

WATER OCCURRENCES AND DEWATERING PRACTICE AT NKANA DIVISION
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ABSTRACT.

Nkana Division operates three mines along the east limb of the Chambishi Basin, from north to south: Migdola Shaft, Central Shaft and South Orebody Shaft. From the beginning of mining operations active dewatering of the hangingwall and to a lesser extent footwall aquifers has been carried out. Several discrete often rather complex aquifers have been delineated. Dewatering is being carried out by means of boreholes drilled into the hangingwall from regular mining development or specially mined dewatering drives in the hangingwall. To date dewatering in advance of the stoping face has been quite successful, but at Central and South Orebody Shafts mining is approaching the complexly folded lower part of the Nkana Synclinorium with equally complex aquifers above it. The necessity to dewater these aquifers before stoping by caving methods can safely be carried out has long been recognised, and several thousands of metres of hangingwall development has been mined for this purpose. More recently the possibility of mining the synclinorium by backfill methods has come into vogue, which would require a substantially smaller dewatering effort, especially for the higher aquifers. A substantial amount of information about the aquifers has already been collected. however, and a qualitative picture of their recharge can be given.

1. INTRODUCTION

Nkana Division of Zambia Consolidated Copper Mines operates three shafts along the southeastern end of the Chambishi Basin in the centre of the Copperbelt (figure 1). The three shafts, from north to south, Mindola, Central and SOB (South Orebody), cover a total strike length of about 14 Km. Central and SOB Shafts actually make-up one orebody (the Nkana Orebody) separated from Mindola in the north by the Kitwe Barren Gap, a patchily mineralized dolomitic zone with a strike length of about 1.3 km. The lowest operating levels are 4180L at Mindola and 3760L at Nkana, but a shaft sinking programme down to 5220L is underway at Mindola with further resources at depth. The Nkana resources are expected to extend to about 5220L at the northern end of Central Shaft against the Barren Gap.

Together the three shafts produce about 3.5 M.tonnes of ore at 1.60% Cu and 0.09% Co. A fourth shaft, Chibuluma, delivering to the same concentrator, is located along the southern edge of the Chambishi Basin, but is of no further concern here.

Traditionally mining has been carried out by caving methods. This has necessitated active dewatering of the hangingwall, which, as had been recognised from the earliest days, contained several discrete aquifers. About 45000 m³/d is presently pumped from each of the Mindola and Nkana Mines. About 75% can be attributed to direct aquifer inflow.

Timely dewatering of the largely unfolded eastlimbs of the orebodies has to date caused no major problems, and large efforts, both by mining special dewatering development and drilling have already been expended to dewater the complex folds at depth at Central and SOB Shafts (known as the Nkana Synclinorium). The latter exercise has recently been downgraded because of a change in mining strategy to backfill. A good understanding of the character of the aquifers and the ways of recharge is nevertheless required as the aquifer nearest to the orebody will still require dewatering.

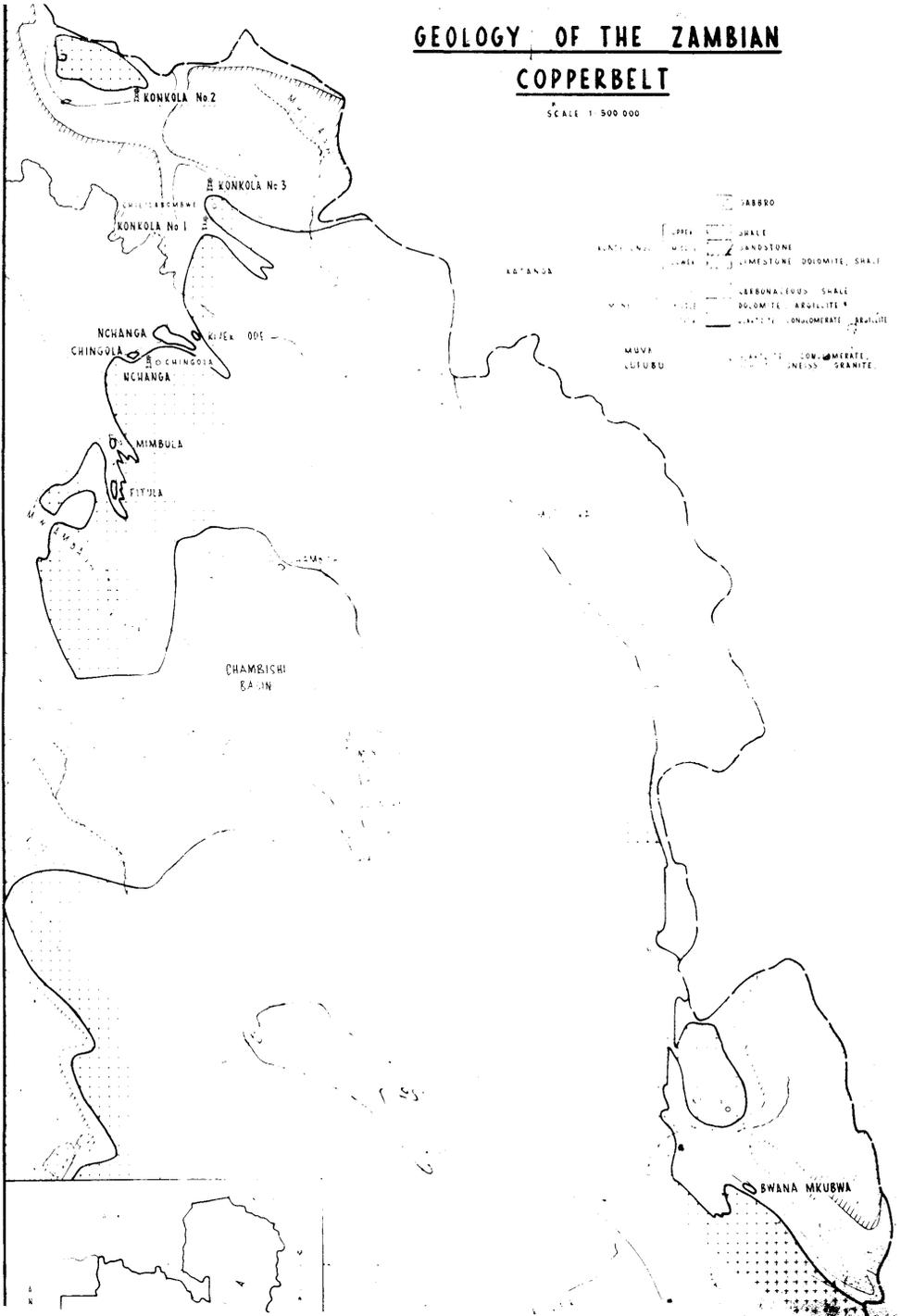
Reviews of the dewatering have been presented by Tomkins and Coles (1971), outlining also a strategy to dewater the Nkana Synclinorium, and by Straskraba (1991), to assess the need of dewatering in the light of a change in mining method from caving to backfill.

2. GEOLOGY

Descriptions of the Geology of the Copperbelt can be found in Mendelsohn (1961), and in de Vletter (1971). A detailed description of the geology at Nkana can be found in the Geological Guide to the Nkana Division (1983). A stratigraphic column is shown in figure 2.

GEOLOGY OF THE ZAMBIAN COPPERBELT

SCALE 1:500 000



LOCAL STRATIGRAPHIC COLUMN

MEMBER - LITHOLOGICAL DESCRIPTION	FORMATION	GROUP	SERIES	SYSTEM	
Quartz-carbonate veins; metabasic Sills and dykes; lamprophyre dyke				Post Katanga	
Purple or grey-black argillites	Not assigned			Kundelungu Series	
Black to grey limestone	Kakontwe Limestone Formation	LOWER KUNDELUNGU GROUP			
Tilloids and Shales	Tillite Formation				
Grey to red limestone and dolomites with thin shales interbeds		MWAMBWA		Katanga System	
Argillite, dolomitic argillite and sandstone. quartzite and minor conglomerates		GROUP			
Argillite, dolomitic argillite and dolomite	Ultra Far Water Formation	UPPER KATANGA GROUP			
Far Water Sediments (shale with grit) Far Water Dolomite	Far Water Formation		Mine Series		
Dolomite Argillite Sequence Upper Quartzite Near Water Sediments Hangingwall Quartzite	Hangingwall Formation				
Hangingwall Argillite Orebody member	Ore Formation	UPPER KATANGA GROUP			
Footwall Conglomerate Footwall Sandstone Lower Conglomerate	Footwall				
Basal Sandstone Pebble Marker Basal Quartzite Basal Conglomerate	Formation				
UNCONFORMITY					
Gneiss, diorite, metabasics and pegmatites					Pre Katanga Post Lufubu
Mica schists, siliceous schists, quartzites, migmatitic and banded gneisses				Lufubu System Basement Complex	

FIG 2

The Roan Group, containing the Ore Formation and the aquifers was deposited on a high relief basement. Basement highs have had an influence on both depositional environment, giving rise to a more dolomitic facies commonly showing only patchy mineralisation, and structure; the highs, having resisted folding, form often the cores of large anticlines.

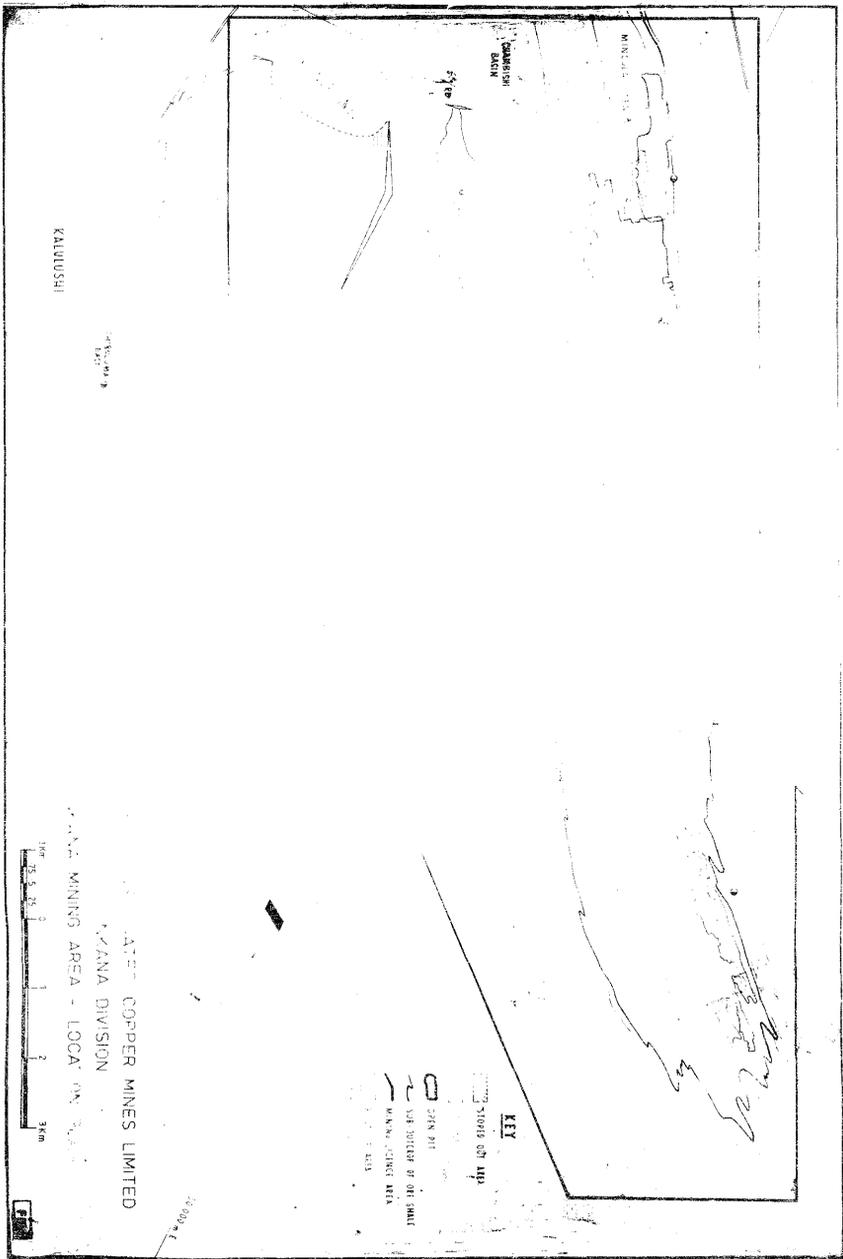
The Mindola and Nkana orebodies (see fig. 3) cover structurally different domains. The Mindola orebody, unfolded, varies in dip from about 35 deg. in the north to 80 deg. overturned in the south. The strike shows an asigmoidal shape, draped around a basement high, the No 3 Shaft Granite. Several fissures radiate from this high, indicating the tensile stresses caused by its resistance to yielding. To the south of the Kitwe Barren Gap, the Nkana Orebody shows several folds on the mined east limb, and at least another four highly complex folds have been delineated towards the base of the synclinorium, which forms a kind of panhandle to the Chambishi Basin. The average plunge is about 25 deg. to the northwest, but steepening, shallowing and even reversal of plunge are common. The strike of the folds in the synclinorium corresponds to the general trend of other basins to the north, but the strike of the synclinorium is about 15 deg. more to the north, which is seen as evidence of later crossfolding. Secondary folding is common and amplitudes can vary greatly over short distances. Jointing, especially axial plane jointing, is common, but actual faulting is rarely observed. Figure 4 gives an impression of the folding in the synclinorium.

3. WATER OCCURENCES.

Three hangingwall aquifers have been recognized: the Near Water, Far Water and the Ultra Far Water. The latter, only present at Mindola and the northern part of Central Shaft, is not actively dewatered and is not of real concern here.

The Near Water Sediments, starting 10-15 metres stratigraphically above the orebody, consist of a succession of sandy argillaceous dolomites with some sandstone bands, and have a thickness of 30-50 metres. The main water occurrences are within the first 20 metres, but water can be intersected virtually anywhere in the formation.

The Far Water Aquifer begins immediately above the Upper Quartzite, 70-100 metres above the orebody. The main water occurrences are found here in the Far Water Dolomite, but frequent intersections are also made in the Far Water Sediments, a succession of argillites and gritty argillites with minor dolomite intercalations. Less frequently, but not uncommonly, intersections are made in the Dolomite Argillite Sequence between the Far Water Dolomite and the Upper Quartzite. The Upper Quartzite, about 10-15 meters thick is therefore the only real aquiclude between the Far Water and the Near Water.



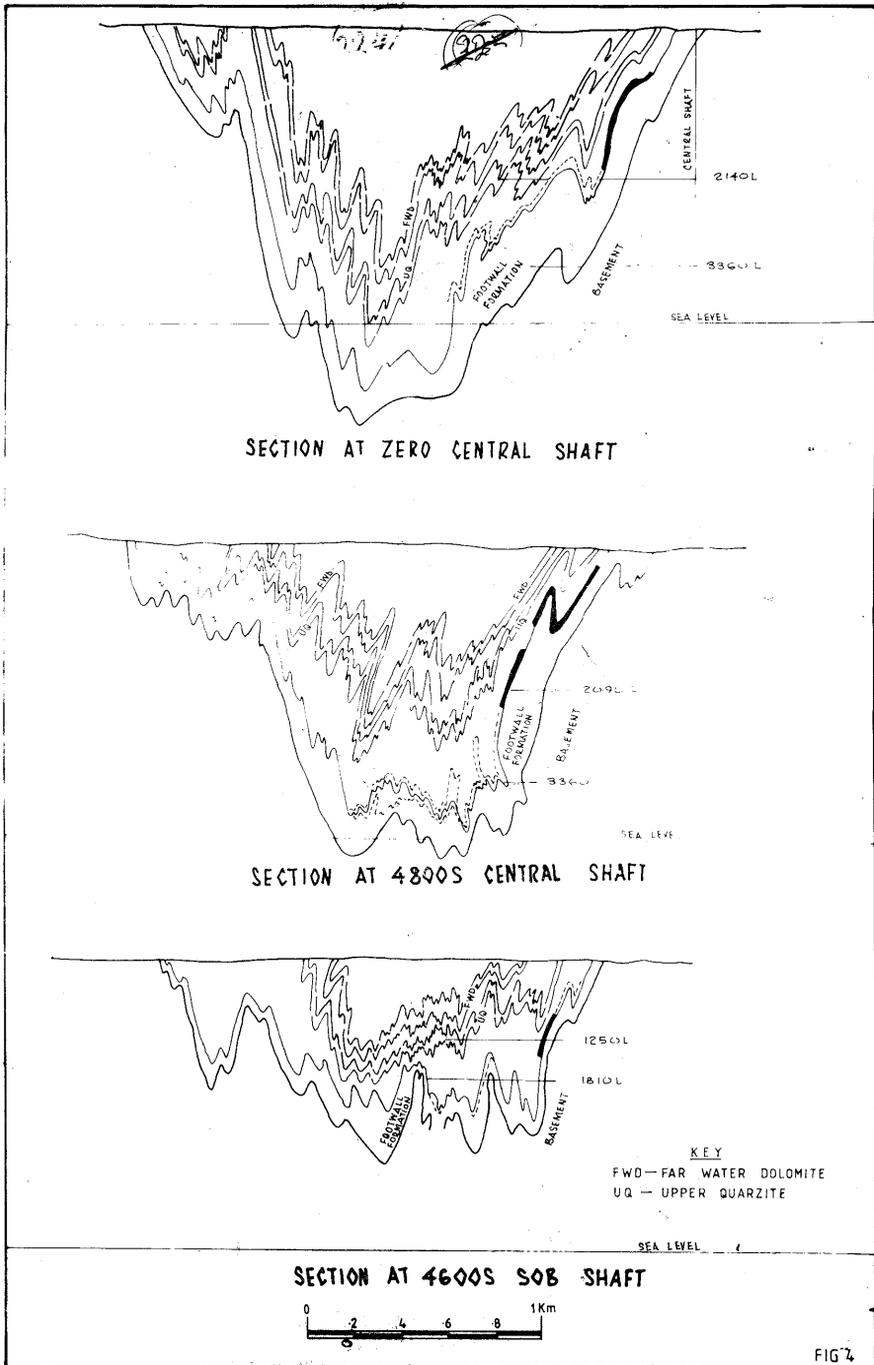


FIG 7

At present the Near Water Aquifer produces about 13000 m³/d at Nkana and about 4500 m³/d at Mindola while the Far Water Aquifer produces about 5500 m³/d at Nkana and 7500 m³/d at Mindola.

At both orebodies the aquifers were continuous down to about 300 metres. At greater depth they are actually dry over large parts of the mines. At Mindola the aquifers are largely confined to the northern part of the mine, where they have been divided into two domains: North Mindola from about 3000N to 8000N, which has, according to water head readings continuous aquifers, and the Far North, where water head readings seem to indicate discontinuous aquifers. The Near Water Aquifer appears to close below 3400L. Some minor Near and Far Water occurrences were found at the south of the mine against the Kitwe Barren Gap. They are dry at present.

At the Nkana Mines, the Near Water Aquifer is present in the far south of SOB Shaft, but from about 5000S to the boundary between SOB and Central Shafts no Near Water has been intersected. The Far Water starts at about 4600S SOB Shaft and continuous intersections have been made to the north of Central Shaft above the synclorium. The East Limb appears to have been largely dry.

Footwall water is also present at all shafts. At Mindola it is predominantly associated with fissure zones; at the Nkana Mines it appears to be most commonly associated with tight folding, but at Central Shaft an extensive zone of stratigraphically controlled water was found in the Footwall Sandstone on 3360L. Footwall Aquifers produce about 8000 m³/d at Nkana and 3000 m³/d at Mindola.

A further source of water inflow is formed by the so-called box-water. This is water flowing through old abandoned stopes and provides about 5000-6000 m³/d at Mindola and about 1000 m³/d at the Nkana Mines. It is of interest to note that at Mindola the area of box water inflow corresponds largely to the area of hangingwall aquifer presence. This would indicate that it is water from aquifers not actively dewatered high up in the hangingwall rather than from recharge through the caving area.

Another 10000 m³/d flow from unspecified sources into Mindola and 5000 m³/d into Nkana. This water enters the mine mainly from abandoned development and the sources are not always clear.

Black (1978) postulated that structural control was actually of more importance than stratigraphic control. At Mindola, water occurrences are related to a tensional zone, where it is warped around the no 3 Shaft Granite, evidenced by the fissure zones, mentioned earlier. At the Nkana Mines water occurrences would be concentrated into anticlinal zones. The total picture is then complicated by crossfolding, as evidenced by the difference in strike between the synclorium axis and the individual fold axes. This crossfolding has created secondary synclines and

anticlines on the folds and so structural domains that are either dry or water containing. Similarly crossfolding was thought to be responsible for the discontinuous aquifers at Mindola Far North.

4. DEWATERING PRACTICE AND ACHIEVEMENTS

At Mindola Shaft dewatering has always been straightforward and easily achieved. Boreholes of 200-250 metres length are drilled from footwall main level development at intervals of about 120 metres. A fan of holes is drilled until further drilling does not increase the inflow. Originally drilling was carried out from each main level, later this was changed to every two main levels, a vertical interval of nearly 160 metres. New drilling brings down the waterhead fairly quickly and flows reduce to a level which then remains more or less constant indicating the actual rate of recharge.

Boreholes are generally drilled for both the Near Water and Far Water Aquifer simultaneously. The Far Water head, being generally higher than the Near Water, is commonly recorded. The Near Water head is established from the few holes that did not pass the Upper Quartzite.

At the Nkana Mines dewatering largely followed the same routine as at Mindola until the late sixties, with the exception of an occasional dewatering crosscut especially mined to dewater a fold. By that time the folded bottom of the Synclinorium had been partly delineated, and it had become obvious that special efforts were required to dewater the complex aquifers above the synclinorium, if the folded orebodies were to be mined without a severe water hazard.

Tomkins and Coles (1971) proposed a basic strategy of crosscuts mined through permanent dewatering pillars and from these dewatering drilling development mined along strike more or less over the centre of the synclinorium. This strategy was accepted and about 9000 metres of dewatering development has been mined since (see figure 5). Drilling followed as quickly as possible but the conventional air rigs in use made slow progress with the long and steep upholes that were required and the programme was soon running severely behind schedule. By the mid eighties it was estimated that about 80000 metres of drilling was left to complete the exploratory dewatering requirement. As quick progress became more urgent four high power electro-hydraulic rigs were purchased, and commissioned during the latter part of 1987. About 20000 metres of dewatering drilling has been achieved since then, but the last few years the rigs have been mainly involved in exploration drilling as priorities have changed with the change of preferred mining method to backfill.

The drilling strategy that was used assumed a down-plunge movement of water so drilling would gradually move from south to

north, continuously drawing down the water heads. A successful example of this theory can be seen at SOB Shaft where water inflows from crosscuts, on 1250L and 1810L were reduced to insignificant when drilling from dewatering development ex 2090L/1030N and further to the north tapped all flows higher up-plunge (see table 1). Flows on 1250L and 1810L were already decreasing as the original water storage above the intersections was drawn down, but this was probably accelerated and recharge has been nearly fully cut-off. It is of interest to note that drilling from 1250L/4600S reduced flows at 3600S, reversing the expected pattern.

At all shafts water flows are measured monthly and water heads quarterly at all accessible borehole collars.

5. CHARACTER OF THE AQUIFERS

It has long been known that the aquifers do not correspond to well defined stratigraphic horizons. Multiple intersections are common and water intersections made at a certain stratigraphic position may not be repeated in another nearby hole. At Mindola Shaft water heads are nevertheless fairly regular, at least in the North section of the mine. At the Nkana Mines both the size of inflow and the water heads can vary enormously from hole to hole.

The most striking example of the latter is found in a Near Water occurrence on the western limb of the B-Fold at 3360L/500S, Central Shaft. Near Water traditionally had not been much of a problem here, and the intersection in the mid seventies of a major aquifer giving large volumes of hot (45 deg.) water at initial pressures up to 25 bars was certainly unexpected. From one site about 30 holes were drilled giving a maximum flow of more than 18000 m³/d. Flows from individual holes varied from a trickle to more than 2000 m³/d, and pressures varied from less than 2 bars to 25 bars (although such pressures reduced fairly quickly to below 10 bars). Flows had dropped to about 9000 m³/d when drilling along strike to the south started over a length of 300 metres to 1500S. As table 2 on the next page shows, the main flows migrated southwards with the drilling. The pressures encountered south of 500S were at a maximum of about 10 bars, so dewatering from 500S had already succeeded in bringing down the water head over a considerable strike length.

At present flows are about 8000 m³/d with the boreholes at 1500S closed. The sites are virtually inaccessible because of ventilation problems.

Obviously the aquifer is of a complex nature. The large flows, which were intersected at close distance from each other, point to an essentially continuous aquifer, where water heads were the same before drilling started. At some intersections the water

TABLE 1

S.O.B	D'70	D'71	S'72	D'73	J'74	D'74	J'75	D'75	J'76	D'76	J'77	J'78	J'79	J'80	J'81	J'83	M'93
1250L/4600S						1405	1260	1180	680	575	405	340	195	180	60	55	
1250L/3600S	2550	2615	1990	3530	1925	905	165	115	65	50	60	60	35	60	120	65	
1810L/700N	2465	2200	1315	2870	1245	1355	1075	1990	1980	1770	1390	685	930	655	480	260	
1810L/760N	1720	2150	750	385	210	175	150	115	115	90	60	60	35	DRY			
1810L/960N	4100	2810	3095	2200	1340	1265	1405	805	790	715	880	540	575	275	240	150	425
2090L/1030N (ZERO-2500N)				910	1380	2415	3700	3680	4960	8545	5010	4545	4640	4230	3100	3425	1615
TOTAL	10835	9775	7150	9895	6100	7520	7755	7885	8590	11745	7805	6230	6410	5400	4000	3955	2040

FARWATER FLOWS 1250L, 1810L, 2090L

M - MARCH
J - JUNE
D - DECEMBER

Table 2

	D'75	D'77	D'79	D'81	D'83	M'85	S'85	M'86	M'87
500S	5065	10715	16100	NR	10330	9560	8630	6730	3890
600S						2105	5390	4600	1570
1100S						800	12590	8370	3050
1500S								1300	10220
Total	5065	10715	16100		10330	12465	26610	21000	18730

Near Water flows at Central Shaft 3360L, 500S-1500S.

M: March, S: September, D: December

head had already dropped significantly by the time the first pressure measurement could be carried out. The aquifer must therefore be characterized by strongly varying permeabilities. In other words, a myriad of high permeability zones occurs in a very low permeability hostrock. Control of high permeability is probably both by bedding and by jointing. So high pressures can exist next to low pressures depending on recharge. Low pressures result where a high permeability reservoir is drained fairly quickly because recharge has to pass through low permeability rocks, while elsewhere a high pressure can be maintained, either because of abundant recharge or because of limited discharge. The reduction in flows at 500S, once intersections were made further to the south, shows that channel ways exist that can tap a large part of the recharge at 500S, the total recharge not being sufficient to keep all sites flowing at maximum capacity.

Similar situations can be found in the Far Water, although the picture is here often more difficult because of folding. Some pressure built-up permeability tests were carried out on some Far Water intersections on 1910L Central Shaft and 2090L SOB Shaft. Nearly all were carried out on steep upholes. Some tests show a rapid built-up of pressure where the borehole is being filled to the point of intersection to remain virtually constant after this point was reached. This reflects exactly what has been mentioned above: a fairly large reservoir is recharged too slowly to show significant pressure built-up in a relatively short time span.

6. RECHARGE

The traditional view has been that recharge took place via rainwater infiltration above the hangingwall of the orebodies. Recharge through the footwall and basement has been ruled out because of the very low permeabilities in these rocks. As rainfall measurements (1250 mm/y) are the only pertinent figures

available, the establishment of a water balance would be highly tentative. Nevertheless attempts were made by Tomkins and Coles (1971) and Straskraba (1992). The rainwater infiltration surface area for the Nkana Orebody was set at about 20 Km² by Tomkins and Coles. This includes a part of the hangingwall over Mindola. An infiltration of 35% was required to obtain a sufficient volume of water (27000 m³/d, allowing for an actual drawdown of 5000 m³/d). The infiltration area for Mindola was reckoned to be about 80 Km² by Tomkins and Coles but this covers also a large part of the area that recharges the Chibuluma Mines to the south.

Straskraba (1991) gives a figure of 10% for infiltration, but he lends great importance to the infiltration potential of Mindola Dam, a surface water expanse of about 3 Km². It is related to a tailings dam and at its design it was stated that a level of 2 metres of tailings would provide an effective seal against infiltration, but it is not known if this was actually achieved. It cannot be claimed as evidence that no or very little infiltration takes place below Mindola Dam, but it worth noting that the water level of the lake was little changed at the end of the dry season 1992, after below average rains which had shown its effect on many other surface waters by much reduced levels. Straskraba also considered that aquifers higher up in the succession could give considerable recharge.

At the Nkana Mines the Far Water Aquifer is currently producing some 6000 m³/d. Considering that few intersections have been made since about 1985, most of this water is probably recharge. Rainwater infiltration of 10% could largely account for this volume, but if infiltration is less, another source of recharge has to be present.

The Upper Quartzite is considered to be an effective aquiclude and because of this the need to dewater the Far Water Aquifer in case of backfill mining has been removed. The only place where pressures in a Near Water intersection indicated a water head above the Upper Quartzite is at 3360/4200N Central Shaft, but this has generally been linked to the nearby presence of a surface hole, through which water from much higher sources was being tapped.

The infiltration surface for the Near Water Aquifer is therefore quite restricted, and there seems to be no simple recharge pathway for the large flows of water encountered at 3360L/500S. Moreover, it should be pointed out that the water at this location is hot, about 45 deg. comparable to the water at the lowest dewatering level at Mindola, 3920L. It is doubtful if water passing through a relative short distance could maintain such a temperature. In this connection it may also be pointed out that box water is much cooler than borehole water on the same level.

A main source of recharge could possibly be the Kitwe Barren Gap, but the fact that flows at the Far South of Mindola Shaft have

dried-up does not point to a large reservoir, that could sustain recharge of the Near Water over a long period. The only possible path of inflow that remains is then from down-plunge, i.e. from far into the Chambishi Basin, and it is from there that it is postulated the main recharge is taking place, the water intersections of the Near Water being likened to artesian wells. This does not prevent the sketched situations as at 3360L/500S where intersections at 1500S, now further away from the source, actually tap more water. Although the distance is longer the pathway is easier, possibly located below 3360L at 500S position.

At Mindola the situation is somewhat different as the surface area available for infiltration is much larger, but the potential for infiltration may well not be sufficient. As has already been mentioned, box water occurs only where aquifers are present. This has been explained by cave cracks tapping higher aquifers, the presence of which is controlled by the same tensional regime, which controls the presence of the Near Water and Far Water Aquifers. So, even over the caving area direct infiltration is probably quite low. Recharge from stratigraphically higher aquifers is a possibility, but the amount of box water flow would indicate that the potential is limited; only 5000 to 6000 m³/d through broken ground would point to lower flows through semi-aquicludes, although recharge could take place over a much larger strike length than just over the dewatered area of Mindola. Direct recharge is considered most likely to come through the Near Water and Far Water Aquifers themselves from the north and from below. With regards to the Near Water Aquifer, recharge can only come from the north as the aquifer appears to close.

A model has then been constructed, that contains a much larger recharge area and aquifers, although highly irregular in permeability, that are essentially continuous.

This model disagrees at least partially with the structural domains as postulated by Black (1978). There is no doubt that the aquifers at the northern side of Mindola are structurally determined if not controlled. However, the proposal of crossfolding breaking-up aquifers in domains is not considered viable, if only because these domains would have very small potential for recharge.

7. FURTHER DEWATERING.

It has been agreed that with backfill mining there is no requirement to dewater the Far Water Aquifer any further. Some minor drilling is still being carried out to check on the continuity.

The Near Water Aquifer will still have to be dewatered. This asks for much less drilling than the Far Water Aquifer as holes can be much shorter and for that reason can also be much better

targeted. However, as 3360L/500S has shown, flows can be significant, and according to the given model they will not decrease down-plunge. Drilling can to a large extent probably be carried out from regular development, but this should be carefully planned so dewatering can be effected in good time. Strictly all drilling could be done from the lowest level at the northernmost position by drilling a very dense fan.

8. CONCLUSIONS.

The aquifers are highly irregular with zones of very low permeability, virtual aquicludes, and zones of very high permeability.

The aquifers are essentially continuous, unless separated by folds or as at Mindola, where the water occurrences on the far south are probably only very indirectly connected with the occurrences on the north side.

In the synclinorium the Near Water Aquifer is mainly recharged from a down-plunge direction, while the Far Water Aquifer is probably recharged both from direct rainwater infiltration above the synclinorium and by up-plunge flow similar to the Near Water. At Mindola recharge occurs both from below and from the north with probably only minor recharge from rainwater falling on the immediate hangingwall area.

The rainwater infiltration recharge area covers a much larger area of the Chambishi Basin than previously assumed.

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