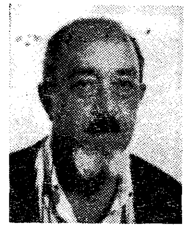

# KONKOLA MINE, ZAMBIA QUANTIFICATION OF WATER INFLOW BY SOURCE

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## ACKNOWLEDGEMENTS

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## 1. INTRODUCTION

*ZCCM* are carrying out a hydrogeological integrated research at Konkola Mine. This paper focuses on and discusses the last information acquired in 1992, to establish the different sources of waters flowing into the mine and to estimate the rates of each source.

The investigation methodologies described in this paper are only the related with hydrochemistry, water tritium content and water microbiology and bacteriology occurring in the Konkola Mine water environment, of natural or anthropogenic origins.

The corresponding analyses were carried out both in Spain (hydrochemistry, bacteriology and tritium) and in Zambia (bacteriology).

## 2. GEOLOGICAL SETTING

According to the previous geological reports, referenced in the attached bibliography, the geology of the Konkola Mine area can be synthesized as follows.

### 2.1. Lithostratigraphy

The orebody, located in a metasedimentary rocks sequence at **Kirilabombwe Anticlinal** (figure 1), has a strike length of over 12 km subdivided into:

- the **South Orebody** mined through **Number 1 Shaft** (figure 2), lying on the southern flank of the Kirilabombwe Anticline, with an average thickness of about 9 m and dips at between 50 to 70 degrees, and
- the **North Orebody** mined through **Number 3 Shaft**, lying across the axis of the Kirilabombwe Anticline, with an average thickness of about 13 m and dips generally shallower, but range from about 10 to 40 degrees.

The geological materials represented in the area (figures 1 & 3) correspond to:

- the **Basement Complex**: igneous and metamorphic rocks, mainly granites, gneisses and schists which outcrop form the cores of the Kirilabombwe Anticline and the Konkola Dome, and
- the **Katanga System**: sedimentary rocks, ranging from quartzites, conglomerates, sandstones and siltstones, to dolomites and limestones. The orebody is located in the **Ore Shale Formation** (Katanga System) (figure 3).

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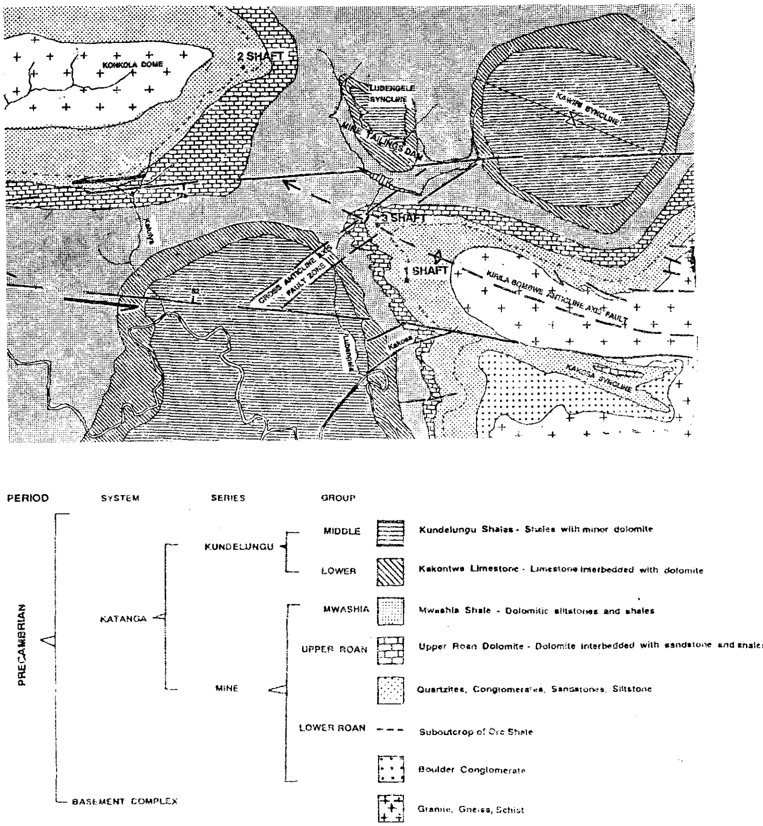


*Figure 1. Geological map of Konkola Mine area (Garlic, 1961 and Drysdall et al., 1972, in Mulenga, 1991).*

### 2.2. Structural geology

The **Kirilabombwe Anticline** is wedged between two major fault zones (figure 1): the **Lubengele Fault** on the northern side, and the **Luansobe Fault** on the southern side.

In addition, there are two other important fracture zones: the **Kirilabombwe Anticline Axis Fault** and the **Cross Anticline Axis Fault Zone**. These are heavily fractured and have extensive tension cracks and joints. Minor faults, with displacements occasionally in excess of 10 m, are common on the west limb of the North Orebody. When these structural discontinuity fracture zones are intersected in underground workings, they present the worst mine water inflow control problems.

## 3. LOCAL HYDROLOGY

The Konkola Mine area it is located on the **Kafue River** basin. This river, one of the largest in the country, flows on the hangingwall rocks in the vicinity of the mine (figure 4).

The **Lubengele Stream** flows north-south over the hangingwall aquifers crossing the

Kirilabombwe Anticline Axis. The **Kakosa Stream** flows on the southern part of the mine. Mine drainage water is disposed of into the Kafue River via the Kakosa Stream. The **Mingomba Stream,** a tributary to the Lubengele Stream is other perennial stream in the area. Other local streams have small watershed and are ephemeral.

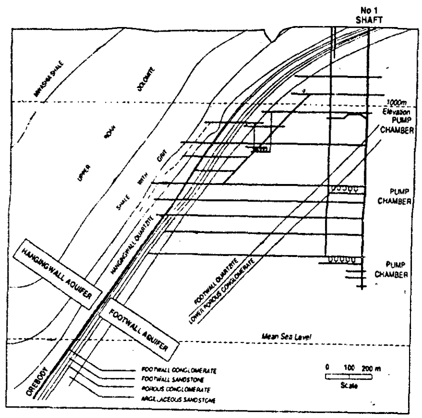


*Figure 2. Generalized geological cross section at Number 1 Shaft (Mulenga, 1991).*

In 1964, upstream of Number 3 Shaft a dam was built on the Lubengele to create a reservoir, which became a **Tailings Disposal Dam.**

The **Mine Township Sewage Ponds** are located downstream of the Lubengele near the Kafue River confluence.

In the Konkola Mine area the tributaries to the main river and streams consists mainly of shallow stream beds and large, grassy saucer-shaped depressions known as ***dambos***. Most dambos are wet and swampy during the rains (October to April), and remain dry in the dry season.

## 4. HYDROGEOLOGICAL SETTING

A **complex multilayer aquifer system** exists at Konkola Mine (figures 2, 3 & 5). The orebody is sandwiched between major aquifers. Those in the hangingwall comprise carbonate rocks and the footwall are composed of mainly siliceous rocks.

The **Hangingwall Aquifers** include:

- the **Kakontwe Limestone Aquifer (KLA)** that correspond to the Kakontwe Limestone, and
- the **Hangingwall Aquifer (HWA)** composed of the Upper Roan Dolomite, the Shale-with-Grit and the Hangingwall Quarzite.

The **Footwall Aquifers** include:

- the **Footwall Aquifer (FWA)** composed of the Footwall Conglomerate, the Footwall Sandstone and the Porous Conglomerate, and
- the **Footwall Quartzite Aquifer (FWQ)** composed of the lower part of the Footwall Quarzite and the Lower Porous Conglomerate.

Prior to commencement of mining activity these aquifers may have mainly confined aquifers with interbedded aquicludes and aquitards. Onset of mining activity has enhanced and in some cases created hydraulic interconnectivity between aquifers and also with the surface drainage patterns.

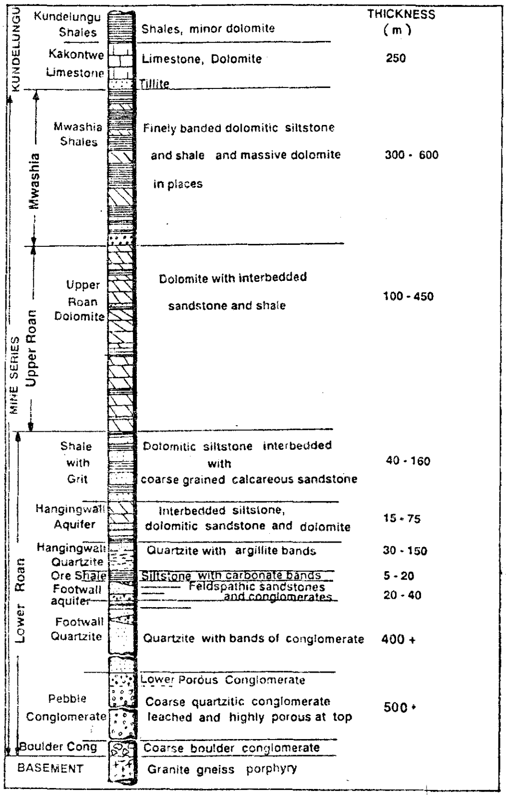


*Figure 3. Konkola Mine stratigraphic column (Mulenga, 1991).*

Given such a hydrogeology setting it is important to emphasize the high potential of surface inflow infiltrating into the mine through:

**Aquifer outcrops:**

- the **Kafue River** flowing over an extensive outcrop of the Kakontwe Limestone Aquifer in the west and east side of the gently Kawumbe Syncline (figure 1). During the rain season due to the low gradient of this river and to the peneplain plateau morphology the surface water covering area is very large (*dambos*),
- the **Lubengele Tailings Dam** flooding a large area of the Kakontwe Limestone Aquifer outcrop in the Lubengele Syncline (figure 2),
- the **Lubengele Stream** crossing the Kirilabombwe Anticlinal Axis Fault and the Cross Anticline Axis Fault zones in the Hangingwall Aquifer outcrop area,
- the **Kakosa Stream** flowing on all the aquifers as well as along the Luansobe Fault, and

- the **Golf Club Pond** located over the Kakontwe Limestone Aquifer outcrop.

**Fault/fracture zones:**

- the **Luansobe Fault** and the **Kakosa Fault** (branch of the **Lubengele Fault**) transecting all the aquifers,
- the **Lubengele Fault** and the **Cross Anticline Axis Fault Zones** intercepting the outcrop of the aquifers above the orebody, and
- the **Kirilabombwe Anticline Axis Fault** intercepting the outcrop of all the aquifers with the exception of the Kakontwe Limestone Aquifer.

All these are potential zones through which surface and groundwater can leak into the mine.

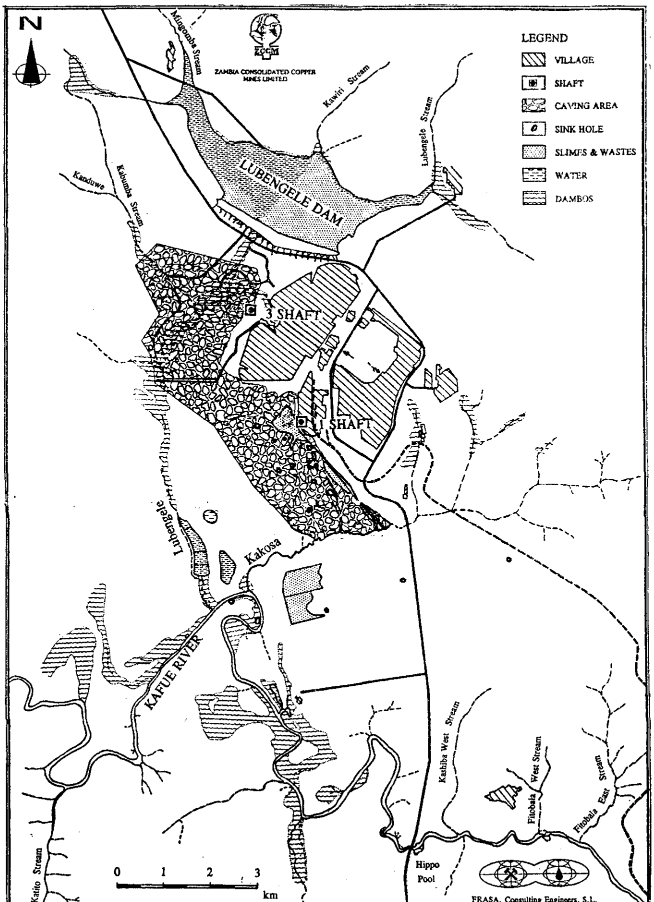


*Figure 4. Surface hydrology patterns around Konkola Mine area (aerial photo-interpretation).*

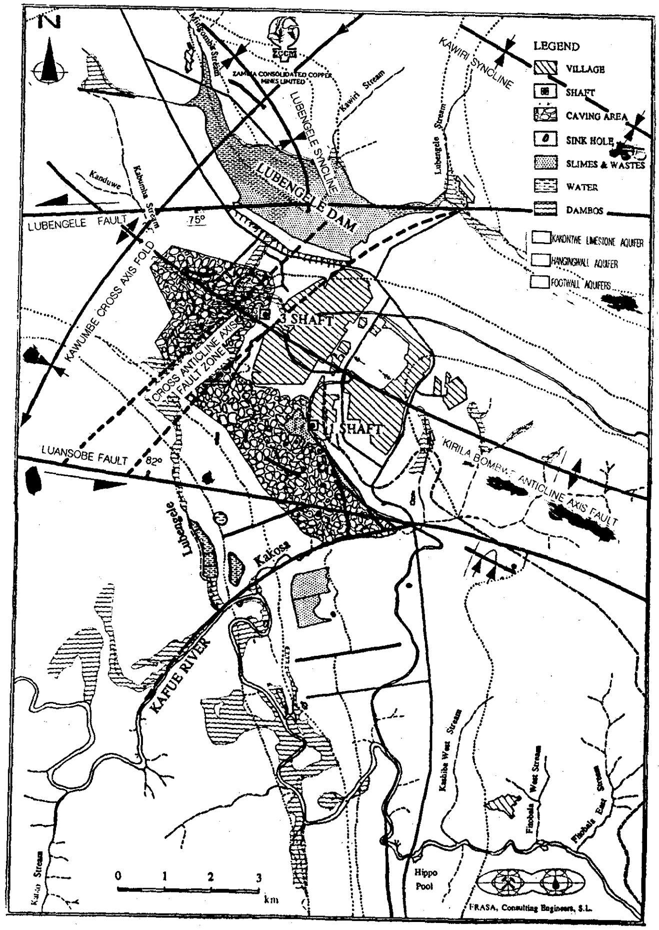


*Figure 5. Simplified hydrogeological map of Konkola Mine area.*

## 5. MINE DEWATERING PROCESS

Mine dewatering is achieved mainly through diamond-drilling boreholes from drain drives and crosscuts. In some cases also through open fissures intercepted by mine development.

Many drainage boreholes, inclined between 0° and 30°, are collared in excavations situated at the end of crosscuts. In every case care is taken to ensure that holes are collared in a tight, relatively unjointed rock face to avoid leakage. Most of the boreholes are fitted with standpipes and valves which can be closed in emergencies (*controllable water*).

## 6. ORIGIN OF MINE WATER INFLOW

Earlier work suggested that Konkola Mine water inflow originated from discharge from the regional groundwater aquifer system without significant connection to the local surface drainage system.

In 1991 Mulenga justified an induced leakage of surface water into the mine groundwater flow regime, supporting his thesis by geostructural and surface hydrology observations, hydrochemical determinations, bacteriological controls and water age determinations.

## 7. HYDROCHEMICAL TRACERS

### 7.1. Fundamentals

Hydrogeological tracers can be used to determine the origin and flow pattern of mine water inflow. Employing dissolved ions as hydrochemical tracers can take two approaches: either using the natural water constituents or added chemical compounds. The natural constituents approach is based on the understanding that dissolved ions in water of different origin will reflect the different geochemistry. Whilst adding chemical compounds to a body of water provides a means of tracing the flow path.

In this investigation we analyzed for those ions that would assist in tracing the origin and quantifying the relative proportions of mine water inflow by source.

### 7.2. Previous research

Mulenga (1991) using xanthates, as anthropogenic tracer in Konkola Mine water, proved a direct link between the Lubengele Tailings Dam water and the mine water. Also he looked into the dissolved ions similarities/differences between water samples on surface (Kafue River, its tributaries and the Lubengele Tailings Dam) and underground mine water samples.

The analysis of such previous data using statistical methods (FRASA, 1993) reveal the following salient points:

- the **chemical facies** of the hangingwall and the footwall aquifers water are different, indicating the presence of water from different origin or flow path,
- the amount of **chlorine** related to the total anions is very low. We interpret such as indicating the absence of fossil water of marine origin and evaporite sediments,
- the ratio of **bicarbonate to sulphate** and the ratio of **calcium to magnesium** is very variable. We interpret such variation as indicating mixing of waters of different origin/flow path and also possibly being due to the pyrite solution local process.

### 7.3. New research

In 1992 we collected and analyzed twenty-two water samples (FRASA, 1993). Nine from surface, ten from underground mine drainage sites and three corresponding to: the total Number 3 Shaft, the total Number 1 Shaft and the total Konkola Mine water discharge.

#### 7.3.1. Surface water

Related to the surface water analysis the more significant aspects are (FRASA, 1993):

- **Bicarbonate** is the predominant anion (figure 6) (more than 50 % of the total anions, except in the Concentrator Plant effluent water (KS-9) where it is 49 %).
- **Carbonates** are not present (as correspond of pH below 8.5).
- **Nitrates** are low: the highest amount correspond to the Total Mine Water Drainage (5.1 mg/l) probably due to the employed explosives.
- **Nitrites** and **ammonia** (the latest being a chemical reduction product of the former) that generally indicate presence of organic pollution appear mainly: downstream of the Lubengele Tailings Dam, after the sewage ponds and in the Concentrator Plant effluent water (in the other samples the amount is low or absent) (figure 7).

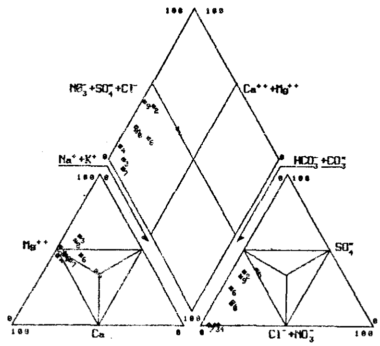

*Figure 6. Piper Diagram including all the surface water analysis (October 1992).*

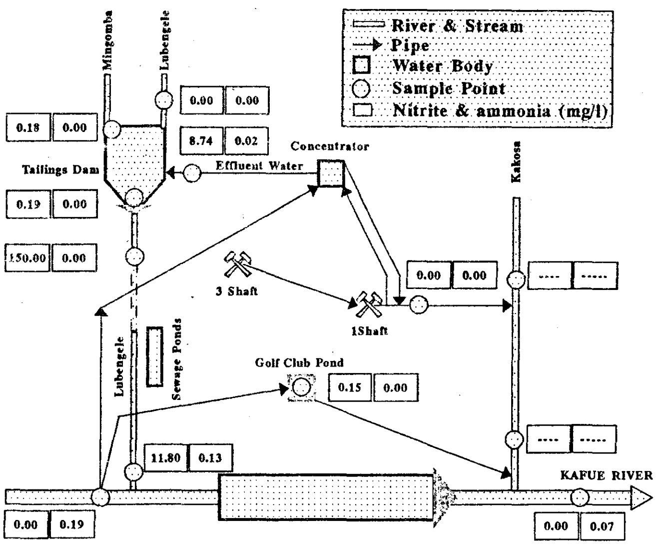


*Figure 7. Nitrite & ammonia contents (mg/l) in surface water (October 1992).*

- **Magnesium** and **calcium** are the predominant cations (figure 8). The amount of magnesium is relatively low: less than 50 mg/l, and the amount of calcium is less than 81 mg/l. The ratio of calcium to magnesium (expressed in meq/litre) ranges between 1.12 to 0.55.
- **Sodium** content is very low: less than 10 mg/l with the exception of the Concentrator Plant effluent water (26.7 mg/l).
- **Potassium** is relatively low with the exception of the Concentrator Plant effluent (39.7 mg/l).

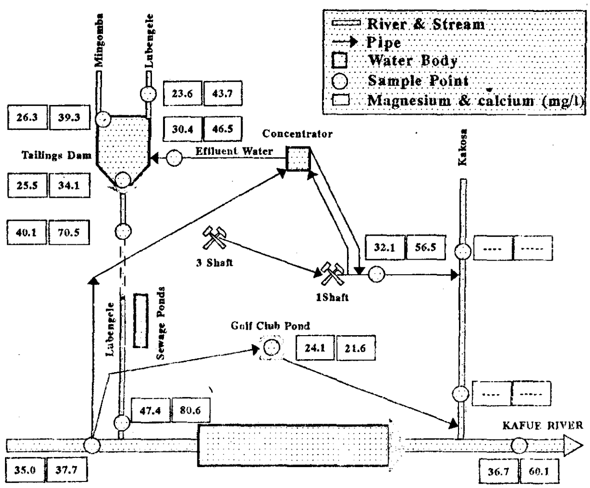


*Figure 8. Magnesium & calcium contents (mg/l) in surface water (October 1992).*

- The highest amount of **silica** correspond to the Total Mine Water discharge (26.2 mg/l), as is normal in deep groundwater. We found also high level of silica at sample collected at Kafue River downstream (23.7 mg/l) due to the mine water discharge. The content of the other samples can be considered normal (ranging between 8.4 and 15.0) (figure 9).

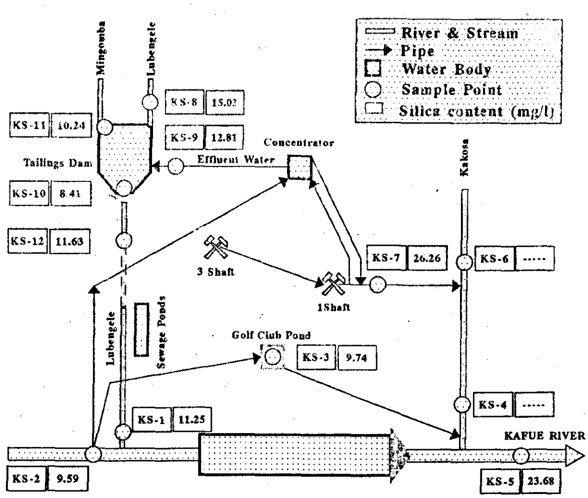


*Figure 9. Silica contents (mg/l) in surface water (October 1992).*

- **Total Dissolved Solids** is relatively low: less than 610 mg/l.

The sample corresponding to the Concentrator Plant effluent water is anomalous due to the chemical compounds used in the copper concentrating process. This sample has the highest concentration of chloride, sulphate, sodium, potassium and manganese of all the samples analyzed.

### 7.3.2. Groundwater

Related to the groundwater analysis the more significant aspects are (FRASA, 1993):

- **Bicarbonate** is in general the predominant anion, as is normal in low salinity water related with carbonate rock aquifer environment (figure 10). The samples corresponding to the Footwall Aquifers have very low bicarbonate content (between 107 mg/l and 139 mg/l). The samples corresponding to the Hangingwall Aquifers have higher bicarbonate content (between 246 and 473 mg/l). The samples corresponding to the total inflow for Number 1 Shaft and Number 3 Shaft respectively, have intermediate value (216 and 244 mg/l respectively).
- **Sulfate** is very variable (between 0 to 139 mg/l). In two samples is the predominant anion, probably due to pyrite mineral solution. In other two it is absent (figure 11).

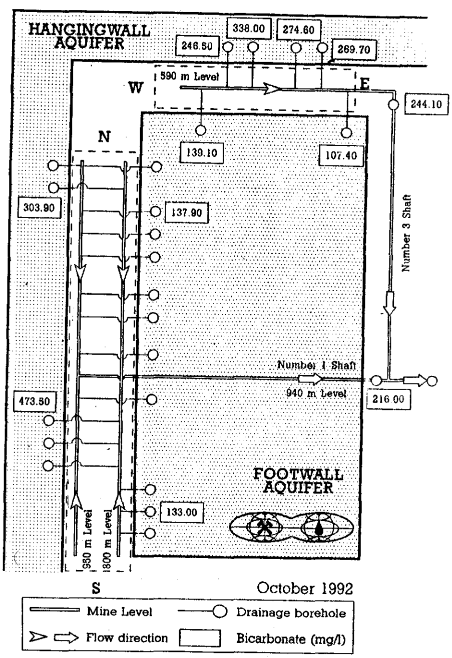


*Figure 10. Bicarbonate content in groundwater (October 1992).*

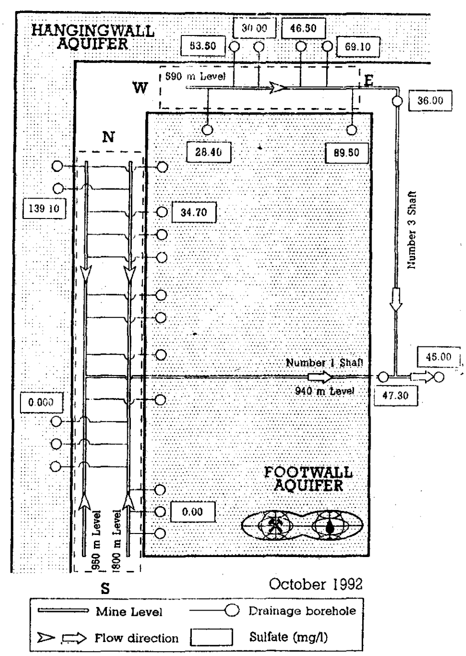


*Figure 11. Sulfate content in groundwater (October 1992).*

- **Chloride** is in relatively small amount (between 7.1 to 29.8 mg per litre). The small amount of chloride content in Konkola Mine groundwater samples, suggest a high infiltration rate of surface water into the mine (equivalent to a low evaporation rate).
- **Carbonate** is not present (because pH is below 8.5).
- **Nitrate** content is very low. This anion could be arising from solution of nitrate compounds present in explosives used for blasting during mining activity (5.1 mg/l in the total mine drainage water).
- **Nitrite** and **ammonia** (the latter being a chemical reduction product) generally indicate presence of organic pollution (figure 12). Samples from the Hangingwall Aquifer in the Lubengele Fault and the Anticline Axis Fault Zone respectively, have significant amount of nitrite and ammonia.
- **Sodium** is very low: less than 10 mg per litre (figure 13). In general, the content is lower at Number 1 Shaft that at Number 3 Shaft. The high sodium content in Number 3 Shaft water can be attributed to the infiltration of Concentrator Plant effluent water (that has very high sodium content) through the Lubengele Tailings Dam. Leaking through the hangingwall this water can arrive to the Number 3 Shaft area which lies closest to the Dam. Using sodium content in the water, to establish the rate of water flow, about 60% of the water is from Number 3 Shaft and about 40% from Number 1 Shaft.
- **Potassium** is relatively small and fairly constant: varying between 6.3 and 9.5 mg/l.

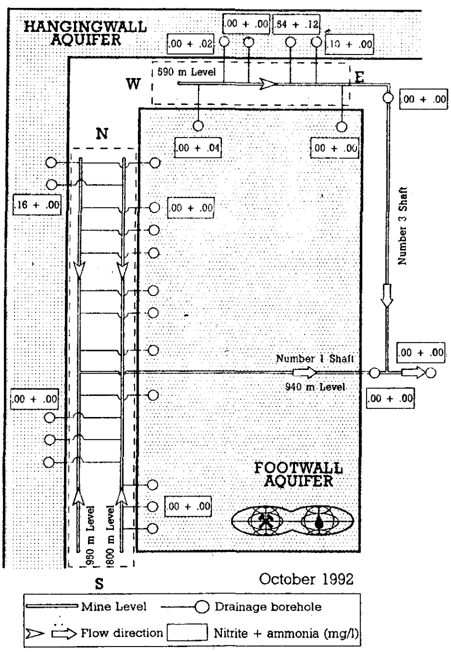


*Figure 12. Nitrite and ammonia contents (mg/l) in groundwater (October 1992).*

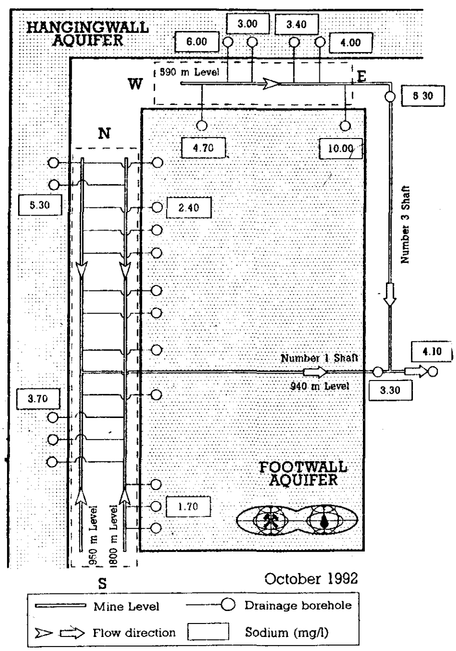


*Figure 13. Sodium contents (mg/l) in groundwater (October 1992).*

- **Silica** content is high in general (figure 14). The highest amount of silica is in samples of Number 3 Shaft. Total Number 3 Shaft discharge has 29.99 mg/l, and Number 1 Shaft 23.22 mg/l, and Total Mine Drainage 26.16 mg/l. Applying silica 66 % of the total drainage discharge would be from Number 3 Shaft and 34% from Number 1 Shaft.
- **Total Dissolved Solids** are relatively low (figure 15). In the Footwall Aquifer the TDS is between 212 and 303 mg/l, and in the Hangingwall Aquifer between 406 and 632 mg/l, as correspond to more soluble rocks (mainly dolomites and limestones).

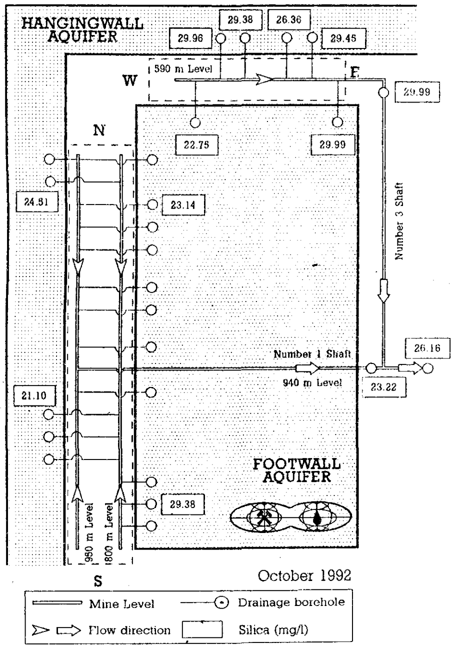


*Figure 14. Silica contents (mg/l) in groundwater (October 1992).*

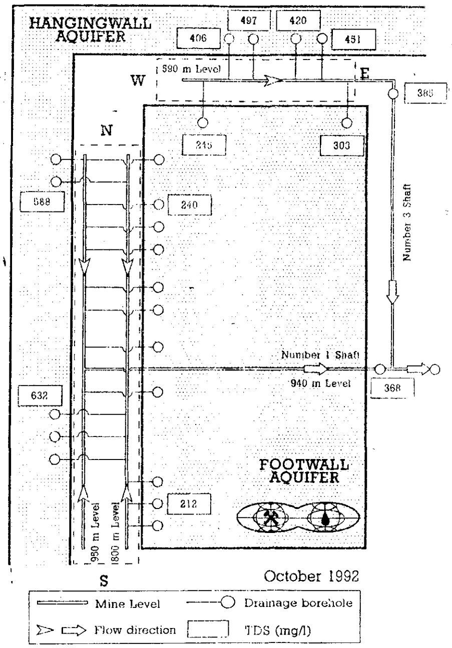


*Figure 15. Total Dissolved Solids contents (mg/l) in groundwater (October 1992).*

## 8. BIOLOGICAL TRACERS

### 8.1. Fundamentals

Biological tracers can be the natural microorganisms living in the water or other microorganisms added into the water as a consequence of human activity.

Most of these microorganisms are filtered when the groundwater flow through rock pores. However, in open fissures and cavities these organisms are more or less freely transported by the water. The presence of surface characteristics microorganisms on groundwater, confirm direct link between surface and groundwater.

## 8.2. Previous research

Mulenga (1991) observed for the first time in Konkola Mine the presence of **Escherichia Coli** bacteria both in:

- **Surface water** samples taken from Kafue River in different places, Lubengele, Mingomba and Konkola streams.
- **Underground water** samples collected in the vicinity of the main faults: Luansobe Fault, Kirilabombwe Anticline Axis Fault and Cross Anticline Axis Fault Zone.

The presence of these bacteria in surface waters is related to the sewage ponds located near the Lubengele Stream and with other sewage water discharges. In the underground mine water the presence of this bacteria is evidence of leakage surface sewage polluted water into the mine. The surface water enter the mine through open fractures, fissures and cavities. As the samples were collected directly from the rock face any possibility of E. Coli having come from men defecation in the mine, is ruled out.

Taking into account the conditions under which the bacteria was found in the mine borehole water, the only origin is the sewage ponds, which lie directly above this area, on surface.

## 8.3. New research

We collected and analyzed twenty-two samples (nine samples from surface waters and thirteen from underground waters) (FRASA, 1993). As these samples were not under refrigeration during transport from Chililabombwe to the laboratory in Spain, an increment in the amount of the existing bacteria could be expected.

To eliminate any bias in the results of bacteriological analyses conducted in Spain, additional biological analysis was carried out at Konkola Mine Hospital Laboratory (twelve from surface water and twenty five from underground water).

### 8.3.1. Aerobic germs

Nearly all the samples from the mine showed hight content of aerobic germs. These organisms are characteristic of oxygenated surface water. This is show evidence of surface water leaking into the mine. Also, countless germs (> 10,000) are present in the water coming from the Concentrator Plant effluent water (KS-9) which is cleaned using Kafue River water.

Groundwater samples analysis (figure 16) show countless amount (more than 10,000) in samples related undoubtedly to the Lubengele losing stream through the Lubengele Fault, immediately downstream of the Lubengele Tailings Dam (Number 3 Shaft). Other samples have high values also, especially the sample located below the Luansobe Fault which crosses the Kakosa Stream and the Kafue River near the sewage ponds. The high content in this sample may be indicating a very high surface water infiltration in this area.

Underground water samples with significant amount of aerobic germs are connected with the Lubengele Stream through the Cross Anticline Axis Fault Zone and with the Lubengele Tailings Dam through the Lubengele Fault and with the Kirilabombwe Anticline Axis Fault zone.

Between the twenty-two samples analyzed in only one the aerobic germs was absent.

The sample corresponding to the total amount of water from Number 3 Shaft has more aerobic germs that the one corresponding to Number 1 Shaft.

Taking into account the amount of aerobic germs the Number 3 Shaft would contribute about 54 % to the total of the water and Number 1 Shaft about 46 %.

However, we should point out that with this data we can not clearly establish the ratio of water coming from different sources.

### 8.3.2. Coliforms, Escherichia coli and Streptococcus

These microorganisms were found in most of the water samples both from surface and the mine, analyzed both in Spain and in Zambia.

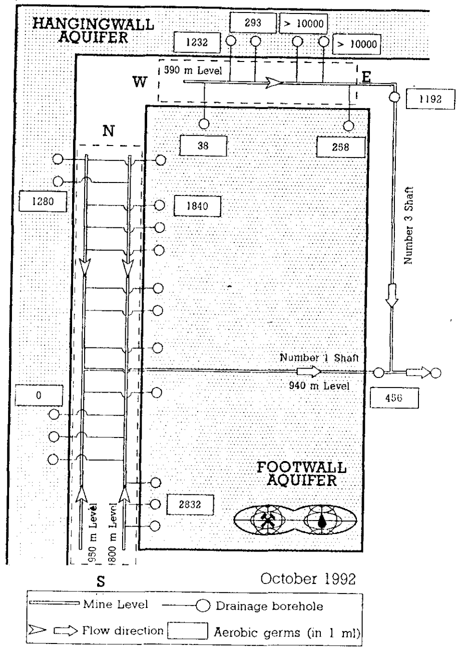


*Figure 16. Total aerobic germs contents (in 1 mL) in groundwater (FRASA, October 1992).*

Coliforms are the most resistant to biodegradation, followed by Escherichia coli, and least Streptococcus. This may explain why the Streptococcus was not found in any underground water samples, and Escherichia Coli was found in two samples, and the Coliforms in three samples.

## 9. WATER TEMPERATURE AS A TRACER

### 9.1. Fundamentals

Water temperature is one of the most useful physical parameters of water that can be used as a tracer.

In the geothermic zone rock temperature is constant in time and increases with depth. Normal thermal gradient averages of 1 °C for every 30 or 40 m. However in Konkola Mine Mulenga (1991) found a gradient of only 1 °C for every 435 m. He observed that on each mine level the water temperature was not in equilibrium with the dry rock temperature. Generally, the water temperature was lower than the rock temperature except in some fracture/fault zones. He interpreted such abnormal condition as consequence of rapid water infiltration through fissures and discontinuities without enough time to reach the equilibrium with the rock temperature.

Also Mulenga reported that the Hangingwall Aquifer water is colder than the Footwall Aquifer water by an average of 2 °C, and that in fault zones the temperature difference is lower than 2 °C as consequence of mixing.

### 9.2. New researches

At the end of December 1992 the water temperature was monitored at 44 sites, both on surface and underground.

### 9.3. Interpretation

In order to obtain valuable information we analyzed the temperature distribution of the mine groundwater (corresponding to 30th December 1992) (FRASA, 1993).

Related to **surface water temperature** we observe that upstream of the mine area, the Lubengele and Kakosa Streams have low temperature (21.5 ° and 22.5 °C respectively). The Kafue River water temperature both upstream and downstream of the mine was constant at 26.5 °C. However, within the mine influence area, as the Kakosa Stream water mixed with warmer mine discharge water, the temperature of the stream water rises.

Related to **mine underground water** we observe that:

- The Hangingwall Aquifers water is generally colder than Footwall Aquifers water.
- The Hangingwall Aquifer water show no an temperature increase with depth, and has the same temperature as the river/stream water, evidence of direct link of such waters and high infiltration rates.
- The Footwall Quartzite Aquifer water in the Kirilabombwe Anticline Axis Zone has the same temperature as the Hangingwall Aquifer and the river/stream waters. This is evidence of rapid direct leakage of surface water into the mine through this zone.
- The Footwall Quartzite Aquifer water on the north limb of the orebody 590 m Level show same temperature as that of the Concentrator Plant effluent water. This may indicate direct leakage.
- All fault zones have mixed aquifer water temperatures showing that they are the major channels through which water is entering the mine.

## 10. RADIOACTIVE TRACERS

### 10.1. Fundamentals

Water radioactive tracers can be natural unstable isotope existing in surface or underground waters (such as $^{14}C$), or other unstable isotope added into the water for research purposes (such as $^{131}I$, $^{3}H$) or present in the water mainly as a consequence of the anthropogenic activity (such as $^{3}H$).

These tracers can be employed to establish the hydrologic connection between surface-underground waters, or between different aquifers, or between underground-surface waters. Also the radioactive isotope can be used to date the water: time elapsed from rainfall to the time sample was collected (also called groundwater residence time).

### 10.2. Previous research

At Konkola Mine tritium (radioactive isotope of hydrogen: $^{3}H$) was employed in July 1989 to determine the water age (Mulenga, 1991). A total of twelve samples were collected, two from surface waters of the Kafue River and Mingomba Stream and ten from underground mine workings. The tritium content was determined at UK. Two different types of water was established:

- **old water (pre-1952)** corresponding to regional aquifers deep reserves, and
- **young water (post-1952)** corresponding to direct infiltration of recent rainfall or surface water.

The highest tritium concentration in groundwater samples (youngest water) corresponded to boreholes located in the Luansobe Fault, Kirilabombwe Anticline Axis Fault and Cross Anticline Axis Fault Zone. These confirmed that these faults were the major groundwater flow channels through which surface water was entering the mine.

**10.3. New research**

In October 1992 we collected a total of eighteen samples for tritium analysis (FRASA, 1993). The tritium content of these samples was determined in Spain.

**10.4. Interpretation**

We make the assumption (FRASA, 1993) that the Kafue River at the Pump Station (18.0 $\pm$ 2.0 T.U.) represent the surface youngest water in the south infiltration potential area, influencing Number 1 Shaft. In the north area, influencing Number 3 Shaft, the Lubengele Tailings Dam (15.0 $\pm$ 2.0 T.U.) is taken as representing the youngest surface water.

In the dry season, the water accumulated at Kafue River and at Lubengele Tailings Dam are recharged by the aquifers outflow discharging old water mixed with relatively young water. In the rain season this surface water body are full mainly by young water from rainfall. As the samples were collected at the end of the seasonal seven-months dry period (October), it is necessary to repeat the sampling at the end of the rain season, to ensure that the surface water being sampled is definitively young water.

If we take as real value of tritium activities the base data of each determination (excluding the margin of error), and we assume as tritium surface water content the value corresponding to the Kafue River at Pump Station (Number 3 Shaft) and the corresponding to the Lubengele Tailings Dam, we arrive to the conclusion that the Number 3 Shaft water has the highest surface water proportion: 34,67 % whilst Number 1 Shaft has 23.89 % of surface water. However it is necessary to repeat this investigation at the end of the rain season to obtain more confident data.

**11. QUANTIFICATION OF MINE WATER INFLOW BY SOURCE**

**11.1. General remarks**

Between 1960 and 1973 studies were carried out at Konkola to investigate potential river/stream water losses into the mine. The general conclusion was that although these losses occur, there were not significant enough to greatly impact the dewatering of the mine in future.

The results of the studies that we carried out show very clearly that there is loss surface waters on the Kafue River, the Lubengele, Mingomba and Kakosa streams and the Lubengele Tailings Dam into the mine groundwater flow regime (FRASA, 1993).

Generally the mine water infiltration increases with increased mining activity mainly if the effects of subsidence become greater. However, mine water pumping at Konkola Mine has remained more or less constant due to:

- the pumping is maintained approximately constant matching the pumping capacity, and
- the infiltration is largely from permanent water surfaces with constant head such as Lubengele Tailings Dam, Kafue River, Kakosa Stream, Sewage Ponds, Golf Club Pond and dambos.

During our study we intend to quantify the mine water inflow from different sources, with the available methodologies. As were exposed in previous chapters such duty is not to easy mainly due to the disturbances created by the mine exploitation and dewatering. In these conditions one of the biggest problems is related with the lack of knowledge of original groundwater characteristics of each aquifer before mining activity begun. Other problem it is related with the seasonal changes in surface water qualities parameters.

Finally quantification of water by source in a mine environment is complex due to the dynamic nature of the environment, and the parameter changes occurring during the groundwater flow.

**11.2. Numerical estimation**

Using numerical analysis we will attempt to quantify the water balance by source (FRASA, 1993). According with the margin of error in some analytical determinations and with the necessary assumptions related to the characteristics of each different water, it would be necessary in future to compliment numerical solution with more details research.

The numerical method employed was the *iterative tangential in advance partial derivative* (100 maximum), applied to non linear systems, solving the equation systems by the Newton method, with a precision of 0.0005, using a personal computer.

The first step was to define the different water sources and characterize corresponding water samples. We determined the origin of the water using the samples listed below as the characteristic ones:

| | | |
|---|---|---|
| **Number 3 Shaft (J):** | | **Sample KW-24** |
| ■ (A) | Concentrator Plant Effluent Water | Sample KS-9 |
| ■ (B) | Lubengele Tailings Dam | Sample KS-10 |
| ■ (C) | Lubengele Stream | Sample KS-12 |
| ■ (D) | Old water (aquifers) | Sample KW-21 |
| **Number 1 Shaft (K):** | | **Sample KW-26** |
| ■ (E) | Kafue River | Sample KS-2 |
| ■ (F) | Lubengele Sewage | Sample KS-1 |
| ■ (G) | Kakosa Stream | Sample KS-7 |
| ■ (H) | Golf Club Pond | Sample KS-3 |
| ■ (J) | Old water (aquifers) | Sample KW-13 |
| **Total Mine Discharge** | | **Sample KS-7** |

The parameters adopted as tracers of each water was the following: tritium activity, silica, sodium, bicarbonate, chloride, total dissolved solids and temperature.

The equation that relate the content of each sample, according with its origin is the following:

$$Q_{\text{Sample parameter KW-24}} = A\,Q_{KS\text{-}9} + B\,Q_{KS\text{-}10} + C\,Q_{KS\text{-}12} + D\,Q_{KW\text{-}21}$$

$$Q_{\text{Sample parameter KW-26}} = E\,Q_{KS\text{-}1} + F\,Q_{KS\text{-}2} + G\,Q_{KS\text{-}3} + H\,Q_{KS\text{-}7} + I\,Q_{KW\text{-}13}$$

$$Q_{\text{Sample parameter KS-7}} = J\,Q_{KW\text{-}24} + K\,Q_{KW\text{-}26}$$

Solving the systems of equations we obtained the following relative inflow rates by source (statistic average):

| | | |
|---|---|---|
| **Number 3 Shaft:** | | |
| ■ Lubengele Tailings Dam | 22 % | |
| ■ Concentrator Effluent Water | 14 % | |
| ■ Lubengele Sewage | 5 % | |
| ■ **Surface water** | | **41 %** |
| ■ **Old water (aquifers)** | | **59 %** |
| **Number 1 Shaft:** | | |
| ■ Kafue River | 2 % | |
| ■ Lubengele Sewage | 15 % | |
| ■ Kakosa Stream | 19 % | |
| ■ Golf Club Pond | 9 % | |
| ■ **Surface water** | | **45 %** |
| ■ **Old water (aquifers)** | | **55 %** |

**Total Mine Discharge:**

- **Number 3 Shaft** **42 %**
- **Number 1 Shaft** **58 %**
- **Surface water** **43 %**
- **Old water (aquifers)** **57 %**

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