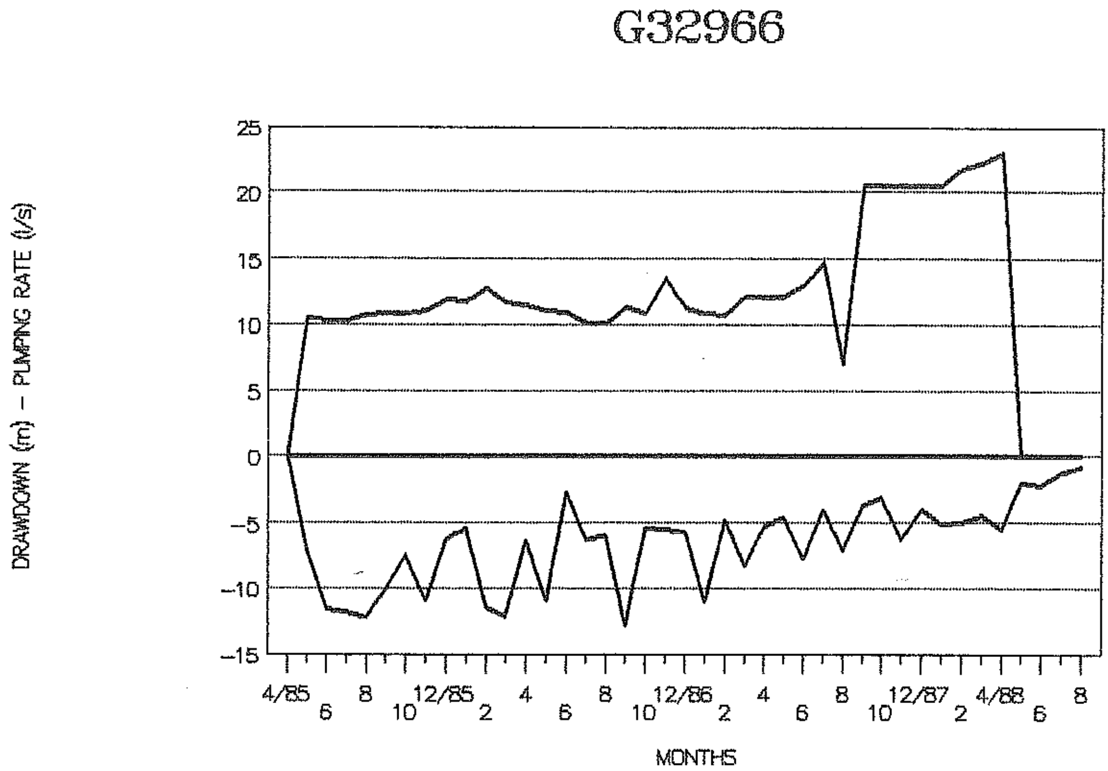


Figure 13: Graph showing drawdown/pumping rate vs. time: G32963 & G32965



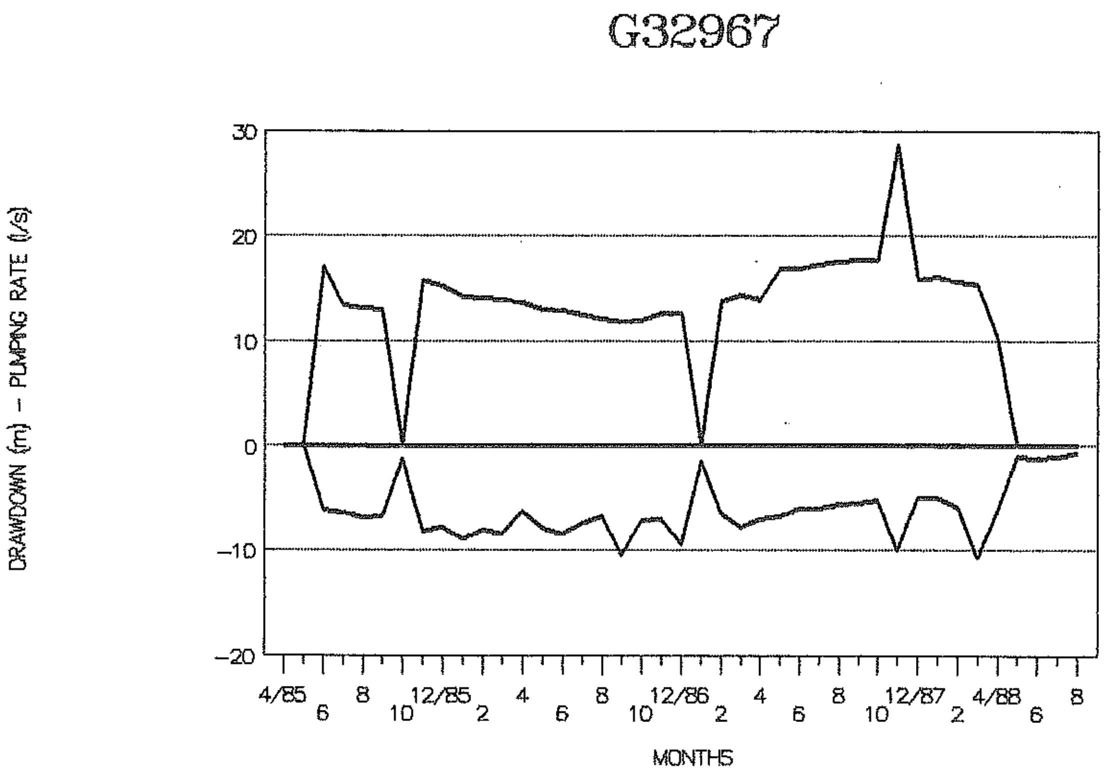
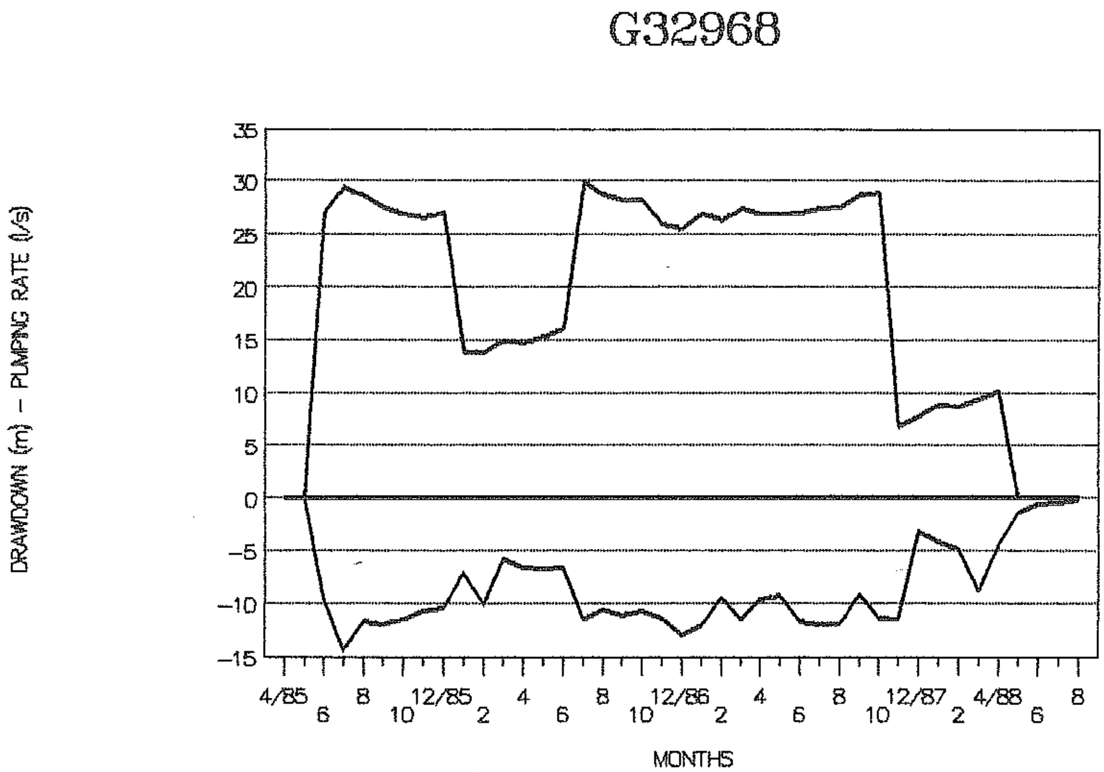


Figure 14: Graph showing drawdown/pumping rate vs. time: G32966 & G32967



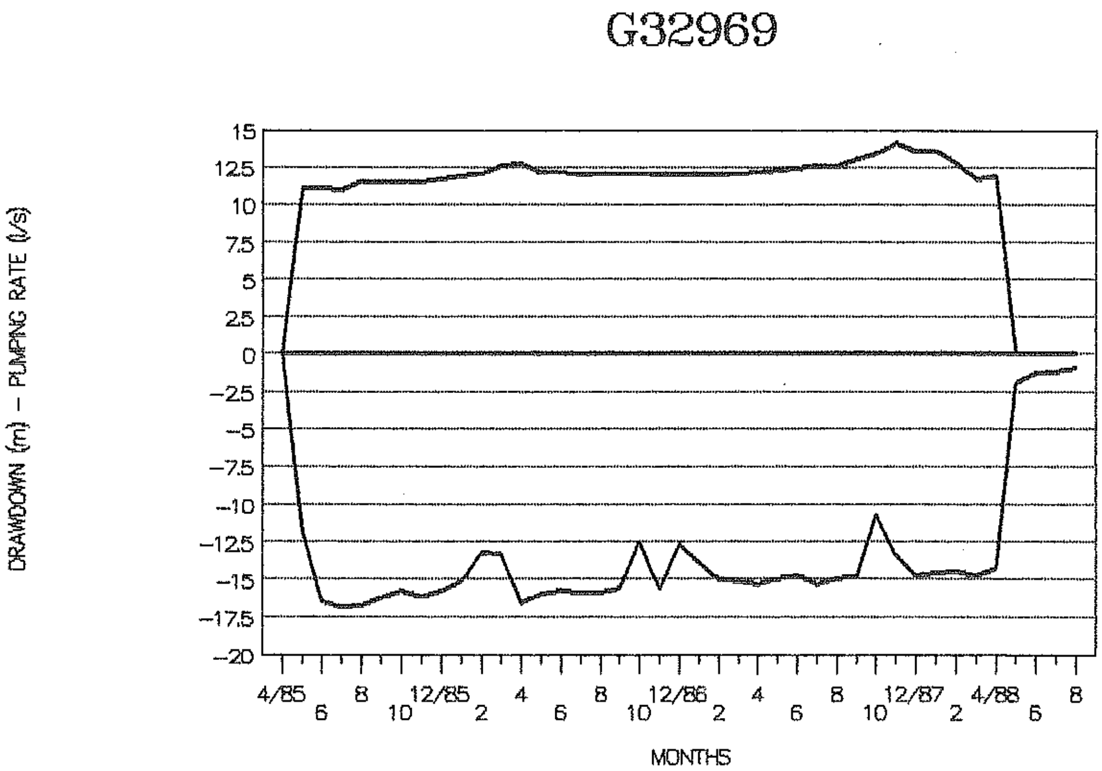
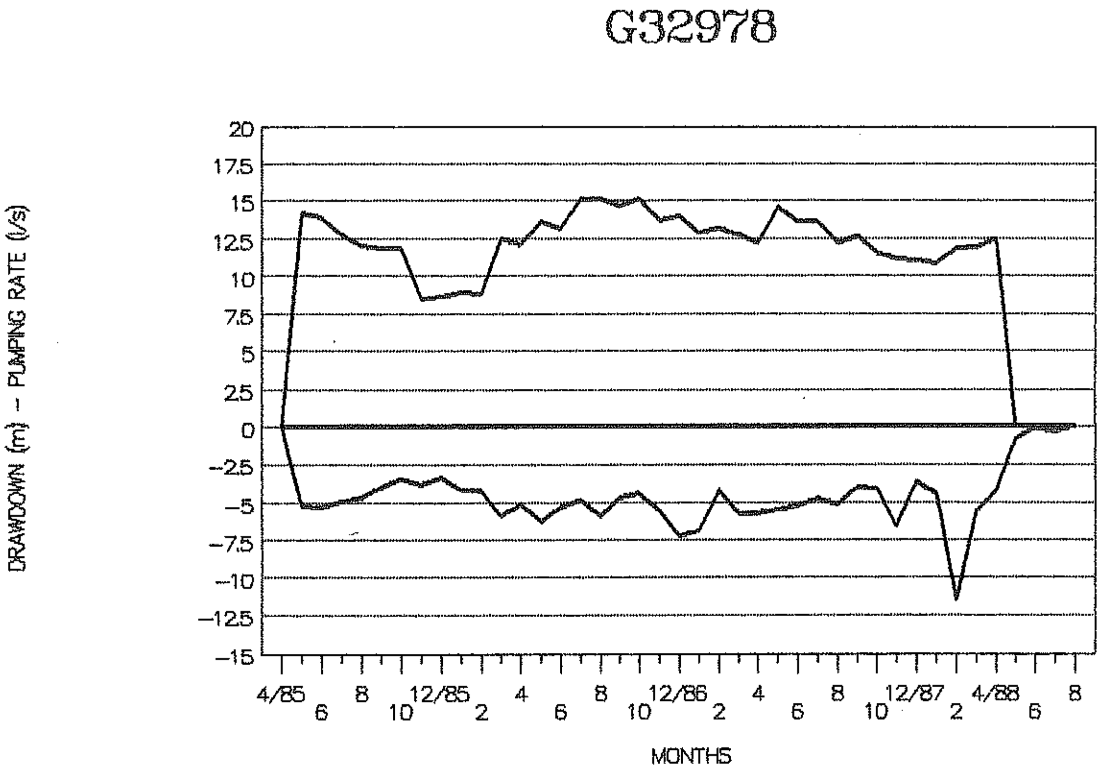


Figure 15: Graph showing drawdown/pumping rate vs. time: G32968 & G32969



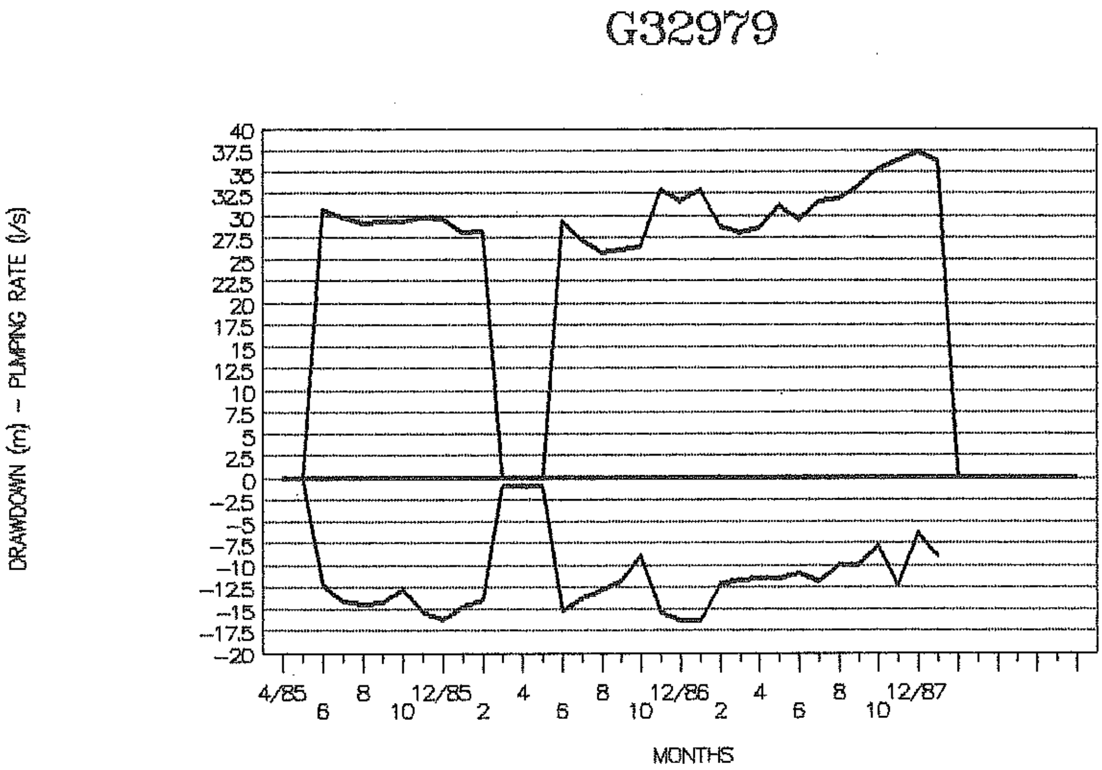
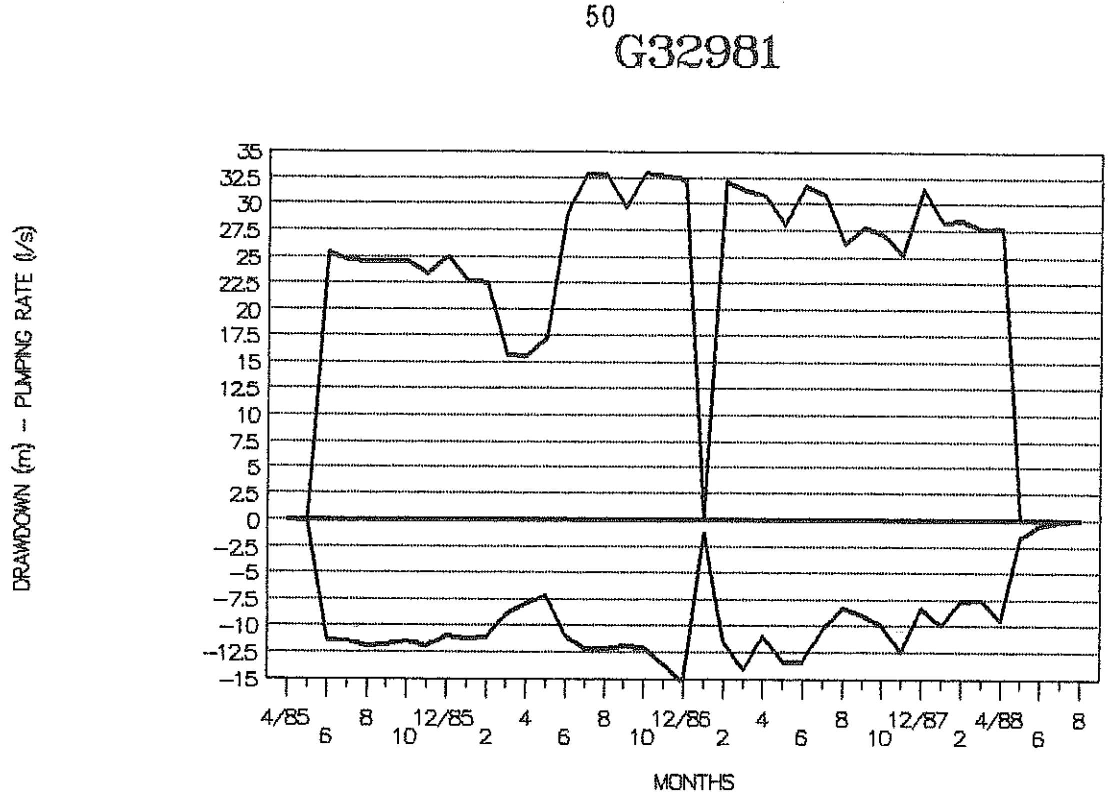


Figure 16: Graph showing drawdown/pumping rate vs. time: G32978 & G32979



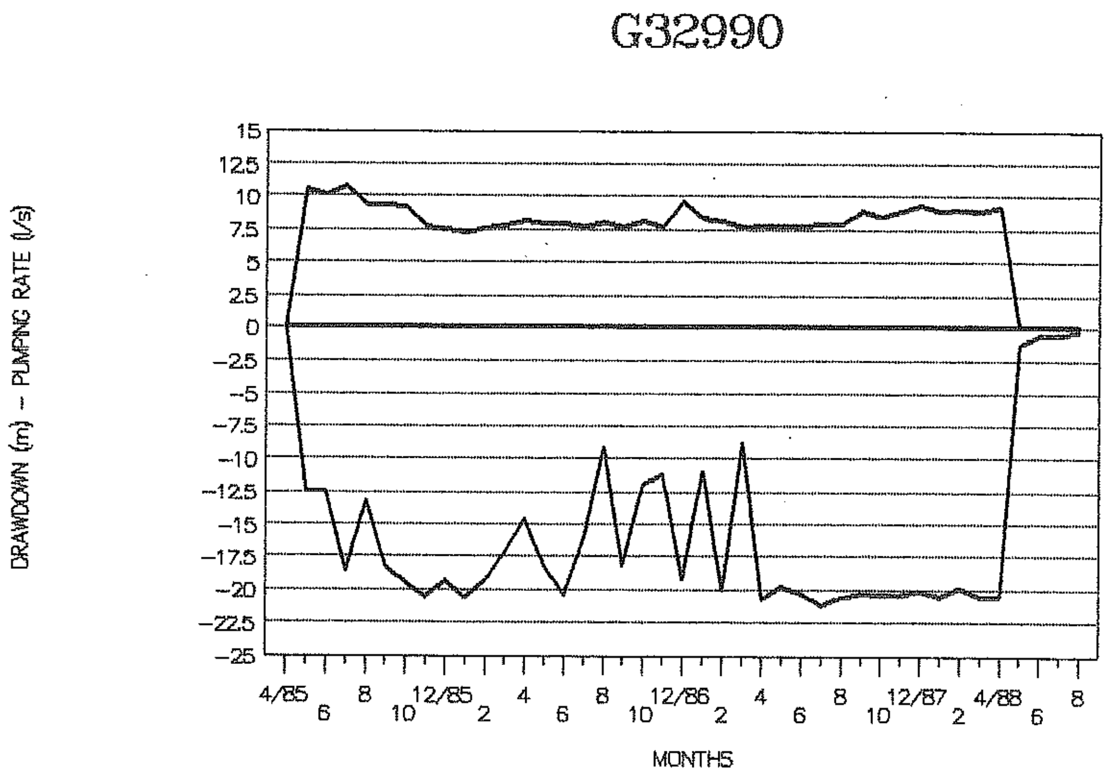


Figure 17: Graph showing drawdown/pumping rate vs. time: G32981 & G32990

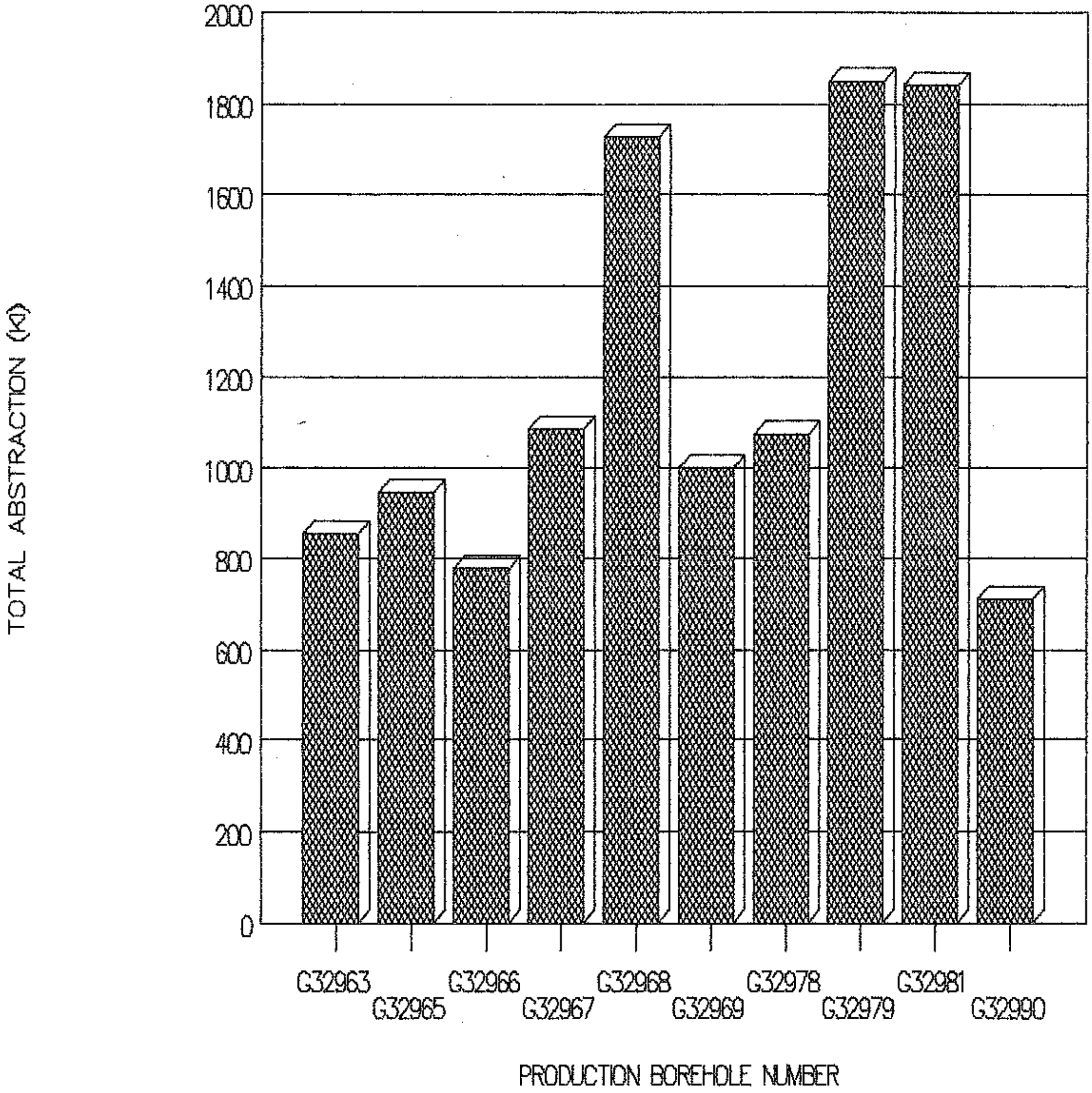


Figure 18: Graph showing total groundwater production of individual production boreholes

Groundwater abstraction was not a novelty in Mitchells Plain in 1985. For a number of years the Municipality's Parks and Forests Department utilizes groundwater for the irrigation of parks and sportsfields. Abstraction boreholes are low-yielding and are all situated well to the east of the Scheme boreholes. The Municipality was nonetheless asked and consented to fit watermeters to the pump outlets. The monitoring system has become derelict in the past year or so. The recorded abstraction figures which are reliable, are given in table 10 below.

It was noticed during the test proceedings that the Parks and Forests Department uses another cost-effective source of irrigation water. Natural groundwater drainage or so-called stormwater base flow is pumped with centrifugal pumps from the stormwater canal in the southern part of Mitchells Plain. Pumping takes place on an irregular basis and no abstraction figures are available. A portion of the discharge from the Scheme was certainly utilized.

The total volume of groundwater that annually leaves the aquifer by way of the drainage system is also unknown. Judged by the summer flow at the canal outlet this type of aquifer loss may be considerable, up to several million cubic metres per year.

Table 10: Municipal abstraction for irrigation in Mitchells Plain (in Kl)

	1986	1987	1988	1989
January	55844	30166	33377	
February	25559	33335	43614	
March	22017	40311	29265	
April	9827	16376		
May	1728	3250		
June	680	0		
July	0	0		
August	0	505		
September	3370	0		
October	12800	11488		
November	17388	29197		
December	42445	23982		
Total	191658	188610		

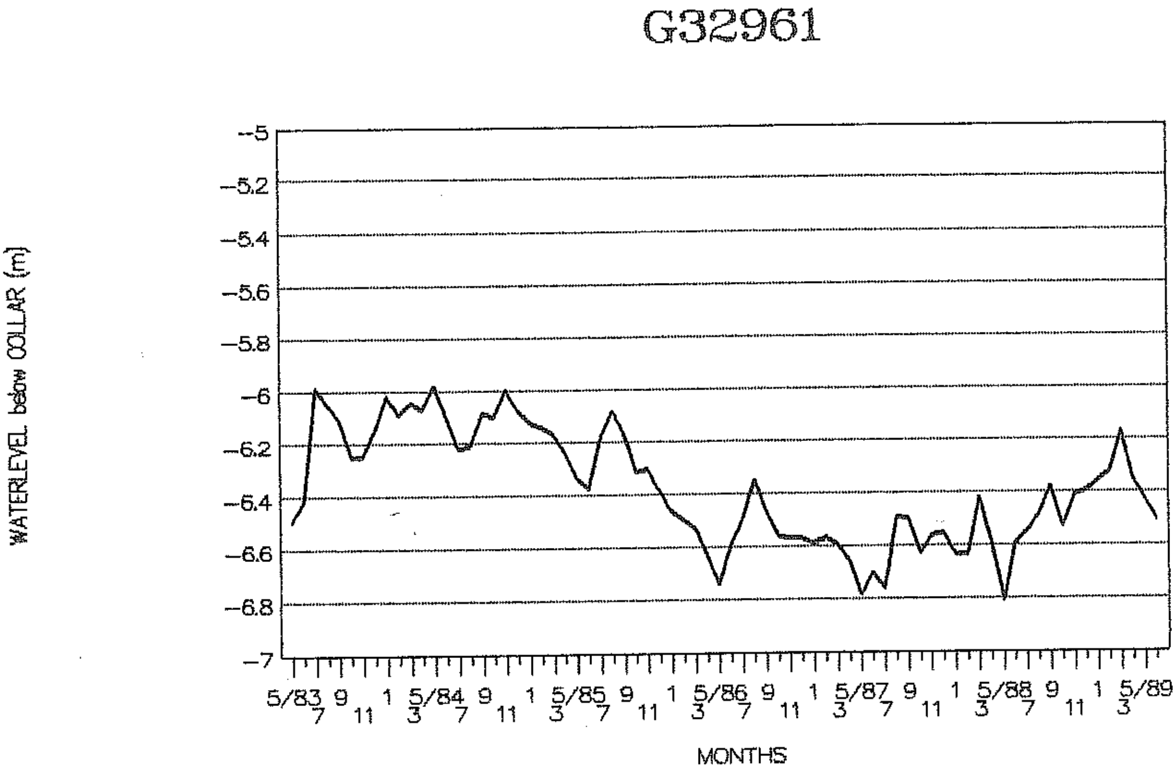
4.2.2 Waterlevels

The waterlevels of both observation and production boreholes were measured by the Directorate Geohydrology on a monthly basis between April 1983 and May 1985. During the abstraction phase waterlevels in the production boreholes were recorded by staff of the Municipality on occasion of meter readings, i.e. principally on a weekly basis. Monitoring of the observation boreholes continued unchanged.

The waterlevel hydrographs of the 18 observation boreholes for the period May 1983 to May 1989 are presented in figures 19 to 27. The waterlevel record of pre-1980 research borehole W152 (station G2N110) of which the position is shown on figure 4, goes back to early 1981.

Four maps have been drawn to illustrate the impact of pumping on the water table:

- the initial (April 1985) watertable configuration (Figure 11)
- the watertable configuration after 2 years of pumping - May 1987 - to show the lowest regional waterlevel position (Figure 28)
- the watertable configuration prior to shutdown - April 1988 (Figure 29)
- the difference between the initial waterlevel configuration and the waterlevel pattern after 2 years of pumping - May 1987 - to show the maximum drawdown that occurred during the test run (Figure 30).



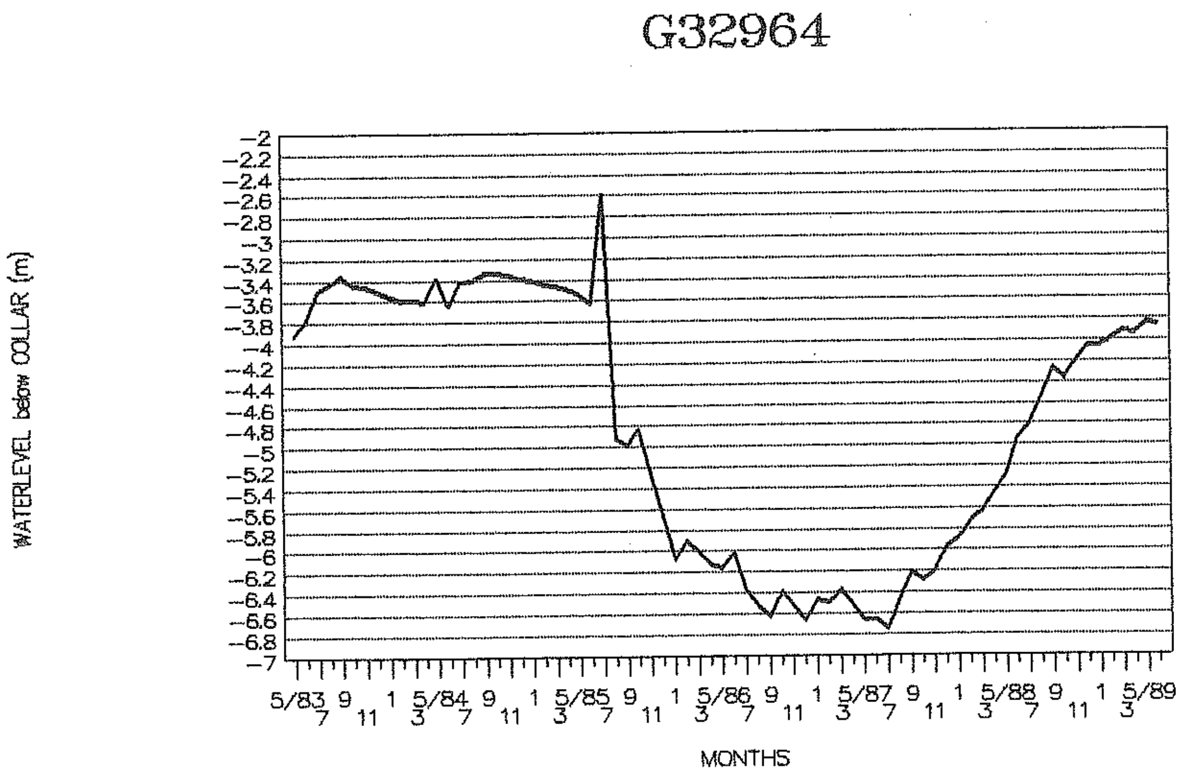
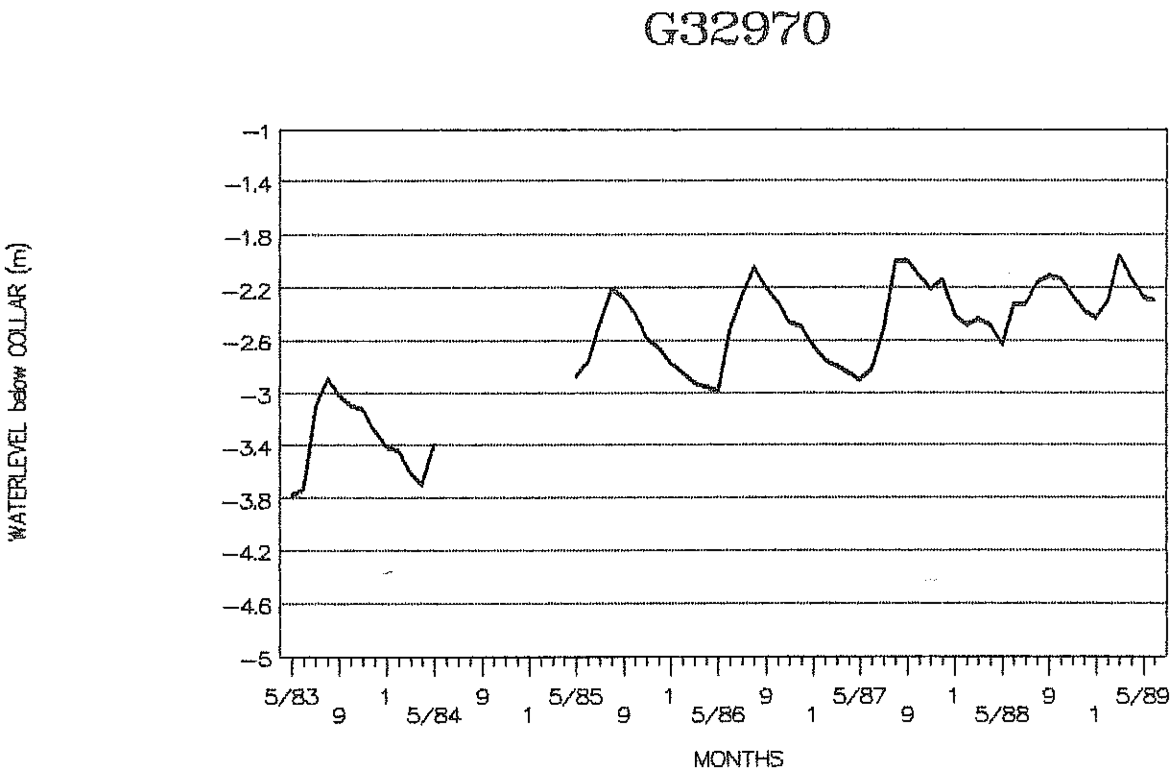


Figure 19: Hydrographs: observation boreholes G32961 & G32964



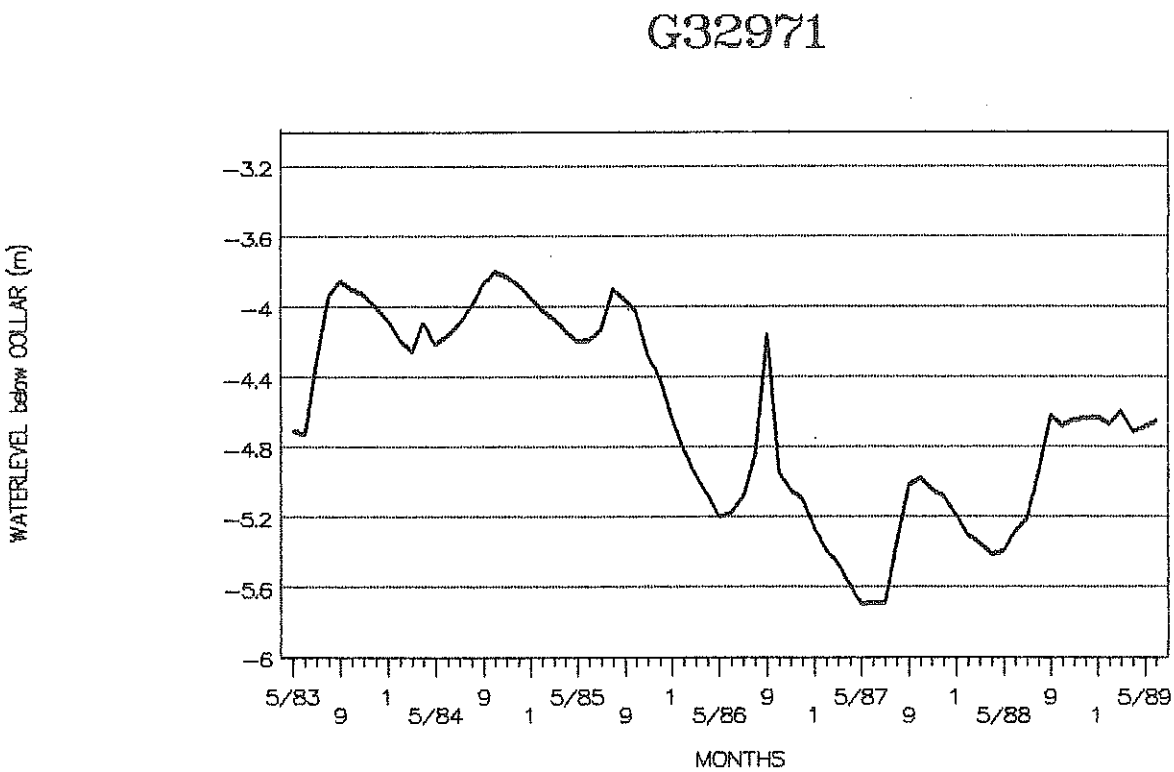
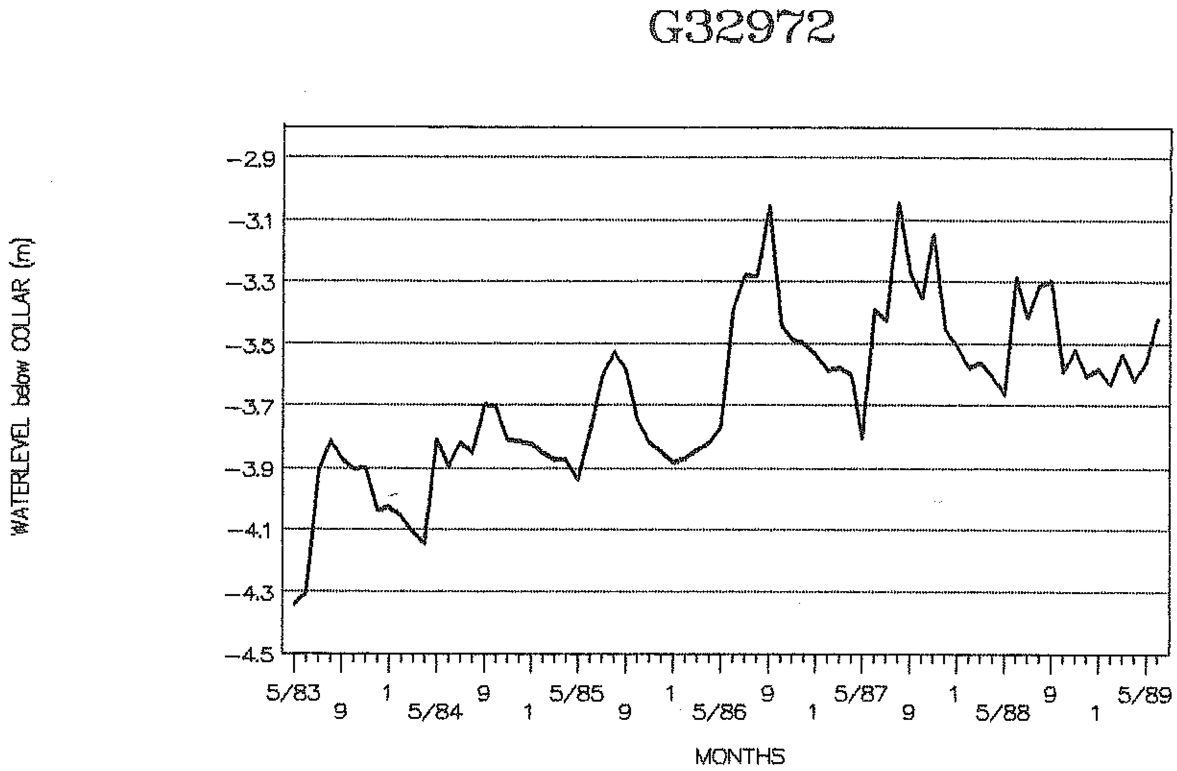


Figure 20: Hydrographs: observation boreholes G32970 & G32971



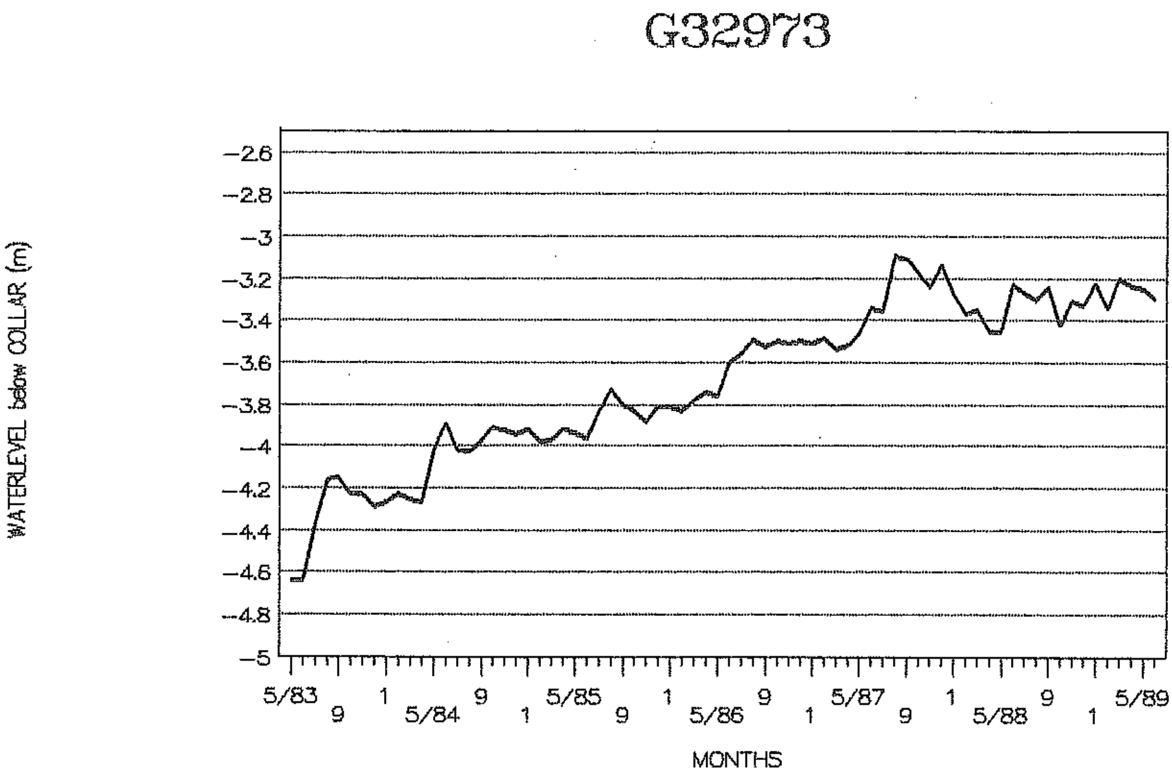
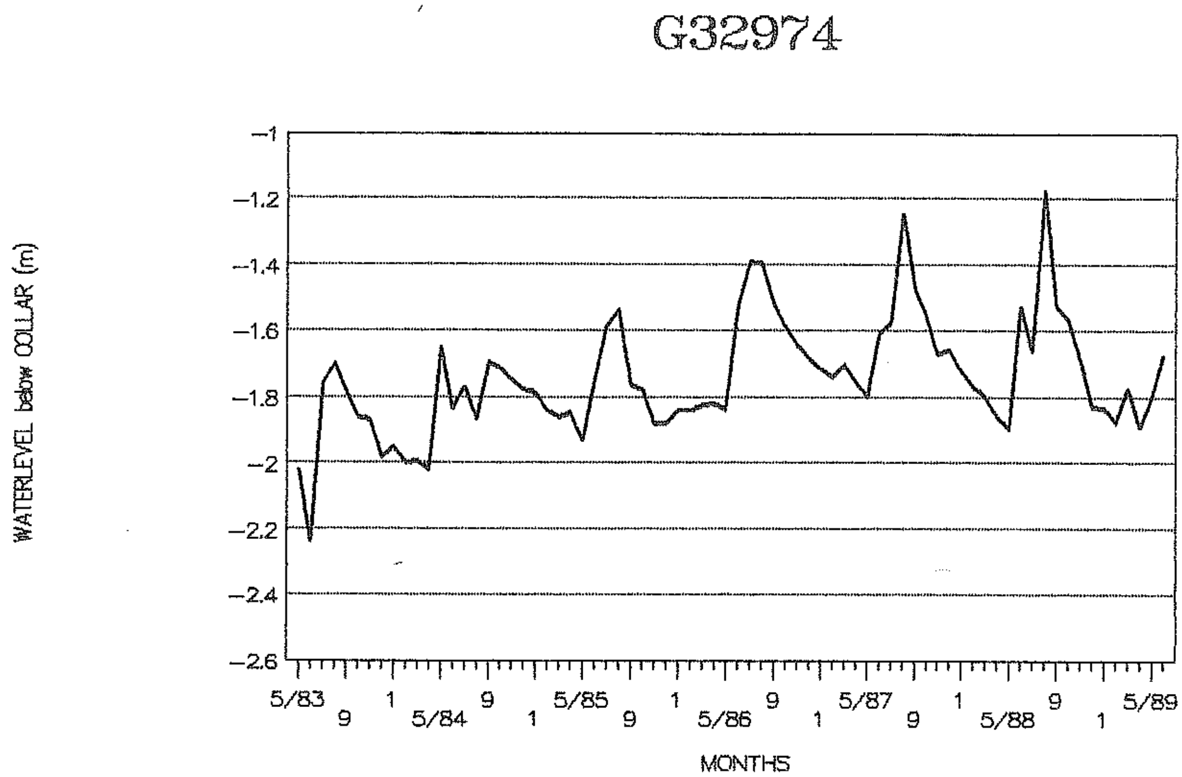


Figure 21: Hydrographs: observation boreholes G32972 & G32973



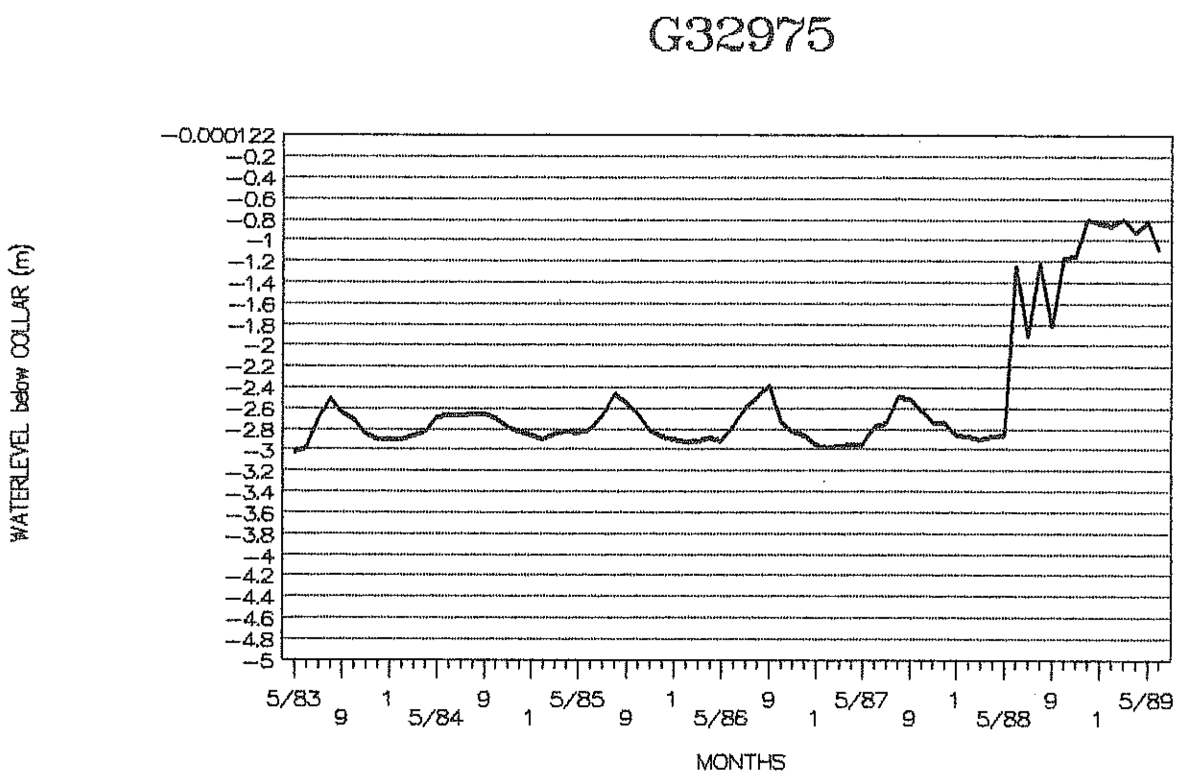
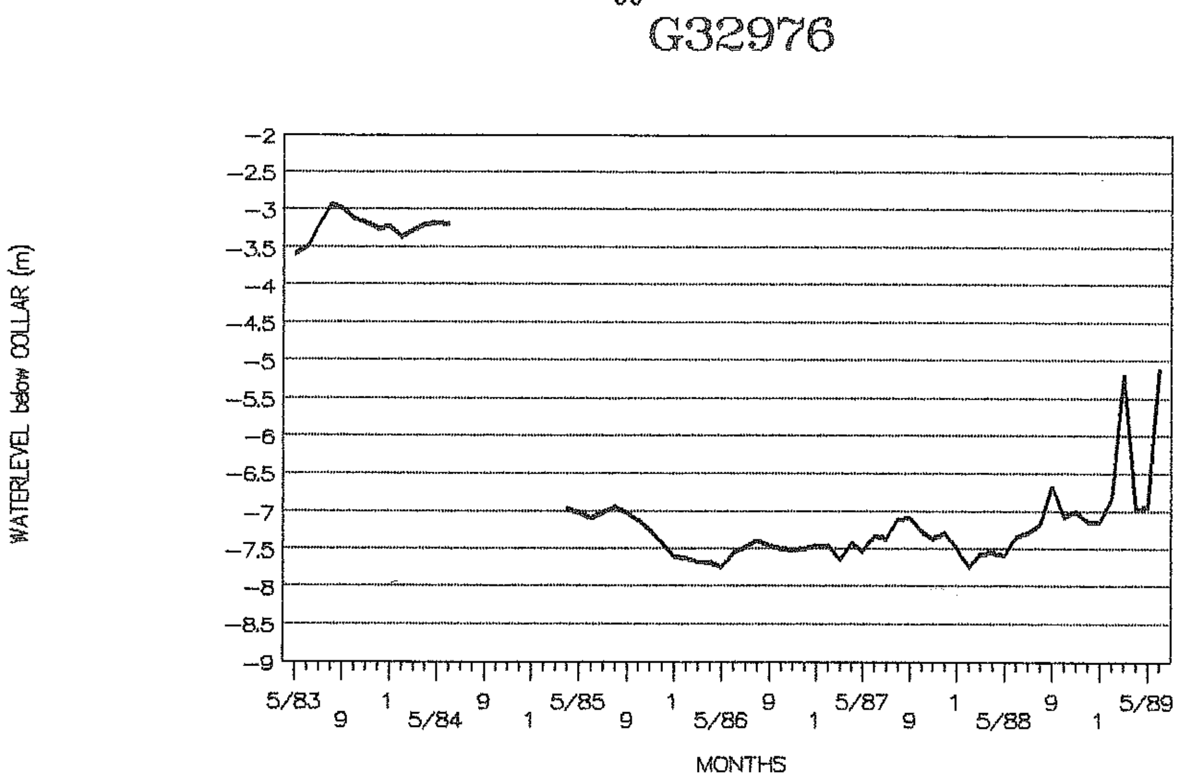


Figure 22: Hydrographs: observation boreholes G32974 & G32975



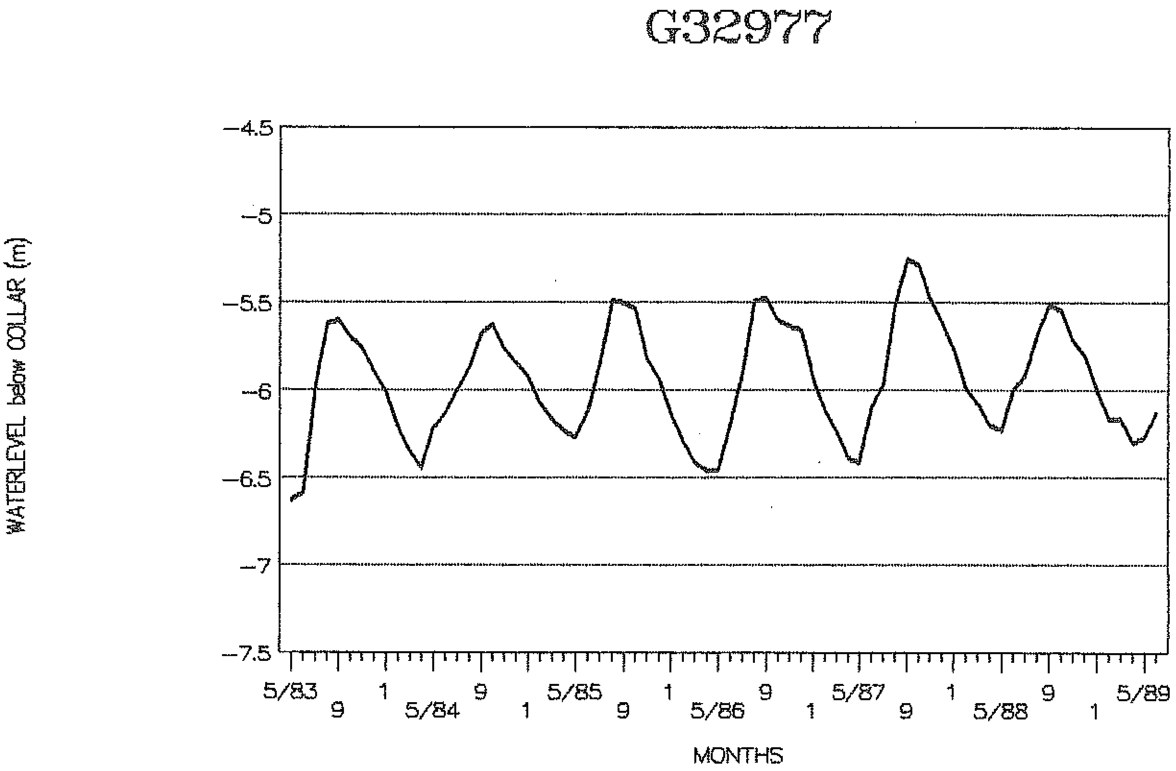
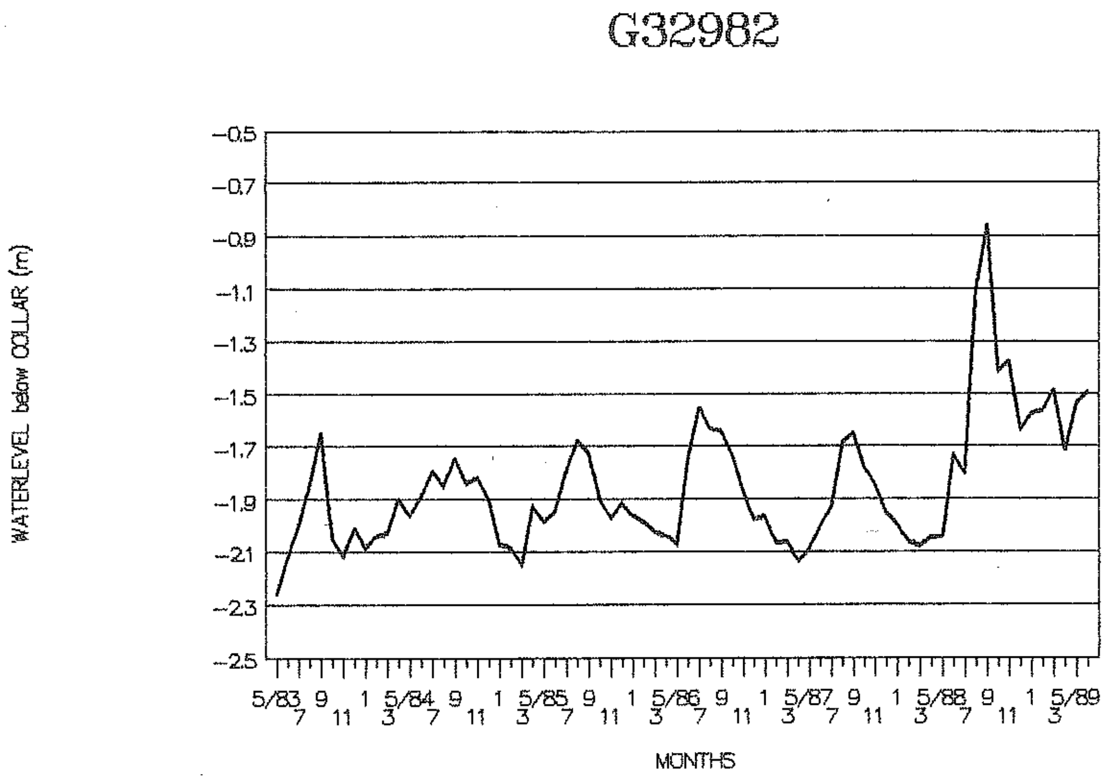


Figure 23: Hydrographs: observation boreholes G32976 & G32977



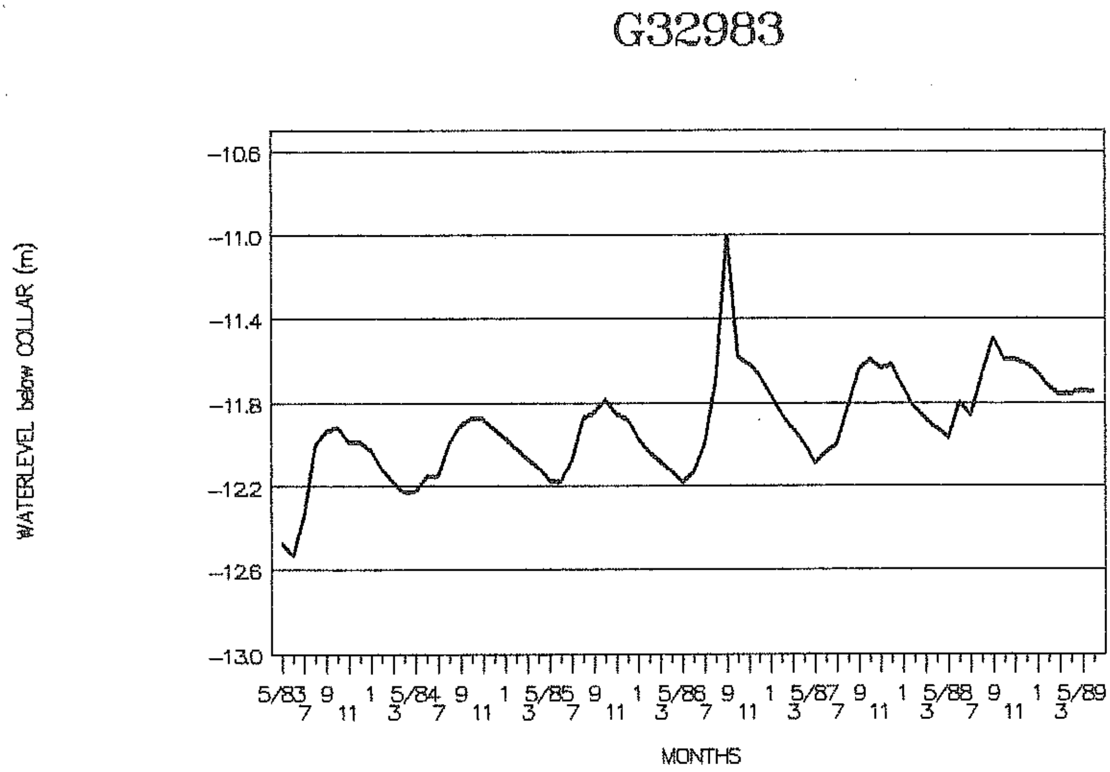
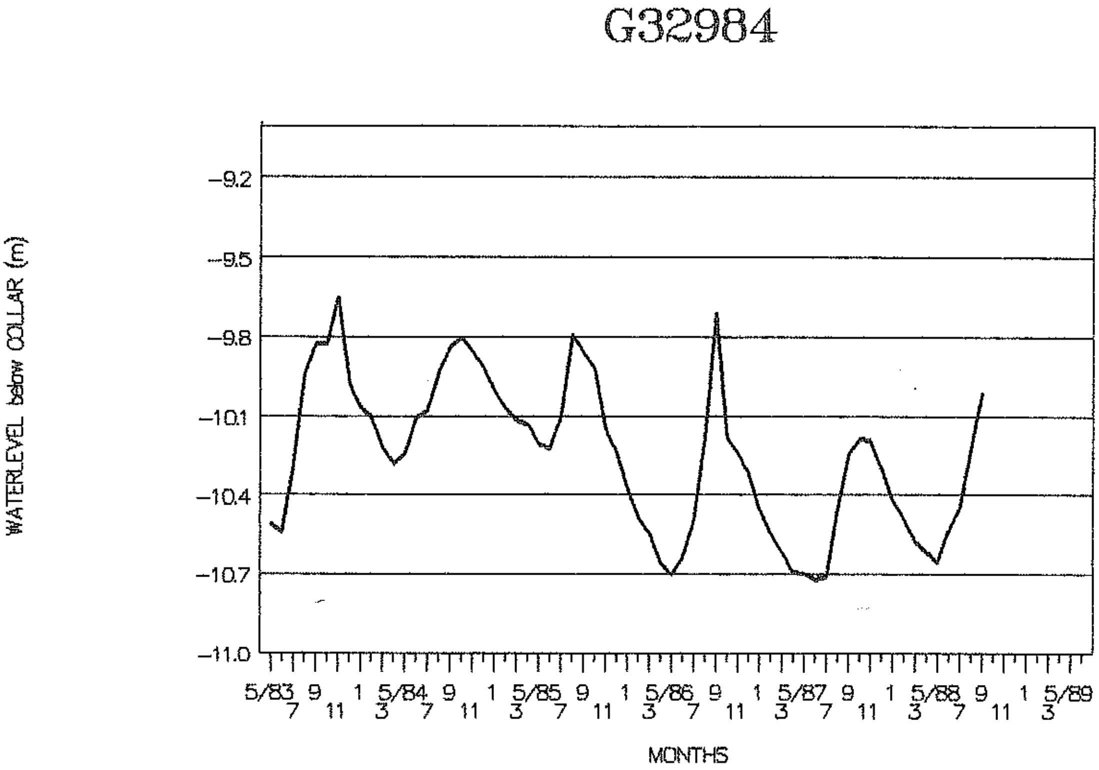


Figure 24: Hydrographs: observation boreholes G32982 & G32983



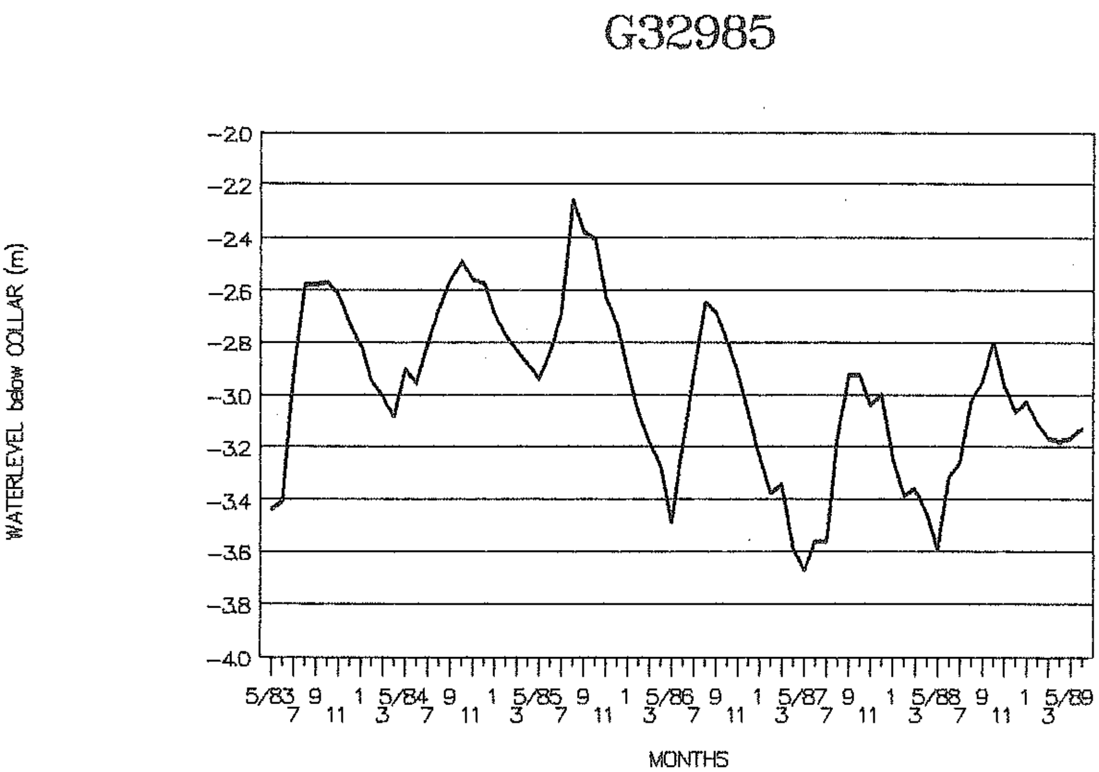
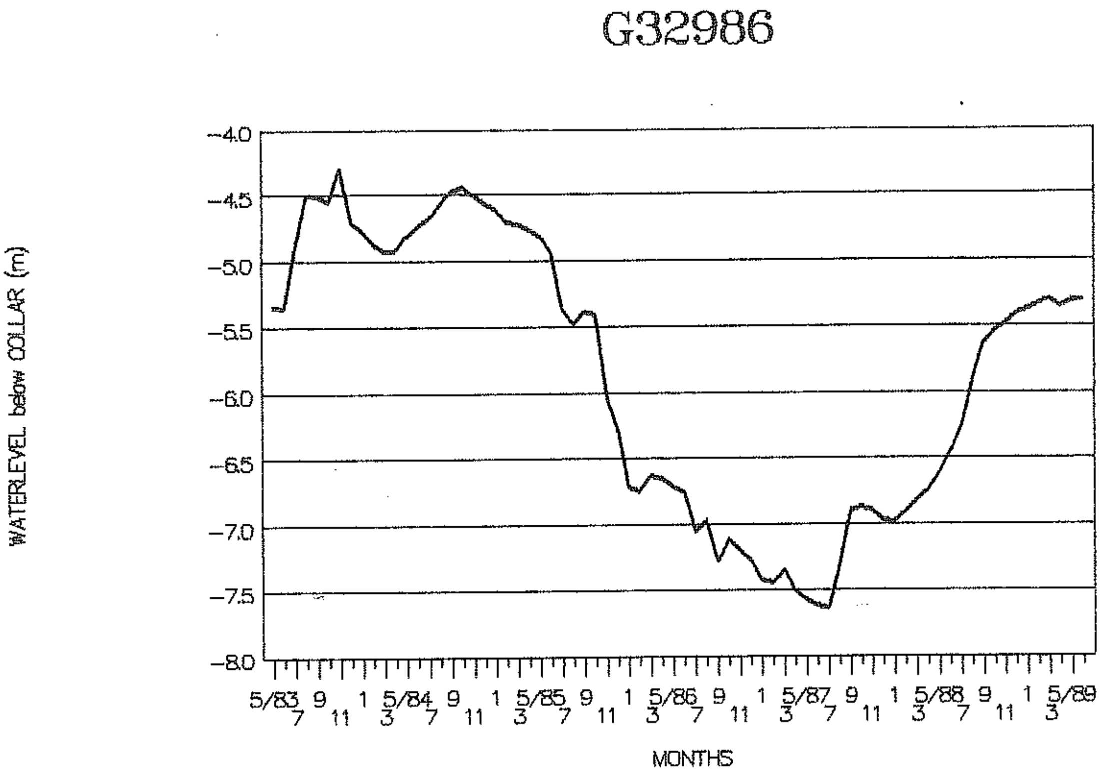


Figure 25: Hydrographs: observation boreholes G32984 & G32985



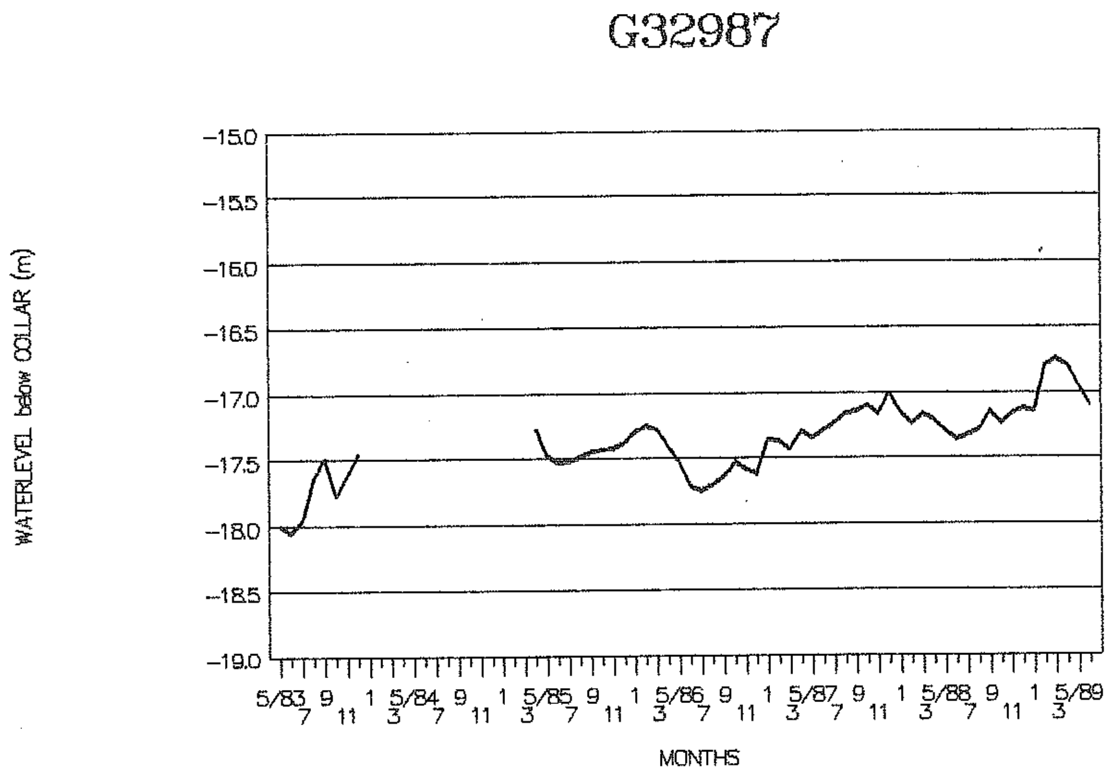
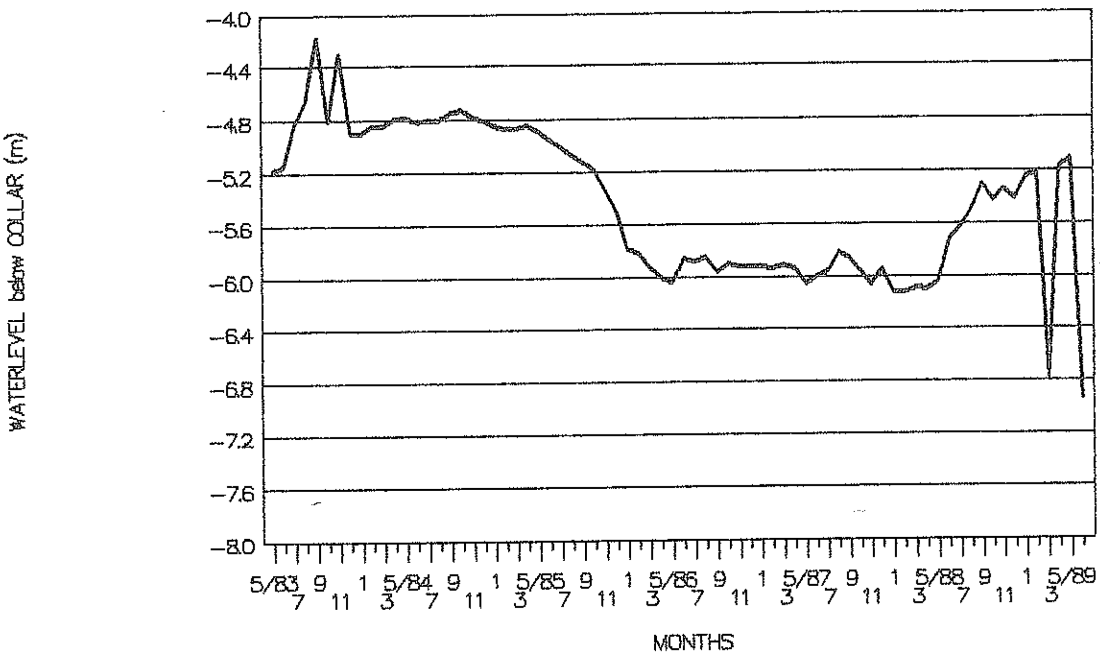


Figure 26: Hydrographs: observation boreholes G32986 & G32987

G32988



G2N110

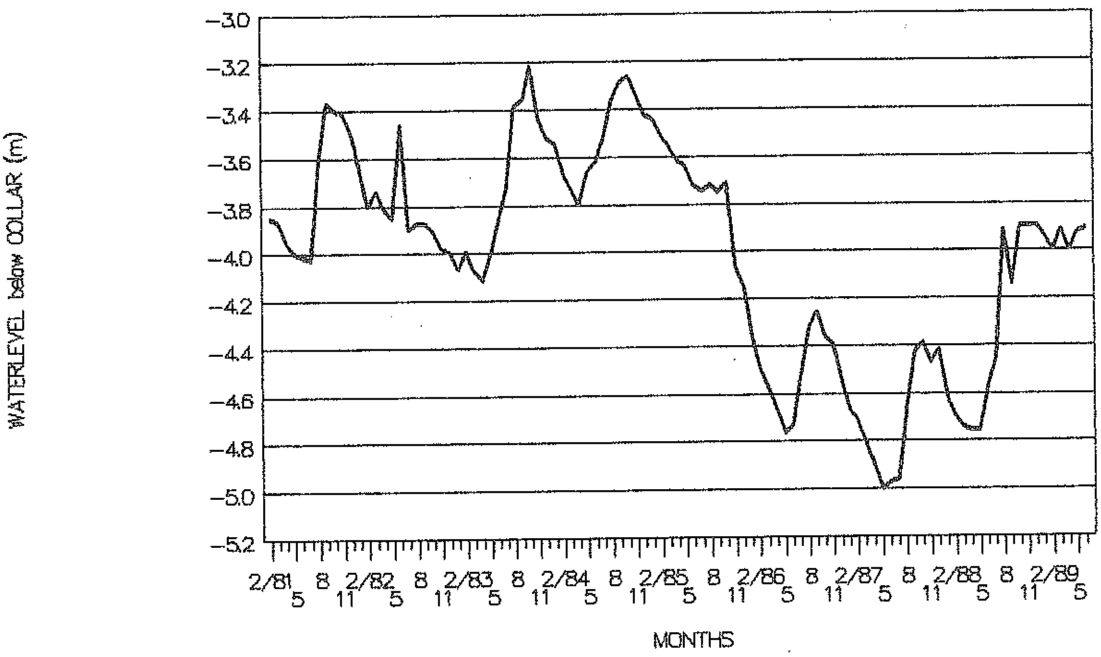


Figure 27: Hydrographs: observation boreholes G32988 & G2N110

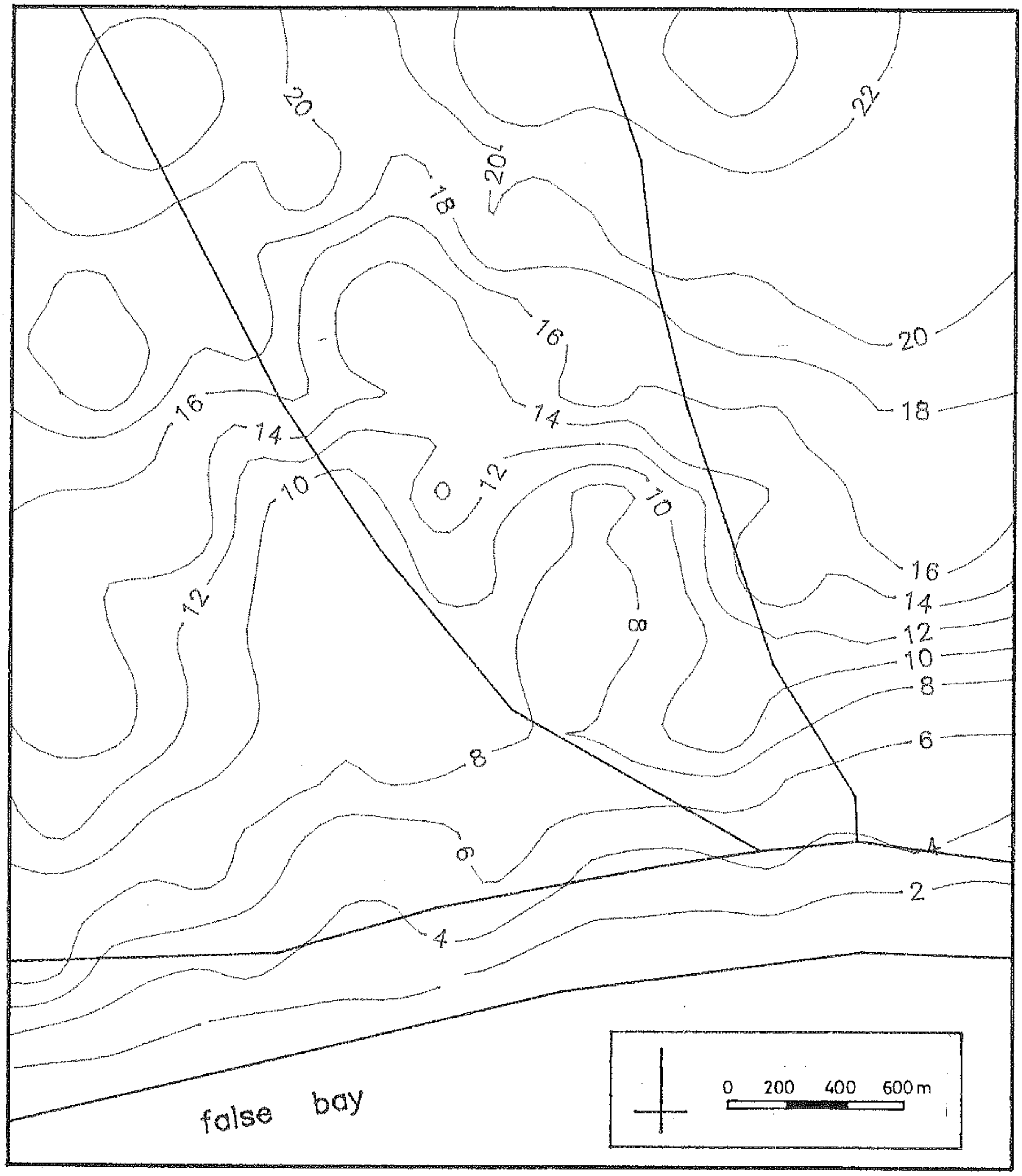


Figure 28: Water table configuration: May 1987

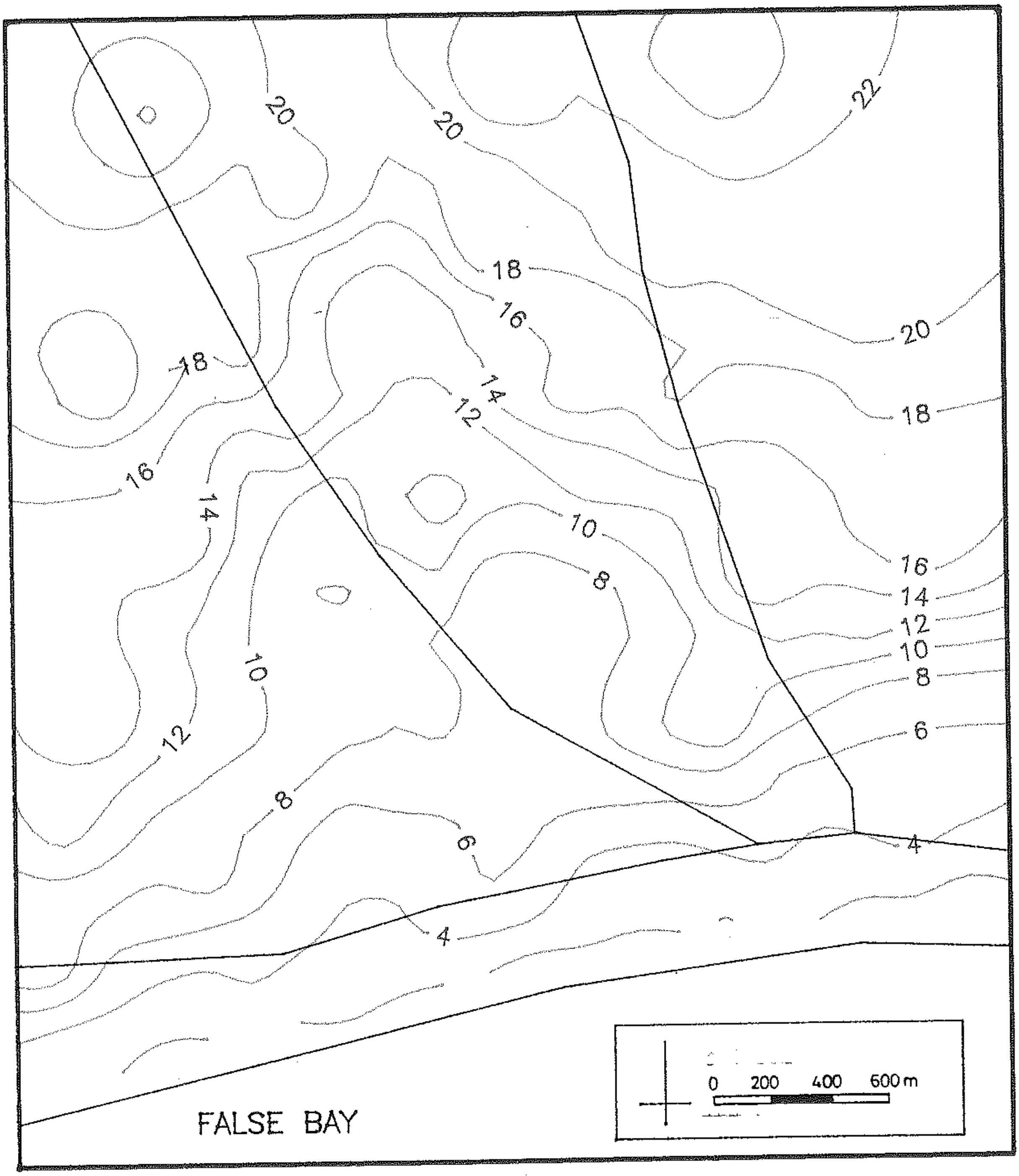


Figure 29: Water table configuration: April 1988

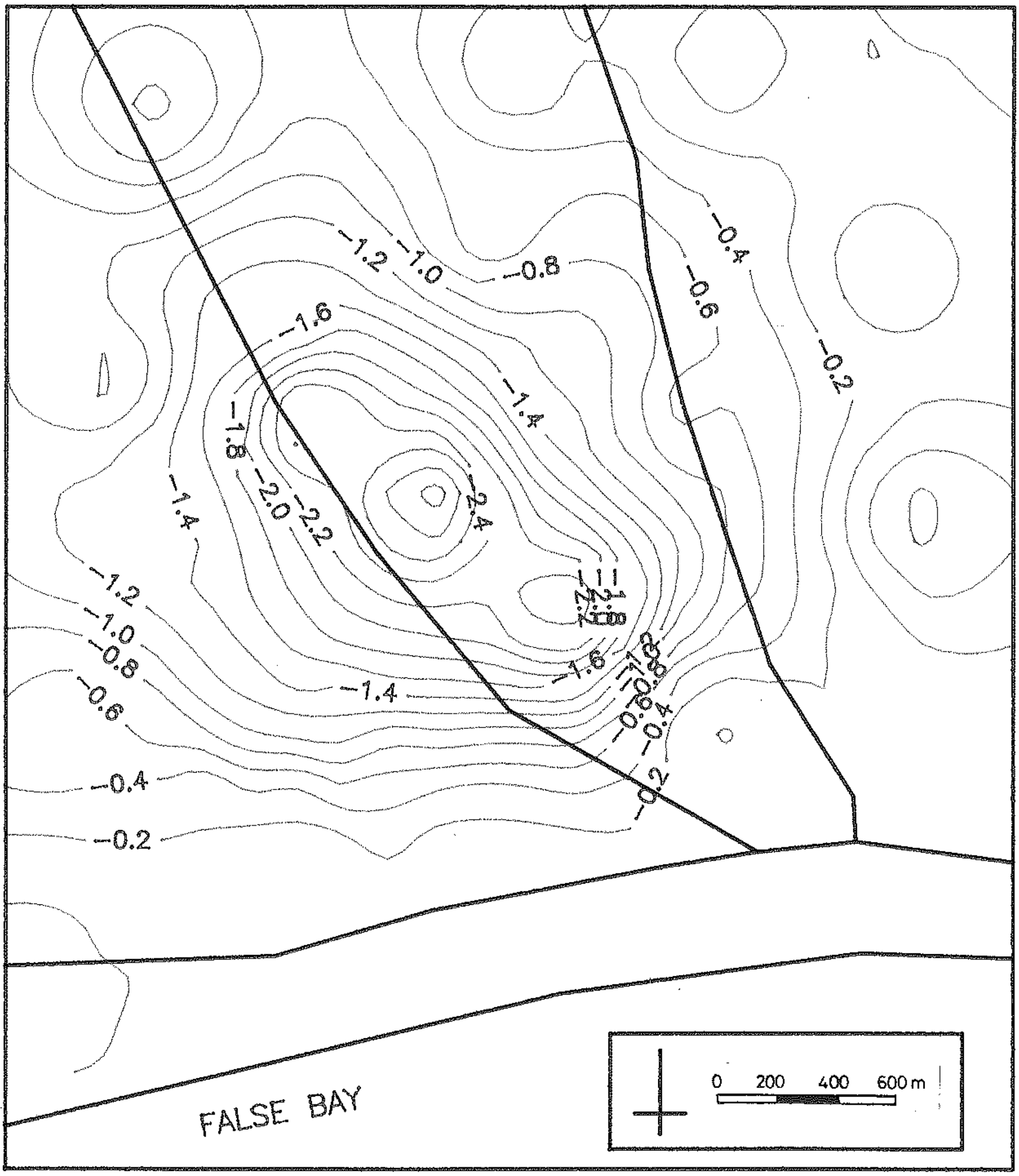


Figure 30: Drawdown configuration: May 1987 (summer)

4.2.3 Waterquality

The investigation of the groundwater quality in the study area was undertaken by the Hydrological Research Institute (HRI) for the Directorate: Geohydrology. It was decided at a meeting in August 1985 that the National Institute for Water Research (NIWR)(now Water Technology Division) of the CSIR in Bellville, funded by the Water Research Commission, would be responsible for the sampling of the 18 observation boreholes at a frequency of 4 times a year. The Cape Town City Engineer's Department undertook the sampling of the 10 production boreholes on a monthly basis. The latter organization and the HRI handled all chemical analyses.
In addition to the routine monitoring programme, samples were taken and analysed for microbiological and organic contamination by the NIWR and the HRI respectively.

The purpose of the study was to establish the ambient groundwater quality in the test area and to detect any possible changes in quality of the abstracted groundwater during the operation of the Scheme.

The data collection and analysis methods, statistical processing techniques, limitations and constraints and, most importantly, the results and findings of the quality study are described under separate cover by Edwards (1989). The more salient of Edwards' findings are transcribed and discussed in section 5.2 below.

4.2.4 Environment

As stated earlier one of the objectives of the Pilot Abstraction Scheme was to study the effect of large-scale groundwater withdrawal on the environment, in casu ground settlement in the abstraction area. Although it was generally anticipated that given the sandy subsurface no ground compaction or expansion was going to occur on dewatering, the Municipality as the responsible and accountable authority of Mitchells Plain required that the eventuality be covered if only to secure indemnification against claims.

The Survey Division of the Department of Water Affairs established and levelled a network of bench marks in the Pilot Scheme Area in March 1985. Bench marks were erected in the immediate vicinity of the production boreholes and with decreasing outward density throughout the Mitchells Plain urban area (Figure 31). Control levelling was subsequently carried out on three occasions. All survey data are included in table 11.

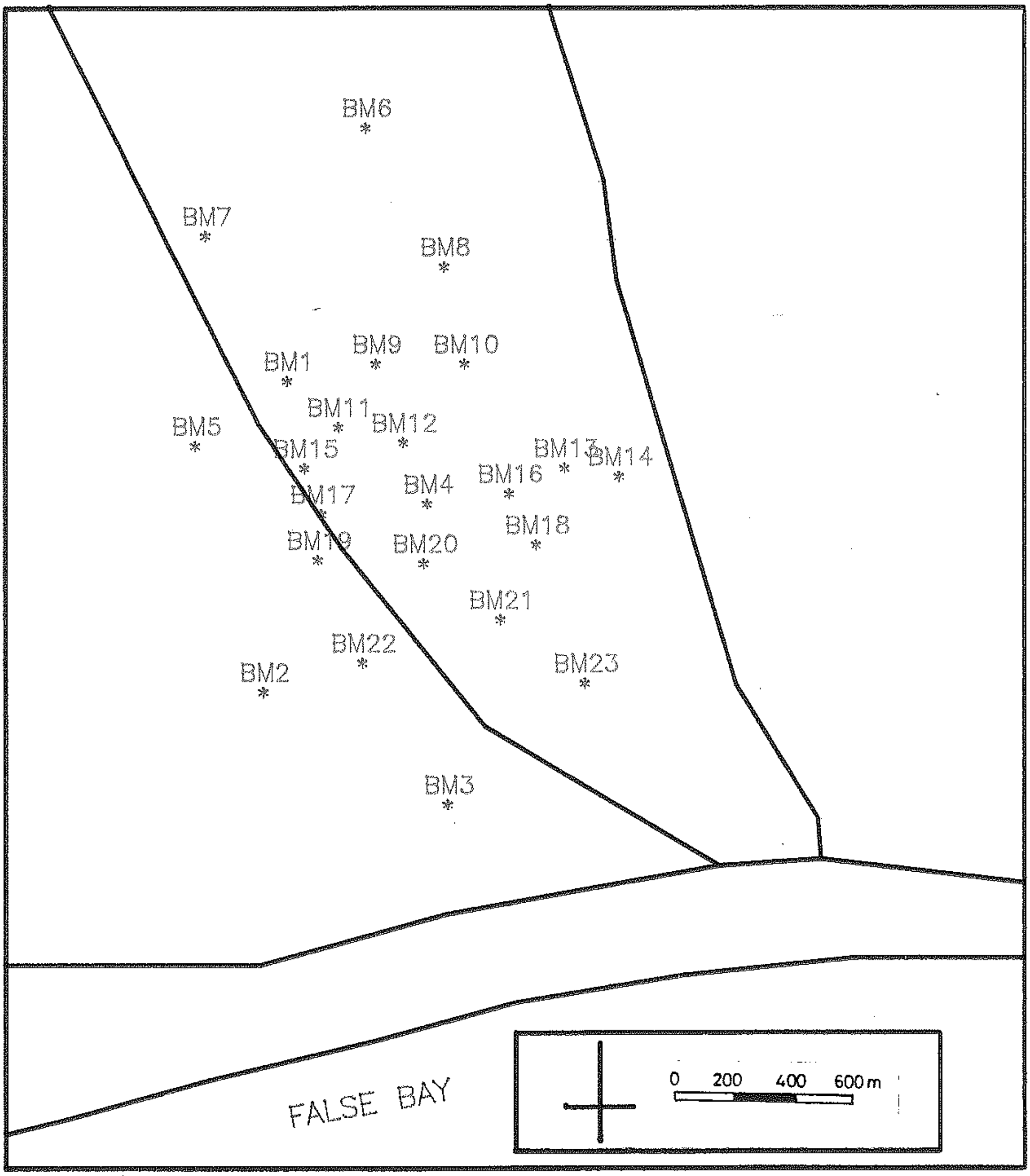


Figure 31: Location of the benchmark network

BENCH MARKS AT BOREHOLES

PEG NO	BOREHOLE	(1) 03/85	(2) 08/85	(3) 03/87	(4) 10/87	DIFFERENCE (4 - 1)	DIFFERENCE (3 - 1)	DIFFERENCE (4 - 2)	DIFFERENCE (4 - 3)	
BH1	632969	27.366	27.370	27.360	27.371	0.005	-0.006	0.001	0.011	
BH2	632981	REPLACED	22.906	22.899	22.907	-	-	0.001	0.008	
BH3	632978	18.622	18.625	18.616	18.624	0.002	-0.006	-0.001	0.008	
BH4	632979	23.133	23.130	REMOVED	-	-	-	-	-	
BH5	632966	26.200	26.206	26.193	26.205	0.005	-0.007	-0.001	0.012	
BH6	632990	21.872	21.882	21.868	21.876	0.004	-0.004	-0.006	0.008	
BH7	632965	21.745	21.744	21.742	21.748	0.003	-0.003	0.004	0.006	
BH8	632967	24.242	24.248	24.238	24.248	0.006	-0.004	0	0.010	
BH9	632963	20.580	20.593	20.576	20.583	0.003	-0.004	-0.01	0.007	
BH10	632968	23.175	23.187	23.173	23.180	0.005	-0.002	-0.007	0.007	
PERMANENT BENCH MARKS										
BM1		25.518	25.516	25.514	25.513	-0.005	-0.004	-0.003	-0.001	
BM2		20.767	20.766	REMOVED	-	-	-	-	-	
BM3		17.348	17.353	17.341	17.352	0.004	-0.007	-0.001	0.011	
BM4		42.794	42.809	42.795	42.810	0.016	0.001	0.001	0.015	
BM5		26.280	DESTROYED	-	-	-	-	-	-	
BM6		28.176	28.175	28.174	28.169	-0.007	-0.002	-0.006	-0.005	
BM7		28.551	28.550	28.546	28.548	-0.003	-0.005	-0.002	0.002	
BM8		26.213	26.216	26.205	26.210	-0.003	-0.008	-0.006	0.005	
BM9		25.268	25.273	25.264	25.274	0.006	-0.004	0.001	0.010	
BM10		23.484	23.489	23.481	23.488	0.004	-0.003	-0.001	0.007	
BM11		23.907	23.906	REMOVED	-	-	-	-	-	
BM12		25.643	25.648	25.639	25.648	0.005	-0.004	0	0.009	
BM13		21.393	21.403	21.391	21.401	0.008	-0.002	-0.002	0.010	
BM14		22.433	22.445	REMOVED	-	-	-	-	-	
BM15		23.608	23.606	23.579	23.578	-0.001	-	-	-0.001	REPLACED
BM16		24.320	24.328	24.319	24.332	0.012	-0.001	0.004	0.013	
BM17		23.201	23.199	23.199	23.200	-0.001	-0.002	0.001	0.001	
BM18		24.069	24.084	-	-	-	-	-	-	
BM19		REPLACED	21.265	21.259	DESTROYED	-	-	-	-	
BM20		20.017	20.023	20.014	DESTROYED	-	-0.003	-	-	
BM21		25.015	25.023	25.011	25.018	0.003	-0.004	-0.005	0.007	
BM22		22.396	22.397	22.369	MOVED	-	-	-	-	REPLACED
BM23		20.913	20.921	20.912	20.914	0.001	-0.001	-0.007	0.002	
MEAN DEVIATION / MARK						0.002	-0.002	-0.001	0.005	
STANDARD DEVIATION / MARK						0.004	0.002	0.003	0.005	

Table 11: Bench mark survey data

5 RESULTS OF THE PILOT ABSTRACTION STUDY

5.1 WATERTABLE BEHAVIOUR

Groundwater withdrawal over a period of 35 months at an average rate of 162 l/s from ten boreholes situated within 1 km² induced aquifer stress (= a statistical significant drawdown) over a maximum area of about 8,5 km². A cone of depression with a maximum diameter of 3,3 km and a maximum estimated depth at its centre of 4 m (individual depression cones about the abstraction points must be discounted) developed. Maximum drawdown occurred during May 1987 (Figure 30).
The cone of depression contracted cyclically to a minimum well after the winter recharge periods (usually in October). The combination of reduced evapotranspiration and recharge therefore exceeded abstraction during the wintertime. There is no evidence to suggest that the cone of depression at shutdown time was still expanding beyond the levels reached in the previous dry season.

Eight of the nineteen observation boreholes were left totally unaffected by the abstraction (G32970, G32972, G32973, G32974, G32977, G32982, G32983, and G32987). The effect on the waterlevel in two boreholes (G32975 and G32976) is inconclusive. The hydrographs of the former boreholes (e.g. G32974; Figure 22) have two features of hydrological interest in common:

(1) waterlevel variations are of a seasonal nature, ostensibly due to the seasonal nature of both recharge and evapo(transpi)ration

(2) the trend of the waterlevels, with the exception of boreholes G32975 and G32982 near the coast, is upward. The implication is that the pilot test took place during an above-average recharge cycle. Precipitation at D.F. Malan weather station was near (1984) or far above average (534 mm /year) from 1983 to 1987 (657, 532, 589, 571 and 651 mm) (Figure 32).

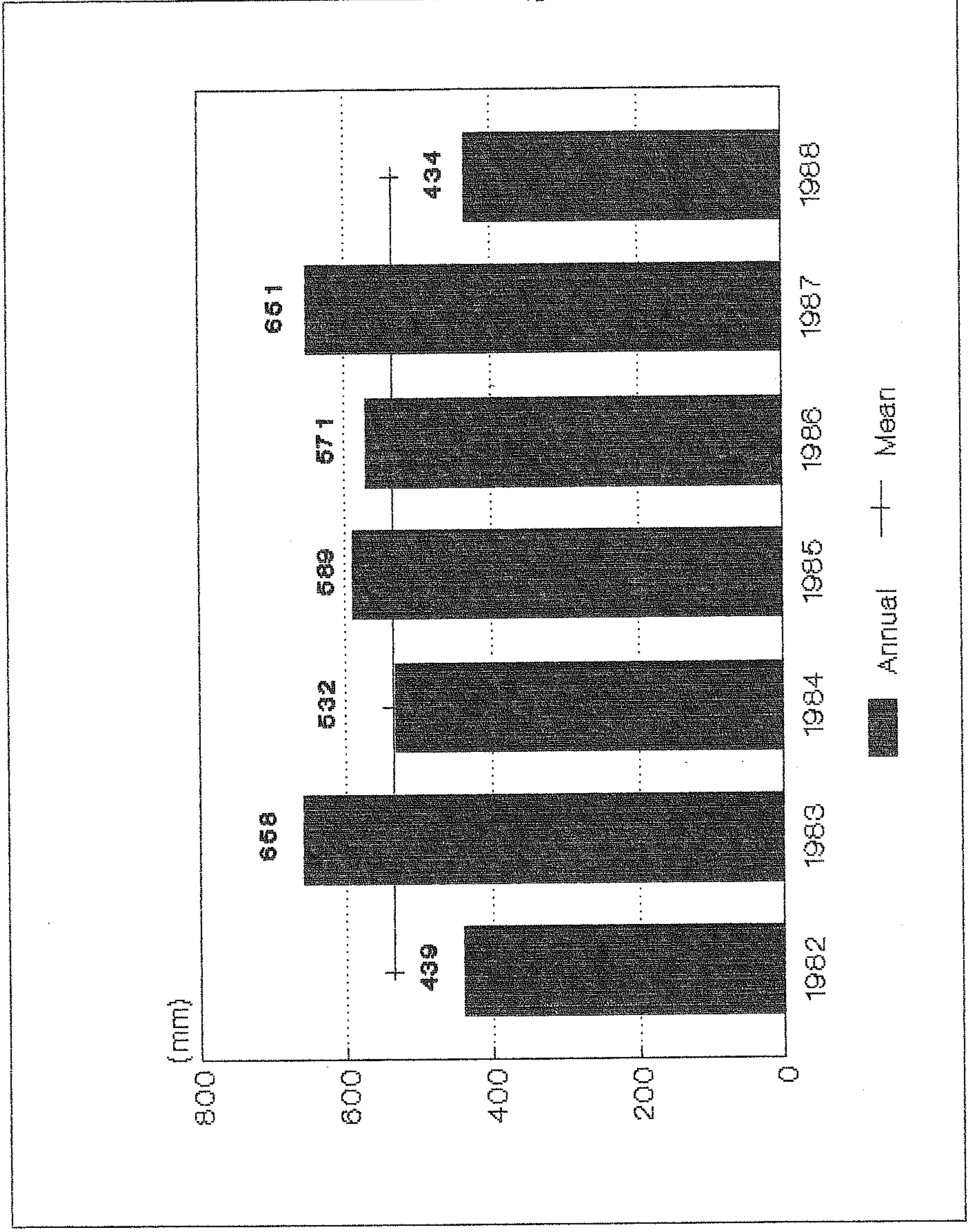


Figure 32: Annual rainfall for the period 1981-88 at D.F.Malan Airport

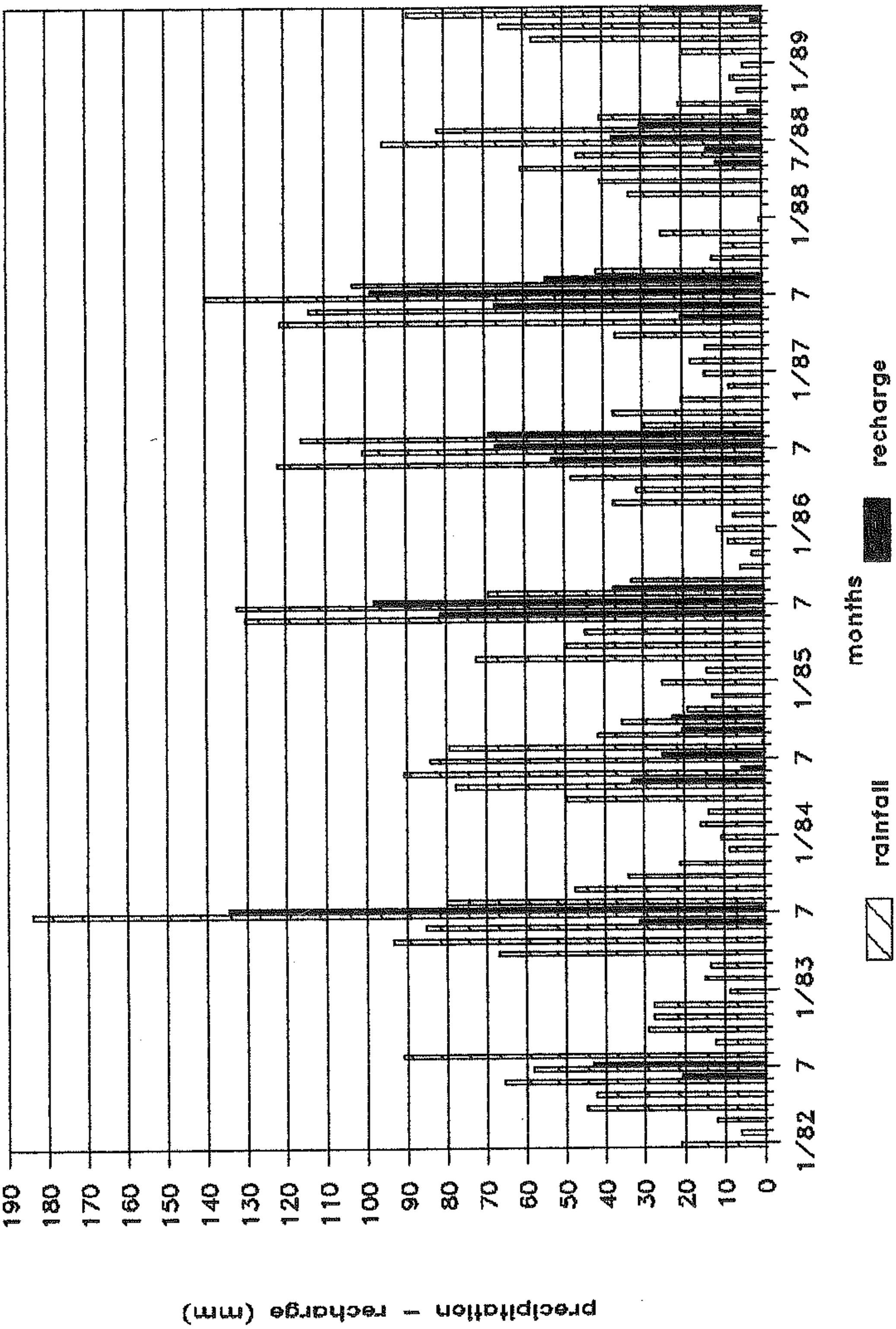


Figure 33: Composite plot showing the relationship between rainfall and recharge.

In addition, a composite plot showing monthly rainfall at D.F. Malan weather station and calculated groundwater recharge is included (Figure 33).

The observed regional watertable decline was not as large and extensive as expected for the given abstraction volume. Two obvious reasons can be advanced to explain the discrepancy:

(1) Favourable recharge conditions:

Evidence that higher than average recharge took place during the test period is available in the form of rising waterlevels along the periphery of the study area as mentioned earlier. The rises observed in boreholes G32972, G32973 and G32974, situated in open zones within a densily paved and roofed area to the east of the wellfield, may be a local rather than a regional phenomenon.
The net recharge as a percentage of total precipitation for a 100 mm sandy soil profile was calculated using the modified Penman method (Timmerman,1987a) and meteorological information of D.F. Malan Airport weather station:

1982	14.6%
1983	25.2%
1984	20.2%
1985	36.9%
1986	33.1%
1987	37.0%
1988	22.4%

The monthly rainfall and recharge patterns are shown in figures 34 and 35 below. The values are reckoned to be on the conservative side as a soil thickness of 100 mm is rather generous for the Cape Flats.
The validity of recharge values of a similar order of magnitude is now generally accepted for the Atlantis aquifer.

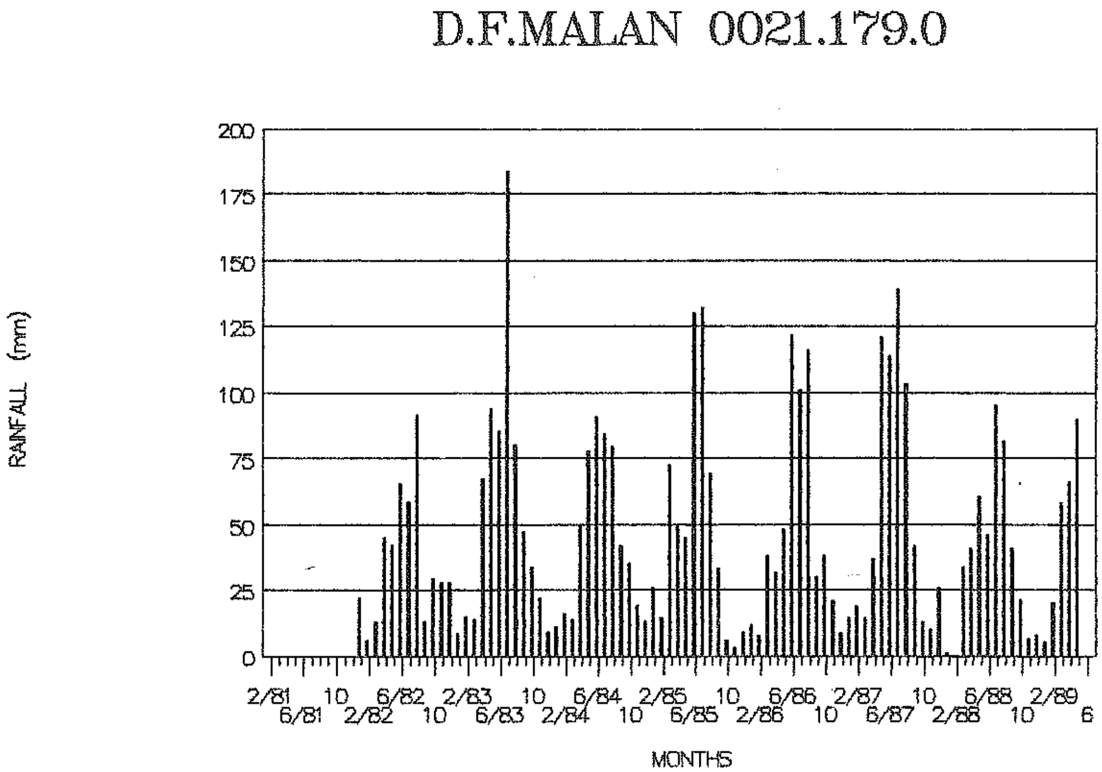
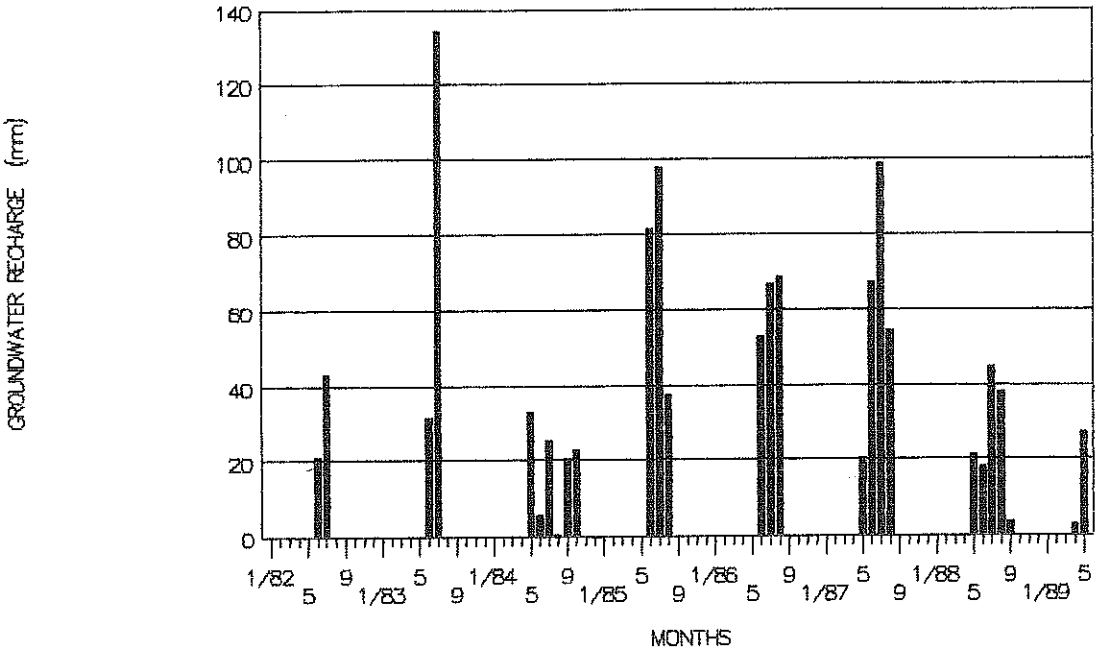


Figure 34: Monthly rainfall pattern at D.F.Malan Airport (1982- May 1989)

GROUNDWATER RECHARGE - 100 mm soil



GROUNDWATER RECHARGE - 50 mm soil

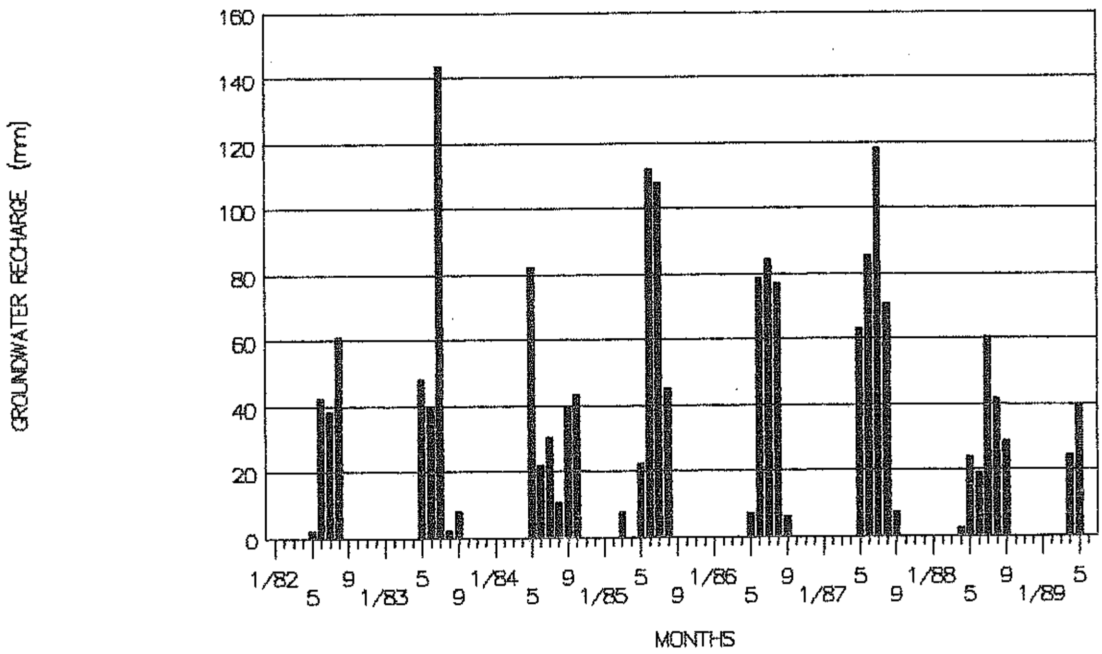


Figure 35: Calculated groundwater recharge (1982 - May 1989)

(2) Favourable storage conditions:

Evidence suggests that the effective porosity of the aquifer, more in particular the Springfontyn sands, is higher than generally accepted.
The mean specific yield value of 12% put forward by Gerber (1980) for the aquifer in the test area is probably an underestimate because of the effect of averaging aquifer and aquitard values.
As indicated in section 5.3 below, S-values between 10% and 40% were required in the mathematical model to obtain an acceptable simulation of watertable behaviour.
Specific yields obtained through tests for similar lithologies in the Atlantis aquifer are in the order of 25%.
Morris and Johnson (1967) put forward a value of the order of 30% for well sorted and rounded, clean fine to medium sand.

Leakage from the Sewage Works maturation ponds and upward leakage from a fractured Malmesbury aquifer may have contributed to the subdued drawdown.

Evidence for artificial recharge is irrefutable. The water quality study (section 5.2) has identified the Sewage Works as a source of groundwater contamination and pollution.
Shortly after completion of the test run, the waterlevels in boreholes G32975 and G32982 rose significantly after new maturation ponds just north of G32975 were taken into use (Figures 22 and 24).

To summarize, it can said that an abstraction rate of 162 l/s for the wellfield appears to be sustainable from a water balance point of view under the favourable recharge conditions prevailing during the test period. The watertable decline was kept far above the level required to induce seawater intrusion.

That the test run took place in less than stringent conditions underlines the inherent risk and the limited value of such exercise. That no provision was made to try and quantify leakage from impoundments and that the Malmesbury bedrock was considered impervious on account of evidence from just a few boreholes here and at Atlantis, were serious oversights.
Despite the above shortcomings it appears that there is room to extend the pilot wellfield. Such extension would have to take place towards the west (beyond the Sewage Works) and north-west of the pilot wellfield where a considerable thickness of highly permeable Springfontyn sands occurs. It is put forward that, under normal hydrological conditions, 10000 Ml per year could be produced from the high transmissivity zone on which the Sewage Works is located by duplicating the Mitchells Plain wellfield immediately west of the Sewage Works.

5.2 WATER QUALITY

5.2.1 Introduction

The contents of the following three subsections is drawn from the specialist groundwater quality report of Edwards (1989). For the sake of completeness and continuity of this report, it was thought that the inclusion of a synthesis of all relevant findings of the groundwater quality study was appropriate.

5.2.2 Spatial variation in groundwater quality

The hydrochemical conditions in the aquifer over the three year test period are summarized in table 12. The distribution of the general groundwater quality is illustrated in Figure 36.
Large ranges in most water quality variables were observed and are ascribed to spurious data, changes in concentration with time and the hydraulic and lithological heterogeneity of the aquifer system on both micro and macro scale.

Of course the values in table 12 do not reflect the quality and chemical characteristics of the water pumped during the test. A comparison of the median values for TDS of the production, observation and all boreholes combined illustrates the point:

Table 12: Statistical summary of water quality variables - all data

Determinant	Maximum	Minimum	Mean	Median
pH (*)	8,5	5,8	7,82	7,8
Conductivity (mS/m)	142	33	89,1	89,5
TDS	1161	218	630	633
Sodium Na	113	22	62,9	61
Calcium Ca	230	16	102,3	103
Magnesium Mg	33	4	12,03	12
Potassium K	8,2	0,6	2,31	1,9
Sulphate SO4	326	0	51,95	45
Chloride Cl	211	17	105,2	102
Fluoride F	3	0	0,5	0,1
Nitrate NO3	19,4	0	2,4	1,53
Silica SiO2	17,5	1	4,25	4,1
Ammonia NH4	31,89	0	1,05	0,12
Phosphate PO4	1,35	0	0,043	0,011
Total Phosphorus TP	1,78	0	0,102	0,03
Dissolved Organic Carbon DOC	7,7	0	2,41	2
Turbidity (NTU)	87	0,1	7,58	4
Total Alkalinity TAL	386	61	225,6	226
Hardness	705	68	305	309

(*) geometric mean for pH

all values in mg/l except where otherwise indicated

SOURCE: Edwards (1989)

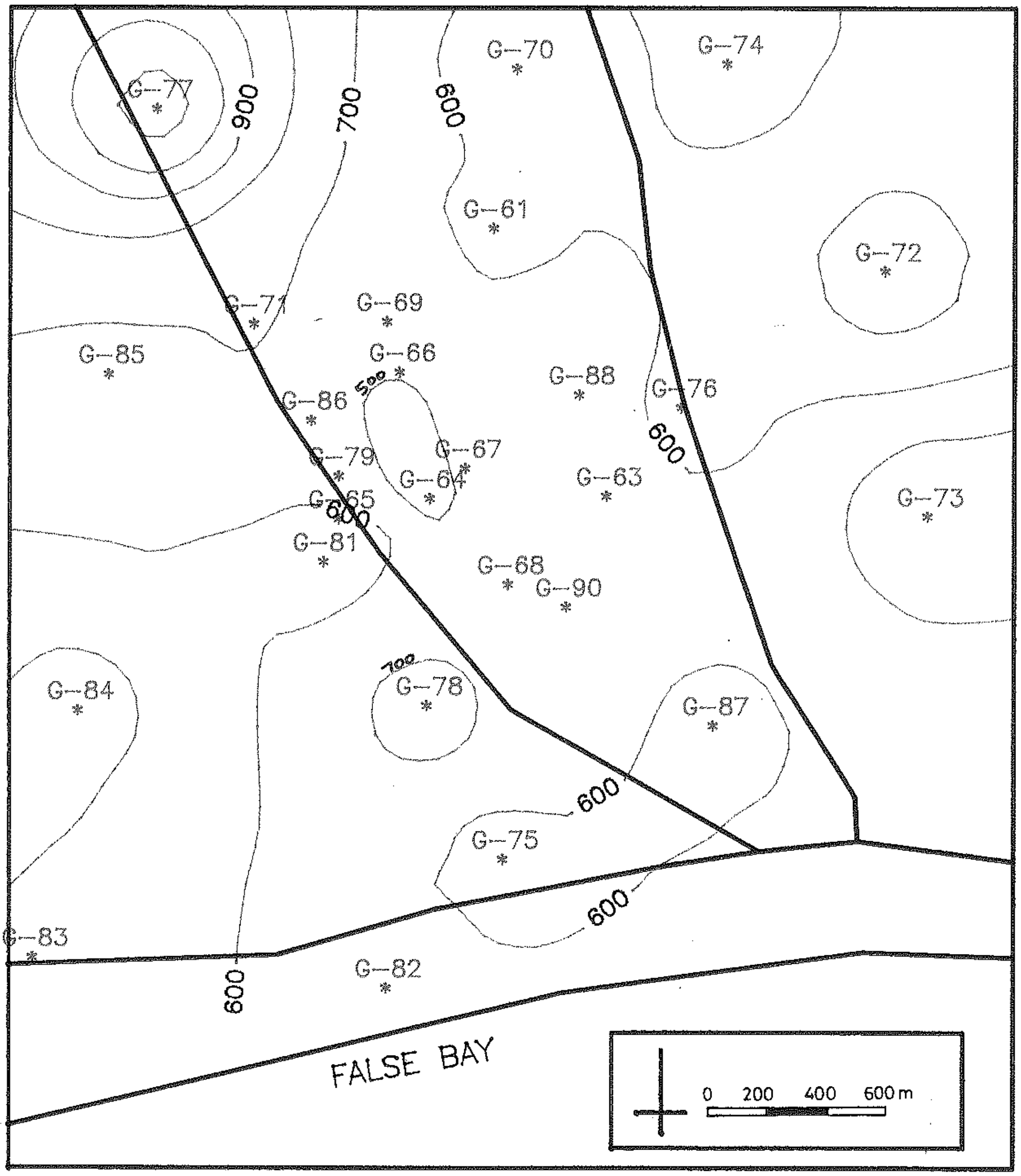


Figure 36: Groundwater quality distribution: median TDS-values (mg/l)

production boreholes: from 566 mg/l (G32981) to 763 mg/l (G32978)
observation boreholes: from 218 mg/l (G32970) to 1161 mg/l (G32977)
all boreholes: from 278 mg/l to 887 mg/l.

The median TDS-content of homogenized wellfield water taken at a fictitious reservoir inlet was 639 mg/l.

Other deductions that were made with respect to the spatial variation of the groundwater quality are:

- No evidence of contamination or intrusion of the groundwater body by saline (sea)water was obtained;

- The values for TDS, Ca, Mg, sulphate, and silica at the upper end of the respective determinant scales in table 12 were usually obtained from borehole G32977, situated just south of Philippi (Figure 4) and are in line with the status of groundwater quality in that part of the Cape Flats. The deleterious effect of large scale irrigation with groundwater over the last few decades in this historic farming area has been reported and described by Bertram (1989).

- Relatively high concentrations of potassium, phosphate, dissolved organic carbon, Kjeldahl nitrogen and relatively high UV absorbance have been noted in borehole G32978. The borehole is situated down gradient of the Sewage Works and it is suggested that the contamination is derived from leakage of the maturation ponds and canals.

- Microbiological contamination occurs in the northern and north-eastern section of the study area (G32970, G32971, G32973 & G32977).

- Consistently high THM formation potentials were found in boreholes G32977 south of the agricultural area and G32978 down gradient of the Sewage Works.

5.2.3 Changes in groundwater quality with time

Only data from the production boreholes were analysed. Too few data points and too much natural fluctuations made a study of quality changes in the observation boreholes rather meaningless.

No seasonal variations in quality variables were observed. This confirms Henzen's findings (Henzen, 1973). It must be added though that detecting any such changes would in any event be difficult, because pumping homogenises water abstracted from different horizons and hydrogeological units.

A TDS-decrease in all pumped boreholes except G32981 was noticed. A decrease in the sodium and chloride content of consecutive samples of seven boreholes was found.
The sulphate concentration increased in boreholes G32967,G32978 and G32981, but decreased in G32965, G32966 and G32990. Large fluctuations in sulphate concentration were however noticed.
Significant increases in nitrate content were observed in G32963 and G32967.

Concentrations of Kjeldahl N, total phosphorus and ammonia moved slightly up as pumping progressed in borehole 32981. Rather dramatic increases of these constituents occurred in production borehole G32978.
Otherwise, any time changes of chemical variables were of a spurious or inconclusive nature.

5.2.4 Water quality types

Groundwater in the Pilot Scheme study area has been characterized as follows:

- the calcium-bicarbonate type dominates, but calcium/sodium-bicarbonate and calcium/sodium-chloride types also occur;

- the water is generally fresh with median TDS concentrations not exceeding 800 mg/l with the exception of G32977;

- the water is hard to very hard;

- water from boreholes in the western portion of the wellfield is characterized by a high chloride content, while sulphates predominate in the northern sector and bicarbonate ions are dominant in the eastern part;

- water types are stable over the period 1985 to 1988, with the exception of borehole G32978. Increases in potassium and sodium and a concomitant decrease in calcium concentration result in the composition of the water from G32978 moving away from that of the other production boreholes and of its original composition.

5.2.5 Utilization of the groundwater

Water quality has been compared with raw and drinking water standards (Kempster & Smith, 1985). The following observations were made:

(1) Overall the groundwater is of a quality acceptable for potable use, provided the water bodies tapped by boreholes G32977 and G32978 are shunned;

(2) Production borehole G32978 has concentrations of ammonia, phosphate, total phosphate and turbidity values that exceed recommended, maximum permissible and crisis limits for drinking water;

(3) A number of production boreholes show high turbidity values;

(4) All production boreholes have median values for TDS, conductivity and alkalinity which exceed the recommended limits but stay within the maximum permissible limits;

(5) Except in very few cases, the concentrations of trace metals and metal-

loids stay well within the limits for drinking water;

(6) Polluted groundwater occurs in the north-western sector of the study area: observation borehole G32977 situated immediately south of the Philippi irrigation area gives water with a salinity in excess of 1000 mg/l, a high calcium and sulphate content, a high THM formation potential, a high total coliform count and above-average traces of boron and iron.

5.3 GROUNDWATER FLOW MODELLING

5.3.1 Introduction

Before leaving the service of the Directorate of Geohydrology in 1987 Mr. L. Timmerman attempted to simulate the groundwater flow pattern under stress conditions in the study area. Firstly, he adapted the finite difference model of Boontra and De Ridder (1981) for three dimensional problems (Timmerman, 1987b), then calibrated the model using historical data for the period January 1985 - December 1986 and ended by simulating flow conditions for 5 and 10 year periods hence under two different wellfield abstraction rates.
The model is briefly described in the following subsection. Subsections thereafter deal with the calibration procedures, the production simulation runs and the salient points that emerged from the modelling exercise. The section also includes a discussion of the value of this modelling exercise and the merits of modelling flow in the Cape Flats aquifer in general.

It must be remembered that what follows, is only a condensed version of Mr. Timmerman's concept report.

5.3.2 Description of the model

Geometry of the reservoir:

The complex geohydrological set-up of the pilot scheme area was brought back to a three layered system which takes all seepage flows into account.

Layer 1, the top layer, includes the calcareous sediments of the Witzand and Langebaan Limestone Members. It is considered to be an aquitard. Wherever the calcareous sediments are absent, similar hydraulic conductivity values were used for layers 1 and 2.
Layer 2 is the aquifer sensu strictu. It consists of Springfontyn sands and locally of Varswater sediments.
Layer 3, a lower aquitard, is made up of clayey Varswater sediments.

Boundary conditions:

Lateral boundaries: north = head controlled and fixed at 27 m a.m.s.l;
south = head controlled and fixed at 0 m a.m.s.l;
west & east = zero flow (coincide with regional flow lines);

The base of the aquifer (Malmesbury metasediments) is considered an impermeable (zero flow) boundary, while the upper boundary is formed by the watertable.

Recharge:

The recharge data are based on the calculation of the daily potential evapotranspiration, derived with the modified Penman method combined with a soil water balance (Timmerman, 1987).
Precipitation in 1985 and 1986 was above-average, resulting in above-average recharge figures and a rising watertable.

Hydraulic parameters:

The hydraulic parameters obtained in the pre-1980 experimentation period by Gerber and others were judged to be generally invalid, unreliable and unrepresentative for the specific study area. The geological logs of the pilot scheme boreholes were compared in detail with logs from West Coast boreholes with similar lithology and sedimentology and to whom reliable

hydraulic parameters were previously attached. The parameters were adjusted through trial and error during the calibration run until a match between the calculated and observed waterlevels was obtained.
The parameter ranges that ultimately produced the most acceptable results are given below to illustrate the hydraulic complexity of the Cape Flats aquifer.

k_H of layer 1 = 0 - 19 m/day
k_H of layer 2 = 0 - 19 m/day
k_H of layer 3 = 0 - 4 m/day
k_V between layers 1 and 2 = 0.5 - 9 m/day
k_V between layers 2 and 3 = 0.5 - 2 m/day
S of layer 1 = 10 - 40 %
S of layer 2 = 2 - 5 %
S of layer 3 = 0.7 - 1 %

5.3.3 Calibration

The model was calibrated using waterlevel data collected between January 1985 and December 1987. The first five months of calibration run therefore involved quasi-equilibrium conditions. An average wellfield abstraction rate of 130 l/s was used during the remaining period.
A number of problems hampered the calibration process:

- the discrepancy between the measured waterlevels in the production boreholes and the calculated average waterlevels in the nodes where abstraction takes place; the waterlevels of nearby observation boreholes had to be used;
- insufficient observation boreholes, especially along the northern and eastern boundaries necessitated a large dose of extrapolation;
- recharge in the northern and eastern parts of the modelled area was overestimated as recharge through clayey, calcareous soils is lower than through sandy soils. Evaporation from these soils was not accommodated.

5.3.4 Production runs

The input variables of the second calibration year were used in the production runs. Above-average recharge conditions are therefore built into the final results.

Run 1:

Abstraction at a rate of 130 l/s (about 4000 Ml/year) using the 10 existing boreholes.

The watertable configurations after 5 and 10 years pumping is shown in figure 37 and 38 respectively.

After 10 years pumping the largest drawdown (about 5 m) is recorded in the vicinity of boreholes G32964 and G32967. Very little additional drawdown is generated until equilibrium conditions are reached after 25 years. The cone of depression merely widens while the watertable stabilises at about 7.5 m a.m.s.l. in the centre of the wellfield. Seawater intrusion is not an issue at the given pumping rate.

Features of interest on the water balance side are:

- inflow through the northern boundary increases from 400 to 500 Ml/annum;
- storage decreases by about 120 Ml in the process;
- recharge is (taken) constant at 5700 Ml/year;
- outflow to the sea decreases from 2500 Ml/year to 2100 Ml/year.

Run 2:

Abstraction at a rate of 300 l/s (about 9700 Ml/year) using 18 boreholes with average individual yields. Most additional fictitious boreholes were positioned to the north and west of the actual wellfield.

A deep depression cone with a vertex at -1.3m (a.m.s.l.) develops in the vicinity of G32965 and G32981. Clearly, a rate of 300 l/s cannot be maintained indefinitely without intrusion of seawater into the aquifer.

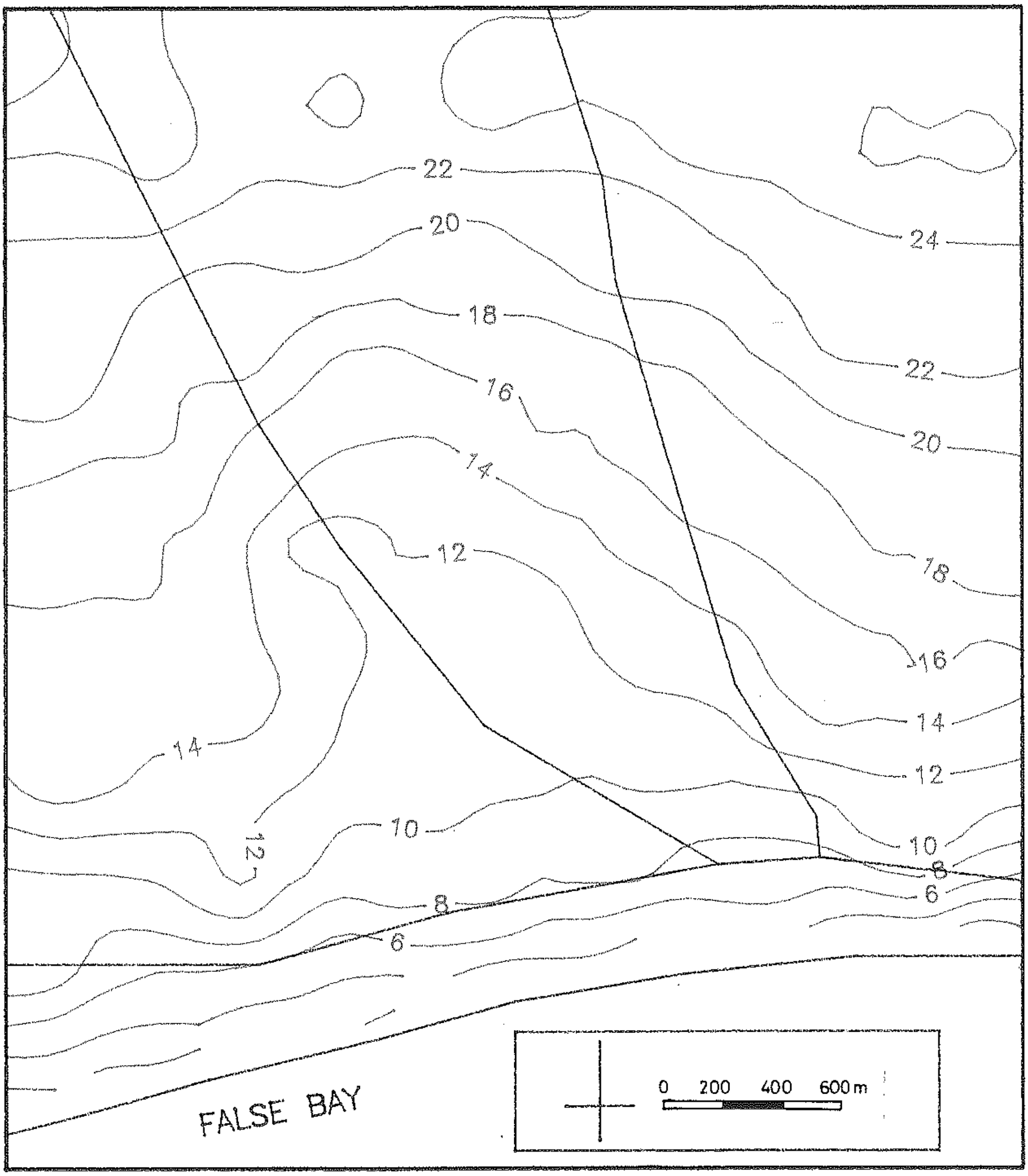


Figure 37: Production simulation run 1: watertable configuration after 5 years of pumping at 130 l/s

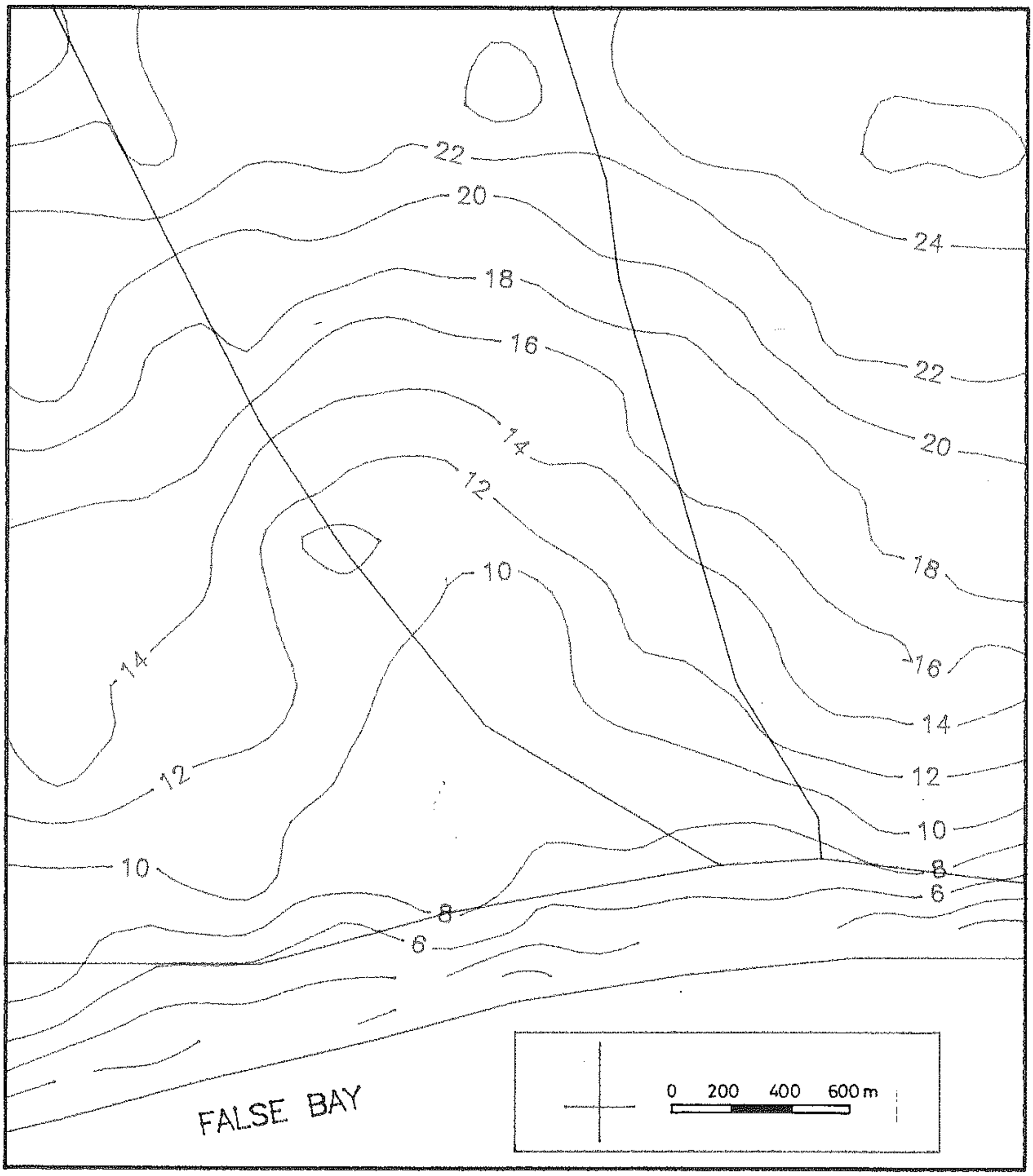


Figure 38: Production simulation run 1: watertable configuration after 10 years of pumping at 130 l/s

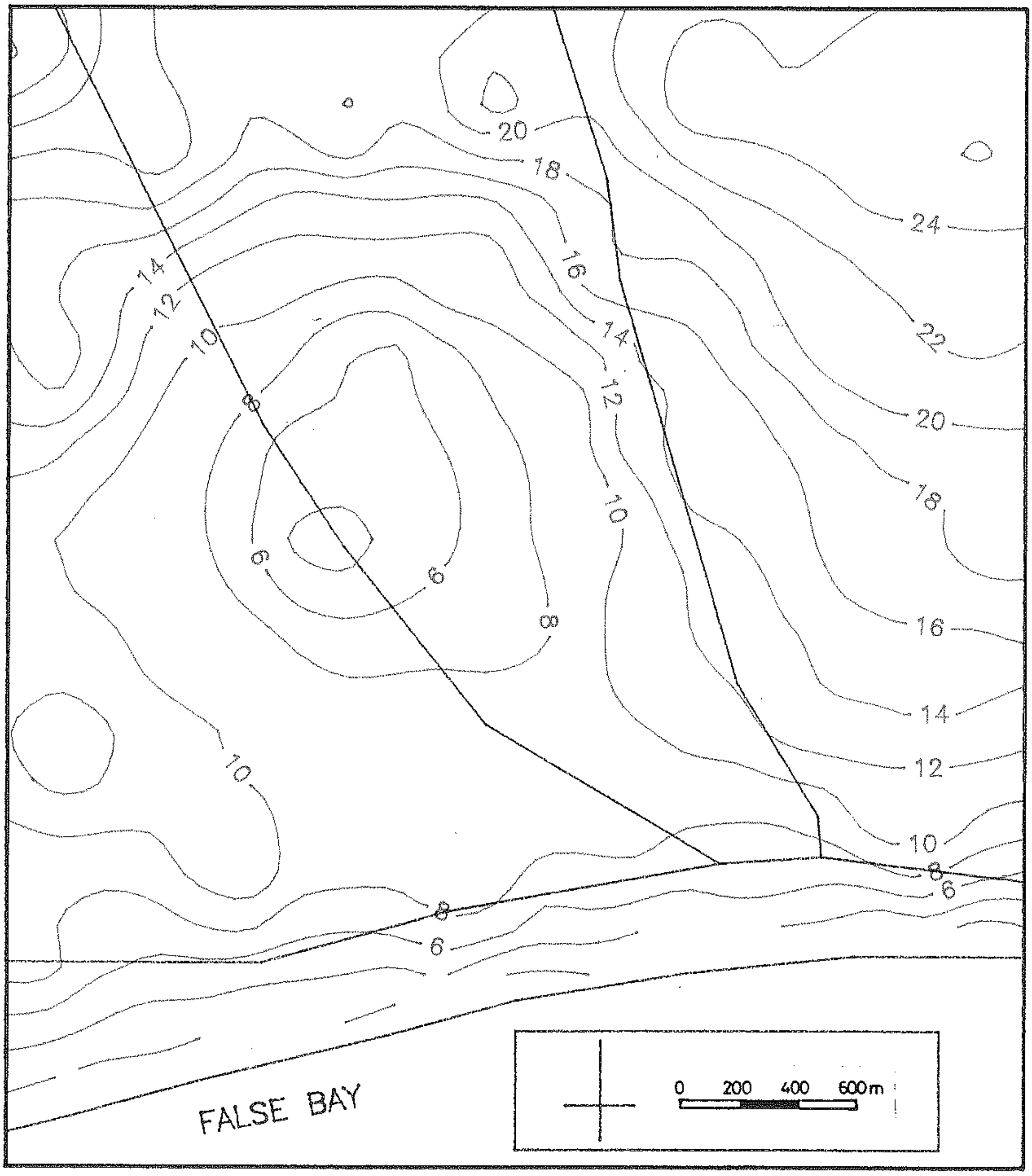


Figure 39: Production simulation run 2: watertable configuration after 4 years pumping at 300 l/s

As from the fourth year the drawdown reaches the western boundary of the study area and increasingly large errors are generated in the calculations. The simulation and resultant water balances figures are therefore unacceptable.

The watertable configuration after a four year pumping period is shown in figure 39.

5.3.5 Discussion: the value of modelling

While the modelling fraternity will no doubt scoff at the mathematical tools and physical framework used in the exercise and argue that much better could have been done with more advanced methods and techniques, it must be said that it was never the intention to try and predict aquifer behaviour in absolute terms, but rather to check and validate the available geohydrological data and certain components of the groundwater balance.

Let us look at the uphill battle any mathematical modelling tool, and for that matter modeller, would have faced under the circumstances.

It is old news that the usefulness of any model depends on its ability to accurately reflect the behaviour of the system being considered. A good predictive groundwater model must incorporate the important aquifer features affecting flow:

the hydraulic properties of the porous medium,
the flow boundaries,
the initial and boundary conditions, and
the inputs and outputs from the system.

If an individual set of features, for instance recharge, is missing or is suspect, the model can be manipulated to ensure a satisfactory outcome. If several aquifer features are of dubious reliability and accuracy, the outcome is an set of permutations with no practical value (garbage in, garbage out).

The shortcomings that hampered the simulation attempt and would have hampered any modelling attempt using different tools, are easily identified:

* insufficient data points, i.e. waterlevels, hydraulic properties,...;
* the hydraulic properties for the available data points were at best educated guesses;
* the necessity to introduce artificial no-flow boundaries: if the modelled area is kept too small, errors are soon introduced by flow deflection, if too large, errors are introduced through lack of data points;
* the reliability of recharge input, more specifically net recharge as it was impossible to mathematically manipulate evaporation from the watertable due to the lack of accurate waterlevel and hydraulic data;
* the " a priori" exclusion of the bedrock from the flow system;
* leakage from the Sewage Works maturation ponds was not incorporated. To quantify this feature within the given unreliable and incomplete hydrogeological framework would have been impossible.

In reflection, no attempt to develop a groundwater model with predictive value could have succeeded under the given circumstances. This finding is not surprising. An acceptable groundwater model has not yet been developed for the Atlantis aquifer against much shorter odds: a four times denser data point cover, a 10-year waterlevel record of transient flow and a much more detailed hydrogeological framework. Where several modelling exercises have succeeded in the Atlantis case is to draw attention to the gaps in knowledge and understanding of the system and to guide the incremental development of the aquifer as a water resource. The value of this particular modelling attempt must be sought along similar lines.

The main objective of the Pilot Scheme, it will be recalled, was to test the [validity and reliability of the] model simulation [of Gerber] and thus to better determine the exploitation potential of the Cape Flats aquifer. How this was supposed to be achieved, was never clarified and spelled out.

Knowledge and understanding of a section or element of a system can possibly be extrapolated over the entire system if the section is in every respect representative of the entire system. A study of the hydrogeological descriptions of the different sections of the aquifer investigated by Henzen (1973), Gerber (1976) and Wessels & Greeff (1980) and the macro-description of the aquifer system by Gerber (1980) shows that the Cape Flats aquifer, like all aquifers, is not physically homogeneous.

Furthermore, it was not even attempted to incorporate the test area and its more detailed characteristics into the Gerber model. The Gerber model is a regional groundwater flow model covering more than 325 km^2 and represented by 456 nodes. The Pilot Scheme wellfield covers slightly more than one grid element in the Gerber model and as such represents a point abstraction source within the regional framework. To rerun the aquifer model would not have produced new knowledge and understanding of the aquifer. In addition, waterlevel monitoring in most of the pre-1980 boreholes stopped after the completion of the experimental phase, not necessarily out of design, but because boreholes disappeared under advancing bulldozers. To refine the model would therefore have been physically impossible.
The Gerber model is now only part of modelling literature.

5.3.6 <u>Conclusions</u>

The groundwater flow model developed for the pilot scheme section of the Cape Flats aquifer has, despite its structural shortcomings, shown that:

(1) the present hydrogeological knowledge of the area and the number of data points are by far not sufficient to arrive at a model that can reliably be used for predictive purposes;

(2) the exploitation potential of the test area lies between 130 l/s and 300 l/s and is probably of the order of 200 l/s under the given dense wellfield configuration.

Nothing was learned that could directly improve the reliability and accuracy of a regional aquifer flow model so that it could be used as an aquifer management or decision making tool.
If the perception existed in 1981 that a regional flow model could be tested and upgraded by way of a limited, concentrated abstraction exercise, it proved to be an expensive conceptual mistake.

5.4 ENVIRONMENTAL EFFECTS

No statistically significant ground movements could be measured in the period up to October 1987. The most significant height deviations are of a seasonal nature ostensibly due to cyclical wetting and drying of the soil. The most meaningful comparison is between the 1985 and 1987 summer elevations which shows a positive mean deviation of 2 mm. The magnitude of the deviations inside and outside the actual abstraction area was virtually identical.

The conclusion is that on a short-term basis groundwater abstraction does not have an influence on ground stability. There is no reason why, in the absence of significant clay horizons, this should not also be the case in the long run and when greater groundwater volumes are withdrawn.

It was indicated in a previous section that the influence of abstraction in the pilot wellfield area at a rate of about 160 l/s did not reach the perimeter of monitor boreholes to the north-west of the study area during the test period. Simulation further showed that this abstraction rate could be maintained indefinitely without affecting the watertable in the Philippi area.
How much more groundwater could be withdrawn without creating interference is unknown. Because the Philippi abstraction area is situated upstream and further to the west of the pilot wellfield area , it can be expected though that the ceiling on abstraction rate would in the first instance be set by the threat of seawater intrusion. Furthermore, it would be inadvisable to

expand abstraction for urban use to the zone immediately downstream Philippi for fear of moving the polluted and mineralized Philippi groundwater into a superior section of the Cape Flats aquifer.

6 CONCLUSIONS

The Mitchells Plain Pilot Scheme has demonstrated and highlighted a number of hydrogeological and practical aspects of groundwater development which will hopefully facilitate decision-making with respect to the future of the Cape Flats aquifer as a water resource:

(1) A mean annual yield of 4130 Ml was obtained during the test under suboptimal operating but favourable recharge conditions. Abstraction generated a rather limited regional watertable decline, did not interfere with the fresh-seawater interface and water usage in the Philippi agricultural area and did not cause ground subsidence. The water produced is potable in bulk supply. Leakage induced from the nearby Sewage Works maturation ponds has a negative impact on groundwater quality.

(2) About 6000 Ml of groundwater can be produced per year from the aquifer by means of ten closely-spaced boreholes at the pilot wellfield site at an operating efficiency of 95% under above-average recharge conditions. The exploitation limit under more stringent hydrogeological conditions as well as the effect of urban development on the water balance could not be determined numerically because of the failure to construct a valid and reliable groundwater flow model for the test area.

(3) The development of a mathematical flow model was hampered by the lack of information on the important aquifer features that affect flow. Apart from a denser and wider network of data points, more reliable and site specific hydraulic parameters will be required to come closer to a model with predictive capabilities. The modelling attempt did however confirm that net groundwater recharge through the sandy soils of the primary aquifers in the South-western Cape varies between 15% and 35% of the annual precipitation depending on climatological factors.

(4) A straightforward extrapolation over the Cape Flats aquifer of the knowledge and insight gleaned from the pilot test is not possible, neither analytically nor by way of flow modelling due to difference of scale, aquifer heterogeneity and lack of knowledge of the physical characteristics of the aquifer as a whole. The Pilot Scheme exercise does not throw more light on the sustainable yield of the aquifer.

(5) The hydraulic conditions appear favourable for the extension of the pilot wellfield in western (beyond the Sewage Works) and north-western direction. The physical limits to the extension will have to be determined by additional exploratory drilling. It is tentatively put forward that, under normal hydrological conditions, 10000 Ml per year could be produced from the high transmissivity zone on which the Sewage Works is located by duplicating the Mitchells Plain wellfield immediately west of the Sewage Works.

(6) The development of the wellfield in an urban environment did not turn up insurmountable technical problems. Borehole protection immediately after establishment is a key issue and can be achieved by keeping collar and cover below surface.
The decision not to drill exploratory boreholes before the establishment of production boreholes was a mistake. Not only could higher production borehole yields have been obtained, but the exploration boreholes could have been used for aquifer tests and watertable monitoring and would as such have benefited the modelling attempt.

The Cape Flats Groundwater Development Pilot Abstraction Scheme was forced into existence as a compromise and may under the circumstances of 1981 have seemed like the right thing to do to get groundwater exploitation in the Cape Flats aquifer going. In the event, it was learned that limited facilities can produce a large volume of groundwater but that exploitation of a primary aquifer in an urban setting is not a straightforward enterprise. These findings are neither original nor unique. The core questions of where, how and how much groundwater can be developed were not really addressed. Nor could they be addressed by way of a limited abstraction facility. Nor should they have been addressed in this way in the face of overwhelming worldwide expertise and experience in this field.

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