adk/10003301.RB/p1s1

English
Republic of South Africa
Deputy Director: Geological Survey
Co-author's: Asst. Chief Engineer, Planning and Design, Department of Water Affairs, Republic of South Africa

THE ASSESSMENT AND POSSIBLE FUTURE USE OF THE DOLOMITIC GROUND-WATER RESOURCES OF THE FAR WEST RAND, TRANSVAAL, REPUBLIC OF SOUTH AFRICA

INTRODUCTION

The Vaal River is an important source of water in the Republic of South Africa. During 1965 the average daily abstraction of water from this river was 620 million imperial gallons per day, i.e. about 228 million imperial gallons per day for irrigation use and 332 million imperial gallons per day for domestic, mining and industrial purposes. The demand is growing steadily and to provide for the future it has become necessary to improve the efficiency of utilisation of the Vaal River's water resources as well as to develop other sources of supply.

Since evaporation losses from surface storage reservoirs in the Vaal River basin are high, one method for making better use of the available water would be to store some of it underground where it will be protected from evaporation. This may conceivably be done in the dolomitic aquifers of the Far West Rand, which falls within the supply area of the Rand Water Board, a corporate body which was established in 1903 to supply potable water to local authorities, mines and industries in the Witwatersrand-Pretoria-Vereeniging complex. The Board's supply area extends over 5,578 square miles and has a population of just over 3 million.

The average daily quantity of raw water abstracted by the Rand Water Board has increased from 2,33 million imperial gallons per day in 1905-6 to 11,9 9n 1923, to 28,45 in 1935-6 and to 230 million imperial gallons per day in 1965-6. Up to 1923 all water was obtained from underground dolomotic supplies, but in 1924 the first scheme for using Vaal River water was put into operation. BY 1965-6 the bulk of the supply viz. 225 million imperial gallons per day, was being obtained from the Vaal River and only 5 million gallons per day was being pumped from dolomite.

Because of the very rapid increase in the demand for water, the use of the dolomitic aquifers for increasing supplies to the Rand Water Board area is again being investigated. If successful this will assist in improving water supplies in the whole Vaal River basin.

GOLD MINING IN THE AREA

Exploration of the extension of the-gold-bearing reefs of the Witwatersrand system towards the Far West Rand had commenced before the turn of the century. Payable reefs were discovered in the Ventерspost area, below the younger Transvaal system. Sinking of the Pullinger Shaft commenced in 1912 but had to be abandoned in the overlying dolomite because the large inflows of water could not be controlled.

It was only on 1934, when the cementation technique of reducing the flow of underground water had been greatly improved, that shaft-sinking was recommended and the Venterspost was brought into production in 1939. At present seven gold mines are producing in the area and a further tow are being developed.

The annual production of gold in this area has progressively increased and was valued at R176 million for 1965/66.

GEOLOGY AND HYDROLOGY OF THE FAR WEST RAND

The Far West Rand area consists of the wide valley of the Wonderfonteinspruit flanked to the north by low rolling hills and to the south by the Gatsrante, in which numerous dolomitic caves are found, and which forms the foothills of a more prominent range of hills with an elevation of about 500 feet above the valley.

The Wonderfontein valley is underlain by the Dolomite Series of the Transvaal system, consisting of about 4 000 feet of dolomitic limestone which contains numerous bands of chert in its upper 600 feet. The hills to the north are formed of the Black Reef series and underlying granite and the prominent hills to the south by the Pretoria series, both of the Transvaal system. The rocks of the Transvaal system dip at a low angle of 5° to 12° to the south, and overlie the Ventersdorp and

Witwatersrand systems discordantly. The latter systems contains the gold-bearing reefs which are extensively mined in the area. (See figure 2.)

The area is cut by a number of syenitic dykes, the majority of which trend slightly east of north. These dykes vary in width from 50 to 200 feet and have been proved to be impervious, thus dividing the dolomite into a number of separate ground-water compartments. The Black Reef series and Pretoria series from the upper and lower boundaries, respectively, of these compartments. The dolomitic reservoirs have overflows or springs at the lowest points on the surface, normally where the dykes cut across the valley. At such springs the surplus water from the upper compartment reaches the surface and flows over the barrier and percolates into the lower compartment, if not used.

The following are the more important compartments, listed from east to west:

TABLE I

COMPARTMENT	SURFACE AREA (sq. miles)	SPRING WHICH FORMS THE NATURAL OUTLET OF THE COMPARTMENT	AVERAGE FLOW OF THE SPRING, BEFORE MINING (m.Imp.g.p.d.)
Suurbekom	38,7	Klip River Spring	Dry
Gemsbokfontein	32,8	Gemsbokfontein Spring	1,9
Venterspost	21,0	Venterspost Spring	4,6 (now dry)
Bank	60,5	Wonderfontein Spring	10,8
Oberholzer	59,4	Oberholzer Spring	11,9 (now dry)
Boskop-Turffontein	272	(1) Turffontein Springs	4,05
		(2) Gerhardminnebron Springs	11,6
		(3) Boskop Springs	
			1,0

Due to pumpage by Rand Water Board. No record of original flow.

The two geological features which have had the greatest influence on the dolomitic groundwater in this area are, firstly the post-Dolomite syenitic dykes, and secondly the extensive crustal movements and faulting which occurred in pre-Dolomite times, followed by further movements along these fault planes as well as along other planes in post-Dolomite times.

The openings in these fracture and fault planes formed ideal conduits for ground-water movement and the concomitant solution of the dolomite. The resultant disintegration of the dolomite along these fault plans as well as along joints, fissures and bedding plans, caused collapse and slumping of the dolomite on a large scale, particularly along the major fault planes where geological "valleys" were formed. Deposits of the younger Karoo system were either deposited or slumped into these valleys.

The chemical leaching of the soluble calcium and magnesium carbonates resulted in the formation of zones of very weak honeycombed structure consisting of weathered chert with some leached dolomite and magniferous earth "wad". This highly porous weathered rock, as well as the fissures and cavities which normally occur at greater depth, from the underground storage for the dolomitic water. Where the fault planes cut the Dolomite series as well as the older Ventersdorp and Witwatersrand formations they act as conduits for water to seep into the mine workings at depth below the Dolomite aquifer. In order to carry on mining operations such water has to be pumped to the surface.

The magnitude of this water problem differs from one mine to the other. The cost of pumping water to the surface from one mine alone amounted to more than R2 million on 1962.

It will be noticed that most of the operating mines are located below two of the ground-water compartments, the Venterspost compartment and the Oberholzer compartment. It is estimated that the Venterspost compartment and Libanon Mines have pumped 90 000 million imperial gallons from the Venterspost compartment during the period 1939-1966 and that the Blyvooruitzicht, West Driefontein and Western Deep Levels Mines have pumped 145 000 million gallons from the Oberholzer compartment. All the water pumped from the mines is derived from storage in overlying dolomite.

When it became clear that some of the mines would have to pump quantities of water far in excess of the recharge of the compartments, and that pumping costs with recirculation, i.e. putting the pumped water back underground by boreholes or disposing of it on the surface or in sinkholes in the compartment, would be much higher that with dewatering, i.e. by disposing the pumped water outside the compartment, the mining companies requested the Minister of Water Affairs that they be allowed to dewater.

An inter-departmental committee was appointed to investigate the effects and implications of recirculation and dewatering. This committee had to carry out a detailed study of the geohydrology of the Far West Rand.

GEOHYDROLOGICAL INVESTIGATION OF DOLOMITIC WATER SUPPLY

Delineation of compartments: The first requirement for the assessment of the groundwater resources was the delineation of the groundwater reservoirs or compartments. This was tackled firstly by compiling a detailed geological map, mainly from available geological maps and other published information and the filling in of more detail by field mapping where required.

The floor and the roof of the compartments, being the Black Reef series and the Pretoria series were detemined from these maps aided by information obtained from a large number of prospecting boreholes. The location of the dykes which subdivide the dolomitic aquifer into separate compartments, proved more difficult. Outcrops of the dykes are rare, and the only other surface indications of the existence of boundaries are the "overflow" springs.

It was thus necessary to trace the dykes by geophysical methods. The magnetic method had been used previously by other investigators, but as the dykes give recognisable anomalies only along part of their strikes, mainly where weathering was shallow, they had not been traced through their entire lengths. It was, however, possible to trace them by the electromagnetic method where they could not be located magnetically. Three dykes, which had not been known previously, and which proved to be of great importance for the hydrological study, were also located and traced by the electromagnetic method.

A detailed survey of more than 5 000 boreholes in the area and the construction of ground-water contours were also carried out. The ground-water contours were found particularly useful for confirmation that the dykes actually form boundaries of the compartments. In each demarcated compartment the ground-water levels forms a continuous plane with gradients towards the points of abstraction which seldom exceed 1/250, whereas discontinuities in water levels exist across the ground-water barrier. Actually a study of ground-water contours gives positive evidence as to whether a known structure, e.g. a dyke does form a ground-water barrier or not. If there is continuity in the water table across a supposed barrier under conditions of ground-water movement or if withdrawal of water at a certain point is reflected by a change in the water level on the other side at a rate which satisfies the applicable ground-water equation, then the structure does not form a barrier.

This is well illustrated in the contour plan. The existence of the Turffontein springs and outcrops of a dyke downstream of the lower one suggested initially that the dyke formed the western boundary of a compartment which was tentatively called the Turffontein compartment. This is disproved by a study of the ground-water contours which show that the main movement of the ground water is in a southwesterly direction and bypasses the springs which are water-table springs. The normal water level of the mass of water moving westward has probably been raised by the narrowing of the dolomite at surface and the presence of the dyke which forms a partial barrier. The Gerhardminnebron spring which lies six miles further west, has also been proved to be a water table spring in the Boskop-Turffontein compartment.

The ground-water contours were also used for the calculation of permeability and specific yield of the aquifer.

Assessment of recharge: The average annual recharge of dolomite compartment is equal to the mean flow of the spring or springs discharging from the compartment, if losses by underground leakage, evapotranspiration from the water table and artificial abstraction are negligible. (See Table I.)

Although the annual recharge may vary within wide limits depending on the rainfall and other factors and may be nil for long periods, the flow of a large dolomitic spring does not vary greatly (with time) and forms a reliable source of supply.

The long-term recharge, as given by the flow of the spring, is derived direct from rainfall as well as concentrations of water which are dependent on the re-use of water from higher-lying compartments for irrigation or the development of the area. It would therefore be unwise to include all of the latter accidental recharge in any assessment of water supplies available for future use.

In Table II a breakdown of the sources of recharge are given for some of the compartments. It is evident that the assured safe yield of some of the compartments is less than 50% of the normal flow of the springs.

Storage of the Venterspost compartment: The combined pumpage of the gold mines in the Venterspost compartment exceeds the natural recharge to that compartment, which is assumed equal to the normal flow of the Venterspost spring before the mines started production.

The water pumped from the mines is not returned to the compartment, but is pumped into settling ponds on the lower-lying Bank compartment and then flows into the riverbed or the irrigation furrows. In addition part of the natural recharge to the Venterspost compartment derived from percolation in the stream-bed of the Wonderfonteinspruit has been out off by the canalisation of all surface flow across the compartment. The result is that the Venterspost compartment is progressively being dewatered as indicated by the lowering of the water table. (See Figure 3.)

The dewatering of this compartment offered a unique opportunity for studying and assessing its storage as a function of depth below surface. The results obtained will be used for determining the storage of other similar dolomitic compartments and will greatly aid in the planning of the use of the dolomitic water resources.

Originally the water level was practically horizontal (5,061 feet above MSL) over the whole of the compartment and the level of the spring was only about 2 feet lower. Water level observations showed that initially the rate of lowering of the water level was practically the same for the whole compartment, but gradually a flat cone of water table depression was formed above the mining areas and the difference between the lowest and highest water levels have now increased to more than 100 feet (4,650 feet to 4 800 feet above MSL).

The weighted mean elevation of the water table is determined from the water level observations and plotted as a function of time, if the depletion of the stored water can be determined for certain periods, the mean depth of the water table at the beginning and end of such periods can be read from the "mean water table time" graph and the storage per foot depth and the specific yield at that particular depth can be calculated.

TABLE II

RECHARGE OF COMPARTMENTS

COMPARTMENT	DOLOMITIC CATCHMENT AREA (Sq. miles)	BREAKDOWN OF PERCOLATION TO GROUND WATER - IN INCHES ON DOLOMITE AREA				PERCOLATION DIRECT FROM RAINFALL	
		AVERAGE FLOW OF SPRING	PERCOLATION FROM STREAMBED, CANALS AND IRRIGATED CANALS	PERCOLATION OF WATER FROM NON-DOLOMITIC AREAS	PERCOLATION DIRECT FROM RAINFALL	PERCENTAGE RAINFALL	MIL. IMP. GAL. PER DAY
Suurbekom	38,799	[a]3,64"	0,10"	0,10"	3,44"	13,0	5,45
Gemsbokfontein	32,8	1,86"	-	-	1,86"	7,5	1,9
Venterspost	21,0	6,93	2,83"	1,82"	2,28"	8,5	1,5
Bank	60,5	4,49"	1,63"	1,40"	1,46"	5,8	3,5
Oberholzer	59,4	5,04"	2,84"	1,27"	0,93"	3,6	2,2
Steenkoppies (north of Far West Rand area)	65,4	3,54"	-	0,75"	2,79"	10,6	7,1

This represents the pumpage by Rand Water Board at Suurbekom.

DEPLETION OF STORAGE

The depletion of storage of Venterspost compartment has been determined for various periods by (a) an analysis of the ground-water equation, and (b) by compilation of monthly and annual water balances for the compartment.

Ground-water equation: Under conditions existing in the Venterspost compartment the recharge to ground-water can be attributed to:

1. Influent seepage direct from rainfall. It has been established that the time lag between rainfall and recharge in the dolomite varies from about one to 14 days, if recharge does take place. There should therefore be periods during the dry winter season (see Rainfall Bistogram, Fig. 3) when no direct recharge from rainfall takes place. These periods should be reflected by the higher rates of lowering of the water level.

2. Influent seepage from the stream-bed and leakage from irrigation canals and influent seepage through over-irrigation.

Losses to the ground-water may be attributed to:

1. Underground leakage from the compartment.

2. Evapotranspiration direct from ground water. This factor is negligible due to the depth of the water level below surface.

3. Losses by pumpage from the mines and from drainage wells.

The flow in the Wonderfonteinspruit has been canalised across the Venterspost compartment and practically no land has been irrigated on the compartment since 1958 when the irrigation canal was cut by a large sinkhole. The ground-water equation therefore reduces to:

Ground-water depletion = pumpage during periods when no recharge from rainfall directly takes place. This equation is used for determining the depletion of storage of the compartment (see Fig. 3).

The water balance equation: In this method it is assumed that the difference between the accretions and the losses equals the change in ground-water storage, as there is no surface storage on the compartment.

The rainfall on the compartment is calculated by the Thiessen method and all surfaces flow across the dykes forming the boundaries of the compartment are gauged. The drainage on to the dolomite from non-dolomitic catchment is measured. The evaportranspiration is an assumed percentage of rainfall derived from an analysis of long-term rainfall and runoff. The runoff from the catchments analysed, which includes base flow as well as flood flow, is assumed to equal the difference between the rainfall and evapotranspiration. Evapotranspiration is thus determined and expressed as a percentage of the rainfall. The average values so determined for each month and for the whole year are applied to the Venterspost equation.

Results obtained

The specific yields for various depths below surface calculated by the above methods are given in Table 3 and compared with specific yields of dolomite derived from a study of the volume percentage of weathered rock as penetrated by prospecting boreholes and shafts in the area.

TABLE III

SPECIFIC YIELDS OF DOLOMITE

WEIGHTED DEPTH BELOW SURFACE	SPECIFIC YIELD OBTAINED BY:	
	STUDY OF DEWATERING DATA, VENTERSPOST COMPARTMENT	ANALYSIS OF LOGS OF SHAFTS AND BOREHOLES
200’	9,1 %	9,7 %
250’	5,5 %	6,0 %
350’	2,6 %	3,0 %
415’	2,00 %	2,0 %
480’	1,30 %	1,6 %

PAST AND PRESENT UTILISATION OF DOLOMITIC WATER

When farmers settled along the valley of the Wonderfonteinspruit and the Mooi River more than a hundred years ago they developed the water supplies of the dolomitic springs for irrigation. More than 8 000 morgen (1 morgen = 2,11 acre) were scheduled under various irrigation boards.

In 1897 the first well was sunk in dolomite on the farm Suurbekom for supplying the fast-growing town of Johannesburg with water. When the Rand Water Board was constituted this had become the main source of supply and it was gradually developed by sinking further boreholes and shafts. At present the average rate of pumping from Suurbekom is 5,77 million gallons per day.

Pumpage at Suurbekom resulted in the gradual decrease in the flow of the Klip River spring. Flow ceased temporarily in 1916 and again in 1936, and finally in 1939. The water level has stabilised slightly lower than the original and pumping equals the safe yield of the Suurbekom dolomitic compartment.

With the development of the gold mines in the Far West Rand area and the increased rate of pumping from the mine workings in the Venterspost and Oberholzer compartments the flow of the springs from these two compartments gradually decreased and the Venterspost spring ceased flowing in 1949 and the Oberholzer spring in 1959. The water which is pumped from the mines is used for mining operations and the surplus water is returned to the Wonderfonteinspruit or put into the canals of the irrigators.

The flows from the other springs are still used for irrigation.

FUTURE DEVELOPMENT FOR USE OF DOLOMITIC WATER

There are two alternatives for developing the dolomitic water supplies to supplement the surface supplies available in the Rand Water Board area and elsewhere in the Vaal River basin.

Firstly, consideration could be given to the continuous use of the resources at rates equal to their safe yields, as in the case of the pumpage at Suurbekom.

In assessing the safe yield for future use it is considered advisable, as already mentioned, to include only recharge direct from rainfall, as the recharge from the other sources cannot be relied upon. According to the calculations given in Table II the assured recharges amounted to less than 50% of the normal flow of the springs for some of the compartments.

It is therefore clear that an additional continuous supply equivalent to the safe yield of a compartment, if made available to the Rand Water Board, would be only a small percentage of its requirements, even if pumped continuously, as is being done at Suurbekom. Such a supply would be of very little use during periods of water shortages, when additional water is actually required.

The second alternative is to use the water stored in the dolomitic reservoirs only during periods of shortage of water by abstracting a supply of water, equal to the difference between that available from surface supplies and the total water requirements until such time as sufficient water from surface supplies becomes available again.

If the storage reservoirs in the Vaal River are operated on a basis of variable draft, which will increase the utilisation efficiency considerably by reducing evaporation losses, the supply obtained from the dolomitic compartment(s) could be used to make good the difference between the higher and lower drafts, during these periods when draft is at the lower yield.

Based on the calculated storages of 100 000 and 150 000 million imperial gallons for the two compartments which are being dewatered, it is acceptable that storage of the other compartments should be of the same order, of which at least 75% is stored within 500 feet of the surface and could be pumped economically for use. This storage is sufficient to consider its incorporation in a planned scheme for variable draft utilisation of the surface storage available in the Vaal Rivier basin.

The utilisation of the dolomitic compartments for reserve storage, as outlined above, has the following advantages: The assured yield of the surface resources will be raised considerably with the resultant decrease in evaporation or other losses and the supply can therefore be stored for any length of time.

There are, however, certain problems associated with such a scheme:

Firstly, boreholes or shafts from which the water could be pumped at a sufficiently high rate to make the scheme economically feasible, even when the water level has been lowered by usage, have to be located and developed. The boreholes and shafts in the dolomite south of Johannesburg used by the Rand Water Board proved to be unreliable because water-yielding fissures had not been struck in them at great depth. It is now possible, however, to locate fault-zones and "valleys" of leaching in the dolomite by geophysical methods, for siting boreholes. Tests are at present being carried out to determine whether it is possible to develop a number of shafts in a compartment for withdrawing water at the rate of 2-3 million gallons per day each, and at a combined rate of 100-150 million imperial gallons per day.

Secondly, it is known that the lowering of the water level in a dolomitic compartment results in the slow subsidence of those areas where the water table was lowered through unconsolidated compacting material which fill geological "valleys" in the dolomite. Such subsidence could also, under certain conditions, be accompanied by the catastrophic occurrence of sinkholes. Those areas which will be subject to subsidence when dewatering takes place can be delineated by gravity surveys. A gravity survey of the dolomitic areas of the Far West Rand is being carried out and it will be possible to plan the development of any compartment, which may be earmarked for utilisation, on the results obtained from the gravity surveys.

Lastly, if the water stored in a compartment is "mined" for and used by the Rand Water Board as supplementary supply during a period of water shortage, the natural recharge will not refill the compartment in time for use during the following period of shortage and water will have to be imported to refill the compartment. Provision will therefore have to be made for recharging the compartment by surplus water available after flood periods.

ACKNOWLEDGEMENTS

The authors wish to express their sincere thanks to Gold Fields of South Africa for permission to use data on pumpage by the mines, to the Department of Mines and Water Affairs for facilities provided to prepare this paper, and to the Chief Draughtsman of the Geological Survey and his staff for preparing the text figures.

BIBLIOGRAPHY

de Kock, W.P. The Geology and Economic Significance of the West Wits Line. The Geology of Some Ore Deposits of Southern Africa. Vol. I. Geological Society of South Africa, Johannesburg, 1964. pp. 375 - 381

Department of Water Affairs: Final Report of the Interdepartmental Committee on Dolomotic Mine Water: Far West Rand, 1960. (Unpublished).

du Toit, A.L. Underground Water in the Dolomite Area. The Geology of the Country Surrouding Johannesburg. Chapter X, 1921. pp. 32-41

Enslin, J.F. A New Electromagnetic Field Technique. Geophysics. Vol. XX, No. 2, 1955. pp. 318-334

Enslin, J.F. and Kriel, J.P. Some results obtained from a Hydrological Study of a Dolomitic Catchment Area in the Transvaal, Union of South Africa, CCTA/CSA Specialists Meeting of Hydrologists, Youande, Cameroons, 1959.

Gelletich, H. Uber Magnetitführende eruptive Gänge und Gansysteme in Mittleren Teil des Südlichen Transvaal. Beitrage zur Angewandten Geopnysik. B.6 , Heft 4, 377-406, 1937.

Krahmann, R. The Geophysical Magnetometric Investigations on Witwatersrand Areas between Randfontein and Potchefstroom, Transvaal. Trans. Geol. Soc. S. Afr. Vol. XXXIX, 1936. pp. 1-43.