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NDOLA WATER SUPPLY STUDY

REPORT ON A VISIT IN OCTOBER 1974

by

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December 1974

INSTITUTE OF GEOLOGICAL SCIENCES

DEPARTMENT

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NDOLA WATER SUPPLY STUDY: Report by Dr E P Wright.

1. The writer visited Ndola on the 24th/25th October 1974 at the request of J N Bulman, SADD Engineering Advisor, in order to appraise the progress of the Ndola Groundwater Study being undertaken by Brian Colquhoun, Hugh O'Donnell and Partners on behalf of the Ministry of Overseas Development and the Department of Water Affairs, Government of Zambia.

2. Preliminary discussions were held in Johannesburg on the 23rd October with various representatives of Brian Colquhoun and Partners and Australian Groundwater Consultants.

3. During the visit to Ndola, a rapid tour of the drilling sites was made on the afternoon of the 24th October and further discussions were held at the Ndola site office on the morning of the 25th prior to leaving for Blantyre and London that same day.

4. The technical appraisal given in (5) below was prepared on return to the U.K. and the gist of the appraisal submitted verbally during a meeting at ODM (Chairman- Mr C M Harrison), held on November 13th. Some differences of opinion became evident between the writer and Mr J M Johnson of Australian Groundwater Consultants, mainly on the question of the effect of the use of bentonite during drilling, and a further meeting was arranged on the following day (November 14th) at the Institute of Geological Sciences to discuss in detail this and other matters. The substance of the discussions and the conclusions are given in Section 6.

5. Progress of the Ndola Drilling Contract

5.1. General Appraisal

Apparent progress of the contract appeared fairly satisfactory in that two of the sites had been completed and pump tested and at several others drilling had been almost completed. However, in the opinion of the writer, and for various reasons which will be mentioned below, neither the test drilling nor subsequent aquifer testing techniques can be regarded as wholly satisfactory and various recommendations for improvements are included in this report.

5.2. Drilling

Observation holes have been drilled mainly by air/percussion method but in some instances have had to be completed by rotary rig (coring and reaming) using either water or mud as a drilling fluid. Production test holes to date have been drilled mainly by rotary rig and to a greater or lesser extent bentonite has been used in virtually all cases. In one well alone, $7\frac{1}{2}$ tons of bentonite was used, and in another $3\frac{1}{2}$ tons. Full details are available in the drilling records. Since lost circulation was experienced during the drilling of all production test holes, and I understand principally within the upper part of the sequence, then presumably most of the bentonite used must have been dispersed into the formation. Development of the wells has been limited to air lift pumping for a few hours prior to the main test pumping.

5.2.1. Effect of Drilling Fluid

Mr J M Johnson of Groundwater Consultants noted in discussion (November 13th) that the bentonite used was of a low yield variety, that not all the bentonite recorded as having been used would have entered the formation (but see 5.2. above) and that on the assumption that the bentonite was fully hydrated, he envisaged it remaining as a fluid within the formation which could be easily pumped out. This viewpoint assumes basically that the formation fluid occurs within a few large interconnected fissures in an otherwise completely impervious rock. There is no substantial evidence for this viewpoint on the structural characteristics of the Kakontwe Limestone other than the drillers quoted opinion of the presence of large fissures (c.2cm width). Core examination indicates the presence of much smaller fracture sizes, and although the relative hydraulic significance of such fractures are not known, it is more logical and initially more appropriate to assume that hydraulic movement may be through an interconnected network of fissures and fractures of variable and varying sizes. In any event, it is wiser to assume structural complexity until proved otherwise, and if this complexity does prevail, the effect of the drilling fluid within the formation could be considerably different to that envisaged by Mr Johnson. Since the matter is of considerable importance, the detailed argument is presented below.

a. Whether the bentonite is completely hydrated will depend on the adequacy of the mud control during drilling.

b. Even if the bentonite is completely hydrated in the drilling fluid, the following possibilities must be considered:-

   i. The drilling mud is likely to have been dispersed widely in the formation during the lengthy periods when circulation was completely lost.

   ii. Mud cakes could be deposited on rock surfaces either on the side of the borehole or within fissures if the limestone rock is even weakly permeable and where a pressure differential exists.

   iii. Mud cakes could also be deposited across fissures where

5.2.1. b. iii. (Cont)

these are sufficiently small and where a fissure narrows to the requisite dimension. In the latter case, a lateral or backward build up of the mud cake could occur into the wider part of a fissure.

iv. When circulation is lost, both mud and cuttings are being dispersed into the formation. A build-up of cuttings in a fissure could readily be associated with deposition of mud within the cuttings as in normal invasion of permeable material.

v. Even where the mud remains fluid, it will after a short time (gel) and in combination with suspended cuttings would form a heavy viscous mass.

c. Deposited mud which has deeply invaded a formation is recognised as being difficult to remove and particularly so when the mud has been deposited, as likely here, under quiescent conditions. It seems also feasible to visualise difficulty in removing the heavy viscous gelled mud where this has penetrated fissures to appreciable distances from the borehole.

The possible circumstances were discussed with Mr Pace, Chief Engineer of Baroids Eastern Hemisphere Division (one of the world's foremost Companies concerned with the manufacture and use of drilling fluids) who concurred with the writer's opinion on the likely effects of fluid and mud invasion, and was even more pessimistic regarding the difficulties of removal. He recommended acidisation and urged alternative methods of drilling.

Although the majority of the observation wells have been drilled largely without the use of bentonite, the use of significant amounts in the adjacent production well could possibly invalidate the analytical conclusions. Damage to the formation by mud penetration could extend into the aquifer to beyond the observation wells (a radial distance of 8m), particularly if fissuring is very localised. Additionally since the main zone of lost circulation occurs mainly in the upper levels of the Kakontwe limestone immediately below the overburden, restriction of flow movements at these levels would introduce vertical flow components into the test 'system' and cause difficulties in analysis.

For these various reasons, it is recommended that every effort should be made to drill all wells by air/percussion techniques. Problems have been encountered in the use of the two air/compressor rigs (a COP 6 and a URB-2A) in consequence of the weight of

5.2.1. (Cont)

cuttings and the amount of water inflow, particularly in the drilling of the larger diameter production wells. However, it is believed that the compressors used are of fairly low rating (c. 100psi) and low output (c. 600 cfm). The compressor designed for use with the COP-6 can give a working pressure up to 250 psi, and by adjustment, an increase in air flow to 1445 cfm. Since the rig is clearly capable of operating at high pressures and with high rates of air flow, the use of two or more low power compressors, operating either in series or in parallel as required, could improve the drilling capacity considerably.

A further possibility to facilitate air/percussion drilling for the production wells is to modify the well design. The present design has 210 mm casing/slotted screen set to total depth. Suggested design modifications which would permit a narrow diameter hole would include the limitation of the larger diameter to that depth at which the pump is to be installed. A second alternative is to use a narrow diameter hole throughout and to produce it by air lifting. The choice of these two alternatives is discussed in more detail below.

Another possibility to assist drilling would be to use a foaming agent. Its use is certainly preferable to bentonite in the long term, since it degrades under bacteriological action. It is possible, however, that it may also inhibit flow in the formation at least for some time after use, and in consequence it would be preferable to avoid its use in the present circumstances.

The extent of 'damage' to the formation surrounding those production wells drilled with significant amounts of bentonite will not be easy to evaluate quantitatively, but in the writer's opinion it is important that attempts should be made to clean the wells and to obtain some indication of the degree of damage. Suggested techniques are as follows:-

i. Repeated gamma-ray logging in production/associated observation wells before and after cleaning (an assumption that bentonite will give a high gamma response - requires checking).

ii. Electrical conductance/turbidity measurements of pumped discharge during cleaning.

iii. Variations in specific capacity during cleaning and possibly more sophisticated evaluation of 'skin effects' by efficiency relationships etc.

5.3. Aquifer Testing

The method adopted here consists basically of pumping from the production well (a variable step and constant discharge) and making measurements of drawdowns in the available observation wells. This limited series of measurements is not likely to provide a very comprehensive analysis and in view of the probable heterogeneity of the aquifer, a more comprehensive testing procedure is to be recommended, of which details are provided below. It is emphasised that most of the suggested measurements can be made with comparatively little effort.

A significant source of error may relate to the disposal of discharge. At one of the two sites examined, the discharge was disposed at some 15m from the pumping well and in another at 40m. In view of the low ground slope, the shallow depth to the water table and the by no means impermeable cover, there is a distinct possibility of recycling effects becoming operative at an early state in the test.

Step drawdown and constant rate tests have been carried out at Q2 and Q8. Some plotted data have been forwarded for Q8 and a summary of analytical results which are listed below.

(Data Submitted by Brian Colcuhoum & Partners)

TABLE 1

			(Min)	T (M3/Day/M)	S
1.	Theis	Q8A	0-420	390	0.00022
		Q8B	0-420	190	0.0008
		W11	0-250	6000	0.26
	After these times. apparent steady-state conditions are reached.				
2.	Thiem (steady state)	Q8A, Q8B, W11	1000	180	-
3.	Jacob	Q8	0-480	8600	-
		Q8A	0-420	9000	5x10 (power-23)
		Q8B	0-420	12000	4x10 (power-23)
		W11	0-300	5700	0.35

The drawdown data cannot be interpreted with any certainty. The levelling-off in water levels in all three observation wells after 200/450 minutes is most likely due to recycling of the pumped discharge. The extremely large order of difference between the Theis and Jacob analysis is anomalous, but it is pointless to speculate too deeply on this aspect in view of the recycling possibility which could have affected drawdowns at an earlier stage than the more obvious changes. The question of turbulent flow is important, but there is insufficient background data to decide on the significance of the indications. Some preliminary calculations based on assumed fissure size and

5.3. (Cont)

numbers, and the rate of well inflow, do not indicate that turbulent flow is likely to occur even at this short distance from the well. Plots of the drawdown data in the multi-rate step tests (Q/S V Q) do not show a constant value which may indicate turbulency, but the plots are in any case suspect since the drawdowns, particularly in the later stages, may possibly have been affected by recycling.

5.3.1. Recommendations on Aquifer Testing

The geological sequence consists of a lateritic overburden underlain by the Kakontwe Limestone. The water table occurs at shallow depths generally within the overburden. The Kakontwe Limestone is known to be heterogeneous and the general concept is that permeability is higher in the upper levels immediately below the overburden. It is on the basis of this concept that drilling depths for aquifer testing have been limited to 80m. The site test arrangement includes two observation wells at 8m away from a production well, one parallel to and the other at right angles to the hydraulic gradient. This arrangement was proposed for all test sites with varying radial distances in accordance with site conditions.

In view of the limited number of observation wells and the likely heterogeneity of the main aquifer, it is important to obtain as much background information as possible in order to ascertain the general boundary and flow conditions and to assist in the interpretation of the drawdown data. Suggested procedures and measurements are as follows:-

a) First observation well.

i. Repeated measurements of production rates, drawdown data, piezometric heads, electrical conductance etc., made during drilling in order to obtain indications of permeability variations in a vertical section and of likelihood of hydraulic continuity. This data can most readily be collected with air/percussion drilling (observed variations in discharge, drawdowns from pressure gauge differentials, piezometric heads at intervals following any cessation of drilling etc).

ii. Slug tests on completed well using analytical techniques of Bredehoeft and Papadopulos with due regard to aquifer accessibility in relation to screen intervals. Open hole completion is preferable if the hole can stand up.

iii. Final specific capacity after cleaning; opportunity should be

a) iii. (Cont)

taken to make drawdown measurement in any associated existing well. This data can be used to assist more logical siting of second observation well and production well. It is recommended that any existing well on site should be cleaned out.

b) Second observation well.

i. Same general measurements as per a(i) - (iii) above.

ii. Mini-pumping test during final cleaning, making drawdown measurements in the first observation well and any existing well.

c) Production well.

i. General measurements as per a(i) - (iii) above.

ii. The location and type of completion of the production well is best decided on the basis of the results of drilling and testing the observation wells. The use of a turbine pump is to be recommended because of the better control on pumping rates and greater facilities for varying the rates. To ensure that flow into the well is maintained as near to horizontal as possible, it is important to keep pumping drawdowns to a practical minimum and to have the pump set as high as possible so that screening/open hole completion can extend over the greater part of the aquifer. It is probably necessary to have blank casing set in the overburden and to avoid possible damage to the pump, this should extend to the proposed pump setting. Pumping drawdowns should preferably not exceed about 6 metres and the pump setting could be at a maximum of around 10m below static water level.

Possible variations in well design for the production test well are shown in Figure 1. Type (1) is the design of those which have been drilled to date. It has the disadvantage of difficult drilling and is likely to result in significant vertical flow components during testing. Type (11) is a cheaper and easier completion but will still give problems of vertical flow effects. Type (III) is preferable for testing and would give facilities for deep setting of the pump for use as a subsequent production well, although it might still be necessary to use a liner. Type (IV) is the cheapest and easiest method of completion and in the circumstance is to be preferred. If the well is to be subsequently used as a production well it would be necessary to modify the completion, but this could be done relatively easily.

c) ii. (Cont)

If the results of testing the first observation well indicate a low transmissibility at the site, and the production rates are likely to be insufficient to permit the proper use of the turbine pump, two alternative procedures may be adopted. A test hole of narrow diameter could be drilled and tested using airlift pumping. Alternatively, site testing could be limited to airlift production from one observation well whilst making drawdown measurements in the other.

d) Aquifer Testing

i. Pre-test site survey (water level elevations, electrical conductance all wells, logging etc).

ii. Production testing including step-drawdown and constant rate tests. The former should be used to make preliminary plots of drawdown data in observation wells to allow consideration of the possible onset of turbulent flow conditions and to choose the most appropriate pumping rate for the constant rate test. It should be noted that preliminary calculations should already have been carried out based on the data from the first observation well to determine the most suitable location for the pumping well in relation to the observation wells.

iii. Discharge must be carried for enough away to avoid significant recycling. If the water table is shallow, auger holes could be drilled at negligible cost between test site and discharge locations. Water level measurements in these holes would indicate the onset of recycling. Drawdown measurements in such shallow auger holes could in any case provide valuable information other than in relation to recycling effects and their use is to be strongly recommended.

iv. Appropriate periodic measurements of discharge (calibrate notch), electrical conductance, temperature etc. Downhole measurements in pumping well of flow velocity and conductance/temperature would be very desirable.

v. Plot drawdown data and discharge rates during test for preliminay analysis.

6. <u>Meeting at the Institute of Geological Sciences on November 14th with the following being present:- Mr R N Skinner (Brian Colquhoun and Partners), Mr J M Johnson and Mr Bell (Australian Groundwater Consultants) and Dr E P Wright, Dr R Kitching and Mr B Adams (Institute of Geological Sciences).</u>

A full discussion was held on the project and the following conclusions agreed upon:-

i. It was agreed that if the conditions prevailing in the Kakontwe limestone are as described in Section 5.2.1, then 'mudding-up' of the aquifer will have occured in those wells drilled with significant loss of bentonite mud. The process could include both penetration of drilling fluid into the fracture system as well as the deposit of bentonite clay within and across fractures.

ii. It was agreed that it would be necessary to clean such wells if valid test results are to be obtained. Mr Johnson of Australian Groundwater Consultants considered that this would be a comparatively easy task which could be carried out by 'rawhiding' which consists essentially of over-pumping and surging with the test pump. His optimism is not shared by Dr Wright or Mr Pace, the Chief Engineer, Baroid Eastern Hemisphere Division. It will be necessary to consider techniques to determine whether a well has been adequately cleaned and whether or not significant 'damage' to the formation has occurred. Various techniques were considered.

iii. It was agreed that cleaning with a pump would be carried out initially. For these wells on which a rig is still installed, other standard techniques of well development would be considered. Whether it will be necessary to rig up on wells which have been completed will depend on the results of 'rawhiding'.

iv. It was agreed that every effort would be made to drill all future wells by air/percussion method. The possibility of running two ordinary low pressure compressors (~100psi) in series or in parallel will be explored. Geomin do, in fact, state in their tender that they have compressors rated at 150 psi and were anticipating delivery of a compressor rated at 180 psi.

v. Modifications to the production well design have been agreed upon which will permit the use of air/percussion drilling techniques. The siting and design of the production wells within the limits of prior costing, general range of design types and <u>suitability for aquifer testing</u>, are best left to the hydrogeologist/engineer on site. Decisions should be based on logical and properly documented and analysed data obtained from drilling the first observation well.

E. Wright

Dr E P Wright
25 November 1974

Figure 1

Various completion designs: test production wells.