

A COMPUTER MODEL OF CIRCULATING SERVICE WATER
IN SOUTH AFRICAN GOLD MINES

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ABSTRACT

Since there is a general shortage of water on the South African goldfields, the re-use and recycling of water in mines is necessary. Water quality deteriorates with recycling and the reasons and extent of deterioration were researched. A large proportion of the inorganic salts appearing in solution in the water appear to originate from the ore. High sulphate concentrations in particular are noticed in the water after a few cycles. The water becomes unusable unless replaced or purified after a few days. laboratory and field leaching tests were performed to determine the factors affecting the deterioration in water quality. The data was used in a computer simulation model to predict water quality at any time throughout a typical water distribution system underground. The computer model can be used to optimize the re-use of water and predict effects of different management policies.

INTRODUCTION

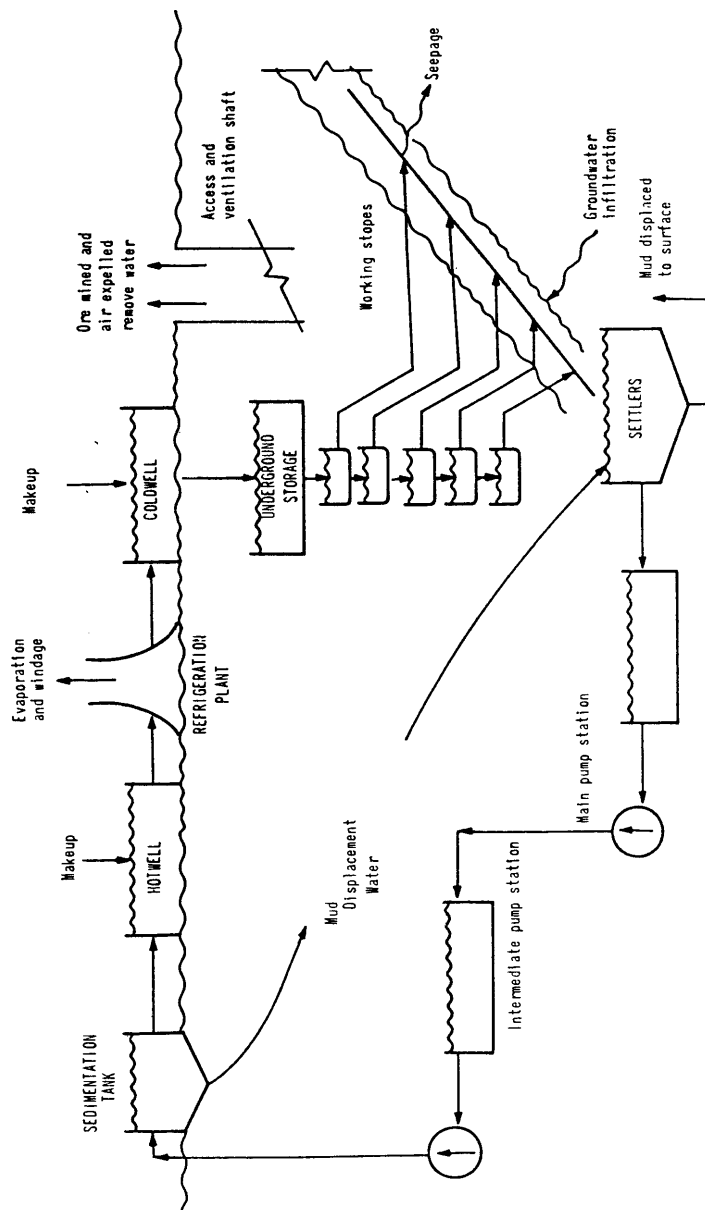
South African gold mines use nearly 2000 million litres of water a day underground. The water is used primarily for dust control and cooling. Owing to the great depths i.e. often over 3000 metres below surface, rock temperatures can reach 65°C. The most efficient method of cooling is by means of spraying chilled water onto the rock. The water is also used for ore moving and to a limited extent for hydraulic emulsions in machinery.

The geological formations in which gold is mined are in the Orange Free State and Transvaal which suffer water shortages. Water is in fact imported from adjoining catchments such as in Natal for domestic drinking purposes. The cost of water is therefore high and re-use of water is encouraged both to conserve water and to minimize the discharge of polluted wastewaters into surface streams. The water requirements of the gold mines are therefore largely met by recycling and only approximately 10% of the requirement is made up from surface water resources. Some mines also have surplus underground water from infiltration and this is used where possible.

The quality of surface water is good and the total dissolved solids content is typically less than 500mg per litre. The quality of ground water where there is any is also generally high as the water originates largely from dolomitic aquifers in the upper strata. Although the water is hard and contains magnesium and calcium carbonates, the dissolved salts concentration is rarely above 1000mg per litre. In the Orange Free State the natural water is known to contain high concentrations of chlorides.

Despite the general high purity of make-up water, concentrations of dissolved and organic salts underground can typically vary from 3000 to 10 000 mg per litre. This water can therefore only be used for limited purposes. Care has to be taken to ensure that it is not used excessively for drinking, in certain machines and with heat exchange apparatus. In many mines there is scaling and fouling of machinery and pipework because of the poor quality of water and in other mines there is corrosion of pipework and other metal-work underground.

Reasons for the deterioration in mine service water can be attributed primarily to leaching from the mined ore. In addition certain pollutants are brought from the source of the water and there is a secondary concentration effect due to the evaporative loss of water underground and in cooling towers. The chemical dosing of water for purification purposes and for corrosion and scaling inhibition can be ruled out as a major contributor owing to the small dosage rates relative to the increase in dissolved solids in the water.



CAUSES OF WATER QUALITY DETERIORATION

After identifying possible sources of chemical salts appearing in the water, laboratory and site testing were performed to evaluate the possible rate of appearance of salts in the water. The complicated nature of the geochemical environment makes an exact quantitative estimation of leaching in any particular circumstance impossible. Nevertheless relative rates of leaching can be assessed with these methods. Once pilot tests had been conducted to identify the prime effects of water quality deterioration, these parameters were studied in more detail. It appeared that the fineness of the crushed ore originating from blasting or drilling was a prime parameter in affecting the rate of geochemical leaching. The composition of the reef i.e. the ore bearing stratum, also is a prime factor. The contact time with the water also affects the amount of leaching from any particular mass of ore. Temperature affects the chemical reaction as well as pH of the water, and in isolated cases possibly the presence of biological matter, in particular thio-bacillus ferro-oxidans and thio-oxidans. The presence of air appeared in all cases sufficient to saturate the water with oxygen and therefore was not a limiting factor.

Laboratory tests were performed by immersing samples of ore crushed to various finenesses in one to two litres of water. Temperature was controlled by means of a bath and air was bubbled through the samples to agitate and provide sufficient oxygen. Datum tests with pure distilled water were performed simultaneously. Tests were run for longer than a month and conductivity and various dissolved salt parameters were measured regularly as well as pH and temperature.

The rate of leaching of a typical batch of samples is indicated in Fig. 2. It will be observed that the leaching rates were most rapid during the first day and then gradually decelerated as the soluble chemicals in the ore were depleted. Confirmatory tests with initial water concentrations at various levels indicated that saturation of the water was not the cause for the reduction in leaching rate. The effects of different masses of crushed ore, different sizes of particles and temperature, presence of air and agitation were studied in different samples.

The increase in total dissolved solids in the water varied from 5 to 30 grams of dissolved solids per kilogram of crushed ore.

The following inorganic salts were detected in the water samples analysed: sulphates, chlorides, carbonates, nitrates, calcium magnesium, sodium as well as other elements in the relative order indicated. The concentration of sulphates in milligrams per litre (mg/l) of SO_4 was typically one half of the total dissolved solids concentrations in

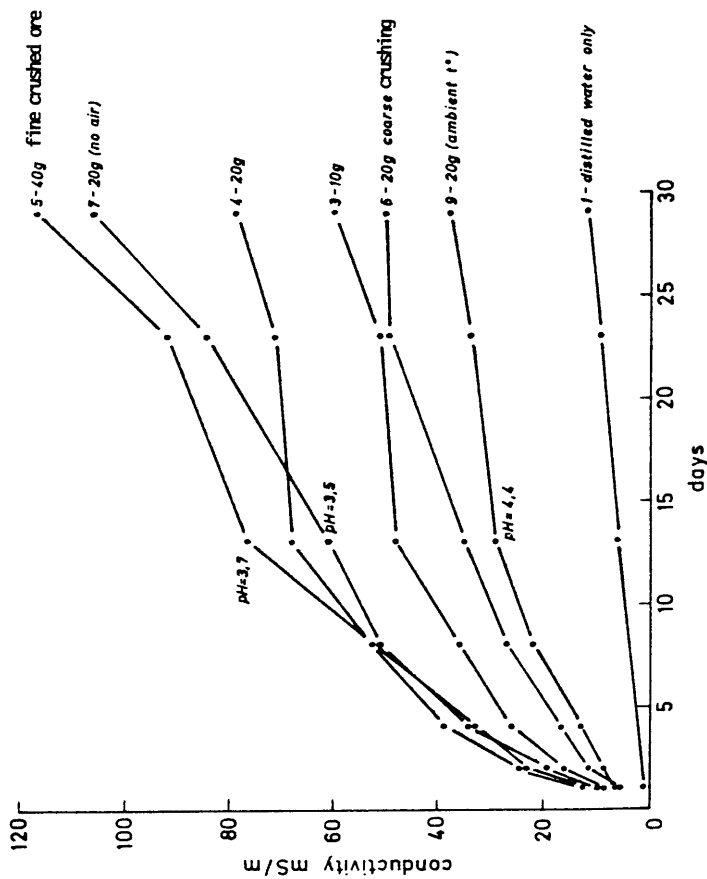
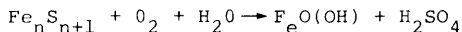


Fig.2: Lab.leaching tests on crushed ore

mg/l. This can be attributed to the high sulphide concentration in the ore (up to 8 percent sulphur by mass). In the presence of oxygen and water some sulphide forms in particular were oxidized to sulphates. The iron from the reaction was often precipitated as iron oxide and the chemical reaction which is well known in both coal mining and gold mining pollution problems is indicated below:



The pH of the solution remained between 6 and 8 for the first week in most cases. By the end of the second or third week the pH often dropped to below four. As the pH dropped an acceleration in the leaching rate, as indicated by an increase in conductivity and total dissolved solids, was evidenced. The presence of bacteria was noticed in isolated samples after a month of testing, but not in all samples in which the pH dropped or the rate of leaching was noted to be particularly high.

It is therefore concluded that the leaching reaction is primarily a geo-chemical reaction and biological reaction can be said to be small in the environment studied.

The application of the laboratory results to the field conditions is particularly complicated. It is not only the total mass of fine ore generated by mining operations which is of importance, but also the exposed surface of the fine which settles out rapidly in the horizontal drains taking water back to the shaft. Only the surface layer appears to leach at a high rate and this may explain the relatively low leaching rate underground as compared with the maximums measured in the laboratory. Tests in the field could only indicate increase in total dissolved solids of the order of 100 to 300 mg/l per cycle as the water ran from the workings back to the shaft.

It was therefore not possible to insert the complete chemical process in equation form into the computer model of the system. Empirical relationships were therefore used and these will have to be verified for each mine and each ore mined.

COMPUTER SIMULATION MODEL

The rates of use of water underground vary considerably during the day and are highest during the drilling and ore moving shifts. Water is often stored in the cascade dams underground or in surface dams at various stages. Fluctuation in water quality is therefore difficult to predict unless the volumes of all the storage dams as well as the flow rates in the various conduits can be modelled. External flows such as evaporation, water removed with the ore, seepage and intermittent make-up additions also affect internal volume, flow rates and quality. The most logical method of simulating the process was with a digital computer model. This was adapted to a micro computer with considerable success.

A general simulation program was developed for simulating specific models of mine water systems. Models are constructed in general form for particular mines. The sizes of dams, the positions and the capacities of conduits and the usage hydrographs can then be specified by the user. The operating relationships which, for example, define the salt leaching rate, criteria for adding make-up water, starting pumps etc. are programmed as part of the model source code. The computer program will then be used to simulate the model. Flow rates, volumes and dissolved salts concentrations are displayed at specified time intervals as output.

Mathematical Basis of Model

The computer model was prepared in a modular structured fashion for easy updating and modification. The varying volumes and salt concentrations are described in models by means of first-order ordinary differential equations. Alternative methods of solving the equations numerically are built into the simulation program and the methods can be selected to suit the particular equations. In many cases a fast algorithm is suitable while in other cases a more accurate algorithm is required to solve the equations with sufficient accuracy on a numerical basis.

In a mine water system many processes occur simultaneously and the net effect is either to increase or decrease the dissolved salt concentration of flows and water volumes with time. The salt concentration of water in a storage element, such as a dam, depends on the mass of salts and the volume of water in storage, and the salt concentration of any inflow and outflow. Denote Q_1 and Q_2 as the inflow and outflow to a dam, and denote C_1 and C_2 as the corresponding salt concentrations. If M is the mass of dissolved salt and V the dam volume at a certain time t , then the rate of change of water volume and salt mass with time is

$$\frac{dV}{dt} = Q_1 - Q_2 \quad (1)$$

$$\text{and } \frac{dM}{dt} = Q_1 \cdot C_1 - Q_2 \cdot C_2 \quad (2)$$

If perfect mixing is assumed to occur in the dam then the salt concentration of the outflow is

$$C_2 = \frac{M}{V}$$

A mine water model basically consists of equations (1) and (2) for each storage element wherein the volume and salt mass change with time. Other relationships govern flow rates and changes in salt concentrations of flows between storage elements.

Starting with known or assumed initial values for all M , V and C the differential equations are numerically solved

using Euler and Runge-Kutta methods. Values of M, V and C are determined at each iteration time-increment during the simulation and can be displayed as output. The stability and accuracy of the solution depends very much on the time step and numerical method selected.

The model was verified using data from a gold mine in the Orange Free State in South Africa. The model is now being applied to different mines.

Considerable effort has to be expended in gathering data for the model it is found. Owing to the unpredictable changes in mining patterns as the characteristics of the Reef change, the water reticulation pattern is continually being extended or altered. The conduits and dams constructed therefore form a complex storage distribution system which is often not monitored as it is designed to operate automatically. Flow rates, stored volumes and times of makeup were therefore often difficult to ascertain. Considerable cooperation was experienced from mine officials which made the program a success.

The model can thus be used to predict the water quality at any time at any point in this system for alternative operating conditions. Fig. 3 indicates a typical variation in flow rate at the workings underground and Fig. 4 indicates the water quality variation in the water pumped to the surface at the same gold mine over a period of a week.

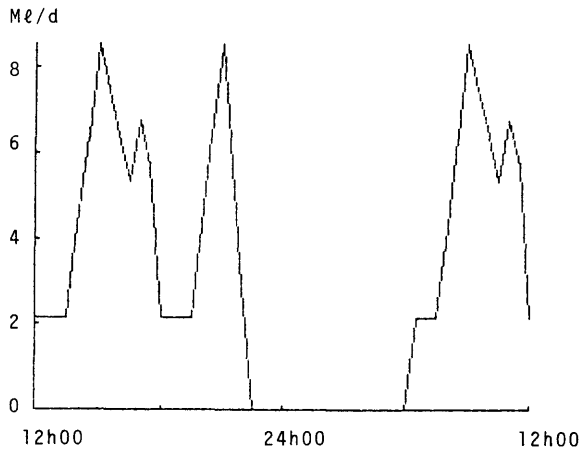


Fig. 3 Flowrate from Coldwell to underground (Me/d)

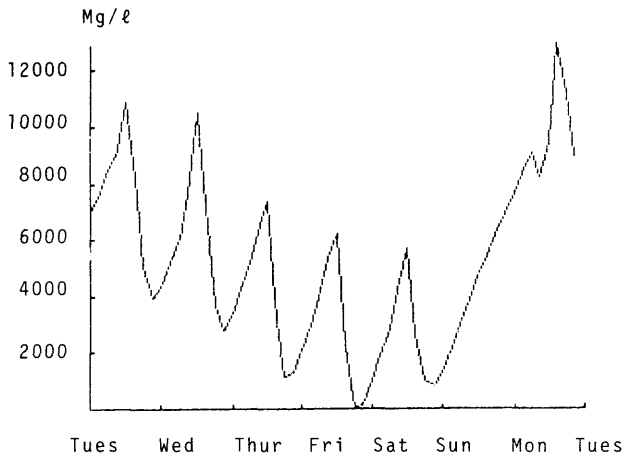


Fig. 4 Salt Concentration in the Settlers

The initial conditions in starting up and running the model could be varied to an extent. That is the initial water quality could be varied assuming that different make-up quantities of surface water could be used to replace poor quality water in the surface storage dams over a weekend when mining activities were minimal. By comparing alternative management policies in this manner it is possible to reach a minimum cost procedure for maintaining the water quality at a certain selected level. The rate of usage underground was assumed fixed by the mining operation and therefore only storage dam capacities and make-up rate could be varied in this way.

It is also possible that mining methods could be varied to affect the water quality. It was recognised that the contact time between fine ore in suspension and in the return water systems had an important bearing on the rate of deterioration in the water quality. Alternate methods of returning the water were therefore investigated in order to optimize the water quality. In this manner the effects of pollution can be minimized, therefore requiring less surface make-up water and reducing mining costs in eliminating to a large extent scaling and erosion.

CONCLUSIONS

Although research still has a long way to go before the water quality problems in South African gold mines can be solved, alternative solutions can now be investigated in a more rational method than without data or tools at the disposal of the planner. The effects of mining operations on geo-chemical pollution of the water can be gauged from laboratory tests and resulting data fitted into a computer simulation model in order to predict in advance the water quality variations throughout the water reticulation system. Alternative reticulation systems can be investigated and the management of the water system optimized in order to minimize the consequences of pollution and the cost of clean make-up water. It is hoped to develop the model to a stage where it can be used in analogue fashion by mine operators for investigating alternatives. This may be possible with a display screen and computer aided design program at the disposal of the mining engineer.

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