

THE WEST RAND DOLOMITIC AQUIFER
BANK COMPARTMENT

J.N.E. Fleisher

7/1978

CONTENTS

1. Introduction
2. Geohydrology
3. Previous Work
4. Results of the present Study
 - The mechanism of replenishment
 - Storage evaluation
 - Hydrometeorologic Study
5. Conclusions
6. Recommendations

LIST OF FIGURES AND TABLES

- Fig. 1 Bank Compartment Key Map.
- Fig. 2 Monthly discharge and rainfall at Bank Spring.
- Fig. 3 Hydrographs of observation boreholes prior to de-watering.
- Fig. 4-21 Hydrographs of observation boreholes during the de-watering period.
- Fig. 22 Monthly amounts of groundwater extracted from Bank Compartment.
- Fig. 23 Annual pumpage figures plotted against the corresponding drawdowns in b.h. G783.
- Fig. 24 Annual pumpage figures plotted against the corresponding drawdowns in b.h.s G511, G986 and G635.
- Fig. 25 Water table contour map 6/1969.
- Fig. 26 Water table contour map 6/1970.
- Fig. 27 Δh thickness of the de-watered aquifer, 6/1969-6/1970.
- Fig. 28 Water table contour map 1/1971.
- Fig. 29 Water table contour map 1/1972.
- Fig. 30 Δh thickness of the de-water aquifer, 1/1971-1/1972.
- Fig. 31 Spring discharge and storage relationship in Bank Compartment
- Fig. 32 Water table contour map October 1963.
- Fig. 33 Rainfall - Recharge relation in Bank Compartment.
- Fig. 34 Schematic hydrologic Cross Section.
-
- Table 1 Monthly pumpage from Bank Compartment.
- Table 1a Annual amounts of pumpage from Bank Compartment.
- Table 2 Monthly discharge amounts from Bank spring.
- Table 2a Annual discharge amounts from Bank spring.
- Table 3 Observation boreholes in Bank Compartment.
- Table 4 Calculation of the annual natural recharge.

THE WEST RAND DOLOMITIC AQUIFER
BANK COMPARTMENT
J.N.E. FLEISHER

5/1978

1. INTRODUCTION

The present report deals with a part of the West Rand dolomitic aquifer currently under investigation. The compartment includes some 154 km², fig. 1. Impermeable boundaries delineate the compartment on all sides. Syenite dykes striking approximately NNE comprise the eastern and western boundaries.

Relatively impervious Black Reef Series outcrops form a rather irregular boundary to the north. In the south the dolomite dips below the impervious shales of Pretoria Series and the aquifer probably extends only a short distance beyond the line of outcrops.

The Wonderfontein River crosses the compartment in an east-west direction. The Ground surface slopes gently towards the river and westwards.

Outcrops of pre- and post-Dolomite outside the compartment form a hilly topography in contrast to the even dolomitic terrain.

Outliers of Karoo beds are commonplace on the dolomite and may reach a considerable depth. The area is soil covered, the thickness of the cover varies considerably.

2. GEOHYDROLOGY

Under natural conditions the dolomitic aquifer in the Bank Compartment was replenished through the percolation of a certain amount of the summer rainfalls, run-off in the river bed, and overflow from the Venterspost Compartment up-stream.

Discharge from the Bank Compartment took place mainly through the spring and through seepages from the effluent section of the river bed.

Because of the shallow depth to the water level in the vicinity of the river, it is assumed that under changing annual rainfall alternating effluent and influent conditions must have prevailed.

Outflow from the spring did not include any surface run-off because the spring issued about one km south of the river course. Some change in the natural hydrologic regime occurred when dewatering commenced in the neighbouring Venterspost Compartment. The outflow from the Venterspost spring diminished, and eventually it dried up in 1947.

A/.....

A profound change happened towards the end of 1968. Mining by West Driefontein gold mine was extended to the Bank Compartment across the dyke separating Bank and Oberholzer Compartments. In October 1968 inflow of enormous amounts of groundwater threatened the workings and the miners. The inflow was eventually overcome and controlled. Details of the three weeks human and technical efforts were described by Cartwright (1969) and Cousens and Garrett (1969).

In the wake of the 1968 events, and in order to provide for safe mining, the Interdepartmental Committee on Dolomitic Mine Water approved the de-watering of the Bank Compartment. Pumpage figures are given in table 1 and 1a.

Simultaneously a gravity survey was carried out by the Geological Survey to investigate sinkhole formation and subsidences anticipated as a consequence of the de-watering. In the course of this survey some 500 boreholes were drilled. Out of the total number of drilled holes 90 were used for groundwater observation.

3. PREVIOUS WORK

Enslin and Kriel (1959) concluded on the basis of gauged run-off loss and estimated evapotranspiration over a period of eleven months, that direct percolation from water channels and the river does take place in this compartment.

Schwartz and Midgley (1975) made use of the water table observations taken at 17 boreholes during the groundwater inflow episode of 1968. They applied the Theis non-equilibrium equation, and by using several assumptions, arrived at a transmissivity constant of $7000 \text{ m}^2/\text{day}$, and a storage coefficient of 1,5%. The bulk of stored groundwater in the Bank Compartment down to a depth of 1000m., according to the above authors, was estimated at $2 \times 10^9 \text{ m}^3$.

4. RESULTS OF THE PRESENT STUDY

The Mechanism of Replenishment

Monthly discharge figures from the spring for the period 1957 to 1969 are available. The annual amounts of discharge observed in this period are in the range of $16-22 \times 10^6 \text{ m}^3$, (table 2 and 2a). Later outflow figures no longer represent the natural discharge.

A comparison of monthly discharges at the spring, fig. 2., with monthly rainfalls reveals a marked systematic delay of about 6 months, when peaks are matched. The annual spring minima, generally in February, often appear simultaneously with maximum rainfall.

On the whole the minima are not repeated exactly at the same month, small variations do occur, but the delay is nevertheless clear.

The phase difference can also be traced in hydrographs of boreholes, fig. 3. The hydrograph from borehole W41 is most closely in phase with the spring discharge.

It should however be borne in mind that the replenishment mechanism in the dolomite involves a two-phase percolation system. One is the delayed phase and the other is a nearly immediate phase (Fleisher, 1978, in preparation). The relative significance of the two phases in each particular case depends on the physical conditions in the vicinity of the boreholes and will shape the hydrograph somewhat differently. Most of the boreholes, shown in fig. 3, are located near to the river course, a fact which may have a bearing on the recharge. In other words, immediate recharge is more important in this case than say, at Maloney's Spring.

The water table behaviour in a number of boreholes in the Bank Compartment, during the pumpage of the reservoir, is shown in figures 4 to 21.

Monthly amounts extracted from the aquifer by West and East Driefontein Mines are plotted in fig. 22.

Table 3 includes relevant information of all available observation holes such as period of observation, nature of the aquifer, elevation and depth.

In the course of the severe pumpage most of the boreholes gradually dried up. Several reasons account for the abandonment of observations:

- (a) Shallow boreholes where the depth of penetration was too small became dry with the drop of the regional water table (saturated aquifer still existing beneath).
- (b) Boreholes which locally penetrated solid dolomite at rather high elevations, dried up though other boreholes around which encountered pervious material to a greater depth remained in operation.
- (c) In many boreholes gauging stopped due to blocking - which is expected where no pumpage is practiced.

The drastic drawdown which developed with the large scale pumpage can be observed in figs. 8, 9, 10, 12, 14, 15, 19, 20, 21. In some of the boreholes seasonal recharge is discernable, superimposed on the otherwise steeply declining water level, figs 13 and 21.

The north-eastern sector has been affected rather late (1972), figs 16 and 17. The water table tends to rise but only due to a temporary decrease in the rate of extraction combined with a good rainfall season. This area constitutes an integral part of the Bank Compartment for all practical purposes.

The Hill method, an empirical approach for the rough estimation of safe yield in a basin where overpumpage has been practiced and the corresponding drawdowns monitored over a long enough period, has been attempted.

In fig. 23 annual drawdowns in borehole G783 were plotted against pumpage and a line fitted to cut the zero drawdown. The safe yield, which in this method equals natural recharge, was found to be $23 \times 10^6 \text{m}^3/\text{year}$. Fig. 24 includes three boreholes where the same method has been applied. Yet in two of them, G635 and G511, the drawdown corresponding to 1970/71 was apparently anomalous and had to be eliminated. The recharge figures are 23 and $25 \times 10^6 \text{m}^3/\text{year}$ respectively.

In the case of borehole G986 the drawdown for 1975/76 had to be omitted.

In a detailed study of springs in the dolomite aquifer, currently in preparation, it could be demonstrated that certain rain seasons differ very much from the average and the annual recharge in such cases is outstanding.

1970/71 and 1975/76 were such exceptionally high recharge seasons. The above method is not applicable if the annual natural recharges differ widely. On the other hand fig. 24 supports the conclusion that outstanding high recharges do occur in this aquifer. The somewhat higher figures for the average recharge arrived at in fig. 23 and 24, as compared to the spring records can be explained if conditions in the aquifer are examined. During the said period, 1969-1976, a considerable part of the aquifer mass was practically empty and no outflow was taking place. This would favour higher intake rates.

Storage Evaluation

Method: Two water balances were prepared to calculate the storage coefficient in the compartment. For each balance period a set of two water level contour maps were prepared, for the beginning and the end of the period.

These maps were superimposed and a third produced showing

Δh , the thickness of the de-watered aquifer. The volumes of the de-watered rock material were calculated with the aid of a planimeter. Groundwater volume extracted through pumpage during the balance period was compared to the de-watered aquifer volume. Allowance was made in each case for natural replenishment during the balance period.

Application: The selection of balance periods has been complicated mainly by the insufficient coverage of the area with boreholes. To a certain extent inadequate depth of boreholes was also an obstacle. With the development of pumpage, boreholes in the vicinity of the pumping mine went out of operation rather rapidly. Up-stream and in the eastern three quarters of the compartment, very few boreholes were available.

The rate of drawdown in an area with a radius of about 4km from the mine can be seen on the key map fig. 1, where the date at which the water table dropped to the datum of 1440m A.M.S.L. is shown.

Drilling/.....

Drilling which commenced in the area for geophysical purposes was applied generally for ad hoc engineering problems. No monitoring net was laid out for groundwater investigation.

Water balance A covers the period 6/1969-6/1970. It includes a full rain season. The water table contour map at the beginning of the balance period A is shown in fig. 25 and at its end on fig. 26. Fig. 27 represents the difference of one map from the other. The volume of de-watered rock material has been calculated by planimetry and consists of $3322 \times 10^6 \text{ m}^3$. The total amount of groundwater extracted during the said period from the compartment was $61,655 \times 10^6 \text{ m}^3$. An allowance has however to be made for a full season of natural replenishment say, about $22 \times 10^6 \text{ m}^3$. The net extraction was therefore: $61,655 \times 10^6 \text{ m}^3 - 22 \times 10^6 \text{ m}^3 = 39,655 \times 10^6 \text{ m}^3$

The storage will thus be $\frac{39,655 \times 10^6 \text{ m}^3 \times 100}{3322 \times 10^6 \text{ m}^3} = 1,2\%$

Water balance B, which includes the period 1/1971-1/1972, was calculated in a similar way. At the beginning of the period (1/71) the water levels in boreholes E1N, E1Q and G403, fig. 1, reached depths of 248, 190, and 150m respectively. This would suggest that the area delineated between E1N, E1Q and the dyke, where the water table dropped below 200m, could for all practical purposes be neglected in the storage considerations. Balance B covers therefore a somewhat reduced area. In the selection of this balance period availability of water level records was the main problem.

The natural recharge during this period includes two incomplete rainy seasons. The first wet months of 1970/71 season are excluded while 1971/72 season includes only the first months. As mentioned before the recharge mechanism involves two phases. In the present setting the recharge will be a combination of the delayed phase of 1970/71 plus the immediate phase of 1971/72. It can thus be assumed that the intake during the said period included a full one year recharge.

Figs. 28 and 29 demonstrate the water table contour maps at the beginning and at the end of the balance period. The volume of dewatered aquifer, $1836,73 \times 10^6 \text{ m}^3$, was calculated from fig. 30. The total pumped volume during balance period B was $97,458 \times 10^6 \text{ m}^3$. The estimated natural recharge was $22 \times 10^6 \text{ m}^3$. The net pumpage is accordingly $97,458 \times 10^6 \text{ m}^3 - 22 \times 10^6 \text{ m}^3 = 77,458 \times 10^6 \text{ m}^3$. The storage is therefore: $\frac{77,458 \times 10^6 \text{ m}^3 \times 100}{1836,73 \times 10^6 \text{ m}^3} = 4,2\%$

Hydrometeorologic Study

The discharge pattern shown in fig. 2 is rather typical to the summer rain climate and the dolomitic aquifer involved. Recharge of the aquifer extends over the greater part of the year. Sometimes the delayed phase of the end of one rainy season may coincide with the start of the next season rainfall. It is therefore only during a limited period of two to three months that a recession curve can be followed.

Depletion/.....

Depletion curves of discharge through a spring system, during a no-replenishment period, can be approximated very closely by an exponential function, sometimes with more than one exponential function, Mero (1963). Discharge-storage relationships can therefore be studied by analyses on semi-logarithmic paper.

Several years of monthly discharges from the short periods of assumed no-intake in every year (December, January, February) have been compiled and plotted together in fig. 31. The result is a straight line which designates the free drainage through the spring provided no recharge takes place. The time units on the horizontal (arithmetic) scale mark months. By selecting a starting point of discharge on the logarithmic scale, and assuming no intake occurs, it is possible to calculate successive monthly discharges of free drainage.

Several practical applications can be worked out based on the depletion line in fig. 31.

The time interval measured in months, horizontal scale, between a starting point "a" and the point where the sloping line cuts the zero discharge represents the time required for the complete drainage of the storage in the reservoir. The reservoir is defined as the mass of aquifer included between the water table surface and a horizontal plane, the elevation of which corresponds to the outflow point of the spring. In the case of Bank Compartment the time required to drain the reservoir would be about 40 months.

Records from the few observation holes which had been operating during 1959-1967 allow the construction of a rough water table contour map, fig. 32. The aquifer volume of the reservoir has been calculated for October 1963. The spring outflow altitude was taken as the base of the reservoir. The aquifer volume fig. 32 totals $1519 \times 10^6 \text{m}^3$. The groundwater storage retained in the aquifer on the above date has been read from the depletion line, fig. 31, in monthly portions of discharge up to the complete drainage of the reservoir. This volume of water amounts to $15,6 \times 10^6 \text{m}^3$. The storage coefficient obtained is:

$$\frac{\text{Groundwater storage}}{\text{Reservoir volume}} \times 100 = \frac{15,6}{1519} \times 100 = 1 \%$$

In order to investigate the relationships between recharge and rainfall, annual net recharge has to be compared with rainfall. The annual discharges at Bank spring have been corrected in the following way: For every year, starting in October, the monthly discharges of twelve months were read-off from the depletion line and summed up. This amount represented the assumed free drainage which would have issued if no recharge had taken place. Each annual free drainage was then subtracted from the corresponding recorded gross annual outflow. Thus corrected annual recharge figures have been arrived at, table 4.

In/.....

In fig. 33 corrected annual discharge figures have been plotted against total annual rainfall. The linear relationship is clearly proved. This relationship enables the forecast of the net recharge for given rainfall amounts.

An additional parameter which can be deduced from fig. 33 is a threshold value of rainfall, 200mm, below which apparently no recharge will occur.

The 1960/61 season was discarded in fig. 33 as the discharge data do not seem plausible. The season 1966/67 does not fall in line with the rest, no explanation is postulated to account for this discrepancy. It can however be concluded from a concurrent study of springs (Fleisher 1978, in preparation) that the replenishment in 1966/67 was below the expected amount.

5. CONCLUSIONS

The storage figures calculated for the Bank Compartment represent most probably a certain average over the whole inhomogeneous aquifer. A more elaborate investigation would reveal locally higher storage as contrasted with other low storage regions.

Some inaccuracies introduced in the said calculations are due mainly to the lack of a proper net work of observation holes. This is also the reason that investigation of a vertical change in storage was not applicable.

Out of the three water balances carried out to determine the storage, two yielded close figures 1% and 1,2%. A higher figure, 4,2% was found through balance B. In this particular case the current assumption was used that below 200 meter depth no appreciable storage was expected. A considerable area has therefore not been taken into consideration. It is possible that porosity extends deeper than suggested. Unfortunately water level records to that depth in the said area were not available.

Nearly all boreholes have now dried up and it is virtually impossible to check the depth to the water table over most of the compartment. Several available measurements for 9/1977 are shown on fig. 1. Water table gauged at the mine shaft is 690m below ground surface.

6. RECOMMENDATIONS

The present hydrological setting: The general geology and the flow of groundwater to the mine workings can schematically be seen in fig. 34. It should be noted that interconnected faults and fissures transmit water from the actual water bearing zone, which is rather limited in thickness, down to the mine.

The major part of the dolomite, Ventersdorp Volcanics and the Witwatersrand System are actually impermeable.

The amount of influx into the mine depends on the potential difference between say, points P and Q and on the specific permeability of the conduits (fissures, faults etc.). Since the water table has dropped considerably, the amount of inflow has also diminished. The pumpage is still much in excess of the natural intake from rainfall.

With/.....

With the de-watering process going on for nine years it is to be expected that part of the permeable aquifer, the upper weathered zone, has been drained. Groundwater however still occupies the deeper basins and troughs which also collect the annual natural recharge. Most of the weathered zone troughs are interconnected as proved by the effects of the de-watering. Faults and joints facilitate to a certain extent descending flow. Nevertheless actual flow occurs entirely due to underground excavations.

Economic Considerations: The present cost of groundwater pumpage from the mines amounts to the order of R80-90 per 1000m³ as calculated by Mr. Engelbrecht, Chief Geologist, West Driefontein (oral communication). The matter has also been discussed with Mr. O'Connor, Assistant Resident Engineer at that mine. This expenditure covers all the stages of the elaborate system. Pumping expenses of boreholes in the different slope levels, delivery of pumped water to intermediate reservoirs, accumulation in the collector dams at the bottom of the shaft and finally uplift to surface.

Such expenses call for a feasibility investigation with the aim of replacing the current abstraction of groundwater by a series of relatively shallow boreholes.

Suggestion for further investigation: It is assumed that the deeper part of the aquifer in depressions and troughs is still saturated, Boreholes G635 and G511, fig. 1. Efforts should be directed to investigate the feasibility of locating these troughs in the eastern part of the compartment. By siting successful borehole fields and the concentration of intensive pumpage, it should be possible to reverse the flow pattern, away from the mine.

The entire area of the Bank Compartment had been gravity surveyed by the Geophysical Division of the Geological Survey. Although this survey was carried out in conjunction with the sinkhole and land subsidence problem, it can nevertheless be utilized in geohydrology for the location of borehole sites.

It has been proved lately that scientifically selected sites led to successful recharge boreholes in the Gembokfontein Compartment. Western Areas Goldmines recharge about $1,8 \times 10^6 \text{m}^3$ per month through 11 boreholes.

High yields could probably be achieved through large diameter boreholes which would reduce the dynamic drop of the water level.

Programme: A tentative working schedule should proceed on the following lines:

- A.
 1. Selection of suitable gravity-low sites.
 2. Drilling of five small diameter boreholes in order to locate the present water table, the depth and thickness of the saturated aquifer.

If successful data have been gained through A:

- B.
 1. Drilling of two large diameter production boreholes
 2. Drilling of four observation holes.
 3. Test pumping of above boreholes.

4. Assessment of the results.

- C. Preparing a detailed plan for pumping sites, additional observation holes and the necessary provision for groundwater delivery beyond the pumped compartment. Existing pipelines system could possibly be utilized.

REFERENCES

- Cartwright, A.P. (1969). West Driefontein - Ordeal by Water
Gold Fields of S.A. Ltd.
- Cousens, R.R.M. and Garrett, W.S. (1969). The flooding at
West Driefontein Mine, South Africa.
9th Commonwealth Mining and Metallurgical
Congress, London.
- Enslin, J.F. and Kriel, J.P. (1959), Some results obtained
from a hydrological study of a dolomitic catchment
area in the Transvaal, Union of South Africa.
Specialists conf. on Hydrology, Yaounde,
Camerouns.
- Fleisher J.N.E. An analysis of Springs in the Dolomite Aquifer,
South Western Transvaal. (in preparation)
- Mero, F. (1963) Application of the Groundwater Depletion Curve
in Analysing and forecasting Spring Discharges
Influenced by Well fields. Symposium on Surface
Waters, General Assembly of Berkeley of IUGG,
pp. 107-117: IASH Publication No. 63.

TABLE 1

Monthly pumpage from Bank Compartment in 10^3 m^3

Month year	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
1969						907	1633	2342	3236	3197	3150	3517
1970	5112	6393	8122	9384	9963	10297	10349	10156	9903	9837	9577	9470
1971	9204	9074	8735	8548	8346	8233	7938	8281	7283	7204	6875	6139
1972	6200	5499	5956	5240	4984	4815	4702	4642	4537	4439	4394	4318
1973	4893	3503	4122	4089	3921	3977	3820	3727	3758	3665	3485	3419
1974	3405	3210	3136	2968	2891	2926	2927	2882	2962	2847	2963	2704
1975	2950	2600	2394	2432	2503	2456	2516	2400	2311	2391	2395	2400
1976	2386	2860	2767	2738	2902	2899	2906	2842	2927	2534	2855	2799

TABLE 1a

Annual amounts of pumpage from Bank Compartment

Year (1/10-30/9)	Q in 10^6 m^3
1968/69	44,290
1969/70	89,543
1970/71	104,526
1971/72	66,793
1972/73	48,961
1973/74	37,876
1974/75	31,076
1975/76	32,413

TABLE 2

Monthly discharge amounts from Bank Spring in $10^6 m^3$

Month Year	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
1957												1,71
1958	1,70	1,54	1,59	1,90	2,00	1,69	1,84	1,85	1,79	1,87	1,81	1,90
1959	1,87	1,70	1,85	1,80	1,85	1,80	1,86	1,87	1,85	1,85	1,79	1,48
1960	1,96	1,70										
1961						1,89	2,00	2,21	1,96	1,91	1,79	1,88
1962	1,93	1,75	1,81	1,39	1,12	1,83	1,90	1,87	1,73	1,79	1,76	1,82
1963	1,75	1,55	1,79	1,83	1,90	1,91	1,96	1,92	1,92	1,96	1,87	1,83
1964	1,72	1,54	1,81	1,74	1,77	1,70	1,77	1,77	1,74	1,79	1,67	1,42
1965	1,12	1,45	1,55	1,53	1,51	1,52	1,56	1,52	1,49	1,49	1,42	1,46
1966	1,47	1,31	0,97	1,36	1,38	1,36	1,43	1,55	1,47	1,42	1,19	1,19
1967	0,97	1,06	1,37	1,49	1,55	1,48	1,47	1,44	1,41	1,42	1,38	1,42
1968	1,31	1,15	1,19	1,15	1,18	1,14	1,16					

TABLE 2a

Annual discharge amounts from Bank spring

Year (1/10-30/9)	Discharge Q in $10^6 m^3$
1958/59	22,03
1961/62	16,86
1962/63	21,90
1963/64	21,22
1964/65	18,13
1965/66	16,67
1966/67	16,04

TABLE 3

Observation Boreholes in the Bank Compartment all figures in meters

Name	Collar Elevation	Depth	Aquifer ^{XX}	Karoo ^{XX}	Period of observation ^{XXX}
G455	1591.92	213.4	P	-	7/1969-9/1970
MW1	1576.86				1/1969-4/1970
G456	1582.16	213.4	P	-	8/1969-11/1970
G457	1564.79	213.4	P	-	4/1970-9/1970
MW2	1559.56				5/1969-3/1970
UD5	1645.07				5/1969-6/1971
E2E					1/1969
E2A	1571.07				1/1969-6/1971
G402	1557.79	129.5	C	50	5/1969-3/1970
E2G	1557.4				6/1969-2/1970
G438	1555.26	79.3	P	-	4/1969-7/1970
UD8	1626.63				1/1969-3/1971
E2J					1/1969
G439	1566.67	86.9	P	41	6/1969-8/1969
E2H	1564.82				12/1968-11/1970
G449	1556.13	213.4	C	90	6/1969-10/1970
G363	1540.99	169.2	P	47	1/1969-11/1970
G403	1523.63	157.9	P	-	3/1969-1/1971
G421	1521.69	91.4	P	-	3/1969-1/1970
G564	1516.94	29.6	P	-	6/1970-2/1972
G501	1516.33	103.6	P	-	4/1970-1/1971
G409	1514.72	48.8	P	-	4/1969-3/1970
G405	1510.66	50.3	P	-	3/1969-4/1971
W41	1510.36				10/1957-3/1966
G470	1519.39	56.4	P	-	9/1969 - Present
UD7	1605.17				5/1969-7/1970
E1M	1585.90				5/1969-5/1970
G441	1581.56	91.4	P	26	4/1969-11/1969
G445	1568.14	59.4	P	-	
W60	1522.03				10/1957-1/1970
G446	1522.18	146.3	P	-	6/1969-1/1971
G454	1520.06	32	P	-	4/1969-9/1969

G414/.....

Name	Collar Elevation	Depth	Aquifer	Karoo Beds	Period of observation
G414✓	1519.87	121.9	P	-	6/1969-10/1970
G834	1517.02	120.4	P	-	1/1972-Present
G487	1524.25	141.7	P	-	3/1970-10/1973
G534	1537.67	91.4	P	-	1/1971-9/1971
W606	1535.21				4/1969-4/1973
W601	1557.44				4/1969-12/1970
W602	1566.45				4/1969-4/1975
W598	1570.91				4/1969-1/1972
W600	1562.33				4/1969-Present
E1D	1634.64				1/1969-3/1969
G750	1572.11		Perched	23	11/70-Present
G610	1572.11		P	15	8/70-9/1974
G452	1562.96		C	75	11/69 - 9/1970
E1Q	1541.52				12/1968-2/1971
G416✓	1532.73	213.4	P	-	6/1969-9/1970
G407	1525.38	79.3	P	-	1/1969-9/1969
G411	1524.39	158.5	P	-	4/1969-1/1971
W62	1525.3				9/1957-2/1970
G431	1524.27	79.3	P	-	4/1969-8/1970
G797	1522.15	195.1	P	-	9/1971-6/1974
G408/2	1521.36	50.3	P	4	3/1969-2/1970
G408/1	1520.92	56.4	P	12	1/1969-5/1970
G504	1525.19	61	P	-	10/1969-6/1970
G676	1523.34	48.8	P	-	7/1970-2/1972
G660	1524.25	45.7	P	-	6/1970-11/71
G415✓	1514.07	208.9	C	9	6/1969-9/1970
E1N	1597.84				1/1969-10/1971
G590	1573.63	153.9	C	50	11/1970-12/1971
W102	1546.43				10/1957-1/1963
G486	1541.46	140.2	C		2/1970-8/1970
W97	1522.35				11/1957-4/1962
W98	1539.38				1/1958-9/1969
G413✓	1520.68	96	P	-	6/1969-11/1970
G591	1573.63	146.3	C	58	8/1970-10/1974
EML3	1553.38				1/1971-4/1972
W106	1550.4				10/1957-9/1969

W131/1/.....

Name	Collar Elevation	Depth	Aquifer	Karoo Beds	Period of observation
W131/1	1547.38				3/1969-1/1970
W108	1550.61				4/1969-8/1970
W100	1545.91				10/1957-1/1962
G506	1534.62	88.4	P	-	11/1969-4/1972
G507	1537.06	82.3	P	-	5/1970-4/1972
G563	1525.17	61	P	-	5/1970-3/1972
G571	1533.70	70.1	P	-	1/1971 -3/1972
MW3	1586.44				6/1969-4/1972
MW4	1567.72				6/1969-4/1972
G592	1572.11	121.9	P	49	11/1970-Present
G451	1566.62	213.4	C	88	11/1969- Present
EM12	1559.51				6/1970-7/1971
G488	1542.85	83.8	P	-	5/1970-5/1971
G508	1539.19	50.3	P	-	5/1970-Present
G579	1536.75	74.7	P	-	6/1970-2/1972
W339	1549.80				11/1968-10/1970
W525	1531.01				1/1971-12/1971
G632	1561.74	100.6	P	27	11/1970-11/1976
W534					1/1971-9/1971
W510	1551.95				3/1969-9/1970
G674	1541.63	32	P	-	8/1970-11/1976
W337	1602.73				1/1957-12/1970
W595	1643.26				3/1969-10/1971
MW6	1556.26				8/1969-4/1972
G510	1552	42.7	P	-	5/1970-2/1972
W610	1539.19				6/1970- 1/1971
G635	1527.30	77.7	P	-	10/1970-Present
W45	1563.12				6/1957-11/1960
G436	1566.64	89.9	P	-	4/1969-8/1972
W75	1553.49				11/1957-10/1970
G432	1552.25	90.5	P	-	3/1969-4/1970
G511	1547.11	59.1	P	-	5/1970-Present
W125	1540.54				10/1957-5/1972
W124	1542.01				3/1969-10/1971
W129	1535.91				1/1958-11/1976
W122	1540.34				10/1957-3/1966

W123/.....

Name	Collar Elevation	Depth	Aquifer	Karoo Beds	Period of observation
W123	1539.86				10/1957-7/1967
G523	1531.66	160.9	P	-	4/1970-10/1974
W571	1610.01				3/1969-Present
G1160	1617.31	33.5	P	-	4/1973-Present
W333	1623.62				3/1969-7/1971
G987	-	167.6	P	-	6/1972-11/1973
MW5	1599.85				9/1969-6/1971
G761	1610.01	128	P	30	3/1971-Present
W46	1571.30				3/1969-8/1970
MW7	1565.70				9/1969-12/1971
W509	1558.92				3/1969-10/1970
W73	1559.12				11/1957-5/1968
G512	1550.12	64	P	-	11/1969-10/1972
W70	1549.91				11/1957-10/1965
W114	1543.29				3/1969-9/1970
W420	1544.07				7/1970-1/1971
W115	1543.52				3/1969-9/1971
W118	1543.33				10/1957-6/1968
G762	1611.82	128	P	47	3/1971-5/1974
G986	1573.68	135.6	P(?)	56	4/1972-Present
G783	1570.13	183.8	P	-	6/1971-7/1976
G582	1553.82	53.3	C	27	6/1970-7/1972
G513	1555.65	140.2	P	-	6/1970-2/1972
G542	1544.53	93	C	24	4/1970-8/1976
G605	1544.70	64	P	-	6/1970-9/1971
G604	1544.52	39.6	P	-	6/1970-3/1972
W425	1538.47				3/1969-3/1972
G535	1543.60	35.1	P	-	4/1970-5/1974
W112	1542.88				5/1960-9/1968
W111	1542.36				3/1969-10/1971
G1134	1534.70	41.5	P	-	4/1973-Present
G1200	1535.05	59.4	P	-	9/1973-2/1976
G1198	1536				7/1973-Present
G1135	1541.09	37.2	P	-	4/1973-12/1975
W428	1549.03				3/1969-1/1972
G1293	1559.97	57.9	P	-	3/1974-6/1976

Name	Collar Elevation	Depth	Aquifer	Karoo Beds	Period of Observation
G522	1563.54				3/1969-1/1975
G1294	1562.35	39.6	P	8	3 /1974-2/1976
G1152	1566.64	50.3	P	-	4/1973-Present
G476	1570.14	91.4	P	-	4/1970-Present
G1218 <i>2A 24 CD</i>	1578.14	45.7	P	-	8/1973-Present
W331	1574.59				10/1958-9/1968
G1159	1594.01	36.6	P	-	4/1973-Present
MW8	1583.08				10/1969-10/1971
G796	1573.03				6/1971-Present
G1042	1569.28	79.3	P	11	7/1972-Present
G514	1559.92	71.6	P	-	6/1970-Present
W110	1546.41				10/1957-12/1973
G1153	1537.80	38.1	P	-	4/1973-Present
G1292	1548.91	42.7	P	-	3/1974-Present
G1185	1562.8	76.2	P	-	7/1973-6/1976
W567	1591.84				3/1969-Present
G516	1565.09		P	10	7/1976-27.7.76
G524	1544.98	161.5	P	-	4/1970-Present
G1341 <i>W107</i>	1552.32	128	P	-	12/1974-Present
G1184	1551.65	539			6/1973-Present
G98	1567.93				11/1965-3/1975
G1221	1577.25				9/1973-Present
G1219	1587.53	48.8	P	-	8/1973
B1	1585.21				6/1965

³⁵The type of the aquifer before de-watering
P = Phreatic; C = Confined

³³³ Penetrated thickness of Karoo Beds.

³³³³ The period may include intervals of no records and different frequencies in measurements

TABLE 4

Calculation of the annual natural recharge
All amounts in $10^6 m^3$. Rainfall in mm

Year (1/10-30/9)	Q1	Q2	Q3	Rainfall
1958/59	22,03	11,89	10,14	712
1961/62	16,86	12,55	4,31	773
1962/63	21,90	11,39	10,51	713
1963/64	21,22	12,55	8,67	608
1964/65	18,13	11,39	6,74	530
1965/66	16,67	9,55	7,12	553
1966/67	16,04	9,00	7,04	897

Bank spring: Total annual discharge (Q1), calculated annual free drainage (Q2), corrected annual discharge (Q3=Q1-Q2)

The corrected annual discharge is equal to the annual natural recharge.