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ARTIFICIAL RECHARGE OF DOLOMITIC GROUND-WATER COMPARTMENTS IN THE FAR WEST RAND GOLD FIELDS OF SOUTH AFRICA

by

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ABSTRACT

The disposal of ground-water pumped to the surface by gold mines underlying the Dolomite Series on the Far West Rand in the past is outlined. The problem of selecting sites for boreholes capable of accepting large quantities of water for recharge purposes was solved after intensive gravity surveys and drilling had been conducted in compartments which had already been dewatered and as a result of which the dolomitic aquifer and its main conduits were better understood. A recharge case-history is included to illustrate the technique used.

RÉSUMÉ

On décrit l'élimination des eaux souterraines pompées à là surface par les mines d'or qui se developpent sous la Dolomie dans le "Far West Rand". Le problème du choix des emplacements de sondages d'injection a été résolu au moyen d'investigations gravimetriques détaillées et de sondages dans des compartiments qui ont été déja vidés. Il resulte de ces investigations que l'aquifère dolomitique et ses conduits Karstiques est mieux compris. Un exemple de recharge est présenté pour illustrer la technique employée.

I INTRODUCTION

The gold-bearing reefs of the Witwatersrand System, which are mined in the Far West Rand, underlie the 1 200 m thick Dolomitic Series of the Transvaal System (1) (fig. 1 and 2). The gold mines in the area, known as the West Wits Line, produced 24 per cent of the Free World's gold in 1975.

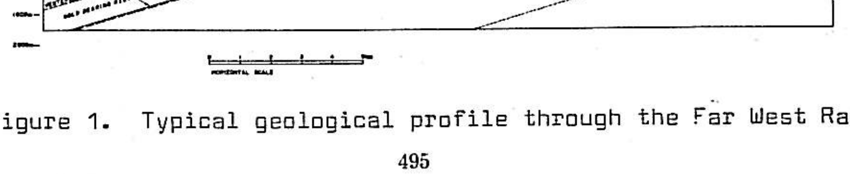

Figure 1. Typical geological profile through the Far West Rand.

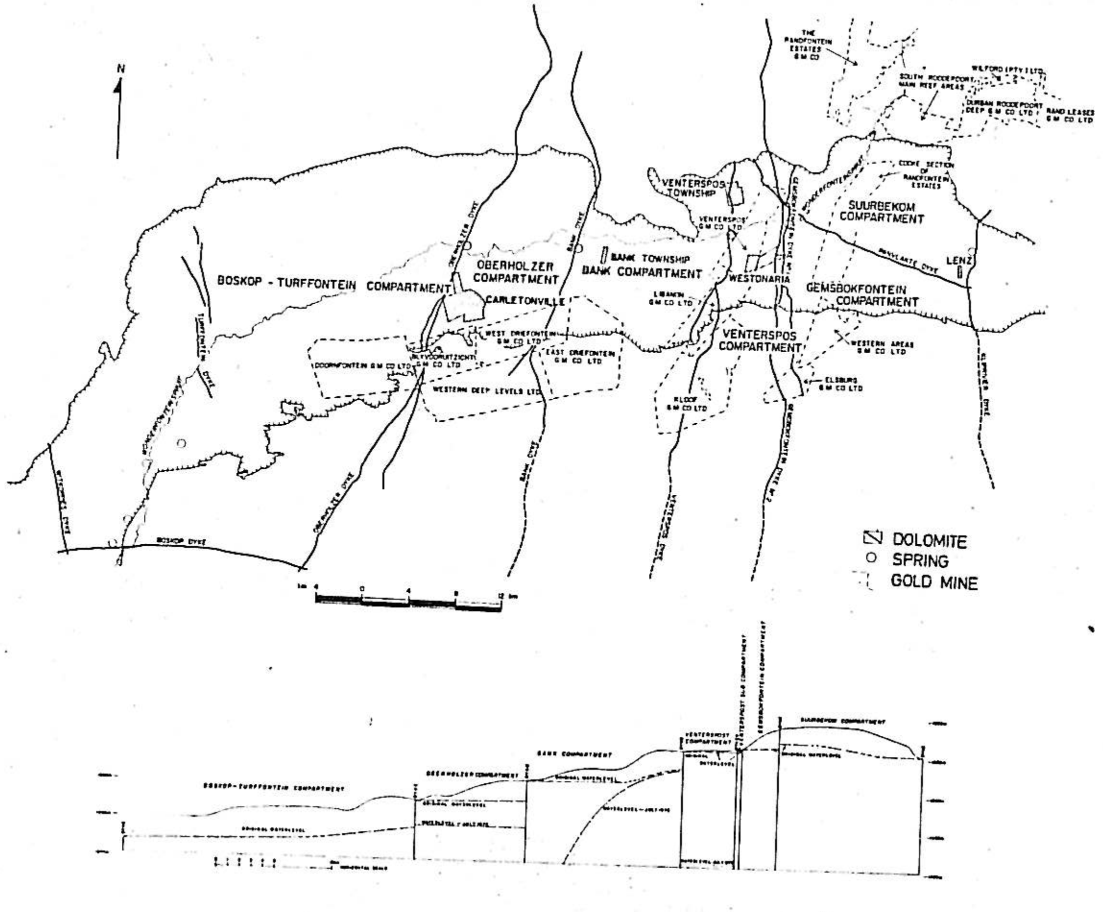

Figure 2. -Dolomitic ground-water compartments in the Far West Rand.

Ground water stored in separate ground-water compartments in the dolomite (2), which is the most important aquifer in South Africa, flows into the mine workings at rates determined by the number of post-dolomite faults and associated fractures which are cut by the workings, the hydrological characteristics of the individual fault zones and the hydrostatic pressure of the water.

The ground water pumped to surface from the mine workings (fig. 3) has to be disposed of either by recharging the dolomitic ground-water compartment from which the water was derived, or by releasing the water outside the compartment, thus gradually dewatering it if the pumpage is more than the natural recharge.

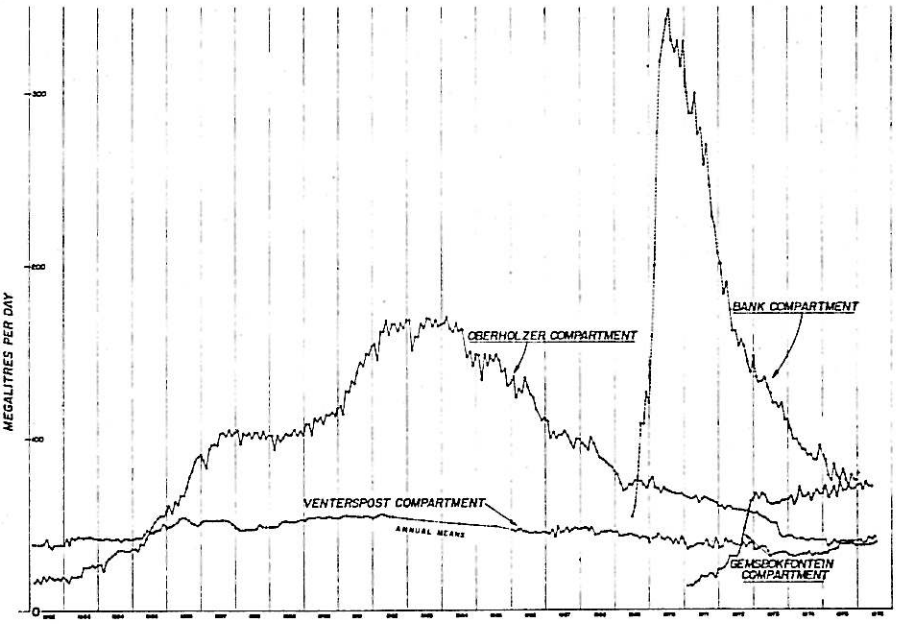

Figure 3. Pumping of dolomitic ground water entering mines for the various compartments on the Far West Rand.

The policy decision (3) as to which one of the above two methods has to be resorted to, for each compartment separately, depends on considerations of

(a) economic factors involved, namely the extent of damage due to subsidence and sinkholes caused by dewatering and the cost of replacement of the spring supplies weighed up against the additional pumping cost required for recirculation. The annual cost of pumping 100 Mℓ to the surface daily is of the order of U.S. Ø 6×10^6 to U.S. Ø 12×10^6, and

(b) safety factors, namely the danger to the miners of flooding of the mine by sudden inrushes of water at high pressure agains the danger to the population of the area of sinkholes caused by dewatering. Between 4 000 and 8 000 miners are underground during a shift on a typical gold mine on the Far West Rand. On 26th October 1968 an abnormally high inrush of 365 Mℓ/d occurred in the West Driefontein mine (4).

Recirculation of water in a particular compartment can only be considered and applied if it is possible to recharge the compartment at the rate of inflow of water into the mines in the compartment. This means that the total inflow into the mines (about 190 Mℓ/d in the Oberholzer Compartment and 56 Mℓ/d in the smaller Venterspost Compartment in 1962) under a pressure of about 1 000 metres or more of water has to be matched by artificial recharge at a pressure of usually less than 75 metres, depending on the depth of ground-water level below surface.

Furthermore, the demand on the water supply from the Vaal River for domestic, mining and industrial purposes in the Witwatersrand Area has been growing steadily. To provide for the future, other sources have to be developed and the existing supplies, which are stored in surface dams, have to be used more efficiently. Storage of some of the supply underground, free from evaporation, is one way of increasing the supply available. The dolomitic compartments on the Far West Rand could form an ideal underground storage for emergency supplies when the mines cease operating and this possibility has been investigated (5). For this purpose water will have to be pumped at rates of up to 500 Mℓ/d, and the recharge of the reservoirs will also have to be at a high rate when surplus water is available.

Recharge boreholes with large intake rates are, therefore, essential for recirculation of pumped mine water as well as for recharging the depleted emergency supplies stored underground.

II RECHARGE OF WATER IN OBERHOLZER COMPARTMENT (1952-1963)

When the inflow of water into the mines operating in the Oberholzer Compartment increased rapidly after 1952, the companies were faced with the problem of disposing of the water pumped to surface. By 1956 more than 90 Mℓ had to be pumped daily and was disposed of as follows:

(a) 40 Mℓ was spread on open ground draining towards the Wonderfontein River, about 8 km north of the mines. This drainage line is crossed by a railway line and two main roads. The recharge rate after saturation had been reached was less than the spreading rate, with the result that about 4 Mℓ reached the river, flowed across the dyke-barrier and was lost to the compartment.

(b) 22 Mℓ was recharged into a number of boreholes, spread over 15 km^2 and into two large sinkholes, one of which choked shortly after being put into operation.

(c) 28 Mℓ was used consumptively by the mines.

The recharge capacity was increased by drilling additional boreholes, and in 1962, when a total of 52 boreholes had been drilled, of which only a limited number could be used, a maximum daily rate of 30 Mℓ was maintained. Water spreading over the areas available to the mines had also reached its limit and a further increase would have been at the risk of flooding part of the Carletonville township, the railway line or the highways and the possible occurrence of sinkholes caused by the flooding. All increases were, therefore, discharged into a irrigation canal or into the river.

The difficulty of recharging the pumped water was one of the reasons for deciding in 1963 to dewater the Oberholzer Compartment.

III DEVELOPMENT OF TECHNIQUES FOR SITING BOREHOLES FOR RECHARGE ON A LARGE SCALE

In the early 1960's it was realised that the development of improved methods of siting recharge boreholes was essential to ensure the feasibility of recirculation in a compartment, should that be the preferred alternative in a particular mining situation or if the compartment should be required for storage of an emergency water supply.

Because at that time it was seldom possible to locate suitable boring sites particularly under a cover of Karoo sediments and aeolian soils, the Dolomite Series was still considered very speculative for drilling in and for developing strong permanent supplies of water.

An electromagnetic technique which had been developed for locating and tracing fissures and fault zones in hard rock formations was considered. The sensitivity of this method is low where the dolomite is covered by an appreciable thickness of younger rocks or rocks of low resistivity, and it is therefore seldom suitable for conditions on the Far West Rand (6).

(a) Gravity surveys for "unstable zones"

A solution to the problem of siting boreholes for large scale recharge or extraction of ground water in the dolomite of the Far West Rand became clear after extensive gravity surveys and intensive drilling had been undertaken to delineate "unstable zones", which are areas liable to subside or have sinkholes as a result of the dewatering (1), (7), (8). This work showed that

(i) the dolomitic bedrock normally occurs within about 15 m of the natural water table on the Far West Rand and is overlain by insoluble residual chert and wad and aeolian soils,

(ii) along fault and fracture zones leaching of the dolomite extends deeper than normal, sometimes to 100 m below the level of the natural water table, over the length of the structure and also laterally to yield honeycombed structures up to several hundred metres wide which tend to compact partially by slumping and settling over geological times,

(iii) these zones lying beneath the water table are thus not always very highly compacted and the lowermost parts are in fact cavernous, extremely porous and highly permeable,

(iv) in the compartments which were being dewatered these areas formed the "unstable zones" when the water level was lowered through the compacting material.

Furthermore, the dolomitic aquifer thus comprises the residual variably compacted material below the water table and its main conduits are the highly permeable deeper parts of these "unstable zones". LOCATING THESE UNSTABLE ZONES BY GRAVITY THUS ALSO ENABLES ONE TO SITE RECHARGE BOREHOLES.

(b) Interpretation of gravity surveys

For the interpretation of the gravity anomaly, the anomalous mass i.e. the deeply leached zone, is assumed to be almost rectangular in shape. This has been confirmed by drilling and by the locations of areas of highest differential ground subsidence where they were interpreted on the basis of such an assumption. The dimensions of the anomalous mass in these cases were determined by using Skeel's (9) curves for determining the depth to a two-dimensional rectangular prismatic body. The method is fast and has given very good results. Such an interpretation for the residual gravity profile through recharge borehole WAW2 is shown in figure 4. Where, for some reason or other, the cross-sectional shape of the anomalous mass is not rectangular an iterative technique based on that described by Bott (1960) is used with a starter model consisting of vertical rectangular prisms centred on the gravity stations or on interpolated residual gravity values. Where rocks of the Karoo System do not extend to beneath the level of the natural water table the mass deficiency below this level reflects the hydrological characteristics of the aquifer as the soluble carbonates have been removed. This holds even if minor compaction of the remaining residuum has taken place but could become less reliable for greater compaction or for cases where a greater percentage chert is present in the residuum.

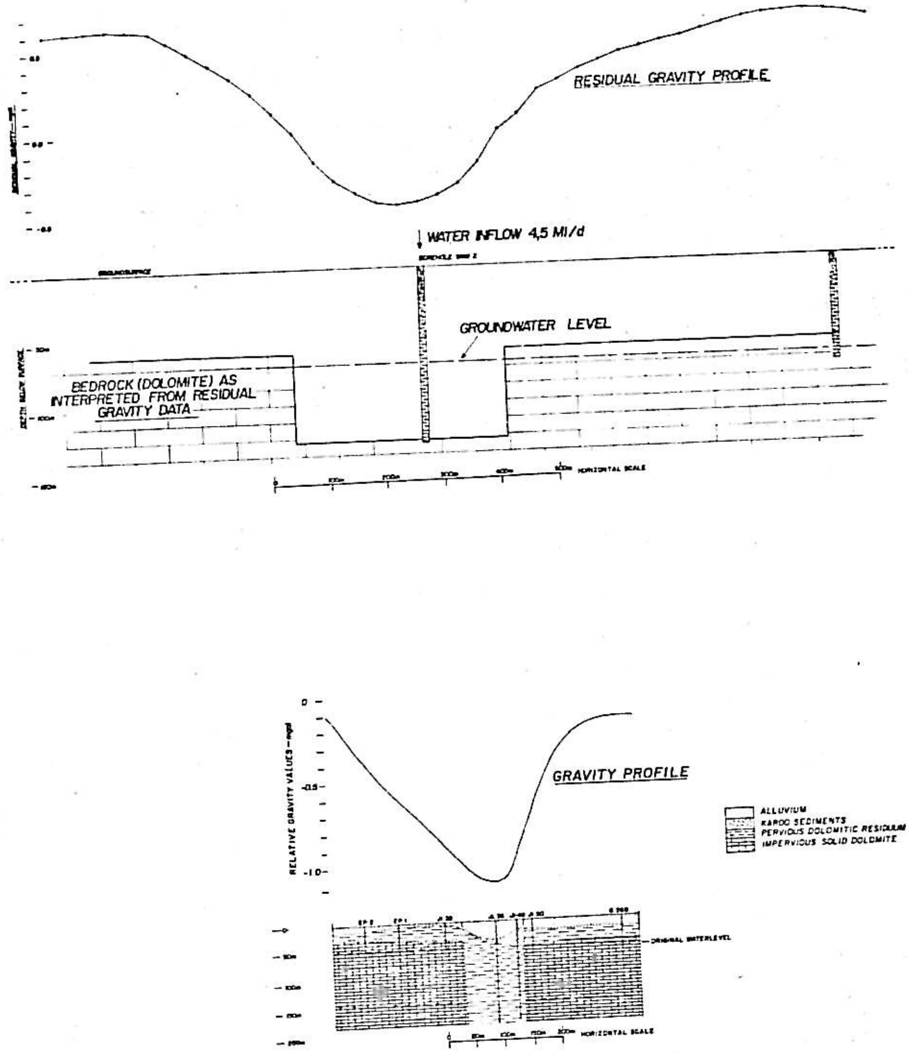

Figure 4. Interpreted gravity profile at recharge borehole WAW2 and a typical geological profile across an "unstable zone" in Carletonville.

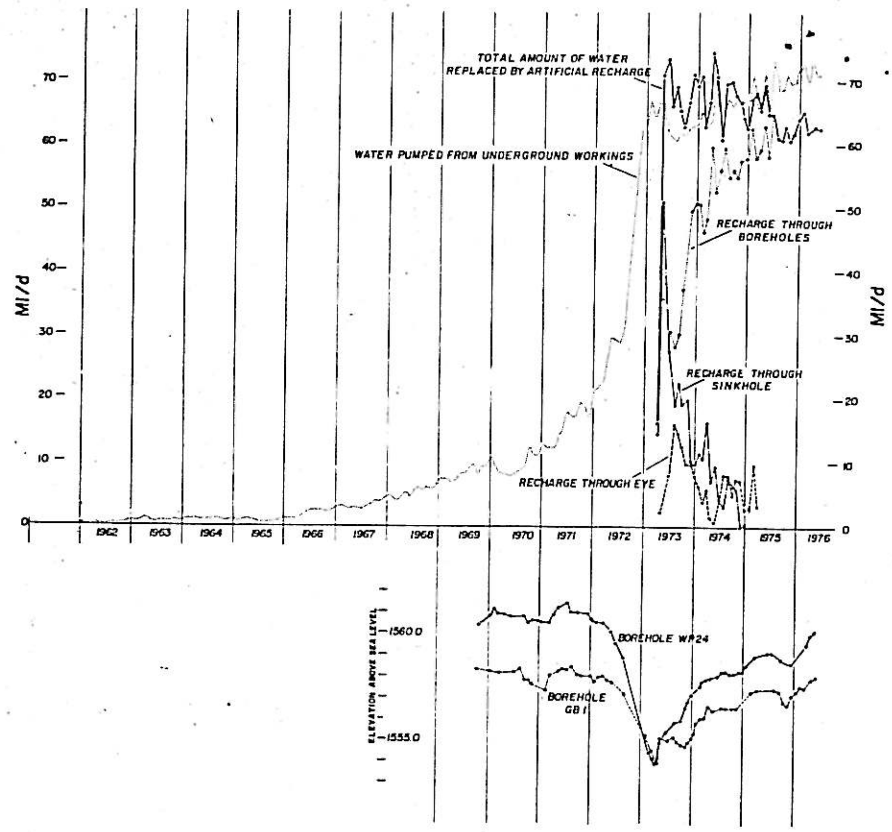

Figure 5. Water table response in the Gemsbokfontein Compartment as a result of water pumped to the surface by the mines and water recharged as indicated in figure 6.

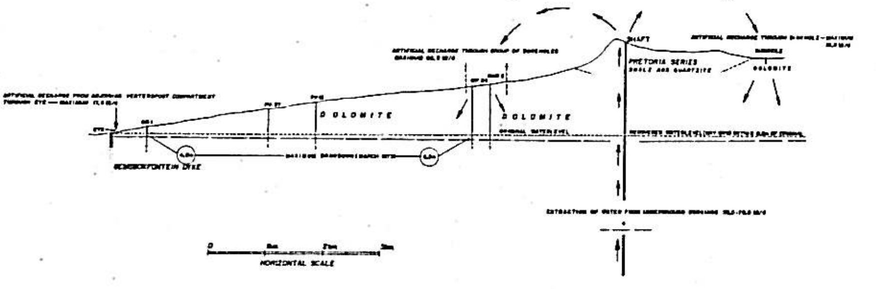

Figure 6. Schematic presentation of water extraction and recharge in the Gemsbokfontein Compartment.

IV. RECHARGE OF THE GEMSBOKFONTEIN COMPARTMENT (1972--)

As can be seen on figure 5 there was a significant increase in the rate of water pumped and disposed outside the compartment from the Gemsbokfontein Compartment in the second half of 1971. Up to that time the loss from the compartment was matched by the natural recharge and no progressive long term lowering of the water table resulted. During 1972 the pumpage increased from 22 Mℓ/d to 65 Mℓ/d and as the water was not returned to the compartment, the water tables dropped sharply as shown in figure 5. When it became obvious that the sudden large inflow of water into the mine could not be controlled, the mine management decided to attempt to curtail the inflow of water into the mine by cementation of the water-bearing fissures and/or sealing off that part of the mine which was making large quantities of water and to keep the water-level static by recirculating the pumped water by recharging into a large sinkhole and into recharge boreholes which still had to be drilled (fig. 6). This was essential as the lowering of the water table was rapidly approaching the 6 m value which is considered to be the cut-off level at which sinkholes and subsidences could start to occur.

The recharge boreholes were developed on sites selected by the Geological Survey by using the gravity contour plan drawn up for determining the unstable zones in the Gemsbokfontein Compartment (fig. 7). These holes were fed with pumped mine water which was allowed to gravitate from a nearby hill.

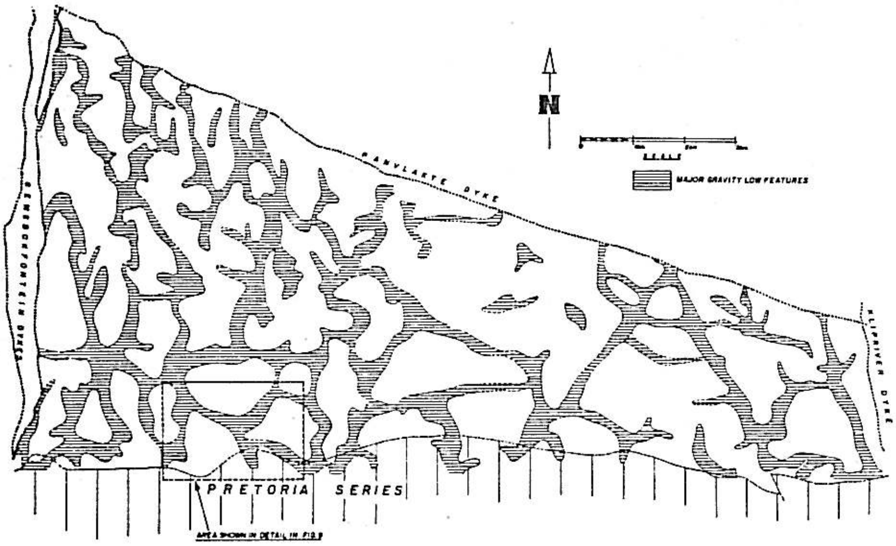

Figure 7. Leached fault and fracture zones in the Gemsbokfontein Compartment interpreted from gravity data. These zones comprise the main dolomitic aquifer and its conduit. With dewatering they form the "unstable zones".

A recharge test was done on the first hole to be completed and the results are shown on figure 8. The hole was recharged through 150 mm slotted casing which was inserted to the depth of solid dolomitic bedrock.

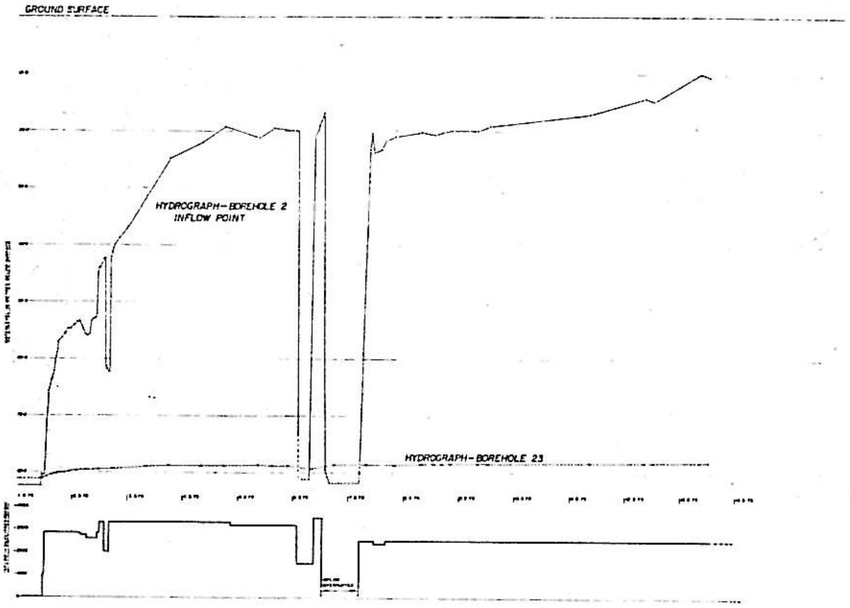

Figure 8. Recharge test performed on borehole WAW2 with observation hole WP23 75 m distant.

A prospecting borehole about 75 m away was monitored during the test. It seems obvious that the amount of water which could be fed into the subsurface formations was determined, within the limits of the experiment, by the slots in the casing and not by the ability of the medium to accept water. Since 1973 all the available pumped water has been returned to the compartment through ten boreholes (fig. 9) spread over an area of less than 1,0 km^2 at an average rate per borehole of approximately 6,3 Mℓ/d and a maximum rate of 9,2 Mℓ/d. This compares with average maximum recharge rates of 2-8 Mℓ/d per borehole in other countries. For a few months water taken from a mine in the neighbouring compartment was returned through the dry "eye" but when the rain season, which was better than normal, ensued this was discontinued. The total loss of water to date has almost been made up.

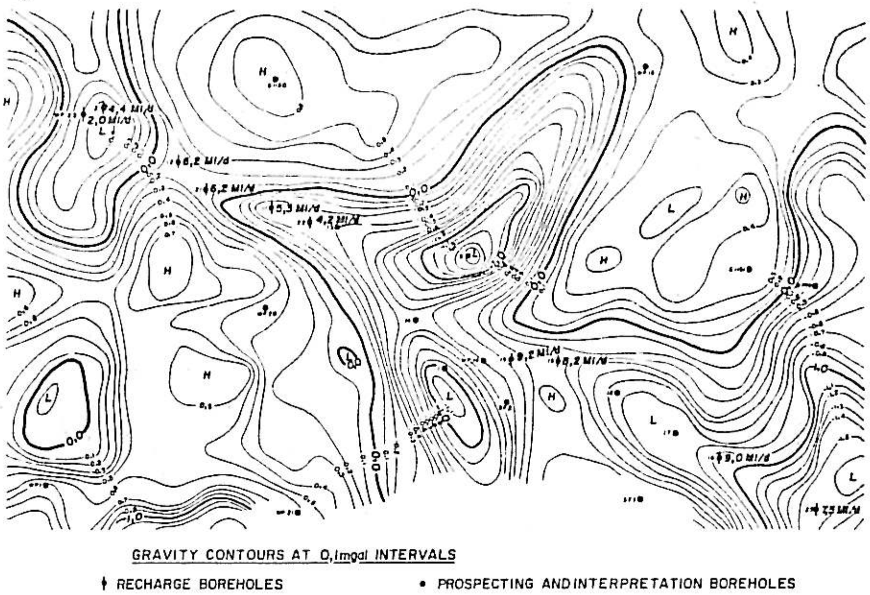

Figure 9. Area of recharge through boreholes in the Gemsbokfontein Compartment.

V CONCLUSIONS

It has been shown that it is possible to recharge dolomitic ground-water compartments on the Far West Rand at a high rate for extended periods of time by developing borehole sited on the basis of gravity data in highly leached fault and fracture zones.

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