SOLUTION TO KONKOLA MINE WATER INFLOW PROBLEM

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ABSTRACT

Konkola is one of the wettest mines in the world, pumping an average of 300 000 m^3/d of water.

This paper presents a permanent solution to the Mine's groundwater inflow problem based upon results of eight-years field-based research undertaken from 1985 to 1993.

To understand how groundwater flows into and through the mine and subsequently formulate a long-term cost-effective groundwater management solution, an integrated study of historical and current dewatering and mining records, structural geology, surface hydrology, rock chemistry, groundwater chemistry, river/stream gauging, evaporation measurements, and groundwater flow numerical modelling, was carried out.

The results obtained clearly revealed that Konkola mine water can be divided into that which originates from surface recharge close to the mine and that which originates from regional aquifers at depth. This has enabled the origin of water in the mine to be essentially established and a permanent solution formulated.

A considerable percentage of the water entering the mine comes via the Hangingwall Aquifer with its connection to the surface sources of recharge. Flow to the mine is dominated by flow through fractures and fissures which form sources of high conductivity.

Significant reduction of water inflow into the mine can be achieved by implementing a water-exclusion groundwater management solution as this removes water at source. At least 40% of the mine recharge could be achieved by the said method.

INTRODUCTION

Konkola Underground Copper Mines has long been recognised as one of the wettest, if not the wettest mine in the world. The stratified copper deposit is sandwiched between two major aquifers (Fig 1.1).

Consequently the large volume of water encountered and expected during mining constitute a major cost in mine planning and development.

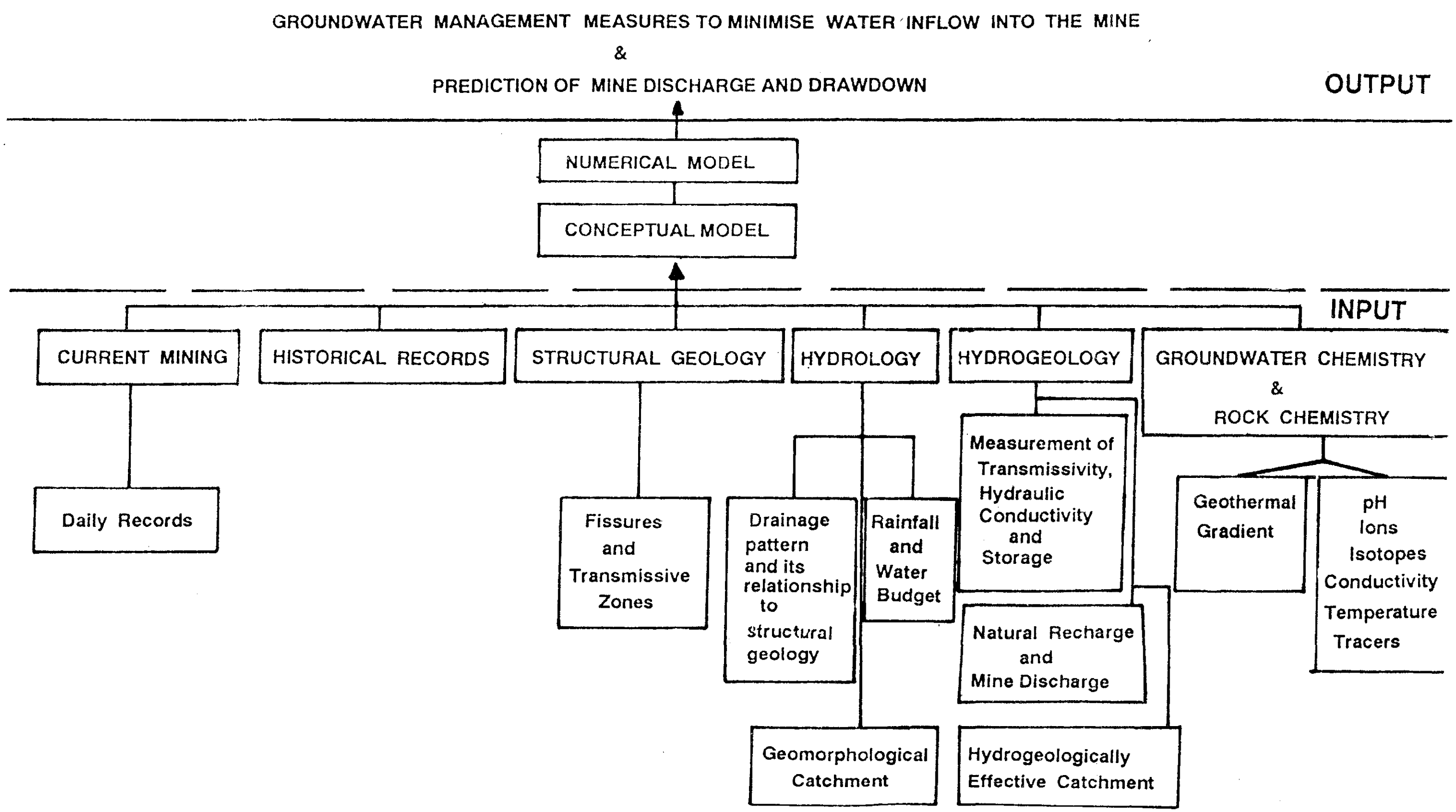
Currently an average of 300 000 m^3/d of water is pumped from the mine, giving a ratio of 58.1 of water to ore ratio. The average ratio of volume of water pumped to the ore hoisted at all other Zambian Copperbelt Mines is 4.1.

The unsupported open-stoping mining method used at the mine requires dewatering of the aquifer during mine development so that collapse subsequent to ore extraction occurs in dewatered strata.

The associated costs of mine drainage are very substantial. Pumping alone, excluding the cost of mining and setting up pumping complexes, accounts for about 10% to 15% of the total mining costs (1984-1993 figures). In the financial year 1992/93, the cost of Drainage and Pumping cost represented about 13.1% of the total mining cost which is equivalent to 7.8% of the total mine operating cost.

This cost is bound to significantly rise as the mine expands and the electricity cost increases.

Figure 3.1 : STRATEGY FOR SOLVING THE KONKOLA MINE GROUNDWATER PROBLEM



These maps were superimposed upon maps of basic geology of the mine, at similar scale, to establish whether or not basic geological controls existed for the movement of water in the mine area.

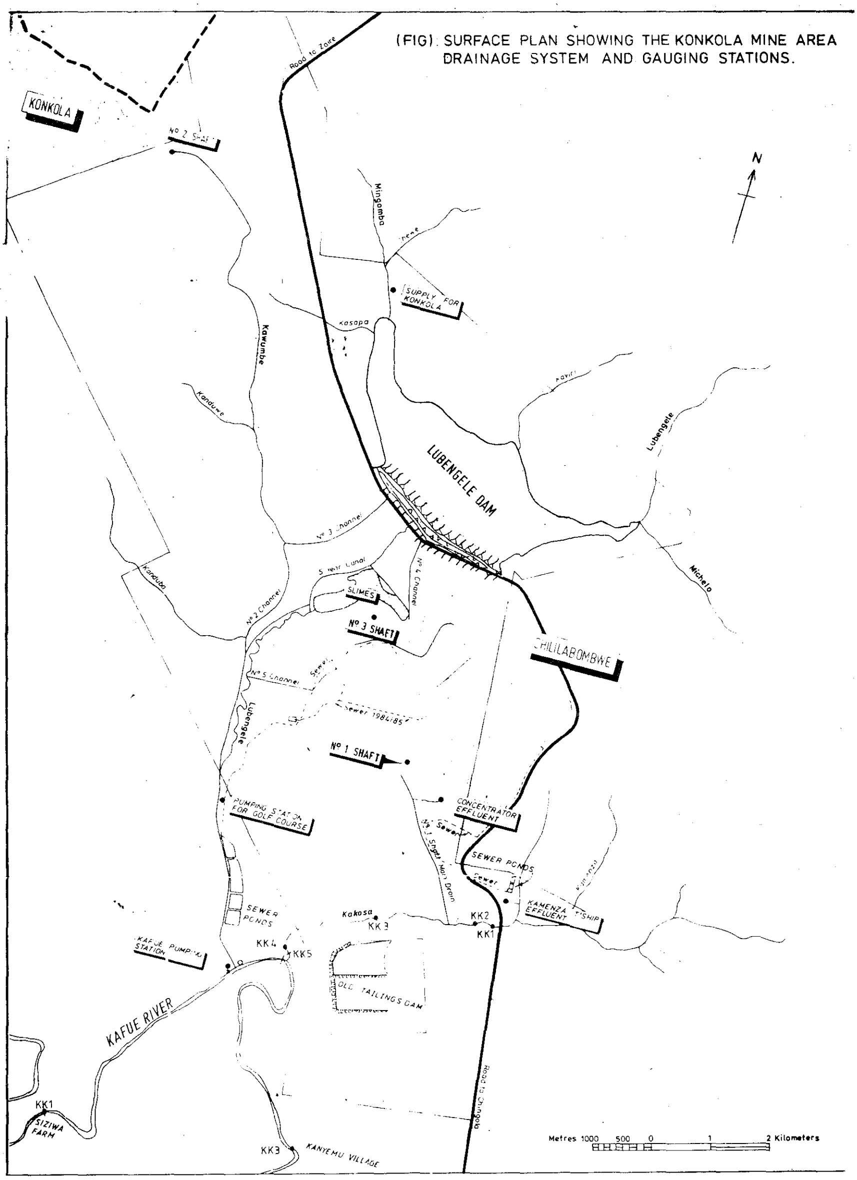
Study of the structural geology and hydrogeology were of critical importance to finding the reasons why the groundwater flow problem exist at all.

The fractured and broken nature of ground in the Konkola Mine area, analogous to a box of sugar cubes, coupled with the effects of mining on the rocks, implies that there is enormous potential of not only surface water leaking into the mine but also adjacent groundwater catchments being hydraulically connected to the mine via the extensive fracture zones. Geological mapping of all accessible mine levels at both No 1 and 3 Shafts was carried out, complimented by surface work.

Thus a usable map of geological structure had to be created in order to identify the location of potential major water - transmitting zones and delineate the effective groundwater catchment area for the mine.

The review of surface hydrology provided an opportunity to study relationship between drainage patterns and structural geology with a view to identifying potential source(s) of recharge to the mine groundwater flow regime.

Thus it was essential to determine the extent to which river flow pattern in the Konkola Mine area is controlled by the structural geology, whether or not the Kafue River and surrounding streams flow along and/or cross the mine fissures and fracture zones.


(FIG). SURFACE PLAN SHOWING THE KONKOLA MINE AREA DRAINAGE SYSTEM AND GAUGING STATIONS.
KONKOLA
Road to Zaire
Mingomba
N
SUPPLY FOR KONKOLA
Kasapa
Kawumbe
Kanduwe
LUBENGELE DAM
Lubengele
No 3 Channel
No 4 Channel
SLIMES
No 2 Channel
Kanduba
No 3 SHAFT
CHILILABOMBWE
Michelo
No 5 Channel
Sewer
Sewer 1984/85
Lubengele
No 1 SHAFT
PUMPING STATION FOR GOLF COURSE
CONCENTRATOR EFFLUENT
SEWER PONDS
KAMENZA EFFLUENT
SEWER PONDS
Kakosa
KK3
KK2
KK1
KK4
KK5
KAFUE PUMPING STATION
OLD TAILINGS DAM
KAFUE RIVER
Road to Chingola
KK1
SIZIWA FARM
KK3
KANYEMU VILLAGE
Metres 1000 500 0 1 2 Kilometers

The method used for determining the geothermal gradient was that recommended by the South African Chamber of Mines (Transvaal & Orange Free State Chamber of Mines, 1965). Chemical analyses were done at the ZCCM Ltd Nchanga Division Analytical Laboratory and the Geochemistry Laboratory of Imperial College of Science, Technology and Medicine, University of London. Tritium-dating (Isotope) samples were independently analysed by the Isotope Measurements Laboratory at Harwell - United Kingdom Atomic Energy Authority (Otlet 1989) and the Centro De Analisis De Aguas, S.A. in Murcia - Spain (Fernandez-Rubio 1993).

With this strategy the results of all previous investigations and records could be incorporated for the first time into an overall picture for the mine hydrogeology, thus permitting proper understanding of how groundwater is moving into and through the mine, and the creation of an adequate data base from which a groundwater flow simulation numerical model was to be made, and a programme of drying the mine formulated. The numerical model became the tool through which accurate predictions of mine water discharge and water level drawdowns could be made and various groundwater control options investigated.

RESULTS

The main findings were as follows:

(i) The mine lies on the nose of an anticline which is wedged between two major faults; the Lubengele in the north and the Launsobe in the south. (Figures 4.1 and 4.2).

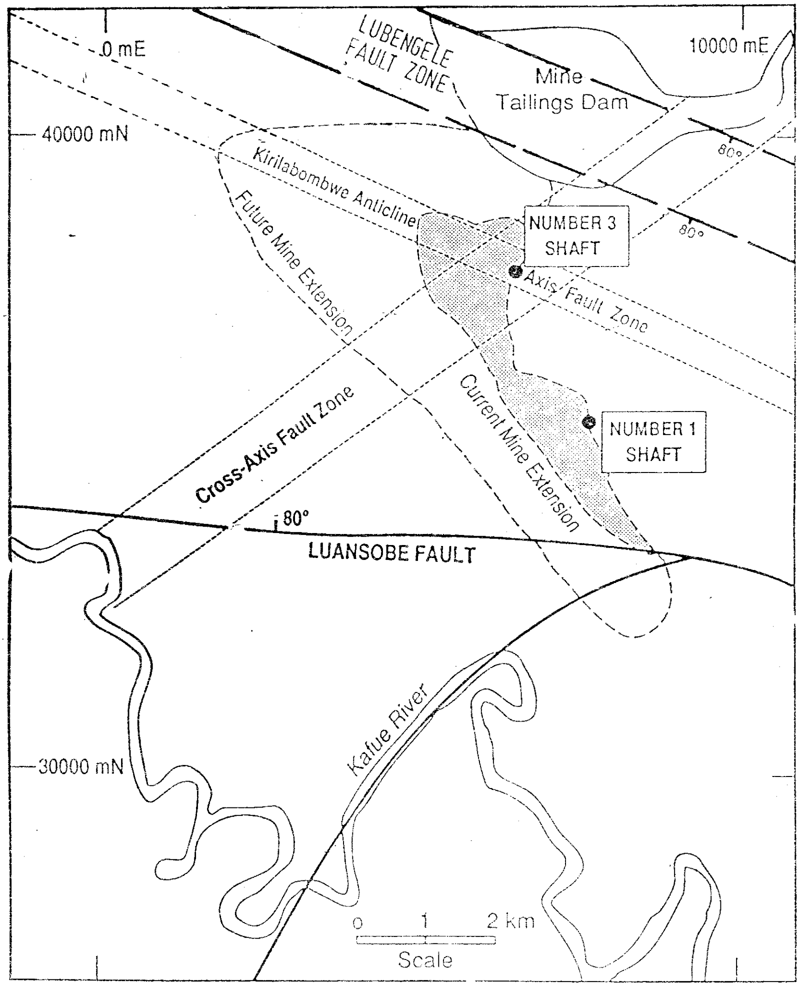


Fig. 4.1 : Map of Konkola Mine showing the faults, river, dam, and approximate limits of mining

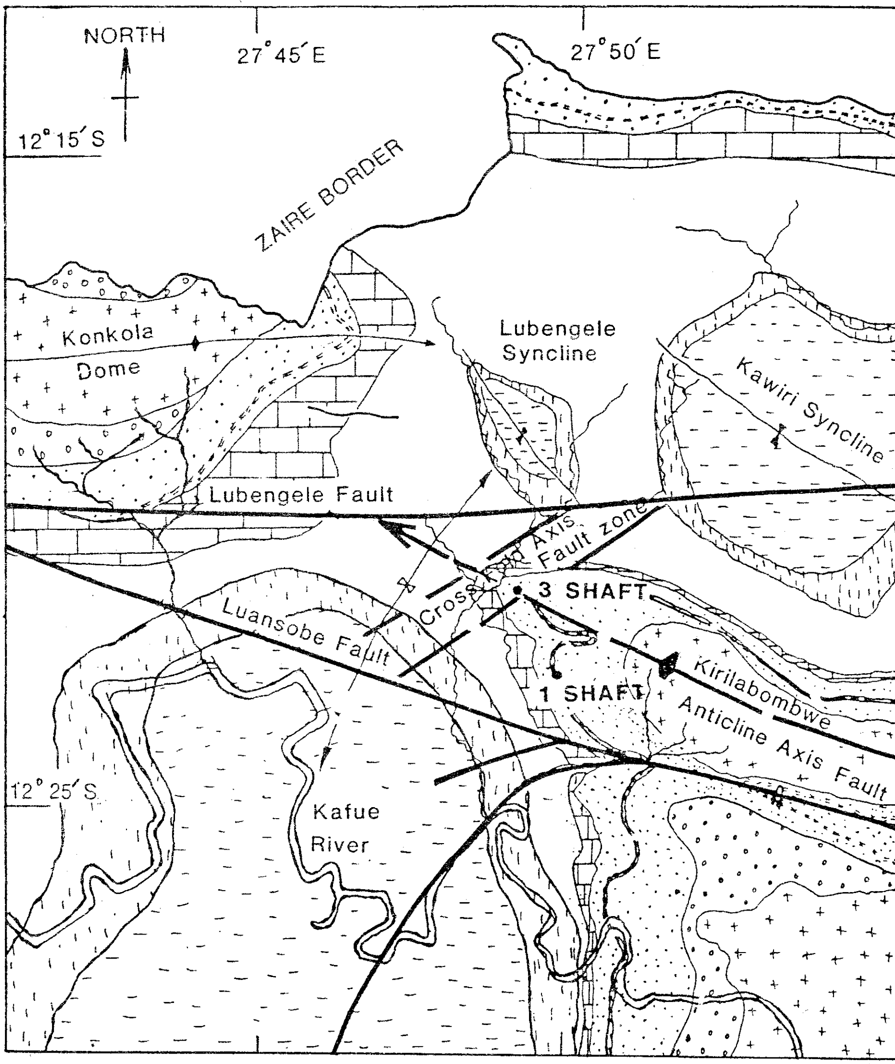


Figure 4.2: GEOLOGICAL MAP OF KONKOLA MINE

LEGEND

- Kundelungu Shales
- Kakontwe Limestone
- Mwashia Shale
- Upper Roan Dolomite
- Lower Roan (Quartzite Sandstone, Conglomerate Siltstone)
- Ore Shale
- Boulder Conglomerate
- Basement Complex (Granite, Gneiss, Schist)
- Fault
- Synclinal Fold Axis with plunge
- Synclinal Cross Fold Axis
- Synclinal Fold Axis with limb overturned
- Anticlinal Fold Axis with plunge

SCALE
0 1 2 km

ii) The surface hydrogeology pattern is controlled by the structural geology of the area. In particular the Kafue River drainage system is in conformity with the discontinuity pattern (Figure 4.3).

(iii) A cone of dewatering depression, elongated in the northwest-southeast direction, has developed over the mine as clearly demonstrated in the groundwater level contour maps (Figure 4.4). The flow directions as indicated by contour gradients, are mainly from the south of No 1 Shaft and north of No 3 Shaft. No 1 Shaft forms the deepest part of the cone, highest drawdowns have been achieved in this area of the mine. No 1 Shaft is the deeper of the two and dewatering drilling is at greater depths than at No 3 Shaft. There has been little change in groundwater levels in the Lubengele Dam and Kafue River areas (Figure 4.5).

The water level does not form a smooth drawdown surface. Instead it had anomalies in its elevation with highs and lows existing rather than a smooth surface.

Basic geological hydrogeological controls exist for the movement of water in the area.

(iv) The effective groundwater catchment for Konkola mine is much greater than that exhibited by the topographic catchment.

Figure 4.3 : KONKOLA MINE AREA SURFACE HYDROLOGY AND FAULT SYSTEM

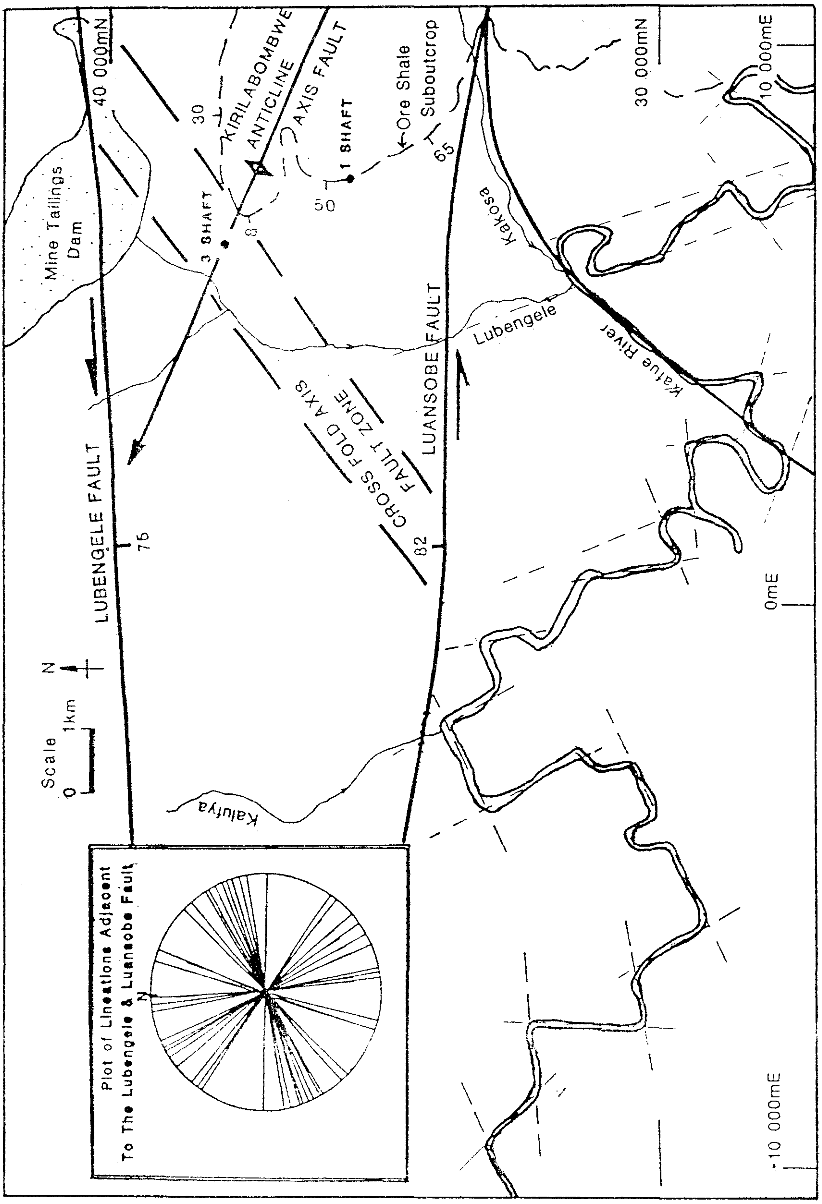


Figure 44 : KONKOLA GROUNDWATER LEVEL CONTOUR MAP

JUNE 1987

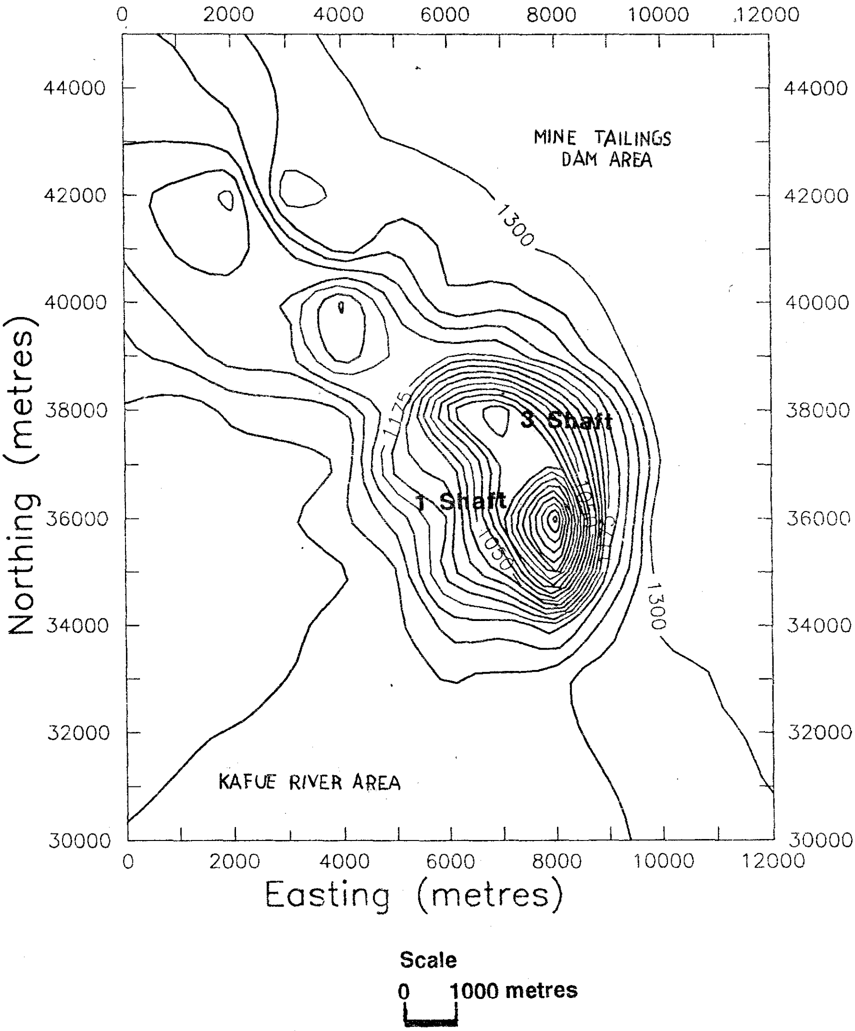
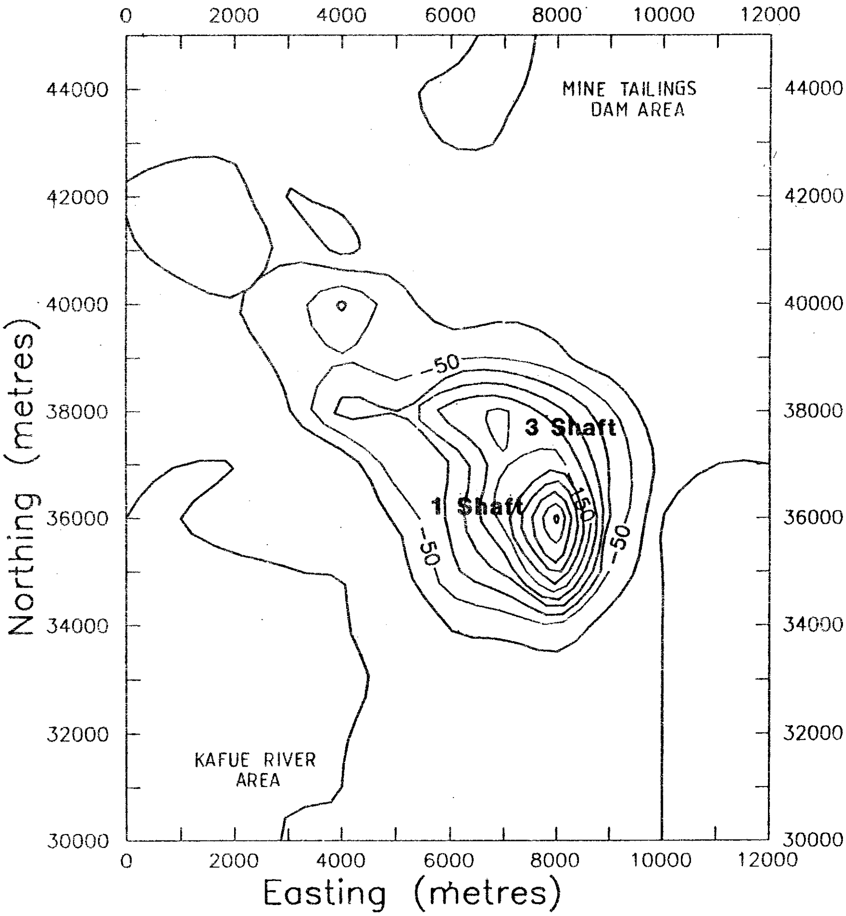


Figure 4.5: KONKOLA GROUNDWATER LEVEL CHANGE 1970 - 1987



Scale
0 1000 metres

There is more pumped from the mine than can be accounted for by topographic catchment rainfall (Figure 4.6). About 70% to 80% of the water pumped from the mine comes from sources other than the Konkola mine topographic catchment rainfall.

(v) Chemical and Tritium-dating (isotope) analyses reveal that there are two chemically and physically distinct bodies of water at Konkola mine: young (post - 1952) and old (pre - 1952) Hangingwall water (cold) is the young water and had the sam age as the Kafue River system water. Footwall water (hot) is the old water and originates at depth from the regional aquifer (Figures 4.7 and 4.8).

Footwall Quartzite and Footwall Aquifers water is warmer than the Hangingwall Aquifer water by an average of 2°C and it is slightly acidic, low in total dissolved solids, Calcium, Magnesium, Potassium, Sulphur, Bicarbonates, and Sulphates. The Hangingwall Aquifer water is colder, slightly alkaline, high in total dissolved solids, Calcium, Magnesium, Potassium, Sulphur, Bicarbonates, and Sulphates.

(vi) Groundwater flow to the mine is dominated by flow through fractures and fissures which form zones of high conductivity. The Hangingwall and Footwall Aquifers water mix in these transmissive zones. The cross Axis fault zone is the main groundwater drainage zone within the mine.

Figure 4.6 : KONKOLA MINE : VOLUME OF WATER PUMPED AND VOLUME OF RAINFALL RECHARGE

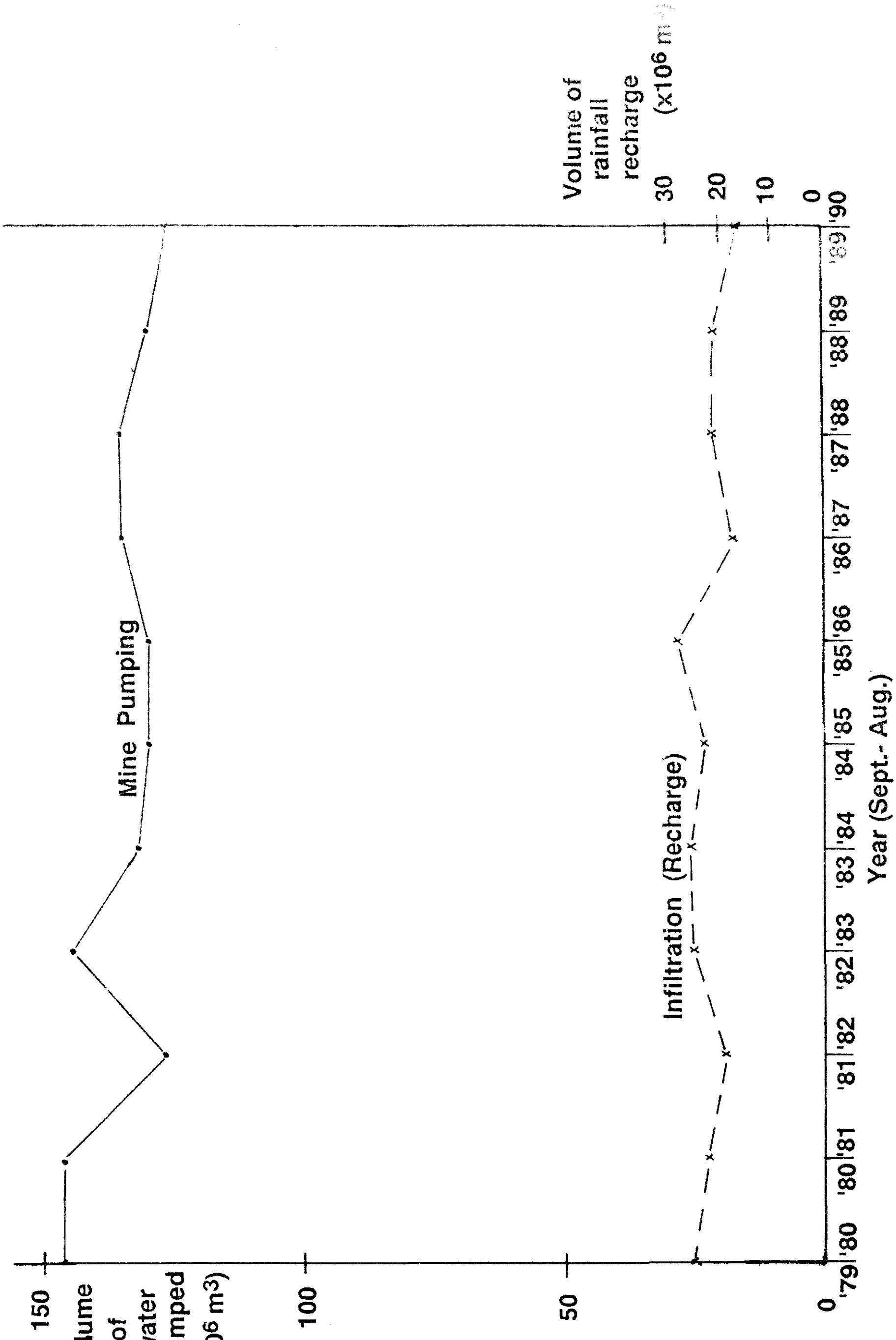


Figure 4.7

AQUIFER WATER CHEMISTRY

(2650ft Level -1000M South)

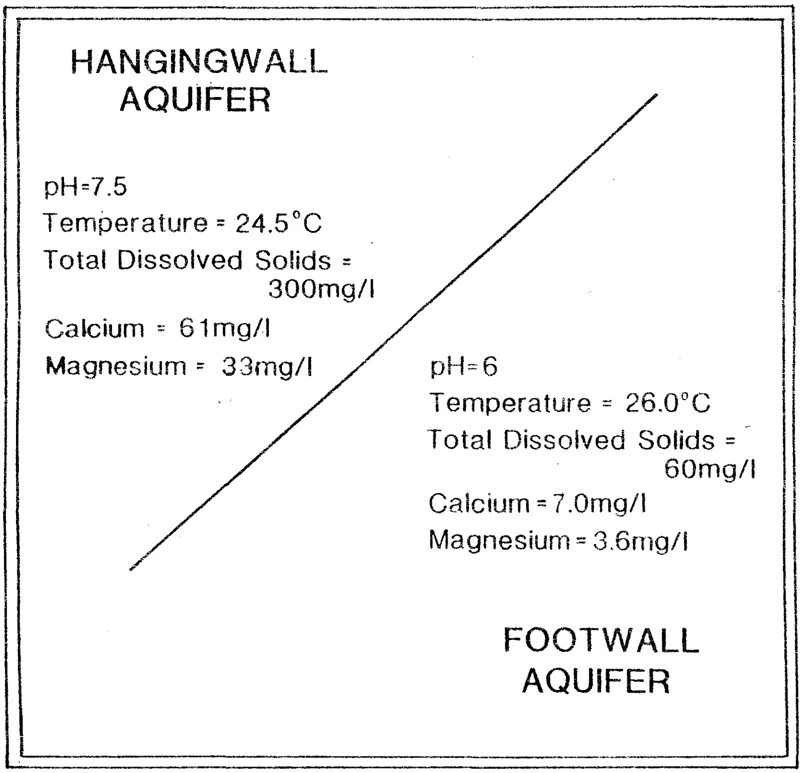
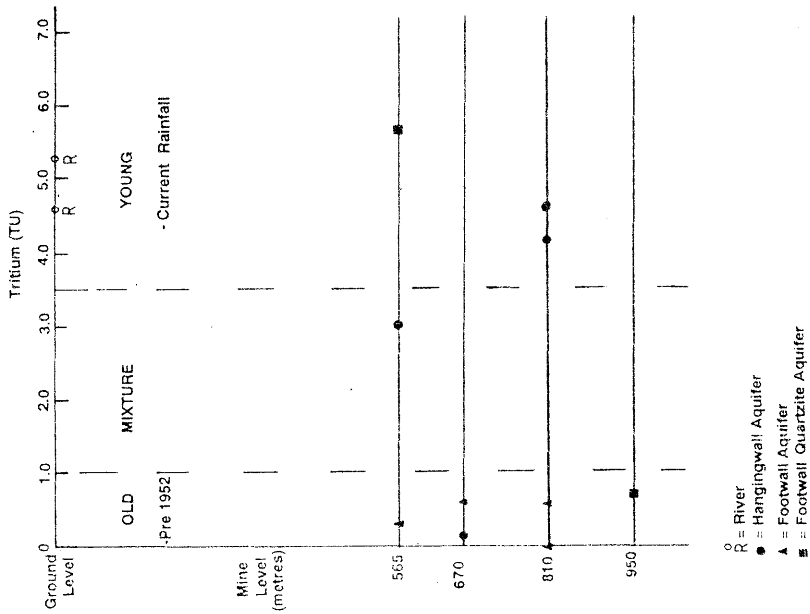
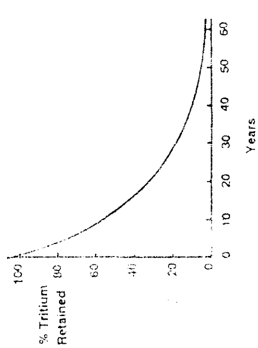


Figure : KONKOLA MINE GROUNDWATER AND RIVER WATER
TRITIUM CONCENTRATION AND RELATIVE AGE - JULY 1989



RADIOACTIVE DECAY CURVE
OF TRITIUM (After Mazor 1991)



After 12.3 years 50% of an initial concentration are left, after 24.6 years 25% are left, etc.

Figure 4.9 : PLAN OF 565m (1850ft.) AND 810m (2650ft.) LEVELS SHOWING DISTRIBUTION OF E. COLI BACILLI IN GROUNDWATER

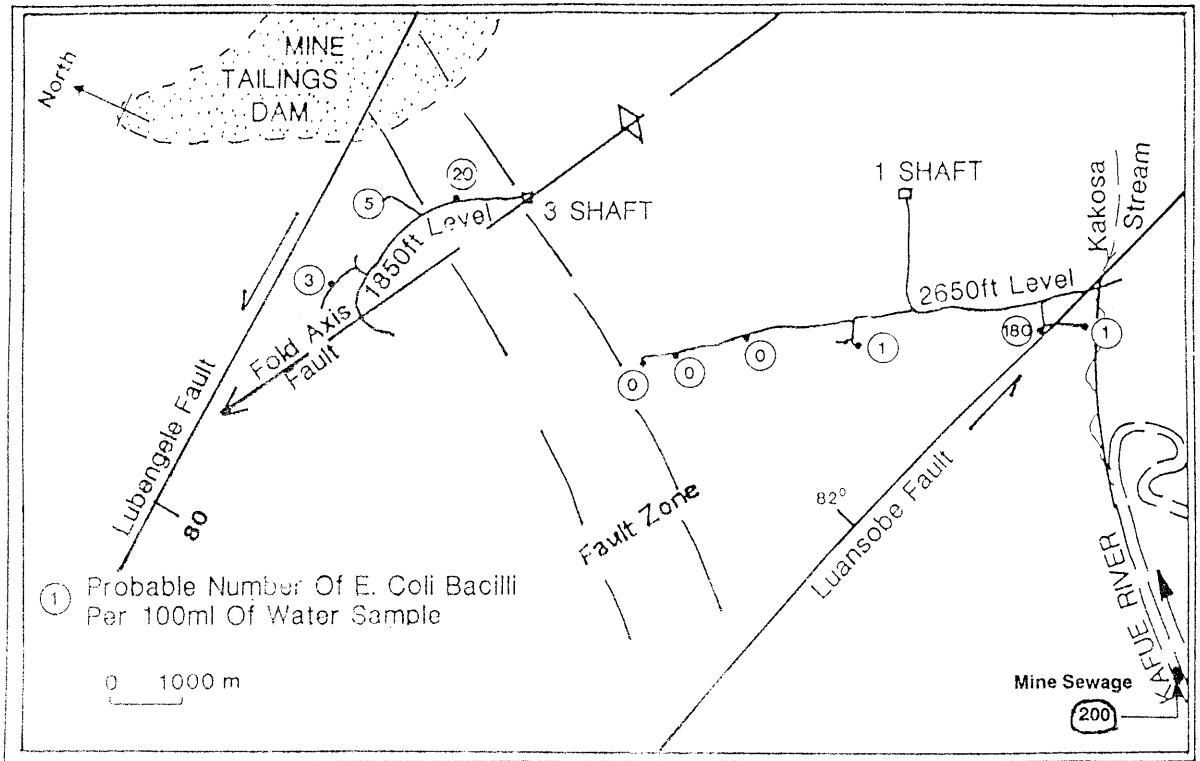


Figure 4.10 : PLAN OF 565m (1850ft.) AND 810m (2650ft.) LEVELS SHOWING THE DISTRIBUTION OF RESIDUAL XANTHATE IN GROUNDWATER

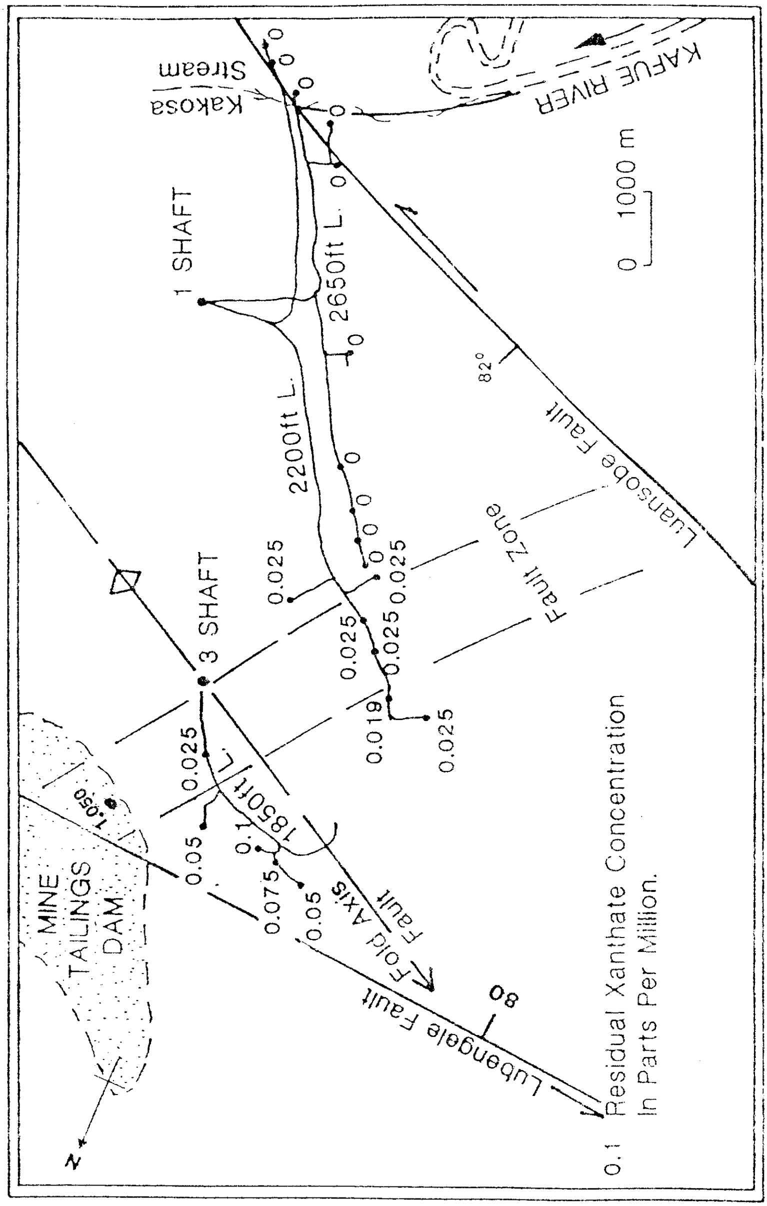


TABLE 1.0 QUANTIFICATION OF SURFACE WATER INFLOW BY SOURCE

SOURCE	MEASURED WATER LOSS (LEAKAGE) IN m^3/d			
	OCT 1992 Peak of dry season	MAR 1993 Peak of rain season	ANNUAL AVERAGE Jun 92 - Jun 93	GEO-CHEMICAL ANALYSIS ESTIMATE
KAKOSA STREAM	69 000	74 000	72 000	78 492
LUBENGELE DAM	8 000	28 000	18 000 (67 000)*	29 700
LUBENGELE DAM DRAINAGE CANAL OVER NO 3 SHAFT SUBSIDENCE AREA	Penstock Valve closed during the period. Therefore canal dry.	21 000 May - June 93	21 000 Estimated	21 000**
KAFUE RIVER	18 000	50 000	36 000	53 036
GOLF CLUB PONDS	25 800***	25 800***	25 800***	25 800
TOTAL	120 800	198 800	172 0000	208 028

* Average daily dam water loss based on 20 year period (1972-1992).

** Measured water loss.

*** Estimated leakage based on geochemical analysis.

(vii) The rock temperature ranges from 29.9°C at 350m (1150 ft) level to 31.2°C on 960m (3150 ft) level.

The geothermal gradient at Konkola is 1°C/435m whilst that of other Zambian Copperbelt mines is in the range of 1°C/30m to 1°C/60m.

(viii) Surface water of the Kafue River, Kakosa Stream, the Lubengele Dam and it drainage canal are leaking into the mine (Figure 4.9 and 4.10). These waters are the main sources of recharge to the hangingwall aquifers as shown in Table 1.

(ix) At No 1 Shaft, the Kafue River water enters the mine mainly through the southern extremity of the orebody in the Luansobe fault zone and flows northwards into the rest of the mine mainly through fissures.

At No 3 Shaft, the Lubengele Dam and its drainage canal water enters the mine through the Lubengele fault zones on the north limb of the orebody, and flows into the rest of the mine via the Cross-Axis fault zone.

This is why the forementioned areas are the wettest parts of the mine and are very difficult to dewater.

(x) The Hangingwall Aquifer water account for a substantial proportion of mine water inflow. The proportion varies from one area of the mine to another and with depth. The lowest is about 40% being greater towards No 3 Shaft, approaching 70%, where the contribution from the Lubengele Dam and its drainage canal is most strongly felt.

The proportion of Hangingwall Aquifer water in Footwall Aquifer water is highest in the upper levels of the mine and falls at deeper levels in the mine.

ORIGIN/SOURCE OF MINE WATER INFLOW

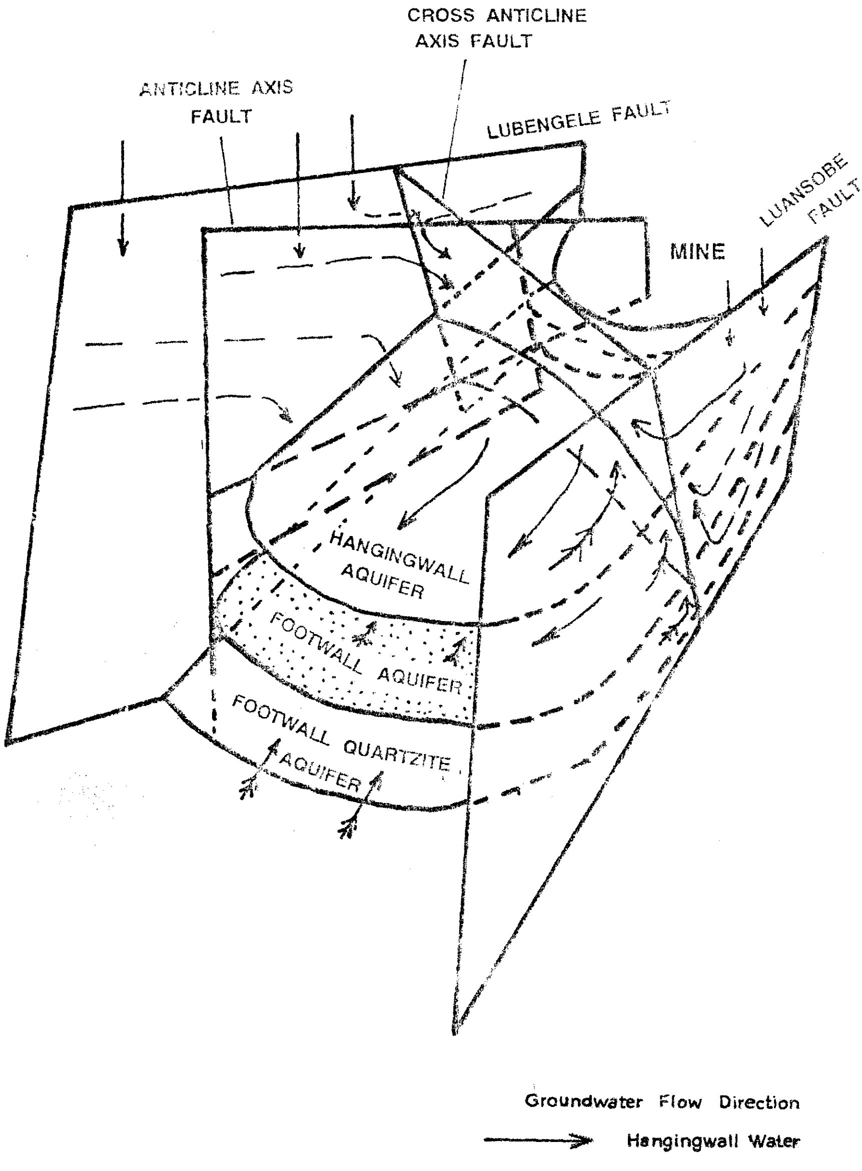
(i) The mine groundwater flow system is recharged from two sources; the regional aquifer at depth and adjacent catchment via regional faults, and from surface water close to the mine.

The fault and fracture zones are the main groundwater flow channels. Hangingwall water flow channels downwards, the Footwall water upwards, as illustrated in Figure 5.1.

The major recharge source is the surface water system which accounts for greater than 50% of mine recharge.

The geothermal gradient for Konkola mine is 1°C/435m, lowest of all the Zambian Copperbelt mines. The values for other mines range from 1°C/30m to 1°C/60m. This low value of geothermal gradient is further positive evidence for the presence of a massive body of cool water that is recharging the mine and consequently lowering the rock temperature far below the range of the regional geothermal gradient.

Figure 5.1 : CONCEPTUAL MODEL OF KONKOLA MINE HYDROGEOLOGICAL SETTING



SURFACE - WATER EXCLUSION METHODS

It is evident that the losses measured in the stream/river gauging exercise from July 1992 to July 1993 can be removed by adopting various methods of water exclusion.

The following options and their effectiveness are presented.

Kakosa Stream (Length 4km)

The Kakosa lies in the Launsobe fault zone and crosses mining subsidence area. The area is subjected to ground movement.
Estimated annual average leakage = 72 000 m^3/d.

Solution options:

(a) Lining stream bed with geomembranes/geotextiles.

- Life expectancy of geomembranes/geotextile over 25 years. Material flexible and thus not susceptible to cracking due to ground movement.

- Estimated volume to be successfully excluded = 57 000 m^3/d, representing 80% removal of leakage.

- Estimated time to complete work = 9 to 12 months.

(b) Concrete Lining

- Life expectancy short because material is brittle and hence susceptible to cracking.
  Ensuring ground movement would accelerate the erosion of the concrete lining.

- Estimated volume to be successfully excluded
  = 54 000 m^3/d, representing 75% removal of leakage.

- Estimated time to complete the work
  = 1 year 6 months to 2 years.

(c) Steel Piping

1.8m diameter and 5mm thick wall pipe, inner wall coated with bitumen for protection from rusting. Pipe fitted with flexible Johnson couplings.

- Long life, minimal maintenance required.
- Estimated that all water loss of 72 000 m^3/d, will be excluded, representing 100% removal of leakage.
- Estimated time required to complete the work
  = 3 months.

(d) Steel Lining

- Long life, minimal maintenance required.
- Estimated that all water loss of 72 000 m^3/d, will be excluded, representing 100% removal of leakage.
- Estimated time required to complete the work
  = 1 year.

Lubengele Dam and Drainage Canal

The dam overlies the Lubengele fault zone and its drainage canal crosses the Kirila Bomwe Anticline Axis Fault zone and mining subsidence area of No 3 Shaft. These zones are major groundwater flow conduits into the mine.

- Estimated average annual leakage from the dam = 67 000 m^3/d
- Estimated average annual leakage from the drainage canal = 21 000 m^3/d

Giving total leakage of 88 000 m^3/d.

Solution options:

(a) Lubengele Dam

Drain the dam in order to remove large body of water lying above the hangingwall aquifers, as this high water level provides a constant-head recharge source to the aquifers. Draining the dam is achievable by adjusting the penstock valve on the drainage canal. It is estimated that 40 200 m^3/d would be successfully excluded representing 60% removal of dam leakage.

(b) Drainage Canal

Stop the leakage by:

(i) Lining the canal with geomembranes in the No 3 Shaft subsidence area, and concrete-line the canal downstream of the mining subsidence zone, up to Golf Club bridge. Distance for geomembranes lining = 3.2 km
Distance for concrete lining = 2.7 km

Drain the water build up in the Lubengele stream immediately below the dam embarkment, by pumping the water into the drainage canal.

(ii) Piping the water from the dam penstock valve uptake, over the mining subsidence fault zones, using a 48 inch diameter pipe.

The pipe drainage system would be based upon a gravity-flow system.

- Estimated volume to be excluded
  = 61 200 m^3/d, representing 69.5% removal of leakage.
- Estimated time to line the drainage canal
  = 1 year 6 months.
- Estimated time to construct pipeline
  = 8 months.

Kafue River

The Kafue River in the vicinity of the southern part of the mine, flows along the Luansobe fault zone, a major route of mine water recharge.
Estimated annual average leakage = 36 000 m^3/d

Solution:

Divert the part of the river closest to the mine, away from the Launsobe fault zone. Estimated distance to be diverted 1km.
- It is estimated that all the leakage will be removed by diversion.

Konkola Golf Club Ponds

There karstic (sinkholes) structures that have been filled with water from the nearby Kafue River to create golfing hazards.

The water is constantly pumped into the ponds from the river to maintain the water level.

These karsts are in the Kakontwe limestone aquifer which is hydraulically interconnected to mine hangingwall aquifers.
Estimated annual average leakage = 25 800 m^3/d

Solution:

Allow natural drainage of the ponds by stopping pumping water into them. If there is an aesthetic golfing need to maintain the ponds, they should be lined with impermeable material to stop leakage.

In conclusion, it is crystal clear that a very significant proportion of surface water ingress into the mine, would be removed by the above mentioned approach.

SOURCE	SOLUTION OPTION	ANNUAL AVERAGE LOSS (LEAKAGE) IN m^3/d	ESTIMATED VOLUME TO BE EXCLUDED IN m^3/d	PERCENTAGE REDUCTION IN MINE PUMPING
KAKOSA STREAM	(A) GEOMEMBRANE LINING	72 000	57 000	19
	(B) CONCRETE LINING		54 000	18
	(C) STEEL PIPING		72 000	100
	(D) STEEL LINING		72 000	100
LUBENGELE DAM	DRAINING THE DAM	67 000	40 200	13
LUBENGELE DAM DRAINAGE CANAL OVER No. 3 SHAFT SUBSIDENCE AREA	GEOMEMBRANE LINING THE CANAL OVER THE SUBSIDENCE AREA AND CONCRETE LINE OUTSIDE THE SUBSIDENCE ZONE	21 000	21 000	7
KAFUE RIVER	1 Km RIVER DIVERSION AWAY FROM THE LUANSOBE FAULT ZONE	36 000	36 000	12
GOLF CLUB PONDS	DRAIN AND STOP PUMPING WATER INTO THE PONDS	25 800	25 800	8
TOTAL		221 800	180 000	59

TABLE 2.0: REDUCTION IN MINE PUMPING BY SOURCE

Table 2 shows that out of the estimated total surface water ingress into the mine of 221 800 m^3/d, at least 177 000 m^3/d would be successfully removed by the forementioned strategy. This would represent a reduction in mine water pumping of about 58%.

CONCLUSION AND RECOMMENDATIONS

The long term cost-effective solution to the groundwater problem at Konkola mine lies primarily in reducing the volume of water entering the mine.

The study highlights that substantial savings can be made as a result of excluding water from the following areas listed in order of priority:

Kakosa Stream

- Lining the stream bed with geomembranes/geotextiles or piping the water over the mine subsidence (caving) and fault zones.
  Percentage reduction in mine pumping = 19%
  Cost Saving = US$821 798 per annum

Lubengele Dam and Drainage Canal

- Drain the dam in order to avoid maintaining a high head (water level) throughout the year, by adjusting the penstock valve on the Drainage Canal. This will remove the large body of water lying above the Hangingwall Aquifers and the Lubengele Fault and associated fracture zones interconnected to mine workings on North Limb of No 3 Shaft.

- Seal off the leakages on the Drainage Canal as it flows over the subsidence and Kirila Bomwe Anticline Axis Fault fissure zone, using geomembranes/geotextiles lining.

  Concrete-line the canal downstream of the subsidence area up to the Konkola Golf Club road bridge.

This will remove recharge through fracture zones into mine workings such as that currently exposed on 590m level (1850 ft) between 1500mW and 1700mW which are hydraulically interconnected to the Drainage Canal.
Percentage reduction in mine pumping = 20%
Cost Saving = US$882 351 per annum

Kafue River

- divert the river away from the Luansobe Fault zone, as it interconnects the river to the mine aquifers.

  Percentage reduction in mine pumping = 12%
  Cost Saving = US$519 030 per annum

Konkola Golf Club ponds

- drain the ponds by stoping to pump water into them from the Kafue River.

  Percentage reduction in pumping = 8%
  Cost Saving = US$371 971 per annum

Although Konkola Mine ore reserves/resources give a mine life of well over 25 years, the short term financing-period of 5 years has been used as a basis for the project financial analysis. This is because all the work involved in each of the options advanced for water-exclusion will be completed within a period of 2 years and yield benefit immediately.

It is strongly recommended that in order to effect significant reduction in mine pumping, Kakosa Stream, Lubengele Dam and its drainage canal leakages should be tackled first. This would result in a reduction of about 39% of total water pumped from the mine.

It is evident that the cost of the proposed surface water - exclusion options fall far below the current cost of pumping. They are cost-effective and provide us with a permanent solution to the problem, by removing the recharge at source.

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