Groundwater Recharge in the Dolomite of the Ghaap Plateau near Kuruman in the Northern Cape, Republic of South Africa*

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Abstract

Several natural springs or eyes exist on the dolomite of the Ghaap Plateau Formation at Kuruman in the Northern Cape of which the flows have been measured since 1959. A geohydrological survey indicated that impermeable dolorite dykes delineate a large groundwater compartment in the dolomite with a surface area of about 1 140 km². The groundwater is drained from this area by four eyes one of which has a flow of about $17-20 \times 10^3$ m³/d.

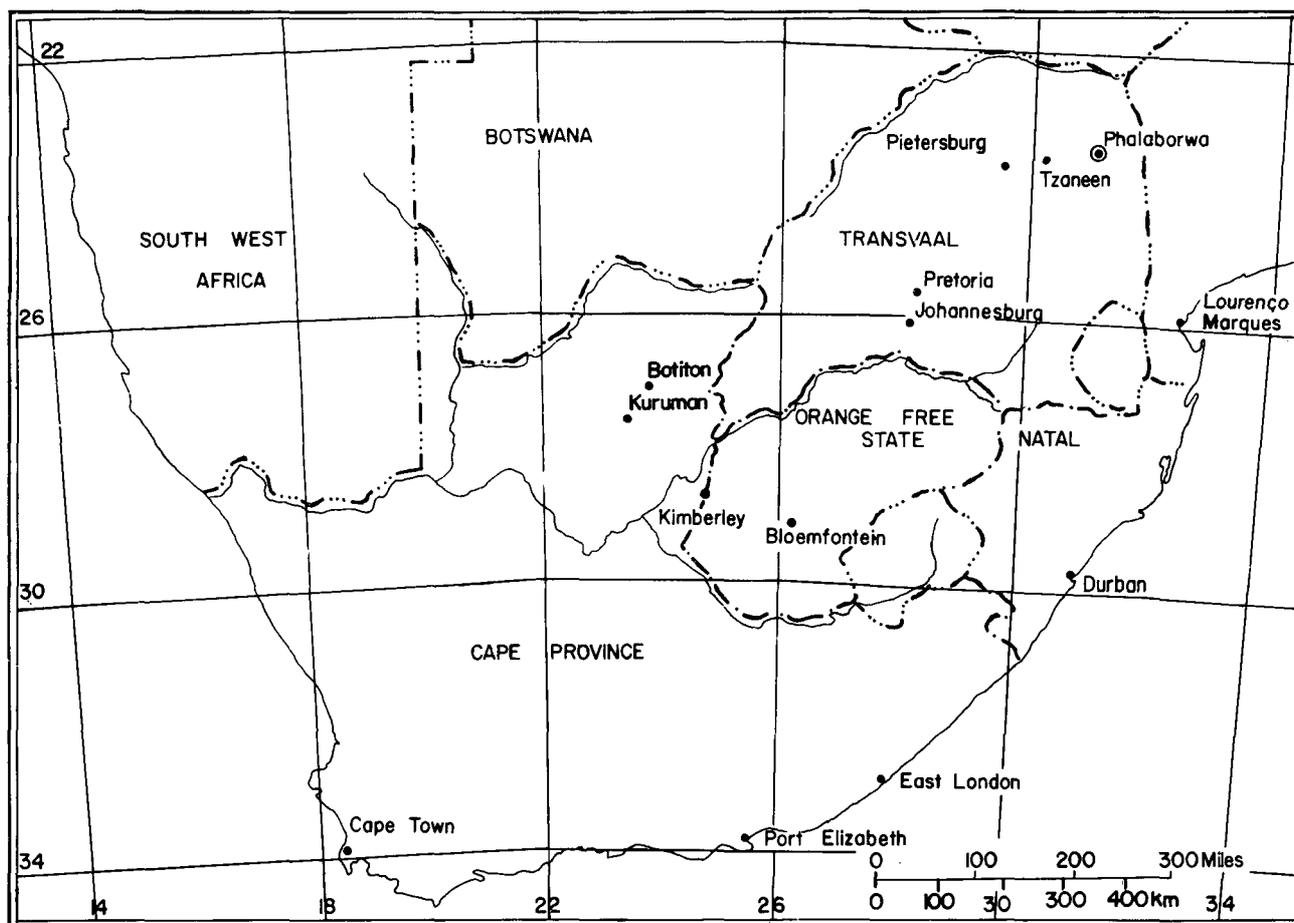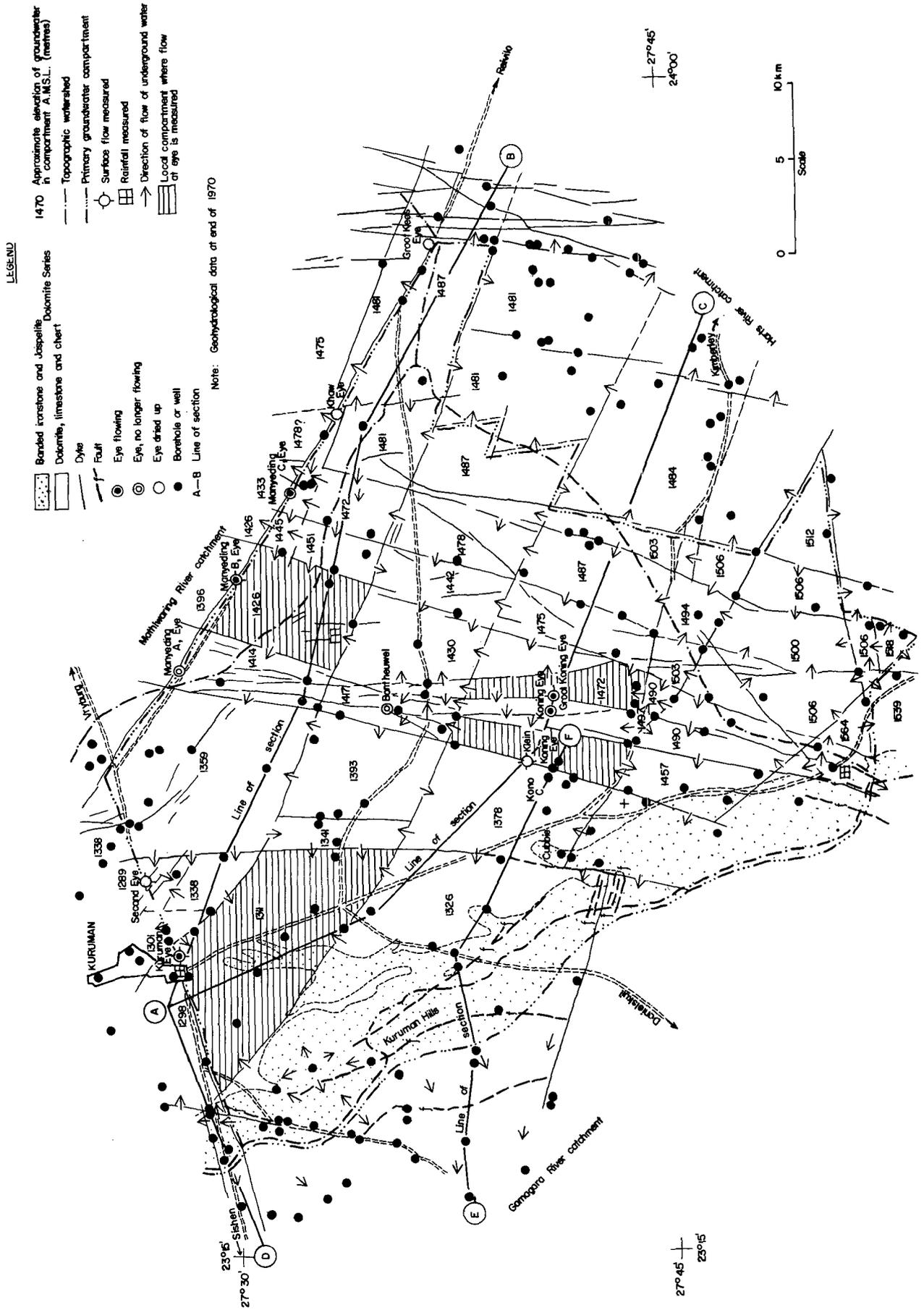The large compartment consists of 50 smaller subcompartments, some with springs draining the underground water

Figure 1
Locality of study area

Figure 2
Groundwater compartments and geology in catchment area

into the adjoining compartment. A groundwater balance sheet was drawn up taking into account all possible losses of groundwater before its flow was measured at the point of discharge at the eyes. The general groundwater level in the area varies between ground level and 200 m below surface, but is seldom less than 20 m below surface and evaporation and transpiration must be regarded as negligible.

From the available data the average annual recharge between 1959 and 1970 was calculated to be 2,5% of the annual rainfall of 346 mm over this period. By means of the Thornthwaite method the average recharge from 1940 to 1970 with a mean annual rainfall of 440 mm was calculated for two meteorological stations in the vicinity. The average of these values, based on a 100 mm soil moisture utilization was 2,9% which is in good agreement with the value calculated from spring flow.

Introduction

The underground water in an area comprising about 1 140 km² on the dolomite of the Ghaap Plateau at Kuruman (Fig. 1) is drained by several springs or eyes of which the flows were measured between 1959 and 1970, thereby providing a means to determine natural groundwater recharge (Fig. 2).

Topography

The area constitutes the upper drainage of the dry Kuruman River. To the south it is bounded by the watershed of the Harts River, to the west by that of the Gamagara River, and to the east by that of the Mathlwaring River. The lowest topographic point is at the eye at Kuruman at an elevation of 1 310 m. Southward and eastward the elevation increases to about 1 490 m and westward to about 1 460 to 1 800 m along the Kuruman Hills.

Geology

The rocks in the area consist largely of dolomite of the Ghaap Plateau Formation with lenses of chert and limestone. Approximately 10% of the surface is covered with sand and scree. Banded ironstone of the Asbestos Hills Formation, which lies conformably on the dolomite, constitutes the Kuruman Hills along the western watershed. Numerous dolorite dykes are present with a general strike in a N.N.E. and N.N.W. direction. Outcrops of the dykes are rare and are seldom more than 15 m wide. Their positions are, however, distinctly marked by linear surface limestone ridges overgrown with thorn trees. The calcrete represents calcified, weathered dolerite and is seldom thicker than 2 or 3 m.

Recent sinkholes are not known and the existing ones are probably of tertiary age. Several thin kimberlite dykes occur. In one locality, Karoo shale occurs in the dolomite and is most probably associated with an ancient sinkhole.

Geohydrology

The water level in the dolomite varies between surface level and 200 m below surface along the western foothills. The groundwater is drained from the catchment area by several flowing springs or eyes. Five of these are situated on a wide dolorite dyke striking N.N.W. along the eastern watershed (Manyeding A, B, C, Khaw and Groot Kees — see Fig. 2) and another two along a dyke striking E.W. through Kuruman (Second and Kuruman eyes). From a survey of the water levels it was pos-

sible to delineate the underground catchment area (groundwater compartment) from which the flows at the eyes are derived. The underground watershed in the south is determined by dolerite dykes and is not the same as the topographic watershed (Fig. 2 and 3). The two prominent dykes on which the eyes are situated are taken as the eastern and northern limits of the compartment. In the west the underground watershed is approximately the same as the topographic watershed (Fig. 2 and 4). The numerous dykes divide the large compartment into approximately 50 compartments with the water level falling stepwise to the level of the Kuruman eye, which has the largest flow (Fig. 3).

Spring Flows

Kuruman eye The flow has been gauged regularly by the Department of Water Affairs since 1959. A seasonal change is present (Fig. 5). The total annual flow changed from about 7 665 × 10³ m³ in 1960 to 6 570 × 10³ m³ in 1970, representing a decrease of 14% between 1963 and 1968.

Second eye The flow has been regularly gauged by the Department of Water Affairs since 1959 when it was 15,1 × 10³ m³/annum. During 1965 the spring dried up completely. A seasonal change is also evident (Fig. 6).

Manyeding A The eye flowed until 1958, but was never gauged.

Manyeding B The flow has been gauged regularly by the Department of Water Affairs since 1960, and a seasonal change is evident. (Fig. 7) The total annual flow was about 2 190 × 10³ m³ in 1961—1963, and 1 168 × 10³ m³ in 1970, indicating a decrease of 47% between 1963 and 1968.

Manyeding C The flow has never been gauged, but only measured in 1970 as 120 × 10³ m³/annum.

Khaw The eye flowed until 1962, but was never gauged. After 1962 it dried up completely.

Groot Kees The eye flowed at times before 1962, but was never gauged. After 1962 it dried up completely.

The flow graphs shown in Figures 5, 6 and 7 are generalised, and only maxima and minima were plotted. After 1973 the gauges on Kuruman eye, Second eye and Manyeding B eye were ineffective and the flow could not be measured.

Rainfall

The average annual rainfall based on the records at three rainfall stations in the area operated since 1958 was calculated for the period 1958 to 1970. This value correspond exactly with the average rainfall based on records of the Weather Bureau at the Kuruman station, and the data for the latter was thus regarded to be representative of the long term rainfall in the catchment area. The rainfall from 1940 to 1970 is shown in Fig. 8.

The average yearly rainfall over this period was 445 mm. There seems to have been a period of above average rainfall (520 mm) from 1949 to 1963 as shown by a gradual increase in the cumulative variation values, followed by a below-average rainfall (346 mm) from 1963 to 1970, indicated by a constant

Figure 3
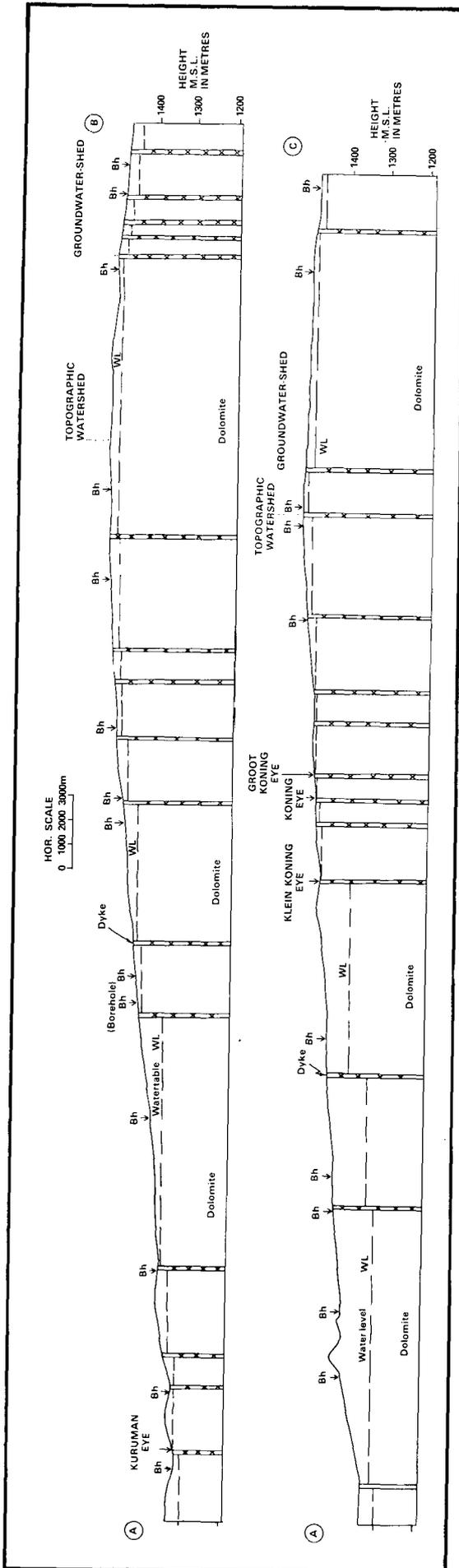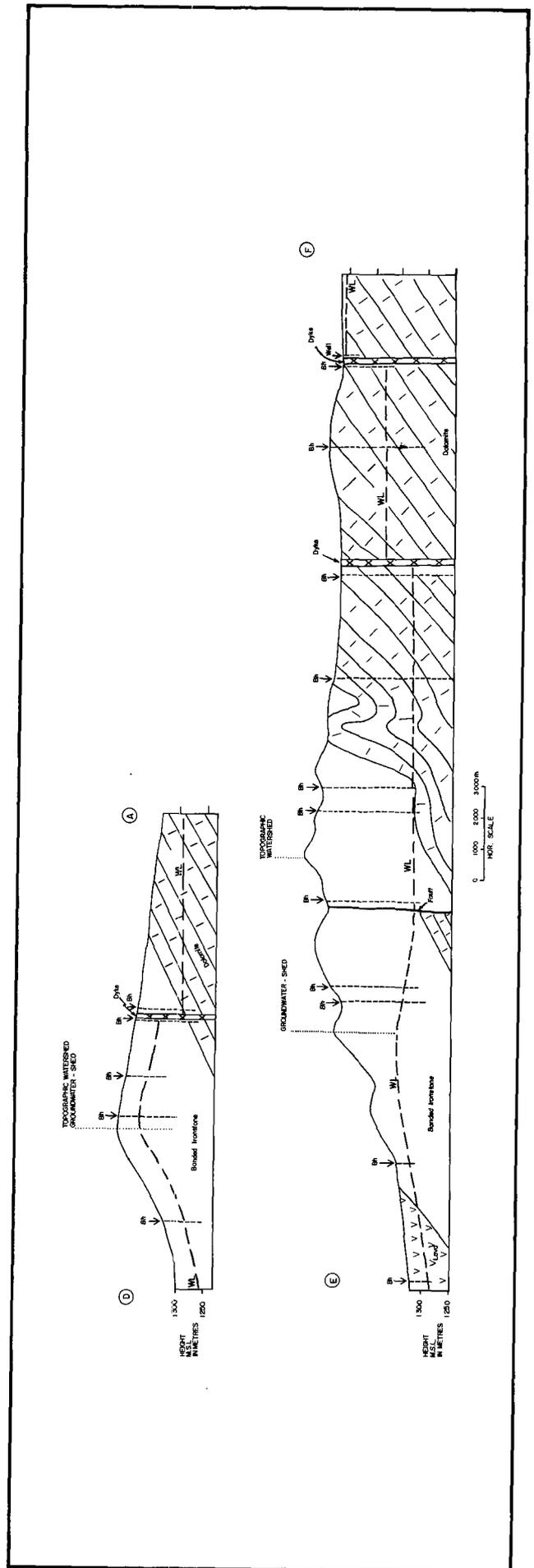*Groundwater profiles along sections AB and AC*

Figure 4
Groundwater profiles along sections DA and EF

decrease in the cumulative values. A period of above-average rainfall is also indicated by Tyson (1977) from 1953 to 1963 and a below-average rainfall from 1963 — 1972.

This change in the rainfall pattern is most probably the reason for the general decrease in the flow of the springs after 1963.

Dolerite Dykes as Groundwater Barriers

A spring should be present in each sub-compartment if the dykes are impermeable. This is however, not the case, and leakage occurs through the dykes or through alluvium covering them in places.

Boreholes in the dykes are either dry or have very low yields (below 3 m³/h). The dolerite is seldom weathered deeper than about 15 m. Boreholes were either drilled on the dolomite or on the contact between the dolerite and dolomite. Large differences in the groundwater levels exist on either sides of the dyke as indicated by boreholes. Such conditions are illustrated on Cubbie where the difference in the water level is 52 m (Fig. 9a) and on Kono C where the difference is 73 m (Fig. 9b). In both cases leakage occurs through the dolerite, through highly weathered or jointed rock near the surface. In groundwater compartments which are not drained by a spring it can thus be assumed that the groundwater drains away through the upper part of the dyke.

If, however, a spring exists, most of the groundwater can be assumed to drain through the spring and the amount which may leak through the dyke is probably negligible. The two dykes along the eastern and northern borders of the area on which the springs are situated may therefore be fairly impermeable and the leakage through them may be relatively small in comparison with the natural spring flow.

No flowing springs are situated along the southern barrier dykes and some leakage may occur. The surface areas of these compartments are however small in comparison with the large compartment and should not result in serious errors in determining the total flow from the catchment area.

Leakage through the Banded Ironstone

The western watershed is formed by banded ironstone. Although the topography and the water level are higher on the dolomite plateau east of the hills forming the western watershed than west of the watershed, the water level along the watershed is higher than on either side, indicating a low permeability in depth (Fig. 4). Dyke contacts and faults in banded ironstone are in general not very good conduits and only a limited success is attained in boreholes. In one instance the water level in a borehole in a large fault was 35 m higher than in the dolomite 1 800 m away.

It therefore seems that the banded ironstone along the western watershed does not allow underground leakage from the catchment area. Probably leakage which may occur will be small in relation to the spring flow.

Considerations of Groundwater Recharge

In calculating recharge based on spring flow, it was assumed that the underground leakage through the eastern and northern dyke barriers on which the main springs are situated, is relatively
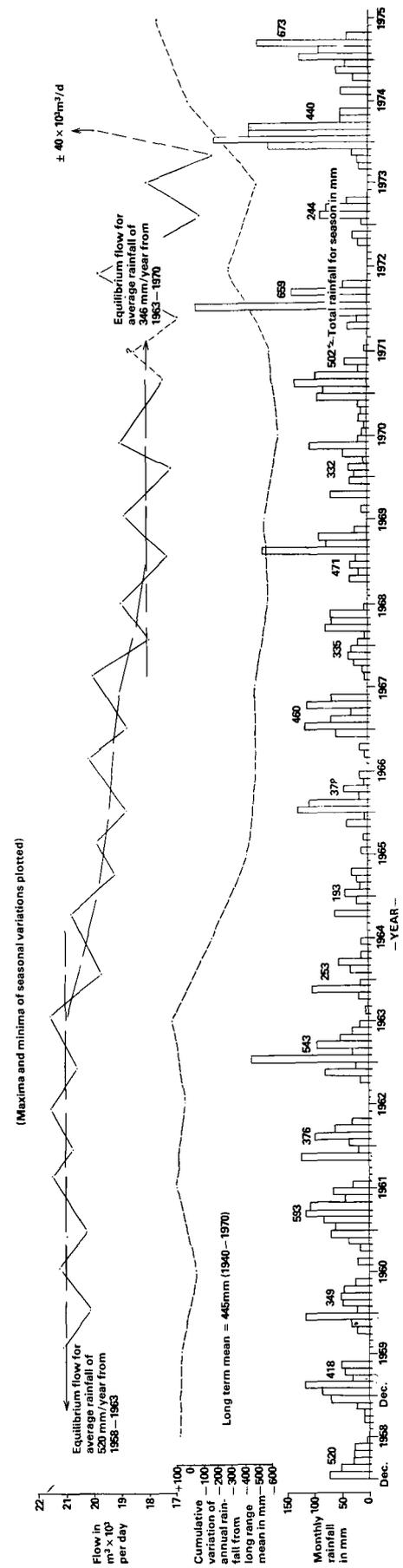

Figure 5
Flow of Kuruman eye

Figure 6
Flow of Second eye

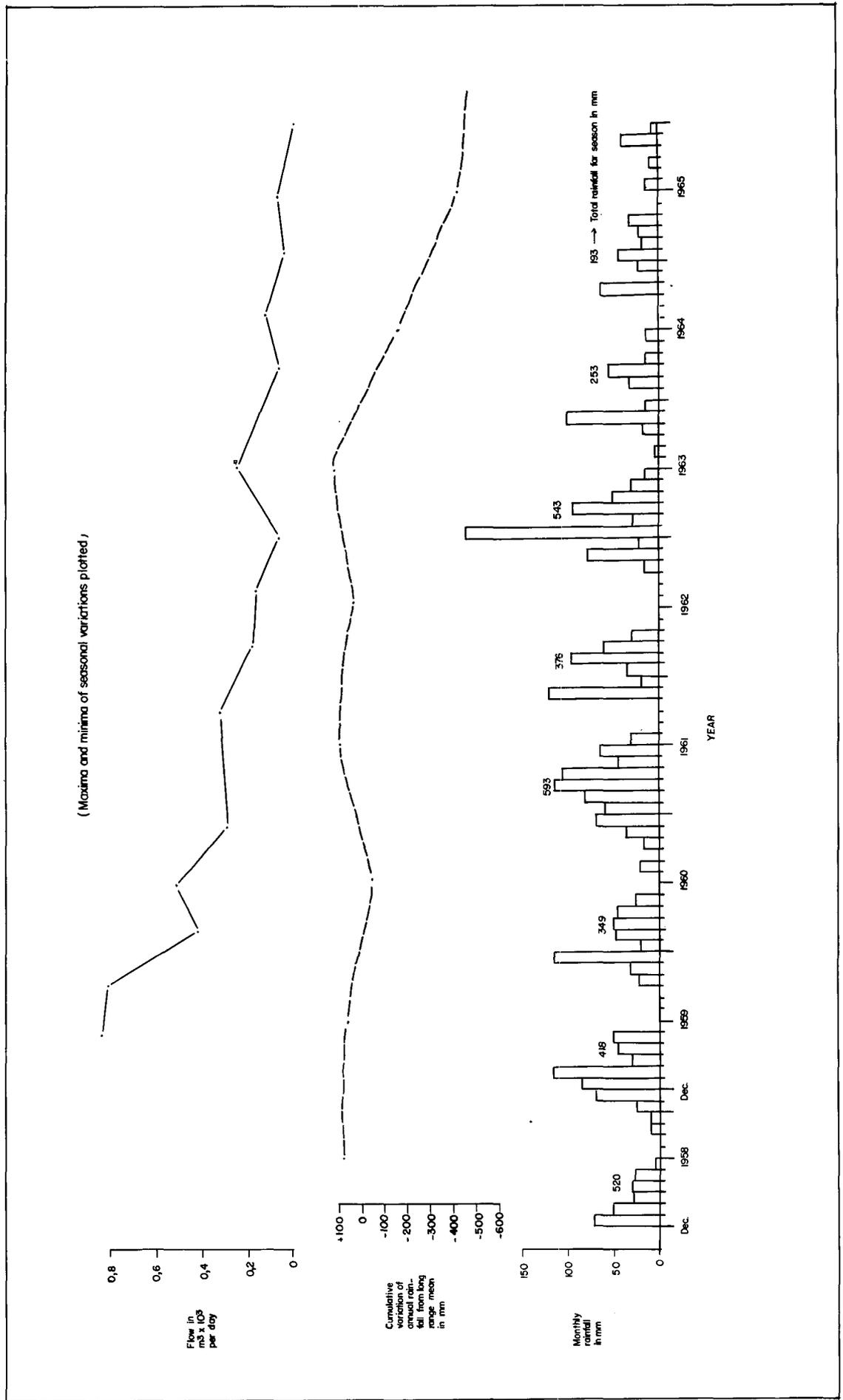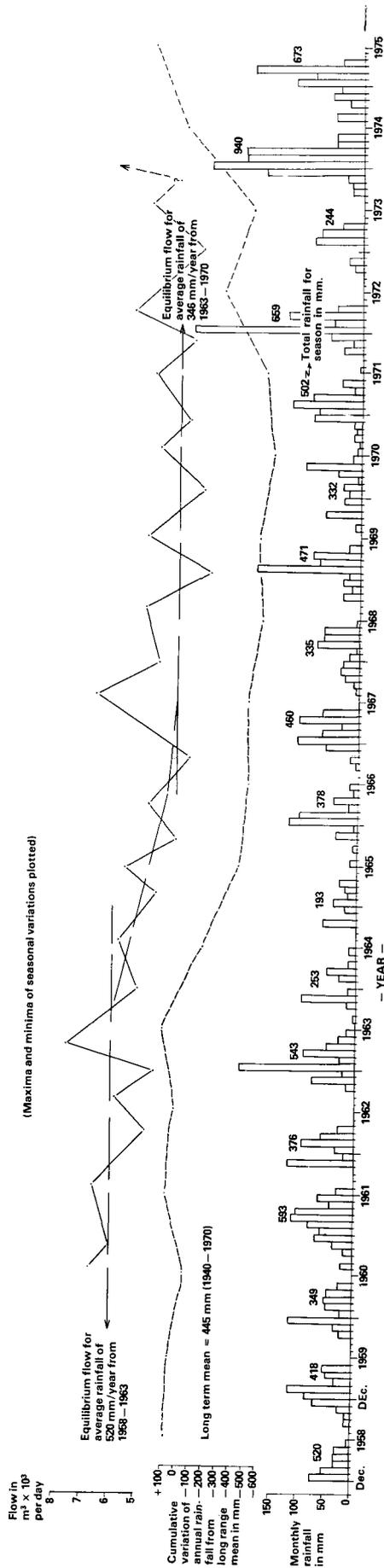(Maxima and minima of seasonal variations plotted)

Figure 7
Flow of Manyeding B eye

small. Leakage through the dykes along the southern watershed and through the banded ironstone along the western watershed was likewise regarded as of small importance.

In the calculation the following aspects were also considered:

1. Surface runoff, which was actually nil from 1959 to 1970.

2. Groundwater pumped from boreholes for

    (i)   White population on the basis of 0,1 m³/d/capita.

    (ii) Black population on the basis of 0,02 m³/d/capita.

    (iii) Cattle on the basis of 8 ha/head and 0,05 m³/d/head.

3. Evaporation from open surfaces at springs and storage tanks at 2 286 mm/annum (1948 map of Department of Agricultural Technical Services).

4. Evapotranspiration from areas overgrown with reeds and where the water level is at a depth of less than 1 m (on the basis of a potential evapotranspiration rate of 840 mm/annum) calculated by means of the Thornthwaite Method (Thornthwaite, 1948).

5. Groundwater use for irrigation on the basis of a requirement of 908 mm for the specific crops (mainly lucern) as indicated by the Department of Agricultural Technical Services.

6. The discharge at the springs on the basis of the mean values obtained from the hydrographs.

The density of the white and black population in the area was calculated from the 1963 census on a proportional basis. Open water surfaces and areas overgrown with reeds were measured individually. Cultivated lands were measured in an area of 395 km² and the total area under cultivation was calculated proportionally for the whole area.

Only three springs flowed during 1970 i.e. Kuruman, Manyeding B and Manyeding C. The hydrographs for Kuruman and Manyeding B showed a decrease in spring flow from about 1963 to 1968, after which the flows were fairly constant. It can thus be assumed that after 1968 the flows were in equilibrium with the low average yearly rainfall of 346 mm over the period 1963 to 1970. The flows before 1963 were likewise in equilibrium with the high average yearly rainfall of 520 mm over the period 1949 to 1963.

The constant total spring flow after 1963 can be calculated but not for the period before 1963 since flows of Manyeding C, Khaw and Groot Kees were not gauged before 1963. No flow measurements are however available after 1970 and even the high rainfall after 1970 cannot be used to calculate recharge.

Calculation of Recharge

The recharge can be calculated for the period 1963 to 1970 on the basis of the groundwater losses from the compartment, the rainfall and the surface area.
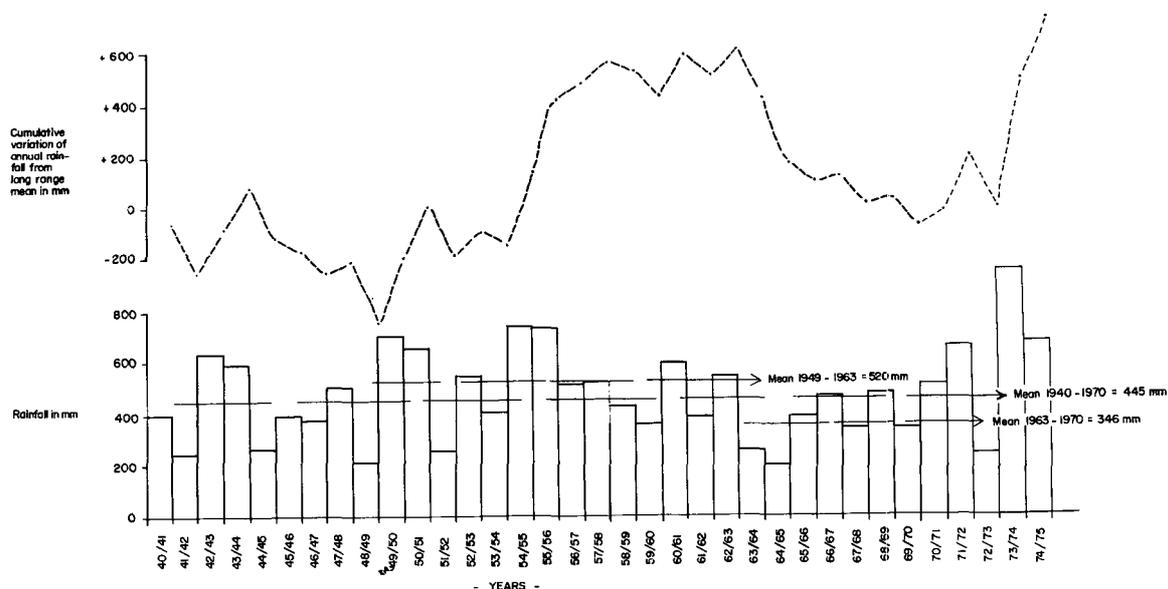
Figure 8
Seasonal rainfall at Kuruman, 1940—1970
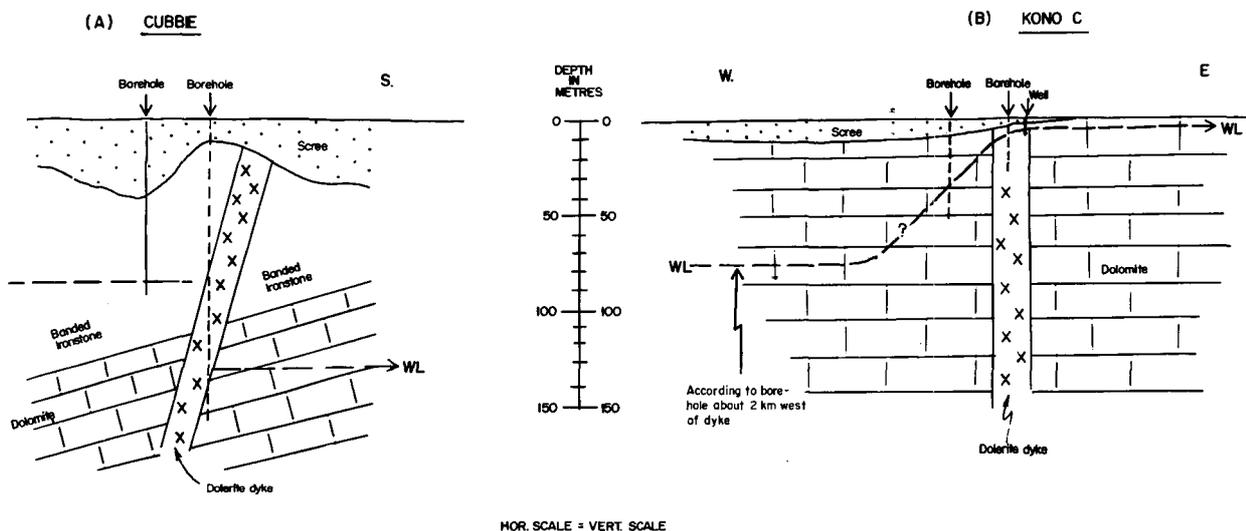
Figure 9
Influence of dyke on groundwater level

Groundwater losses

Domestic consumption	$= 102 \times 10^3 \text{m}^3/\text{annum}$
Stock consumption	$= 277 \times 10^3 \text{m}^3/\text{annum}$
Evaporation (from open pools and tanks)	$= 41 \times 10^3 \text{m}^3/\text{annum}$
Evapotranspiration (reedy areas)	$= 39 \times 10^3 \text{m}^3/\text{annum}$
Irrigation	$= 1\ 550 \times 10^3 \text{m}^3/\text{annum}$
Spring flow (Kuruman and Second and Manyeding B and C Eyes)	$= 7\ 848 \times 10^3 \text{m}^3/\text{annum}$
TOTAL	$= 9\ 857 \times 10^3 \text{m}^3/\text{annum}$

Rainfall

Average annual rainfall	$= 346 \text{ mm}$
Surface area of compartment	$= 1\ 140 \times 10^6 \text{m}^2$
Volume rainwater	$= 394 \times 10^6 \text{m}^3/\text{annum}$

Recharge

The average annual groundwater loss of $9\ 857 \times 10^3 \text{m}^3$ which is equal to the average annual groundwater gain or recharge, represents 2,5% of the average annual rainfall of 346 mm. If normal evaporation and transpiration of the groundwater is not taken into account the recharge is 2,48%, a difference of only 0,02%.

As probable underground leakage from the compartment has not been taken into account the value of 2,5% will represent a minimum percentage recharge.

Recharge Calculated on the Basis of the Thornthwaite Method

An attempt was made to calculate the groundwater recharge on the basis of the Thornthwaite Method. By this method the average monthly potential evapotranspiration is compared with the average monthly rainfall to calculate surplus water which is available for runoff or recharge of the groundwater. If no runoff occurs, the surplus water will be added to the groundwater.

Monthly potential evapotranspiration is first calculated according to the formula (Henzen, 1974).

$$e = 16\frac{(10t)^a}{(I)}$$

where t = average monthly temperature in °C

I = Heat index equivalent to the 12 values of the monthly heat index (i) where

$$i = \frac{(t)^{1,514}}{(5)}$$

I and a are functions of t with

$$a = 6,75 \times 10^{-7} \times I^3 - 7,71 \times 10^{-5} \times I^2 + 1,7921 \times 10^{-2} \times I + 0,49239$$

The potential evapotranspiration (e) is further corrected for latitude using a factor for daylight duration. The potential evapotranspiration is that amount of the rain which is evaporated or transpirated from the soil under particular climatic conditions assuming that sufficient soil moisture is available according to the biological requirements.

In the calculation of the water surplus it is assumed that —

1. soil moisture utilization is equivalent to an average of 100 mm rain, although this is dependent on the vegetation and the storage capacity of the cover;

2. if the monthly rainfall is greater than the potential evapotranspiration, the actual evapotranspiration is equal to the potential evapotranspiration;

3. if the potential evapotranspiration is greater than the rainfall the actual evapotranspiration is equal to the rainfall plus part of the moisture available in the soil;

4. if the available ground moisture is nil, the actual evapotranspiration is equal to the rainfall; and

5. if the available ground moisture is insufficient, the actual evapotranspiration is equal to the rainfall plus the amount of moisture in the soil.

As long-term meteorological data on average rainfall and monthly temperatures are required, the calculations can only be made at localities where these data are available. The calculations were accordingly made for the two meteorological stations at Kuruman and Botiton, close to the area under investigation (Fig. 1).

The average monthly rainfall and potential evapotranspiration for Kuruman (which is similar for Botiton) are shown in Fig. 10. It is evident that on this basis no surplus water is available for runoff or recharge. This is obviously not the case.

Another approach was made by using the individual yearly rainfall pattern in relation to the average monthly potential evapotranspiration pattern. It was argued that the temperature is likely to vary to a lesser degree than rainfall. The calculations were thus made on the basis of the actual monthly rainfall for each year over the arbitrary period 1940 to 1970. Examples of the relation between rainfall and potential evapotranspiration for the years 1950 and 1955 for Kuruman are shown in Fig. 11.

On this basis surplus water was available at Kuruman in 1950, 1953, 1955, 1956, 1957 and 1967 (Fig. 12) and at Botiton in 1950, 1957 and 1961 (Fig. 13). Data on water level fluctuations in boreholes in the area are unfortunately not available for the relevant years.
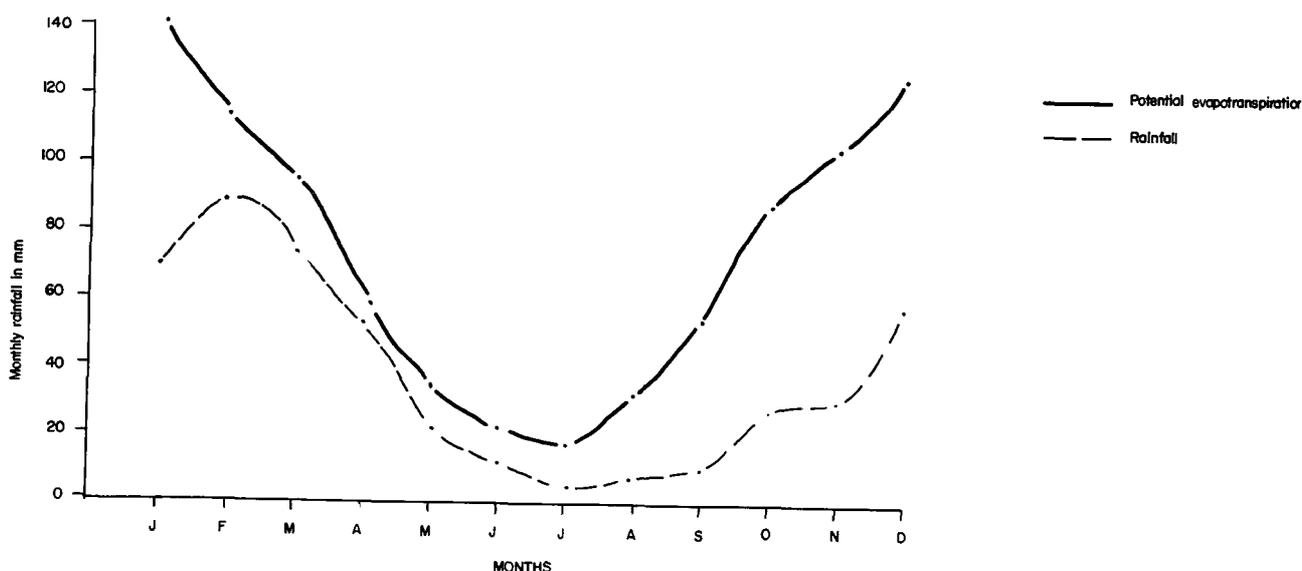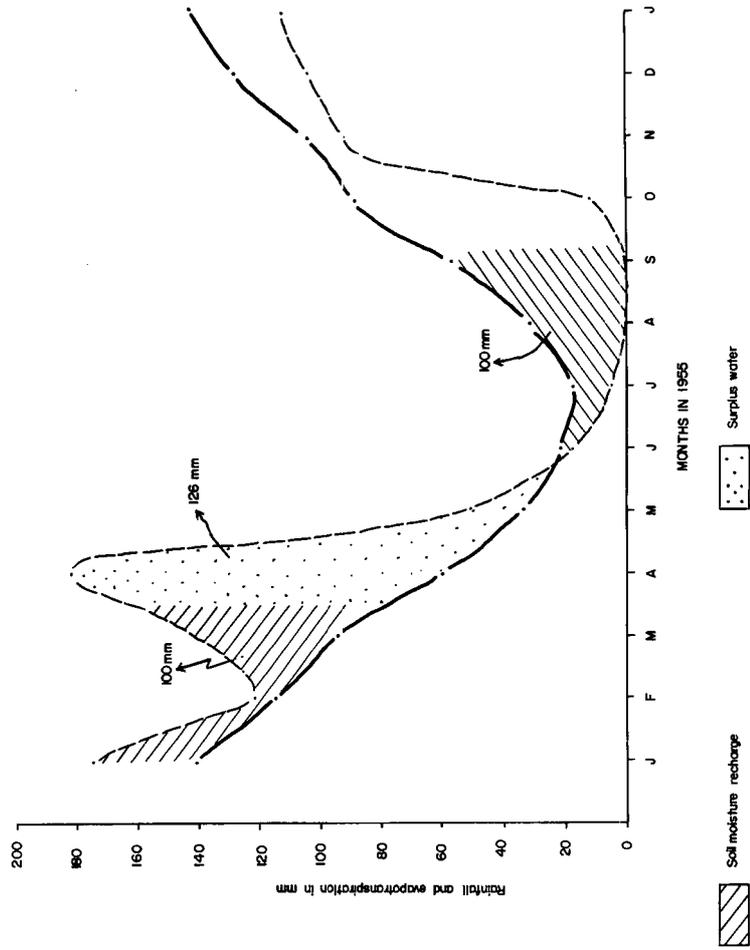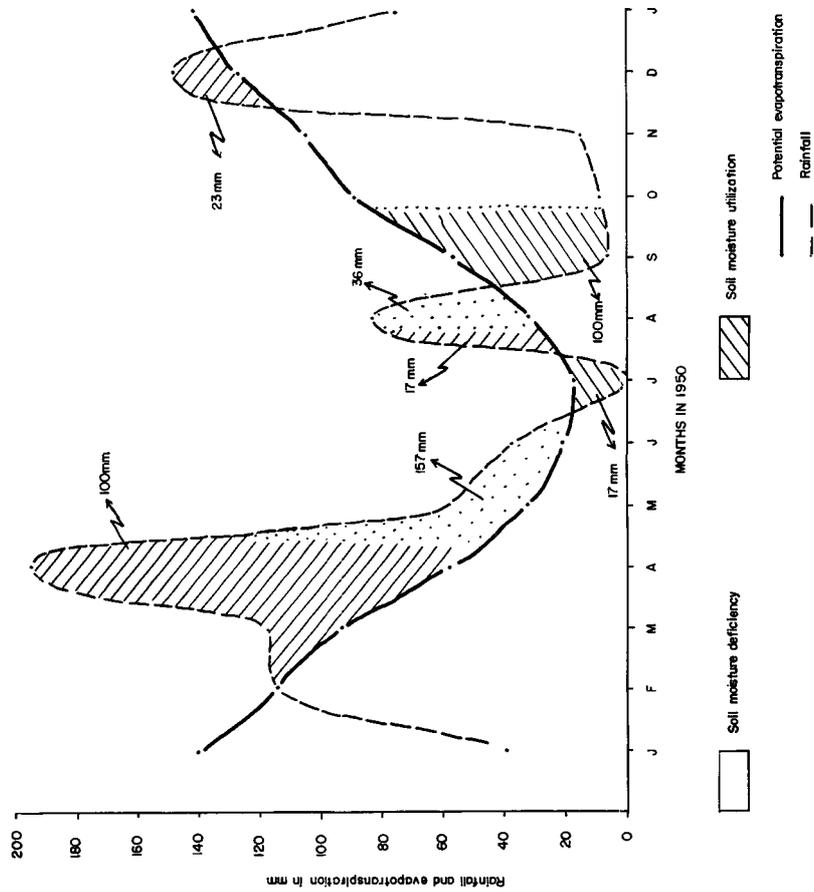

Figure 10
Monthly potential evapotranspiration and rainfall at Kuruman

Figure 11
Monthly potential evapotranspiration and actual rainfall at Kuruman
for 1950 and 1955

Figure 12 — Groundwater recharge at Kuruman between 1940 and 1970

MONTH	1940	1941	1942	1943	1944	1945	1946	1947	1948	1949	1950	1951	1952	1953	1954	1955	1956	1957	1958	1959	1960	1961	1962	1963	1964	1965	1966	1967	1968	1969	1970
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SEASONAL RAINFALL IN MM	243	628	585	258	385	366	497	204	698	644	280	539	400	731	728	505	520	418	349	593	376	543	253	193	378	460	335	471	332	502	
RECHARGE AS % OF SEASONAL RAINFALL	—	—	—	—	—	—	—	—	—	23	6	—	5	—	17	12	4	—	—	—	3	—	—	—	—	—	—	—	—	—	—
AVERAGE ANNUAL RECHARGE 1940 - 1970	3,39%																														

● Water surplus

Figure 12
Groundwater recharge at Kuruman between 1940 and 1970

Figure 13 — Groundwater recharge at Botiton between 1940 and 1970

MONTH	1940	1941	1942	1943	1944	1945	1946	1947	1948	1949	1950	1951	1952	1953	1954	1955	1956	1957	1958	1959	1960	1961	1962	1963	1964	1965	1966	1967	1968	1969	1970
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SEASONAL RAINFALL IN MM	405	259	524	593	323	353	253	499	256	711	591	357	344	322	341	498	365	376	264	403	468	255	612	214	178	340	633	385	259	330	490
RECHARGE AS % OF SEASONAL RAINFALL	—	—	—	—	—	—	—	—	17	13	—	—	—	—	—	—	11	—	—	2	25	—	—	—	—	—	—	—	—	—	—
AVERAGE ANNUAL RECHARGE 1940 - 1970	2,47%																														

● Water surplus

Figure 13
Groundwater recharge at Botiton between 1940 and 1970

No runoff takes place except in local areas and it can be assumed that all the surplus water, calculated on the basis of a 100 mm moisture utilization, is available for groundwater. recharge. Recharge accordingly takes place only during certain years of high rainfall. If taken as an annual mean over the period 1940 to 1970, recharge at Kuruman is 3,39% and that at Botiton 2,47%. Both localities are in the same geographical area with an average annual rainfall of about 445 mm. An appropriate value will probably be the mean of the two determinations i.e. 2,94%.

Conclusions

Annual groundwater recharge based on springflow is approximately 2,5% of the average annual rainfall of 346 mm.

Groundwater recharge based on the potential evapotranspiration rate, calculated according to the Thornthwaite Method is an annual average of 2,94% for the period 1940—1970 with an average rainfall of 445 mm. The values compare reasonably well considering that 2,5% represents a minimum.

The way in which the Thornthwaite method was applied might result in a disputable value but if it is applied over a long enough period, the value obtained may be correlated with recharge determined by direct methods.

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