

# EVALUATION OF AN ALLUVIAL AQUIFER AT CAROLUSPOORT

DE AAR, SOUTH AFRICA

by

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## ABSTRACT

To augment the water supply of De Aar station, the South African Railways were advised to develop the water contained in silty alluvial deposits at the confluence of the Brak River and Stofpoort tributary above Caroluspoort. High yields can not be obtained from the underlying Karoo strata. After sinking several successful wells, the extent, thickness and nature of the mainly silty alluvial deposits were determined by means of electrical resistivity and seismic refraction surveys as well as exploratory drilling. Various field and laboratory determinations were made to estimate the permeability and storage of the alluvial deposits which are up to 15 metres thick. These values were checked against a groundwater inventory of the Railway land which was drawn up for a dry spell of several months. The maximum perennial supply that can be developed is limited to subsurface inflow estimated at  $1250 \text{ m}^3/\text{d}$  and recharge by infiltration of rainfall and runoff which is likely to be less than an average of  $15 \times 10^4 \text{ m}^3$  per annum. Safe yield was as a first approximation put at  $1350 \text{ m}^3/\text{d}$ .

An analysis of water level fluctuations in a number of observation holes, pumpage and rainfall over the period 1960-71 indicates that the previously mentioned estimate of  $1350 \text{ m}^3/\text{d}$  for safe yield is conservative. It could possibly be  $1600 \text{ m}^3/\text{d}$ .

## Introduction

For many years - apparently from before 1916, judging by a report of A L du Toit - a large proportion, if at times not the whole of the water requirements of the De Aar station has been and still is being supplied from a Railway reserve of about 200 hectares on the farm Caroluspoort, which is situated about 13 km to the east of De Aar.

Investigations carried out by the Geological Survey at the request of the South African Railways in 1948, 1954 and 1959-1960 and the subsequently continued observations at Caroluspoort illustrate the development of a groundwater resource and the successive approximations in determining its safe yield.

### Physiography and Geology

The Railway reserve (figure 1) comprises the Caroluspoort which is a gorge cut by the westward-draining Brak River through a range of flat-topped hills, capped by a dolerite sheet, as well as a tract of eroded land at the confluence of the Stofpoort Stream and the Brak River immediately to the east of the poort. The Brak River and the Stofpoort Stream have cut donga's up to 10 metres deep in alluvial deposits. The solid geology comprises horizontally disposed bluish Karoo shales and mudstones with sandy horizons. These have been intruded by a transgressive dolerite sill which lies at river-bed level west of the poort and outside the Railway reserve, and caps the previously-mentioned hills to the east.

### Historical Outline

At the time of the first investigation in 1948, the Railways were dependent on the so-called Stofpoort springs for a water supply. (At some time in the past a water supply had been obtained from a small dam at the lower end of the poort which was washed away by floods.) The springs are really seepages mainly from alluvial deposits and to a lesser degree from Karoo mudstone exposed higher up in the Stofpoort donga. This supply amounted to about 600 to 750 m<sup>3</sup>/d depending on rainfall.

In an attempt to augment the supply, several boreholes were drilled in 1949 on the advice of the Geological Survey through the alluvial deposits into the underlying shale/mudstone. No attempt was made to develop water in the alluvium. The yields of the shales/mudstones in these holes were too small to warrant pumping.

It is now well-known that the highest yields in Karoo strata are mostly obtained from the heavily jointed and weathered contact zones of intrusive dolerites i.e. either from the baked sedimentary

Appraisal of the various determinations of the coefficients  
of storage and permeability

Too much weight should not be given to the coefficients of storage calculated according to the non-equilibrium equation of Theis, especially the figure derived by the straight line solution for the second test.  $S$  is extremely sensitive to small changes of slope of the best-fitted straight line. Curve matching also presents difficulties because of scatter of points.

$S$  as calculated from the volume of the cone of depletion, increases with period of pumping as is to be expected because drainage is a gradual process. After a lengthy period of pumping the figures may be expected to approach a constant value. Extrapolation of the  $S$  figures, seems to indicate a constant value of 0,07 for the first and 0,11 for the second test.

The different values may possibly be ascribed to the fact that different layers were being dewatered because the water level at the start of the second test was roughly 0,55 m lower than at the beginning of the first. On the other hand the pumping rate during the second test was nearly half that of the first. It could therefore be expected that drainage would lag further behind in the first than in the second test.

However,  $S = 0,07$  for the first test

compares reasonably well with the direct inventory method and three of the Theis figures. On the other hand the figure of 0,11 for the second test is more in line with the specific yield deduced from the moisture desorption determinations.

With the exception of the straight line solution for the second test (which also yields an anomalous  $S$  value), the Thiem and Theis values for  $P$  agree quite well. They are about 100 times higher than most of the laboratory determinations which all fall short.

The reason for these different results is not clear. The alluvium is apparently not only permeable at its base but seems to contain permeable zones or horizons throughout its saturated thickness. Being probably friable these may have escaped sampling and testing.

For the further evaluation S was assumed to be 0,10 and P  $7,6 \times 10^{-4}$  m/s.

Groundwater inventory for the period 10 July to  
20 October 1959

The reliability of the figures assumed for P and S may be gauged by a groundwater inventory. The above-mentioned period was selected for an inventory, because firstly with the exception of 12 mm on 7th July no rain fell from 6 June to 20 October. The assumption of zero replenishment from infiltration of rainfall during the period under consideration seems reasonable and should in any case not introduce a significant error. Secondly except for effluent seepage, there was no surface flow which could have caused replenishment. Fortunately this period also falls within the period of fieldwork so that sufficient water level data are available. The area for which the inventory was drawn up is shown in fig. 1.

The general storage equation for an aquifer is  $F + R_s + R_u + R_l + R_w = E + D_s + D_u + D_l + D_w \pm \Delta S$ ;

- when F = recharge from infiltration  
R<sub>s</sub> = recharge from surface bodies of water  
R<sub>u</sub> = recharge from lateral underflow  
R<sub>l</sub> = recharge by leakage through an aquitard  
R<sub>w</sub> = recharge by wells, trenches or infiltration devices  
E = discharge by evapo-transpiration  
D<sub>s</sub> = discharge to surface bodies of water  
D<sub>u</sub> = discharge by lateral underflow  
D<sub>l</sub> = discharge by leakage through an aquitard  
D<sub>w</sub> = pumpage from wells etc.  
 $\Delta S$  = change in storage volume.

Let us consider each item:

F is taken as nil

R<sub>s</sub> from four small water bodies behind conservation embankments is estimated at  $6,0 \times 10^3$  m<sup>3</sup> from drop in water level corrected for evaporation loss (0,67 of Class A evaporation pan)

R<sub>u</sub> is estimated at  $1,8 \times 10^5$  m<sup>3</sup>, as follows: Ground water

enters the area through the alluvial deposits and Karoo strata. The cross-sectional areas of water-bearing alluvium perpendicular to the direction of flow are 3070 m<sup>2</sup> in the south east and 3990 m<sup>2</sup> northeast of well G.6778. With hydraulic gradients of 1:420 and 1:210 respectively, the flows are 480 and 1220 m<sup>3</sup>/d. Recharge will also take place by groundwater flow through the shale underlying the alluvial deposits as well as between the two cross sections of alluvium. With an estimated coefficient of transmissibility T of  $8,0 \times 10^{-5} \text{ m}^2/\text{s}$  and an average gradient of 1:300 over a length of 3000 m, the flow through the Karoo strata is about 70 m<sup>3</sup>/d. Total flow 1770 m<sup>3</sup>/d x 102 days.

- R<sub>1</sub> Nil
- R<sub>w</sub> Nil
- E is estimated by assuming 0,67 x Class A pan evaporation over the area of open and shallow ground water in the dongas which is mostly overgrown by reeds and poplar trees. The loss amounts to  $1,9 \times 10^5 \text{ m}^3$  for the whole period of 102 days.
- D<sub>s</sub> effluent seepage was measured at the downstream end of the area. The total flow was  $5,7 \times 10^5 \text{ m}^3$ .
- D<sub>u</sub> estimated to be  $1,1 \times 10^4 \text{ m}^3$  by calculating underflow through 510 m<sup>2</sup> cross-sectional area of alluvium and an hydraulic gradient of 1:315. Underflow through the shale is assumed to be insignificant.
- D<sub>1</sub> Nil
- D<sub>w</sub> pumpage over the whole period from wells No's G.6778, G.6779 and 4 and of effluent seepage in the Stofpoort tributary amounted to  $7,5 \times 10^4 \text{ m}^3$ .
- ΔS a decrease in storage of  $2,7 \times 10^4 \text{ m}^3$ .

The inventory therefore reads

Gains:	F = $0,0 \times 10^4 \text{ m}^3$ R <sub>s</sub> = $0,6 \times 10^4 \text{ m}^3$ R <sub>u</sub> = $18,0 \times 10^4 \text{ m}^3$ R <sub>1</sub> = $0,0 \times 10^4 \text{ m}^3$ R <sub>w</sub> = $0,0 \times 10^4 \text{ m}^3$	Losses:	E = $1,9 \times 10^4 \text{ m}^3$ D <sub>s</sub> = $5,7 \times 10^4 \text{ m}^3$ D <sub>u</sub> = $1,1 \times 10^4 \text{ m}^3$ D <sub>1</sub> = $0,0 \times 10^4 \text{ m}^3$ D <sub>w</sub> = $7,5 \times 10^4 \text{ m}^3$ ΔS = $-2,7 \times 10^4 \text{ m}^3$
	Total = $18,6 \times 10^4 \text{ m}^3$		Total = $13,5 \times 10^4 \text{ m}^3$

Balance can be achieved by decreasing gains ( $R_S + R_W$ ) and storage loss ( $\Delta S$ ) and/or increasing loss through evapotranspiration and underflow ( $E + D_W$ ). As items  $D_S$  and  $D_W$  have been measured, they can not be changed. Further, as  $E$  has probably been over-estimated and  $D_U$  and  $\Delta S$  are rather small, balance can most easily be obtained by decreasing  $R_U$  i.e. by assuming a smaller coefficient of permeability -  $5,1 \times 10^{-4}$  m/s instead of  $7,6 \times 10^{-4}$  m/s.

Groundwater inflow during the period for which the inventory was drawn up, then appears to have been  $1250 \text{ m}^3/\text{d}$ . Subsurface inflow would be reduced by about 20% with a watertable drop of 1 metre.

#### Replenishment by rainfall and runoff

The maximum quantity of groundwater that could be pumped indefinitely, if evapotranspiration losses and underground outflow could be obviated and all the effluent seepage salvaged, would be equal to the groundwater inflow plus replenishment by infiltration of rainfall and runoff.

Estimation of infiltration to groundwater presents serious difficulties as facilities for determining a complete hydrologic balance are not available at Caroluspoort and furthermore would have to be determined over a period of years to obtain a reliable average annual figure.

In March 1961 rainfall at Caroluspoort amounted to about 150 mm, i.e. roughly half the annual average. From the rise of the water level as measured in April 1961, storage increased by an estimated  $5 \times 10^4 \text{ m}^3$ . It is assumed that over the period March - April 1961 in which replenishment took place and groundwater levels rose to their maximum, subsurface inflow to the inventory area was more or less balanced by pumpage, underflow and evapotranspiration losses. The loss of ground water by effluent seepage which was not collected, was probably  $2,3 \times 10^4 \text{ m}^3$ . The total replenishment by rainfall and runoff over the period is therefore estimated at about  $7,3 \times 10^4 \text{ m}^3$ .

With the high rainfall over a short period, conditions for recharge were probably at their optimum. Replenishment will probably be less for an equal rainfall over a longer period. It would thus

appear that on the average annual replenishment can not exceed  $15 \times 10^4 \text{ m}^3$ .

### Safe yield

Groundwater storage in the inventory area amounts to about  $1 \times 10^6 \text{ m}^3$ . Taking in consideration that the subsurface inflow is obtained from alluvial deposits which extend upstream for many kilometres, a pumping rate of  $2000 \text{ m}^3/\text{d}$  and more can be maintained quite easily for several years without any replenishment by rainfall and runoff. Storage is therefore not the factor limiting safe yield.

The maximum continuous supply from the inventory area is limited to the subsurface inflow (which amounts to  $1250 \text{ m}^3/\text{d}$  under high water table conditions) and replenishment by rainfall and runoff which presumably does not exceed an average of  $15 \times 10^4 \text{ m}^3$  per annum. The safe yield can therefore not exceed  $1600 \text{ m}^3/\text{d}$ ; as a first approximation the safe yield was put at  $1350 \text{ m}^3/\text{d}$ .

### Pumpage and water level fluctuation over the period 1961-1971

In fig. 4 water level fluctuations as recorded in two of the four boreholes equipped with automatic water-level recorders (about 36 other holes are measured monthly) are shown together with monthly pumpage and rainfall histograms. Up to about the middle of 1963 the monthly pumpage averaged about  $22 \times 10^3 \text{ m}^3$ , which is considerably below the predicted safe yield of about  $41 \times 10^3 \text{ m}^3/\text{month}$ . From middle 1963 to middle 1967 the quantity pumped gradually increased to an average of about  $70 \times 10^3 \text{ m}^3/\text{month}$  which was then maintained to early 1969. Until the middle of 1971 pumpage remained fairly constant at a lower level of about  $50 \times 10^3 \text{ m}^3$  per month.

It can be seen that sharp rises of the water levels can be correlated with rainy periods. The water levels reached maximum in 1963 and 1967 after seasons with rainfall about 75% above average. The 1967-68 season was more or less normal and the following two seasons were about 15 and 30% below average. The decline in the water level from middle 1967 to March 1969 when pumpage averaged  $70 \times 10^3 \text{ m}^3$  per month, indicates that this rate definitely exceeds the

safe yield, especially when taking into consideration that periods of 3 to 5 years duration with subnormal rainfall may be expected. The fact that water levels have stabilised at the lower pumping rate of about  $50 \times 10^3 \text{ m}^3/\text{month}$  in spite of the subnormal rainfall and even stand higher than in the beginning of 1960 may indicate that the safe yield figure could possibly be raised to  $50 \times 10^3 \text{ m}^3/\text{month}$  or a about  $1600 \text{ m}^3/\text{day}$ .

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