GROUNDWATER RECHARGE ON THE DOLOMITE OF THE GHAAP PLATEAU NEAR KURUMAN IN THE NORTHERN CAPE R.S.A.

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by

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Introduction

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

Topography

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

Geology

The rocks in the area consist largely of dolomite of the Transvaal System with lenses of chert and limestone. Approximately 10% of the surface is covered with sand and scree. Banded ironstone of the Transvaal System, which lies conformably on the dolomite, constitute the Kuruman Hills along the western watershed. Numerous dolerite 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

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more than 15m wide. Their positions are however distinctly marked by linear surface limestone ridges overgrown with thorn trees. The calcrete represents calcified, weathered dolerite and is never very thick.

Recent sinkholes are not known and most of the existing ones seem to be of Tertiary age.

Several thin kimberlite dykes occur. In one locality Karoo shale occur in the dolomite and is most probably associated with an ancient sinkhole.

Geohydrology

The water level in the dolomite varies between surface level and 200m along the western foothills. The groundwater is drained from the catchment area by means of several flowing springs or eyes. Five of these are situated on a wide dolerite dyke striking N.N.W. along the eastern watershed (Manyeding A, B, C, Khaw and Groot Kees - see plan A) and another two along a dyke striking E.-W. through Kuruman (2nd and Kuruman). From a survey of the water level heights it was possible 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 (see plan A and fig. 1). 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 (see plan A and fig. 2). The numerous dykes divide the large compartment

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into a number of sub-compartments (about 50) with the water level falling step-like to the level of the Kuruman eye, which has the largest flow (see fig. 1).

Spring Flow

Kuruman eye: The flow has been gauged regularly by the Department of Water Affairs since 1959. A seasonal change is present (see fig. 3). The total annual flow changed from about 7 665 x 10^3m^3 in 1960 to 6 570 x 10^3m^3 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 x 10^3m^3/year. During 1965 the spring dried up completely. A seasonal change is also evident (see fig. 4).

Manyeding B: The flow has been gauged regularly by the Department of Water Affairs since 1960, and a seasonal change is evident on the hydrograph (see fig. 5). The total annual flow was about 2 190 x 10^3m^3 in 1961-1963, and 1 168 x 10^3m^3 in 1970, indicating a decrease of 47% between 1963 and 1968.

Manyeding C: The flow was never gauged, but only measured in 1970 as 120 x 10^3m^3/year, and no continuous graph is available.

Manyeding A: Flowed until 1958, but was never gauged.

Khaw: Flowed until 1962, but was never gauged.

Groot Kees: Flowed at times before 1962, but was never gauged.

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The hydrographs shown in figures 3, 4 and 5 are generalised, and only maxima and minima were plotted.

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 corresponded exactly with the average 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 range rainfall in the catchment area. The rainfall from 1940 to 1970 is shown on fig. 6.

The average yearly rainfall over this period is 442 mm. There seems to have been a period of above average rainfall (520 mm) from 1949 to 1963, followed by a below-average rainfall (346 mm) from 1963 to 1970.

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

If the dykes are in fact impermeable, a spring should be present in each sub-compartment. As this is not the case, all dykes are in fact not impervious, and does leakage occur through them or through alluvium covering them in places.

Boreholes in the dykes are either dry or have very low yields (below 3 m^3/h). The dolerite is seldom weathered deeper than about 15 m.

Boreholes in the dykes are either drilled on the dolomite or on the contact between the dolerite and dolomite. Large differences

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in the groundwater level exist on either side of the dyke as indicated by boreholes. Such conditions are illustrated on Cubbie where the difference in the water level is 52m (see fig. 7a) and on Kono C where the difference is 73 m (see fig. 7b). In both cases leakage occur through the dolerite, either 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 on the other hand, 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 in comparison.

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 relation to 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 is 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

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higher than on either side, indicating a low permeability in depth (see fig. 2). 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 35m higher than in the dolomite 1 800m away.

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

Groundwater recharge: considerations

In the calculation of 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 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 of groundwater recharge the following other aspects were considered:

(a) Surface runoff, which was actually nil from 1959 to 1970.

(b) Groundwater pumped from boreholes for
    (i) European population on the basis of 0,1 m^3/day/person.
    (ii) Non-European population on the basis of 0,02m^3/day/person.
    (iii) Cattle on the basis of 8 ha/head and 0,05 m^3/day/head.

(c) Evaporation from open surfaces at springs and storage tanks at 2 286 mm/year (average value of Weather Bureau).

(d) Evapotranspiration / .....

(d) Evapotranspiration from areas overgrown with reeds and where the water level is at a depth of less than 1m on the basis of a potential evapotranspiration rate of 840 mm/year calculated from the Thornthwaite formulae.

(e) 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 Agriculture.

(f) The discharge at the springs on the basis of the mean values obtained from the hydrographs.

The density of the European and non-European 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 km^2 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 show 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 346mm 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 springflow after 1963 can be calculated but as Manyeding C, Khaw and Groot Kees were not gauged during the flow period before 1963, a constant total springflow before 1963 cannot be calculated.

Calculation / .....

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.

Groundwater losses

(i) Domestic consumption = 102 x $10^3 m^3$/year
(ii) Stock consumption = 277 x $10^3 m^3$/year
(iii) Evaporation (from open pools and tanks) = 41 x $10^3 m^3$/year
(iv) Evapotranspiration (reedy areas) = 39 x $10^3 m^3$/year
(v) Spring flow (Kuruman + 2nd + Manyeding Band C) =7848 x $10^3 m^3$/year
Total =9076 x $10^3 m^3$/year

Rainfall

(i) Average annual rainfall = 346 mm
(ii) Surface area of compartment = 1 140 x $10^6 m^2$
(iii) Volume rainwater = 394 x $10^6 m^3$/year

Recharge

The average annual groundwater loss of 9 076 x $10^3 m^3$ which is equal to the average annual groundwater gain or recharge represents 2,3 per cent of the average annual rainfall of 346 mm.

If normal evaporation and transpiration of the groundwater is not taken into account the recharge is 2,28 per cent a difference of only 0,02 per cent.

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As probable underground leakage from the compartment has not been taken into account the value of 2,3 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 Thornwaite Method (Thornthwaite, 1948). 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

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

where t = average monthly temperature in ^{o}C

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

$$i = \left(\frac{t}{s}\right)^{1,514}$$

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 involving 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

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available according to the biological requirements.

In the calculation of the water surplus it is assumed that

(i) soil moisture utilization is an average of 100 mm rain, although this is dependent on the vegetation and the storage capacity of the cover;

(ii) if the monthly rainfall is greater than the potential evapotranspiration, the actual evapotranspiration is equal to the potential evapotranspiration;

(iii) 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;

(iv) if the available ground moisture is nil, the actual evapotranspiration is equal to the rainfall;

(v) 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 of 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.

The average monthly rainfall and potential evapotranspiration are shown on fig 8 for Kuruman which is similar for Botiton. It is evident that on this basis no surplus water is available for runoff or recharge. This is a condition that is obviously not valid.

Another / .....

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 temperatures are likely to vary to a lesser degree than the rainfall. The calculations were thus made on the basis of the actual monthly rainfall for each year over the period 1940 to 1970. Examples of the relation between rainfall and potential evapotranspiration for the years 1950 and 1955 for Kuruman are shown on fig. 9.

On this basis surplus water was available at Kuruman in 1950, 1953, 1955, 1956, 1957 and 1967 (see fig. 10) and at Botiton in 1950, 1957 and 1961 (see fig. 11).

No runoff takes place except in local areas and it can be assumed that all the surplus water is available for groundwater recharge. Recharge evidently only takes place during certain years of high rainfall. If taken as an annual mean over the period 1940 to 1970, recharge at Kuruman is 3,39 per cent and 2,47 per cent at Botiton. Both localities are in the same geographical area with an average annual rainfall of about 440 mm. An appropriate value will probably be the mean of the two determinations i.e. 2,94 per cent.

Conclusions

Annual groundwater recharge based on springflow is approximately 2,3 per cent of the average annual rainfall of 346 mm.

Groundwater recharge based on the potential evapotranspiration rate calculated according to the Thornthwaite method and the actual yearly rainfall is an annual average of 2,95 per cent over the period 1940 - 1970 with an average rainfall of 440 mm.

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The values compare reasonably well considering that 2,3 per cent represents a minimum.

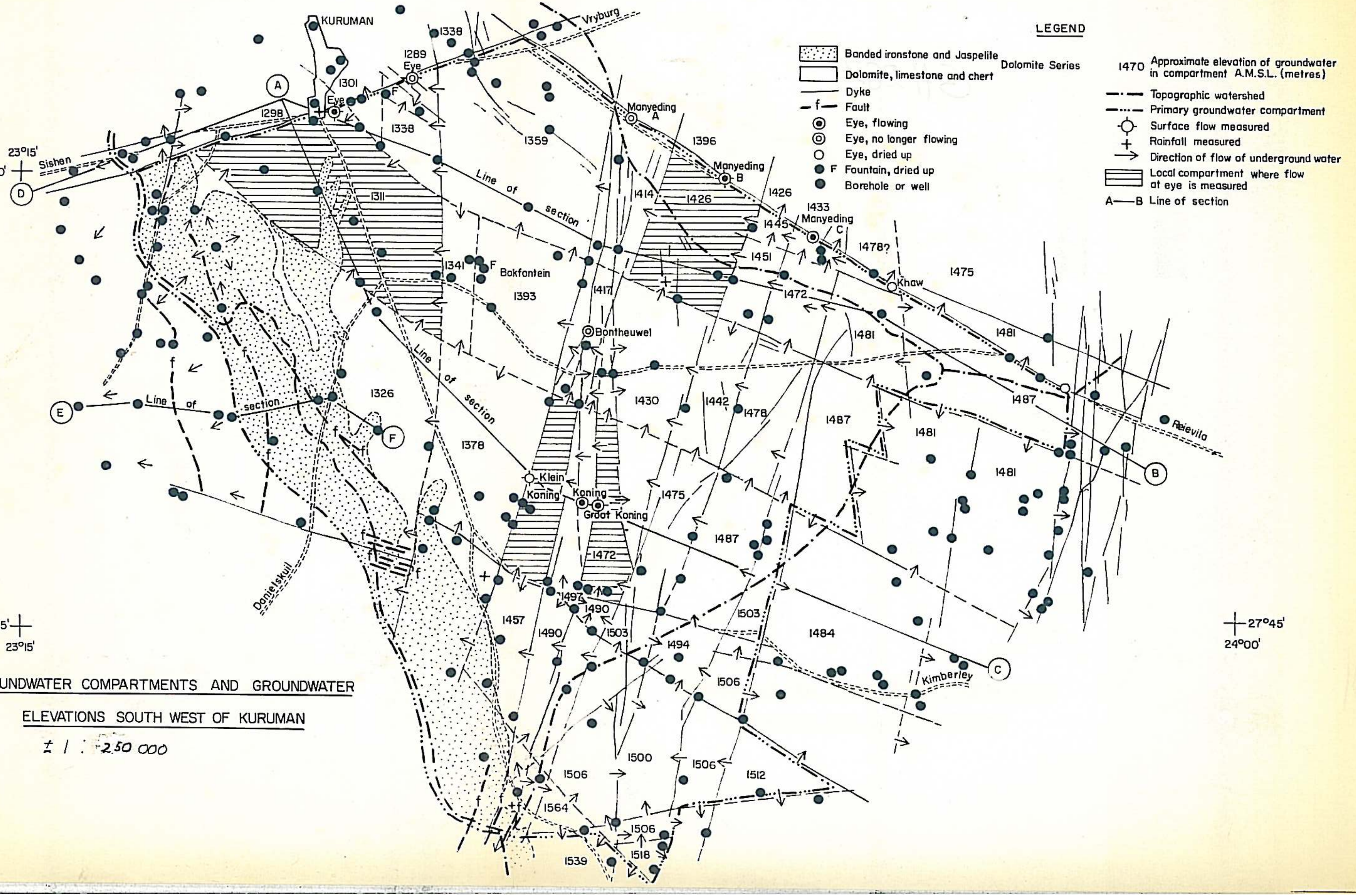
The way in which the Thornthwaite method was used may not give a correct answer, but providing it is applied over a long enough period, the value obtained may apparently be correlated with recharge determined by direct methods.

Maps and Figures

Bibliography

Thornthwaite, C W, 1948. An approach toward a rational classification of climate : Geogr. Rev., 38, 1 - 4, p. 55 - 94.

Plan A.



GROUNDWATER COMPARTMENTS AND GROUNDWATER

ELEVATIONS SOUTH WEST OF KURUMAN

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