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APPENDIX A.

# AN INVESTIGATION OF THE GROUNDWATER POTENTIAL OF THE NYL RIVER VALLEY

## ABSTRACT

Experimental drilling and an initial evaluation of the groundwater potential of the alluvial basin of the Nyl River and surrounding decomposed basalt, proved that a full hydro-geological investigation is warranted to assess the feasibility of a water supply scheme based on artificial recharge of the groundwater from floodwater, which is normally lost by evapotranspiration in the vleis areas.

The emphasis falls on the assessment of the storage capacity, natural recharge, pumpage and artificial recharge possibility of the alluvial basin and decomposed basalt.

The storage capacity is derived from pumping tests by interpretation of the rate of drawdown and also the use of dye tracers, to determine the specific yield of the aquifers, while the extent of the alluvial basin and decomposition of the basalt was inferred from borehole logs.

The natural recharge was assessed from the pumpage and water level response, supplemented by tritium profiles to check the rate of moisture movement in the soil. The results proved that the recharge in the vleis areas is small.

The water abstraction was based on the irrigated areas and water requirements of crops.

## 1. OBJECTIVE

The availability of spasmodic floodwater from the upper Nyl River, the Klein Nyl and other small tributaries which exit from the western mountain range, and the fact that most of this water is lost by evaporation in the flood plains of the central portion of the Nyl River, generated the idea of a water supply scheme based on artificial recharge by means of floodwater, use of the storage capacity of the alluvium and extraction of water from it by gradual pumpage.

The need for such a water supply scheme arose from the inability of the supplies to meet the demands of local primary consumers such as Potgietersrus and Naboomspruit, and also various mining groups and holiday resorts in that area.

At present both Naboomspruit and Potgietersrus obtain their water from dams in the Sterk River. Naboomspruit also supplies the Buffalo fluorspar mine and derives its water from the Welgevonden Dam (Fig. 1), which has an assured supply estimated at  $0,84 \cdot 10^6$  m<sup>3</sup>/year. At present the mine uses about one third of this water, but due to enormous expansion in production its demand will greatly increase. Not only will the mine require up to  $0,52 \cdot 10^6$  m<sup>3</sup>/year, but the towns own consumption is expected to increase by the same amount. The Welgevonden Dam has failed twice during the past 10 years at a draft of only  $0,66 \cdot 10^6$  m<sup>3</sup> which further emphasises the urgent need for a reliable additional water supply source.

With regard to Potgietersrus, this town is supplied from the Doorndraai Dam situated lower downstream in the Sterk River (Fig. 1). Its consumers have also run into water supply problems. The allocation to Potgietersrus ( $1,6 \cdot 10^6$  m<sup>3</sup>/year) proved to be inadequate during periods of peak demand - the main restriction being the stipulated maximum draft of 4 500 m<sup>3</sup>/day. An increase of the latter was granted to a maximum of 7 230 m<sup>3</sup>/day provided that the total allocation of  $1,6 \cdot 10^6$  m<sup>3</sup>/year was not exceeded.

Recently the Minister of Water Affairs permitted the allocation of Potgietersrus to be increased to  $2,0 \cdot 10^6$  m<sup>3</sup>/year, which should meet their water requirements for the next five years, by which time an additional water supply should be in operation (Reg. 160 letter dated 14-8-1972).

As far as Potgietersrus is concerned there are three possible solutions to the existing water problems:

a. The capacity of the Doorndraai Dam can be increased and a higher allocation obtained from it. Raising of the wall is apparently planned to start soon. Analysis has shown that a 3 meter rise would increase the assured draft by  $3,26 \cdot 10^6$  m<sup>3</sup>/year. The cost of raising is not yet known but is estimated to be about R1 million.

b. Groenvlei Dam.

The construction of the Groenvlei Dam, estimated to cost up to R11 million, would provide an assured supply of about  $15 \cdot 10^6$  m<sup>3</sup>/year. This could be a permanent solution to the water problems of Potgietersrus but the water so gained would be at the expense of the Glen Alpine Dam and other irrigators further downstream.

c. Nyl River Valley.

The third possibility is to utilise the groundwater of the alluvial basin of the Nyl River. This source would apparently also provide a solution for the water problems of the Zebediela Citrus Estates, which have tried unsuccessfully to fully augment their inadequate water supplies from the Olifants River. Zebediela was in fact the first consumer to investigate the feasibility of pumping water from the Nyl River area, and to have explored systematically for water. They have nevertheless deferred their activities pending the outcome of our final report and the implications of the proposed water scheme.

A first assessment of the water potential of the alluvial deposits of the Nyl River basin, was made by Mennè and Porszasz,<sup>1)</sup> on the basis of data available at that time. A re-evaluation of this water source as a possible water supply, became essential in the light of the water problems already experienced by the town of Potgietersrus and the Buffalo fluorspar mine near Naboomspruit. Furthermore additional data have been obtained during an intensified investigation.

The present report deals with the relevant aspects, such as the water potential and feasibility of the water scheme and should expedite the implementation of any practical scheme which is dependent on the groundwater in storage supplemented by artificial recharge of surface water.

## 2. INTRODUCTION

A survey of the groundwater situation of the northern Springbok Flats, excluding the Nyl River area, commenced in 1964. On account of water problems encountered in the dolomites to the north of the Flats, the groundwater investigation was subsequently extended to the Zebediela, Mogoto and Makapan areas.

The survey was thereupon diverted to the as yet uninvestigated western portion of the Springbok Flats i.e. mainly the drainage basin of the Nyl River. The investigation at the time was purely of a research-motivated nature but coincidentally aroused interest as offering a possible solution to the water problems of consumers in the area, such as Naboomspruit and Potgietersrus areas, who require more water for mining and industrial development, and the increased irrigation requirements of Consolidated Citrus Estates at Zebediela.

Based on the water level observations and the continual increase in irrigation from boreholes, the indications are that the groundwater is being overexploited, especially in the northern region. The need to prevent further deterioration of the groundwater resources has led to the proclamation of the area, delineated in Fig. I, as a Subterranean Groundwater Control Area. (Proc. 56 dated 26-2-1971).

Simultaneously the proclamation of the surface water was also recommended in order to control further development of the surface water in the catchment areas. A decision on this recommendation was deferred pending the outcome of this report.

The artificial recharge still requires further investigation but a tentative assessment was based on the pilot recharge wells, constructed at experimental sections. It revealed that the recharge would have to be greatly increased to accommodate 50% of the expected mean annual recharge.

Tentative conclusions on the feasibility of a water scheme based on the utilisation of the groundwater in storage and supplemented by artificial recharge is discussed.

## 3. TOPOGRAPHICAL FEATURES AND SURFACE DRAINAGE

The area of investigation forms part of the northern Springbok Flats which is discussed in great detail in the report by Wagner 2). Details of the topography of the area have been omitted in this report and only certain relevant aspects will be mentioned to provide a general impression of the area.

The dominant topographical feature is the Nyl River, which forms the main drainage system for surface water. In the southern region the river channel is adequately defined up to the point where the main tributary, the Little Nyl, merges with the Nyl at about 7 km east of Nylstroom. Below this point the central basin begins to assume the character of a succession of shallow marshes and a less defineable channel.

From about Nyls Vlei the flood plain takes the form of an extremely flat basin, completely lacking any definition of a proper river channel. The water course is plainly visible only during times of excessive rain, when it is transformed into an enormous sheet of sluggishly moving water - often several kilometers in width and only 0,5 - 1 meter in depth. The average gradient of the floodplain is very low, being about 1:1250, sloping to the north, and on account of this the flood plain has a tremendous flood absorption capacity. From water level records at Moorddrift, the Nyl River flowed on only 5 occasions during the past 20 years beyond this point into the Magalakwen River. As a result of the increasing interception of surface water by upstream development the progression of the floodwater is certainly impeded even more now than in the past.

The flooding of the Nyl River emanates mainly from the southern end and to a large extent also from the smaller drainage basins to the west, as shown in Fig. 2. The estimated mean annual runoff from each of these basins is indicated on the attached map. These values were taken from the previous report 1) and are subject to reassessment from more recent records. Nevertheless the floodwater expected to reach the flood plain is estimated at about  $75 \cdot 10^6 \text{ m}^3/\text{year}$ , which on account of future development may decrease to about  $60 \cdot 10^6 \text{ m}^3/\text{year}$ .

In the southern region floodwater frequently extends up to Num Num and the flow often becomes perennial during years of good rainfall, sustained by seepage emerging from numerous small springs in the alluvial sediments.

Because of the sporadic flooding of the Nyl River Control Area and the marshy character of the northern flood plain no permanent agricultural development is possible in the flooded areas. In some cases this water is channelled to irrigate grazing outside the inundated areas but most of the water is lost through evapo-transpiration and only a very small percentage serves to replenish the groundwater. This is attributed to the impermeable upper soil mantle.

#### 4. GEOMORPHOLOGY

The geomorphological character of the Nyl River basin developed progressively by changes originating before the pleistocene era. The changes were induced by the erosive action of the existing river systems. The following picture of the geomorphological development emerges, from the present data.

Originally the Nyl River drained towards the Olifants River, debouching at Bokpoort. By gradual erosion the Nyl River drainage was eventually captured by the Magalakwin system and the outflow to the Olifants River ceased. The juvenile character of the geomorphology at the bottleneck between Volspruit and Zoetfontein is evidence of this capture.

At a later stage the erosive action of the Olifants River eroded the eastern portion of the flats so that at present the Nyl River basin is about 150 metres higher than the Roedtan area.

The capturing action of the Magalakwin was reduced and the sediment filling of the Nyl River proceeded. The deposits consisted originally of coarser materials and later changed as the more clayey and silt layers settled out. In the mature stage meanders developed over the flood plain and shifting of the river occurred several times as inferred from the patches of limestone found in the auger-borehole surveys. These geomorphological changes explain the peculiar pattern of the sedimentary deposits. The present summary is sufficient for the purpose of this report, but it might be discussed separately at some later stage.

## 5. GEOLOGY

The geology of the area has been mapped by the Geological Survey (1926). Thus the geological map Fig. 3 has been compiled from this original survey with certain adjustments based on more recent geological data.

The area can be divided into three physiographical units. The subdivisions are the following:

1. Kransberg Hills and surrounding drift.
2. Piedmont areas.
3. Alluvial plain consisting of (see Fig. 5)
  - (a) Active flood-plain.
  - (b) Abandoned flood-plain.
  - (c) Uplands.

### Kransberg Hills

This occurs as a series of isolated outcrops of bedrock in the southern part of the basin. These hills are prominent local features, rising to as much as 250 metres above the vast alluvial plain of the project area. The northeastern alignment of these outcrops coincides with the trend of a bedrock ridge that is largely buried by drift and alluvium.

### Piedmont areas

These represent the transitional zone between the flats and the mountainous area of the Waterberg and Strydpoort foothills. The piedmont areas consist largely of alluvial fans which have been dissected by hill torrents and small intermittent streams. The lower piedmont merges with the alluvial plains without a distinct boundary.

### Alluvial plain

The valley fill deposit along the Nyl River flood-plain is the dominant physiographical unit. The alluvium consists of sand, gravel, silt and clay deposited by the ancient Nyl River and its tributaries. The alluvial deposits are heterogeneous, depending on their mode of deposition and are of limited horizontal and vertical continuity. From the pilot boreholes drilled in the Nyl River flood plain an isopach map of the alluvial basin of the ancient river was compiled (Fig. 4(a), 4(b) and 4(c)). The thickness of the basin varies between about 5 metres on its periphery to a maximum depth of 35 metres in the middle region i.e. on the farms, Grootvalley, Brak and portion of Olifantsklip. Towards the north the depth of the alluvial basin decreases and deviates from the present floodplain towards the east, more or less at Bokpoort. The alluvial basin is displaced slightly to the west of the present flooded area. The further subdivisions are based on the present relationship between the surface features and the river.

### Active flood plain

This includes the meander belt in the southern part of the valley and the present flood-plain of the river area.

### Abandoned flood-plain

These areas which are only a few metres higher than the flood-plain and are situated mainly on the western side, have resulted from the stream capturing process in the northern part of the valley. The original valley has been diverted from an easterly direction towards the northwest by the capturing stream, the Magalakwin, at about the Vaalkop bottleneck. The abandoned flood-plains are of hydrological significance in that they provided sites of recharge by streams in the recent past.

### Uplands

Large areas of relatively older alluvium are found in the central parts of the valley on the western side. Generally these sediments are above the present groundwater level.

### Bedrock (See Fig. 3).

### Distribution and characteristics

The bedrock formations in the area consist of igneous, metamorphic and sedimentary rocks. The principal rock types are:

- (i) The Bushveld Igneous Complex - norite and pyroxenite.
- (ii) Matsap beds as quartzites.
- (iii) Stormberg series - as basalt and sandstone.

The age of the rocks ranges from Mesozoic to Proterozoic. The bedrock formations have been fractured and are faulted at places. The general structural trend is south-west to north-east. The waterbearing properties of the different bedrock types are variable and the general waterbearing features of each are listed in Table 1. The outcrops of bedrock are of small areal occurrence and generally lie at fairly shallow depths (about 20 metres) beneath the river sediments.

The Waterberg system, exposed in the southern part of the Nyl River valley known as the Kranskop Hill and ranges, and also elsewhere in the basin, lies at a moderate depth under the flood-plain.

The Mesozoic formations include the Stormberg series of sandstone and basalts. Both rocks, exposed in the upper part of the Nyl Valley sides, are largely covered by alluvium. The formations are continuous in the subsurface throughout most of the valley between Vogelsfontein and Vaalkop. The sandstone is mainly medium grained but it contains a few beds of fine grained sandstone.

In the southern part of the valley a south-west/north-east fault trends through the middle of the Springbok Flats. From surface indications this fault can be mapped for only part of its total existence. Towards the middle portion of the Flats the thickness of the basalt is conformable with the depth of the tectonic basin and extends to more than 300 metres. The depth of boreholes normally does not penetrate the basalt so that the existence of the fault cannot be detected and surface indications have been wiped out by superficial alluvial deposits.

The presence of the fault could nevertheless be traced from the steep discontinuity of the order of 40 - 50 metres, in the water table. This fault may well influence the course of the longterm underflow from the Nyl River Valley towards the southeast. The age of the fault is post-Karoo and it seems to be fairly fractured judging by the high yielding boreholes occurring on both sides of the fault, viz. in the Voordeel and Amsterdam areas. As for the middle portion of the Nyl Valley, where a high anomaly of waterlevel deviation exists, so far no explanation of the abnormal pattern of water contours could be given.

## 6. GEOPHYSICAL SURVEYS

The Groundwater Section of the Geological Survey has conducted geophysical surveys in the area, more particularly to test the applicability of the methods to elucidate the hydrogeological picture. From 12 - 18 August 1970 a few gravity surveys were made east of Naboomspruit on the farms Haakdoornkuil, Olifantsklip and Mosdene Estates. No significant results were obtained except that a gravitational decline occurred from west to east.

During the period 24 May to 15 November 1971 resistivity measurements were made using the Wenner electrode configuration. No distinction between the alluvial deposits and decomposed basalts could be made.

Another resistivity survey was tried out during the period 1 June to 27 July 1972. Traverses were taken on Zoetfontein, Bokpoort, Haakdoornkuil and Derdekraal using the direct current method and Slumberger method of interpretation.

The transition from well-weathered basalt to slightly weathered basalt could be detected and good correlation with borehole logs were found. An anomaly was found in the region of the Zebediela fault and the thickness of the basalt round the edge of the basin could be estimated.

Traverses in the Olifantsklip area did not yield any results.

## 7. GROUNDWATER

### 7.1 Occurrence

In the past the Springbok Flats was known for its abundance of groundwater, but excessive pumpage which commenced around 1955 has depleted the supplies to an alarming extent.

In the Nyl River basin itself, however, the situation is less serious except that in the northern parts evidence of over-exploitation exists. In the central and southern parts the groundwater is still more or less intact. This is partly due to the fact that the flood plain is often inundated and as such inaccessible. Just outside the vlei area there has been large scale irrigation development lately.

After the promulgation of the area as a subterranean groundwater control area, a complete survey of all the existing boreholes was made and relevant data on yields, waterlevels, irrigation practices etc. have been collected. This information is tabulated in appendix A.

The position of some of the surveyed boreholes are indicated in Fig. 6. All boreholes are not shown because of the high density of boreholes on some of the farms. The numerical values presented are an indication of the total number of boreholes on each farm. The general distribution of boreholes is nevertheless clear and the high density of boreholes depicted in the northern region conforms to the general yield pattern.

## 7.2 Yields of Boreholes

The borehole yields have been plotted in Fig. 7, which has been compiled from the individual survey sheets (appendix A). The originally tested yield of the boreholes, as supplied by the farmers, was used. Although not truly comparable due to the fact that they were not drilled at the same time and often not properly tested, the map nevertheless indicate the areas of good groundwater supplies. This is illustrated by differential colouring according to yield categories. The map does not reflect the extent to which the boreholes have diminished in yield. Such a map could be produced only after complete re-testing of the boreholes.

The yield pattern is very variable in the north, which is indicative of the irregular weathering in the underlying basalt. The concentration of boreholes in the vicinity of the Zebediela fault running across Zoetfontein, Bokpoort and Doelen to the Zebediela area is apparently related to the fault.

The fault seems to have had an influence on the general weathering around it and accounts for the good yields of the boreholes. The yields on Volspruit inside the vlei area are also good but in this instance originate from the boulders underlying the sediments. The large variation in yield over short distances is seemingly related to the intersection of highly permeable interstices in the basalt, suggesting that the basalt has been subjected to stresses which have caused a great deal of this intersticing; this phenomenon apparently did not occur in the central region of the flood plains more to the south. Fairly extensive prospecting by the Buffalo Fluorspar Mine proved on the other hand that the basalt is poorly weathered in the Du Toitskraal area.

A number of high yielding boreholes have recently been drilled in the area east of the proclaimed region viz. on Voordeel and Amsterdam (see Fig. 7). This water also seems to be related to the fault nearby (see Fig. 3). A fluoresceine pumping test carried out on Amsterdam proved the existence of a very permeable interconnection, pointing again to good fracturing or weathering. The Amsterdam boreholes derive their water from the basalt whereas those on Voordeel were struck in the sandstone.

To the south of du Toitskraal the geological formation underlying the alluvial sediments is mainly sandstone and felsite, both lacking favourable waterbearing properties; consequently the yield of these boreholes is generally low. Portions east of Nylsvlei and Vogelsfontein are completely dry, and numerous boreholes have had to be sunk outside the flood-plain, in an attempt to find water.

As is evident from Fig. 7 the yields of boreholes are very low - less than 1,3 l/s over very large areas of the actual river valley in the southern region in the vicinity of du Toitskraal, Zandpan, Leeuwkuil and Olifantsklip, where the alluvial sediments are in fact at their deepest. The exploration drilling by the Buffalo Fluorspar Mine showed that the basalt is fairly solid. However, moderately good supplies were found east of Naboomspruit on the farm Grootvalley.

### 7.3 Water Quality

The total dissolved solids viz., the nitrate and fluoride content of the groundwater samples in and around the region of investigation have been determined. These results have been plotted in Figures 8(a), 8(b) and 8(c) respectively.

As several analyses are available for some farms, only the maximum and minimum values have been mapped to obtain an overall picture of the quality of the water. A full table of the results appears in the preliminary report 1). On each of these maps the permissible range of the chemical constituents is indicated, serving as a basis for evaluating the groundwater quality.

From the first map, Fig. 8(a) it is evident that the content of total dissolved solids in the southern region is well within the permissible range for drinking water. However to the north, on Zoetfontein, the total dissolved solids exceed the upper limit in a few cases. It is worth mentioning that three boreholes drilled very close to each other vary significantly in quality. The water obtained from a shallow depth is superior to that of water extracted from greater depths.

This clearly reflects that the upper water, which is being recharged from the surface, is of a better quality. This also implies that saline water encroachment could certainly be expected once the groundwater is overtaxed and the water table continues to decline. On the other hand the quality of the water could be improved if artificial recharge is practised.

The nitrate content Fig. 8(b) is well within the permissible limits in the southern regions of the Nyl River valley and although increasing to the north, the concentrations are still acceptable. Outside the river valley on either side, the upper values are in excess of the permissible value. The latter however is still debatable and standards for this limit vary according to the age of the consumers. The extreme value for intake by children is lower than for adults.

The high nitrate content values found around Roedtan in the central Springbok Flats have been noticed previously and tentatively investigated by Porszasz 3), and are at the moment being extensively studied by the Hydrological Research Institute.

The fluoride concentrations are of great importance as these greatly exceed the health standards in some localities. These high values are associated with the abovementioned extensive fault and are derived from the effusive formations.

Similarly on Vogelsfontein the fluoride content is very high as proved by the analysis of samples from one of the pilot boreholes and from others taken elsewhere. Again the fluoride originates from demineralisation of the felsite and from the underlying formations.

In the valley to the north and over the entire eastern regions of the Springbok Flats the fluoride content is within the standards of potability.

#### 7.4 Water Contour Map - Fig. 9

A map of the water-level contours relative to sea-level was compiled from the observed water table below surface and from collar elevations as derived from the 1:50 000 maps. The latter were interpolated from spot heights and contour lines and are sufficiently accurate because of the flatness of the terrain. The present pattern of the water-levels indicated in Fig. 9 at contour intervals of one metre, is peculiar in many respects.

Certainly the most inexplicable feature is the groundwater depression over an extensive area in the centre around Brak and Olifantsklip. The piezometric heights indicate that the water table slopes towards this sink from all sides, implying that no groundwater can flow via the alluvial channel to the northern part of this basin.

This is indeed a remarkable phenomenon especially in view of the fact that the alluvial basin is of much more recent geological origin and cuts through the underlying base rocks. Incidentally the thickness of the alluvium is highest in this specific region and this could reasonably be expected to enhance rather than impede the groundwater movement. The yields of test boreholes drilled so far in the Olifantsklip area are low and although the basalt was penetrated a few metres only, the water-level rose quite well into the alluvium above. A tracer test carried out on these boreholes proved that there was a good hydraulic connection between them. The reaction of the water-level to pumpage was also very rapid and the same was found for the recharge. However once the recharge had been stopped the water-level gradually dropped back to its original level. (See Fig. 10(b)).

The reason for the anomalous low groundwater level in this region is still obscure and further study is necessary.

North of Vogelsfontein the water-levels are higher outside the flood plain, both east and west, thus indicating movement of groundwater towards the alluvial basin. This is an important point since it proves that water recharged in the basin will not be lost by seepage to the east. This pattern also exists in the region of Bokpoort and Doelen where the spur of the ancient river debouches towards the east. It therefore appears that the leakage from the Nyl River valley should also be negligible along this ancient conduit.

In the southern part of the valley the groundwater slopes away from the flood plain to the east. The contours are virtually north to south indicating seepage losses to the east. This means that water recharged in the area of Vogelsfontein would not benefit the northern alluvial groundwater.

The geological fault cutting through Klipput, Amsterdam and Gruisfontein causes a sudden drop in the groundwater level and a steepening of the gradient towards the east. The extent to which these water-levels have been affected by the heavy pumping on Amsterdam has not been conclusively ascertained. Further drilling across the fault is recommended to clarify the position.

The cone of depression in the region of Zoetfontein and Platdoorns, other than the sink on Brak, is unmistakably due to excessive pumping on Zoetfontein, where large areas are being irrigated.

From the water-level contours it is now clear that groundwater is flowing from the northern area of the river channel, that is, from the Volspruit area to the heavily pumped area around Zoetfontein. This reverse flow is due partly to pumpage but probably also to recharge which takes place readily in the Volspruit area. The recharge comes from the frequent flood accumulation in this part, as was plainly illustrated by the municipal boreholes which showed a constant rise while the surface water in the vlei area persisted.

The prominent cone of depression in the Jaagbaan area is caused by severe pumping and is aggravated by the limited extent of the aquifer. The second cone of depression is due to the mining activities of the chrome mine which although at present not pumping out much water, yet has caused severe drawdown because of the paucity of available groundwater.

## 7.5 Aquifer Characteristics

The general characteristics of the geological formations which form aquifers for storage and transmission for groundwater, have been summarised in Table 1 (Sec. 4.4). However, this qualitative classification of the waterbearing properties of the aquifers is not quite adequate, particularly in view of the importance of the assessment of the water potential of the area.

### 7.5.1 Specific Yield

This is one of the most important parameters necessary for a reliable estimation of groundwater in storage, or total storage capacity. In the preliminary report the specific yield was assumed to be 7%-22% but in the present investigation a great deal of emphasis was placed on a more refined determination of the specific yield of the various geological strata.

### Alluvial Deposits

The alluvial sediments of the Nyl River valley have been regarded as the main storage reservoir in view of their high specific yield. Whereas the previous values of specific yield were taken from tables, actual tests have now been carried out to determine these values for some of the representative samples.

First the field capacity was determined of soil samples obtained from the auger boreholes, by drying of the samples. The moisture percentage by volume was subsequently derived from the dimensions of the auger boreholes in each instance with due regard to the sampling interval, which was generally 0,3 metre. The saturated waterbearing capacity was then determined by simulation of the field compaction in a centrifuge with the sample fully saturated. The results from the samples analysed are listed in Tables 2 to 5. The specific yield results shown in these tables are the differences between the saturation values and field capacity of the particular samples. The grading analysis of the samples obtained from the auger holes is also given in the tables, reflecting the compaction of the alluvial samples.

#### 7.5.2 Pumping Tests

The specific yield of the aquifers concerned has also been deduced from pumping tests carried out in the area. The normal procedure was to perform a preliminary test after completion of a borehole, followed by a proper test when warranted. Initially serious problems were encountered as a result of the unreliability of the pumps, but conditions improved when a newly designed test pump was used.

Some tests had to be repeated because of pump failures but eventually reliable tests were carried out enabling some of the aquifer characteristics to be deduced from the rate of drawdown of the water-level. The tests showed that the water-level reacted largely to the fissuring in the weathered basalt which has a higher permeability, but smaller specific yield than the overlying alluvium.

The results of the drawdown tests are listed in Table 6, from which it can be concluded that the transmissivity of the selected sections as obtained from the tests gave the highest anticipated values. These are naturally favourable points for diverting surface water underground.

Even though the high transmissivity values are not very favourable when compared with other formations - such as the dolomite for instance - yet the proof now exists that the hydraulic conductivity in the northern area is far better than in the south.

The specific yield derived from the drawdown data is very low and the validity of the formulae, being applicable only to homogeneous aquifers, was suspect in view of the existence of highly permeable fissures. There was furthermore the possibility that confined flow conditions may exist as the transmissivity of the overlying clayey alluvial sediments is much lower than that of the weathered basalt.

Since the specific yield cannot be determined from the drawdown rate under confined conditions, merely the storage coefficient, special tests were carried out using fluoresceine as a tracer. The dye was released in the observation borehole and the time of arrival at the pumping borehole was noted. The tracer was detected visually but the fluoresceine content of samples taken at regular intervals was also tested. The peak of the tracer recovery curve was accepted as the reference point reflecting the average specific yield, and the first arrival of tracer as representative of the minimum specific yield.

The results of these tests are listed in Table 7 but to facilitate comparison they are also shown in Table 6. The tracer results yielded higher values for the specific yield than the drawdown data, a good example for this being the test on Volspruit.

The tracer results generally indicate rapid movement of water in the basalt, confirming that the specific yield is not high, being on the average about 1,8%. The specific yield of the alluvium is higher but only a few tests have been carried out at spots which derive their water exclusively or predominantly from the alluvial portion of the two aquifers.

At Rondeboschje the tracer had not appeared when the test was discontinued, so that only the minimum order of the specific yield could be estimated.

An excellent example of the extent to which open fissures can exist over relatively large areas is a pumping test carried out on Doelen. The tracer was expected to appear only at the pump 75 metres away but in fact was observed to have reached a point 349 metres from the point of injection only 29 hours after being released.

The results of the specific yield estimates obtained from the tracer tests have been mapped in Fig. 11.

## 8. RECHARGE

It is essential to determine natural recharge in order to assess the groundwater potential of the region. The natural recharge is a most difficult quantity to evaluate and for this reason the previous report 1) assumed a figure based on the knowledge and experience of the authors.

### 8.1 Natural Recharge

#### (a) Water table observations

The water-level response is a sensitive qualitative indication of recharge or depletion of groundwater. Interpretation of these fluctuations for quantitative deductions of the recharge is at present virtually impossible. However, some useful conclusions concerning recharge can be made from a closer scrutiny of the fluctuations that occurred in the observation boreholes within the area of investigation - see Fig. 10.

The water-level recordings are of different duration; the longest in existence is that of Bokpoort Station Nr. A6N034. It shows a continuous decrease of the water-level since as far back as 1961, signifying that the pumpage exceeds natural recharge in this region. It should be mentioned that subnormal rainfall has been experienced during the period 1962 - 1970, over the whole area and the decline of the water-level is only slightly interrupted during periods of good rainfall. This does not necessarily imply that recharge took place, but could also be just temporary recovery of the cone of depression, when irrigation requirements are at their minimum.

The second longest record is that of du Toitskraal Station Nr. A6N017 which started in January 1967. In this region there was no excessive pumping - only modest amounts for stock watering. The response of the groundwater level to the 1967 flood is an evidence that recharge of the groundwater occurred. It is uncertain whether the recharge originated from outside the flooded area or from within the flood-plain, the latter probably being the case. Accidental recharge through existing boreholes can be excluded as a possibility seeing that they were not submerged. Similar recharge opportunities occurred in 1969 and 1970.

Since January 1971 artificial recharge has taken place and the separation of the effects of natural and artificial recharge has become impossible. A great deal of recharge data are still required to illuminate more accurately the whole question of recharge.

The remainder of the observation records are of much shorter duration and do not permit any definite conclusions. There is, however, an indication that recharge took place in the southern region of Zandfontein and Vogelsfontein, showing a direct relation to the occurrence of floodwater. Towards the north the water-level trend is downward, and the long record of A6NO34 likewise indicates overtaking of the groundwater by heavy pumping.

(b) Carbon-14 Analysis - See Fig. 12

The question of recharge was also studied by means of Carbon-14 age determinations of some of the groundwater samples. This survey was done in 1971 and showed that the groundwater in the northern region contains a bomb component of Carbon-14. This indicates that a significant proportion of the groundwater is of an age of less than 14 years (before present data) and that recharge therefore does take place.

Towards the south only one analysis, that on du Toitskraal, was done and proved to contain no water of post-bomb origin. It appears now that the sample from de Hoop is unreliable having been taken after artificial recharge had started. The natural groundwater was therefore contaminated with juvenile water which rendered the sample unsuitable for any interpretation.

This is important, since according to the tritium results (see section 8.1(c)) the groundwater at the depth of the water-level should not have contained any bomb Carbon-14.

The northern samples, however, are obtained from a shallow depth and infiltration appears to occur there more readily, originating from bomb rainfall infiltration, and the presence of Carbon-14 is therefore not unnatural. The  $^{14}\text{C}$  content of the du Toitskraal sample yields an age of approximately 485 years which does not appear to be too high if judged by the rate of downward movement from the tritium profiles (section 8.1(c)).

A sample from Vogelsfontein was not forwarded for analysis, since it was obvious from the rapid response of the groundwater level that recharge had taken place and that the age would be small. One of the pilot boreholes drilled on Vogelsfontein actually became semi-artesian for some time during the occurrence of the flood.

(c) Tritium Analysis

A quantitative assessment of the natural recharge was made from the tritium content of soil moisture in the samples obtained from different horizons. The sampling points were selected across the river channel to ascertain whether there was preferential recharge within the flood-plain, or outside of it.

Several sections were sampled but only two of these were analysed. These are on Haakdoornkuil and on Olifantsklip. The tritium results are shown in Table 8 together with the calculated recharge. The most accurate assessment of recharge could be made from the depth to which the 1962/3 rainfall, detectable from the sudden step in tritium, had penetrated. This indicates the net downward movement of soil moisture, which is actually a direct measure of the recharge at a specific locality. To detect the 1962/3 tritium step, analysis of a full profile would normally be required. However, the recharge could also be interpreted from single values, but with less accuracy.

(i) Haakdoornkuil Profiles

Profile No. 3, taken further away from the river channel shows an average recharge rate of  $\pm 2\%$  of the mean annual precipitation, compared with 4,1% at No. 11 and 3,4% at No. 16, situated progressively more to the centre of the flood-plain. The value of 2% is however the more reliable one, and is incidentally the same figure as the one assumed in the preliminary report 1).

Profile No. 3 was assayed up to the watertable and proved that very little bomb tritium could yet have reached the groundwater - this confirmed that the  $^{14}\text{C}$  content of the de Hoop sample was unreliable (Sec. 8.1(b)).

(d) Stable Isotopes

The following table reflects the stable isotopic composition of the soil water extracted from the soil samples at Haakdoornkuil No. 3.

TABLE 9 : STABLE ISOTOPE ANALYSES

LOCALITY	SAMPLE NO.	DEPTH (M)	<sup>18</sup> O
			per mil relative to SMOW*)
Haakdoornkuil No. 3	SM180	0,3 - 0,6	-4,4
	"184	1,2 - 1,5	-6,75
	"187	2,4 - 2,7	-7,82
	"191	4,8 - 5,1	-6,06
	"201	10,5 - 10,8	-6,75
Olifantsklip	S1947	Surface Water	+1,43

\*SMOW - Standard Mean Ocean Water.

The results indicate a slight enrichment of stable isotopes in the upper soil layer brought about by evaporation losses, whereas the deeper water is fairly consistently of a lighter isotopic composition. The variation results from the fact that the water represents an average sample of the rainfall responsible for the recharge. By the same token as for the tritium results the interpretation presupposes a successive movement of moisture downwards without excessive admixture of the different layers.

The Olifantsklip sample was taken from stagnant water over the flood-plain, subjected for a considerable period to evaporation. The deviation in its isotopic composition is a proof that very little of the standing water ever recharges. This may appear at variance with the tritium results, yet it indicates the probable mechanism for recharge in a clayey soil overburden. The light isotopic composition, being now even less than the average content of the rainfall, indicates that recharge would come from heavy downpours which as a rule are of a lighter isotopic content. The recharge therefore seems to take place through the cracks to be found in the overlying clay and turf, whilst they are still dry. Rapid seepage to well below the zone of evaporation losses would then result, but the surface would soon be sealed off by swelling of the clay and any excess water accumulating on the surface would then in due course be lost by evaporation.

Further isotopic analyses are required to elucidate the situation further and to allow more definite conclusions to be drawn.

## 8.2 Artificial Recharge

The pilot boreholes sunk at the five experimental sections have been constructed to serve as actual artificial recharge points but also for experimental purposes to test the absorption capacity of the respective aquifers. Normally one of the boreholes at each section is used for recharge, the other to observe the water-level response. At the de Hoop section four boreholes were equipped for recharge. A typical recharge installation is shown in plate 1, surrounded by floodwater.

A full evaluation of the actual success of the recharge was so far not possible due to lack of time and staff. Calibrations needed for establishing the rate of water absorption are still to be carried out, as well as a study of the clogging effect of the pores caused by bacteriological activity or fine silt.

The relative suitability of the boreholes for recharge can be judged from their respective yields. Naturally it must be a function of the hydrostatic head that could in its turn be induced, but as a first approximation the rate could be assumed to be equal to the tested yield of the borehole. In this manner the recharge potential of the special recharge boreholes is listed on a comparable basis in Table 10.

According to the table the potential recharge rate possible by means of the existing boreholes intended for this purpose is  $1,5 \cdot 10^6$  m<sup>3</sup>/year. This is based on the assumption that the recharge rate is equal to the yield of the borehole, which is obviously not always the case, and that the rate is not reduced by clogging of the aquifer pores.

The total potential recharge rate of all suitable government boreholes amounts to  $0,17 \cdot 10^6$  m<sup>3</sup>/year. It is apparent from Table 10 that the maximum recharge that could be effected at the present sites during an estimated period of 17 months of floodwater prevailing, was at most  $0,5 \cdot 10^6$  m<sup>3</sup>. Even this figure is probably too high due to a smaller inflow rate into the boreholes.

Although an accurate assessment of recharge possibilities could not be done, a coarse analysis of data reveals some interesting facts.

The estimated average annual runoff available for recharge is about  $60 \cdot 10^6$  m<sup>3</sup>. The area of the alluvial basin is about 17620 ha, which implies an average depth of 0,34 metres of water if the area is uniformly covered.

The net evaporation as obtained from station A6E05 on du Toitskraal is about 0,103 metres/month. Assuming the effective area of the exposed surface during periods of recharge to average one third of the total area, then

$$\begin{aligned} \text{Evaporation losses} &= \frac{17620 \cdot 10^4}{3} \cdot 0,103 \cdot 12 \\ &= 72 \cdot 10^6 \text{ m}^3/\text{year} \\ \text{Present Recharge Potential} &= 2,0 \cdot 10^6 \text{ m}^3/\text{year} \\ \text{Total Recharge required} &= 72,0 \cdot 10^6 \text{ m}^3/\text{year} \end{aligned}$$

Thus, the average annual runoff of  $60 \cdot 10^6 \text{ m}^3$  would be dissipated in 9,7 months and 97% of the losses would be by evaporation (natural recharge losses having been disregarded).

It therefore appears that in order to recharge 50% of the estimated runoff, the rate of recharge should be equal to the evaporation losses.

$$\begin{aligned} \text{i.e. Recharge rate} &= 72,0 \cdot 10^6 \text{ m}^3/\text{year} \\ &= 0,2 \cdot 10^6 \text{ m}^3/\text{day} \end{aligned}$$

The latter is about 36 times more than the present potential recharge rate, and if the full water scheme is to be put into effect recharge structures must be able to cope with this quantity.

## 9. WATER POTENTIAL

This is certainly the core of the whole investigation and is closely related to the feasibility of the proposed water scheme. Most of the effort of the extended investigation was aimed at assessing the critical parameters involved in the evaluation of the water potential.

### 9.1 Water Storage Potential

As previously indicated there are two main aquifers that could be utilised for groundwater storage, namely the alluvial basin and the underlying basalt. To the north there is also the decomposed norite to consider but this is of less importance owing to its smaller aerial extent.

Certain relevant data shown in comparison with the previous assessments are listed and discussed below.

9.1.1 Alluvium

Areal extent of the alluvial basin:

Previous: 27200 ha - this figure represents the whole of the flood-plain area.

Present : 17620 ha - based on the 5 - 5 metre contour map of the alluvial basin. - Fig. 4.

(a) Total volume of alluvial basin:

Previous: 3450.10<sup>6</sup>m<sup>3</sup>

Present : 2330.10<sup>6</sup>m<sup>3</sup>

The latest estimate differs from the first because originally the volume of the alluvium right up to the surface was considered. This is not quite correct since the alluvial basin would only be recharged up to about 5 metres from the surface.

(b) Volume of the unsaturated alluvium

Previous: 2070.10<sup>6</sup>m<sup>3</sup>

Present : 1400.10<sup>6</sup>m<sup>3</sup>

The latter is now smaller and was determined from the ratio of the previous value representing the relation to the previous storage capacities.

(c) Total Porosity:

Previous: 40%

Present : 45%

The latter is obtained from laboratory tests of actual samples whilst the first one was only an estimate.

(d) Specific yield

Previous: 7% - 22% - Average 14,5%  
Present : 9% - 40% - Average 25%

This value is much higher than the previous one and to be on the safe side a value of 15% is assumed here for calculation of the volume of water in storage.

(e) Water required to saturate (b)

Previous: 830.10<sup>6</sup>m<sup>3</sup>  
Present : 210.10<sup>6</sup>m<sup>3</sup>

The latter value is now far below the previous one, firstly because of the smaller estimated volume of the unsaturated alluvium, and even more so, because the previous calculation was erroneous inasmuch as the alluvium is already at field capacity, so that the specific yield and not the total porosity should have been used to calculate this quantity on the previous occasion.

(f) Present extractable water from unsaturated alluvium i.e. from (b):

Previous: 290.10<sup>6</sup>m<sup>3</sup>  
Present : 210.10<sup>6</sup>m<sup>3</sup>

(Specific yield taken at 15% in the latter case).

This value is the same as that of the volume of water required to saturate (b) completely.

(g) Total volume of extractable water from (a), when fully saturated:

Previous: 490.10<sup>6</sup>m<sup>3</sup>  
Present : 350.10<sup>6</sup>m<sup>3</sup>

The lower value is due to the reduced value of the total volume of the alluvial basin (specific yield 15%).

9.1.2 Decomposed bedrock

The water storage capacity of the underlying decomposed bedrock formations was not taken into account in the previous assessment. Subsequent drillings however revealed that the decomposed basalt extends to an average of about 20 metres below the alluvial basin. From the pumping tests it is apparent that this formation is of an even greater importance than the alluvial deposits, by virtue of its higher permeability which is necessary if recharge is to proceed at a reasonable rate.

Assuming the areal extent of the weathered basalt to be only equal to the area of the alluvial basin, and using an average specific yield of 1,8% as determined by pumping tests (Table 6), an additional storage for groundwater totalling  $65 \cdot 10^6 \text{m}^3$  could be utilised. (Average depth 20 metres and area  $17620 \cdot 10^4 \text{m}^2$ ).

(i) The total potential storage is therefore :

<u>Alluvium</u> :	$350,0 \cdot 10^6 \text{m}^3$
<u>Basalt</u> :	$65,0 \cdot 10^6 \text{m}^3$
Total :	$415,0 \cdot 10^6 \text{m}^3$

(ii) Total groundwater supplies at present

<u>Alluvium</u> :	$140 \cdot 10^6 \text{m}^3$
<u>Basalt</u> :	$65,0 \cdot 10^6 \text{m}^3$
Total :	$205,0 \cdot 10^6 \text{m}^3$

9.2 Natural recharge

The present investigation has not shed much light on this aspect and further study is required. For the time being the previous recharge calculations are still accepted. This was based on the assumption that the recharge is about 2% on the flood plain and 4% on the adjacent area. It follows then:

Estimated recharge:  $16,7 \cdot 10^6 \text{m}^3/\text{year}$ .

### 9.3 Volume of Water Pumped

The estimation of pumpage by farmers from the electricity consumption of pumps, is still to be carried out. Some data have been collected but a full-scale survey is necessary before a more direct estimate is possible.

For the time being the estimate of pumpage is based on the areas irrigated and the water requirements in this area. Previously the water requirements were taken to be 600 mm per year per ha, but at present are based on the allocation at Doorndraai Dam i.e. 710 mm/ha/year.

This brings the water extraction for the estimated 2620 ha under irrigation to

Pumpage: 2620.7100 m<sup>3</sup>/year

i.e. 18,6.10<sup>6</sup>m<sup>3</sup>/year.

as compared with the previous estimate of 18,0.10<sup>6</sup>m<sup>3</sup>/year (based on 3 000 ha of irrigated land).

### 9.4 Summary of Water Potential

(a) Total present water in storage

$$= 205,0.10^6 m^3$$

(b) Pumpage = 18,6.10<sup>6</sup>m<sup>3</sup>/year

(c) Natural recharge = 16,7.10<sup>6</sup>m<sup>3</sup>/year

(d) Water requirements from the Nyl Valley -

Immediate requirements/year

(i) Potgietersrust = 2,6.10<sup>6</sup>m<sup>3</sup>

(ii) Buffalo Fluorspar Mine = 0,6.10<sup>6</sup>m<sup>3</sup>

(iii) Zebediela = 5,2.10<sup>6</sup>m<sup>3</sup>

Total = 8,4.10<sup>6</sup>m<sup>3</sup>/year

The water required by the Wonderkrater holiday resort is not yet known.

(e) Future requirements from the Nyl Valley

1970 = 0,0.10<sup>6</sup>m<sup>3</sup>

1980 = 19,4.10<sup>6</sup>m<sup>3</sup>

1990 = 26,6.10<sup>6</sup>m<sup>3</sup>

2000 = 34,0.10<sup>6</sup>m<sup>3</sup>

Estimated potential artificial recharge ultimately =  $30.10\text{m}^6\text{m}^3$   
/year  
(See section 8.2).

In order to supply the immediate water requirements of the major consumers, totalling  $8,4.10^6\text{m}^3$ /year, the present potential recharge rate of  $0,20.10^6\text{m}^3$ /year should be increased fourfold.

## 10. FEASIBILITY OF THE WATER SCHEME

From the calculations in the previous section it is obvious that the water scheme is a feasible proposition, though certain possible constraints have to be mentioned - especially the availability of water to be recharged and the rate at which it could be accomplished.

- (a) There is a serious imbalance between the areas where water is required and the areas where water for recharge is available.
- (b) The unnatural groundwater depression in the middle portion of the flood-plain is a serious obstacle for the proposed artificial recharging of surface water occurring in the south.
- (c) There are definite indications of overpumping in the northern portion of the valley i.e. the Zoetfontein area. This limits the quantity of water in storage that could be utilised before artificial recharge is put into practice.
- (d) The overtaxing of the groundwater reservoir could aggravate matters, especially if consumers like Potgietersrust and Zebediela extract water from points too close to each other.
- (e) The practical feasibility of the proposed water scheme is dependent on the availability of surface water for recharge. This could be a serious constraint because of the high flood-absorption capacity of the flood-plain.
- (f) The limited absorption capacity of the recharge boreholes and the expanse of the flood could result in high losses of water by evaporation. The recharge potential would have to be increased immensely if the required  $30.10^6\text{m}^3$  is to be recharged annually.

## 11. CONCLUSIONS

The investigation has clarified several aspects of the groundwater situation and should be of great assistance in evaluating the feasibility of the proposed water scheme based on the groundwater of the Nyl River Valley and augmented by surface water by means of artificial recharge.

With the completion of the hydrogeological study of the Nyl River Valley yet another area of the Springbok Flats has been covered. It seems thus logical to try to complete the remaining unstudied area of the flats and to consolidate the information into a report covering the entire Springbok Flats, thereby completing the study of this hydrogeological unit.

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