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CALCULATION OF MINE WATER INFLOW USING INTERACTIVELY A GROUNDWATER MODEL AND AN INFLOW MODEL

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ABSTRACT

The uncertainty of the pre-evaluation of potential ground water inflow rates in underground mines results in difficulty in planning and costing the water related activities of the mines. This paper presents a procedure for making a rational assessment of the potential inflows.

The method is based on an interactive operation of two computer models: an inflow model and a ground water finite element model. Both are first calibrated using existing information obtained from aquifer monitoring. In a second phase, the models predict the potential inflows as well as the impact of mine dewatering on the piezometric surface. Both the models used are based on a non linear relationship between tonnage mined and inflows. A phased behaviour in the rates of inflow increase is noted.

The interactive mode of operation of the models results in confidence in the prediction because the models output (calculated inflow rates and piezometric levels) during the calibration phase are checked against the historical data. It is concluded that the method can provide mine management with guidelines for dewatering requirements under the condition that reliable data on the history of piezometric levels be available.

1 INTRODUCTION

The gold mines in South Africa are known to have a wide range of ground water inflow rates during the course of their life. Magnitude of inflows have been known to vary from "dry" to more than 100 Ml/day. The uncertainty in the pre-evaluation of inflow rates results in difficulties in planning and costing the dewatering system, the water treatment plant as well as the mine water supply. This paper presents a procedure for making a rational assessment of the potential ground water inflows in gold mines, with particular reference to geological conditions in the Free State Gold Fields.

The magnitude and duration of ground water inflow in underground mine depends "inter alia" on the nature of the water bearing horizon, and in consolidated rock, one can distinguish:

- the sudden inflow of high magnitude occurring when a major structural feature such as a fault is encountered
- the fairly steady inflow from fractures and joints in the rock mass assimilated to a homogeneous aquifer.

Prediction of the location and magnitude of the inflow from a major structural feature is based on a thorough structural analysis of the geology, and this aspect is not covered in this paper.

The method proposed in this paper makes use of computer modelling techniques, and relies on existing historical hydrogeological data for calibration purposes.[1]

2 GEOLOGY

The geological succession includes a sequence of sub-horizontal Karoo sediments up to 800 m thick in places, underlain by variably dipping and faulted Ventersdorp lavas, in turn underlain by Witwatersrand Supergroup rocks.

The rocks of the Witwatersrand Supergroup in the area have been displaced by a number of north-south trending normal faults. The area has also been intruded by dolerite dykes and sills of post-Karoo age.

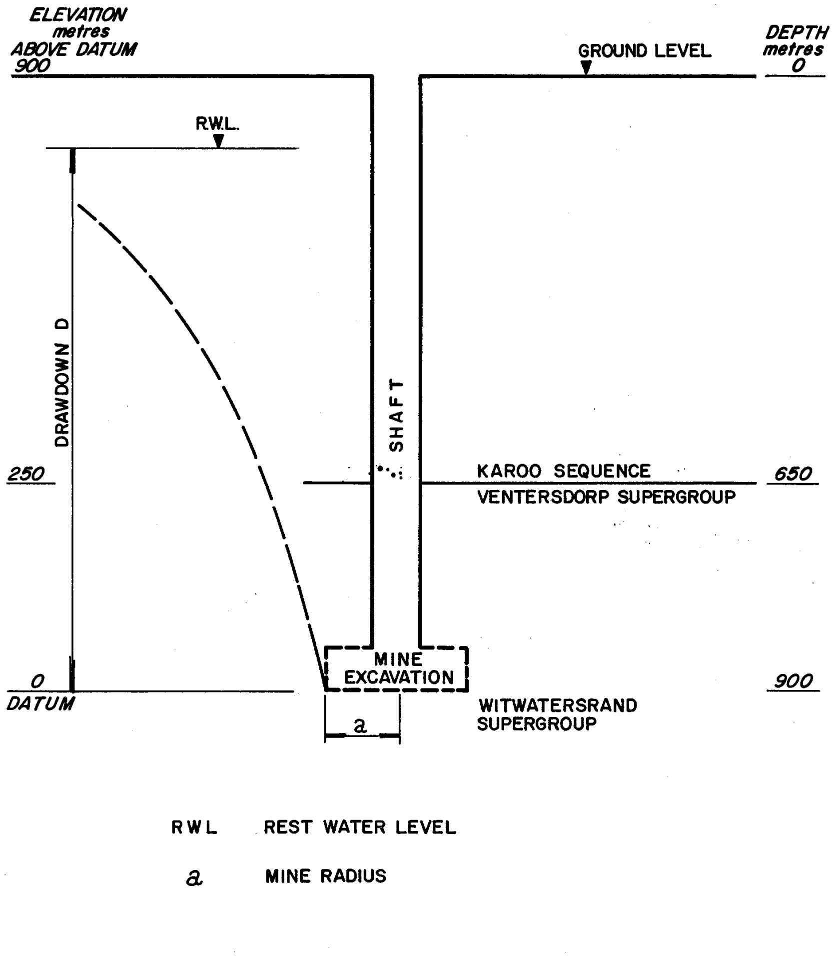


FIG 1 AQUIFER AND MINE CONFIGURATION

The thick sequence of Karoo sediments throughout the gold field of the Orange Free State are relatively impermeable and it is the underlying faulted and folded Ventersdorp and Witwatersrand rocks that form the main confined to semi-confined aquifers, which are the main sources of inflows into the mines.

BASIC CONCEPT IN INFLOW CALCULATIONS

3.1 Inflow model

Mine dewatering problems can be simulated by assuming a large diameter well and a series of linear underground roadways.
The mine geometry consists of an excavation about 2 m high, roughly plan circular at the bottom of a grouted vertical shaft. This geometry is similar to a large borehole, of radius equal to the approximate mine radius, over the length of the cased shaft but only open over the last 2 m of the bottom. (Fig 1).

The conventional approach to dewatering prediction is to calculate inflow from an aquifer at a flow rate which will lower the piezometric surface below the bottom level of the excavation at the assumed mine radius. The pump rate of the well is taken as equivalent to potential inflow quantities.

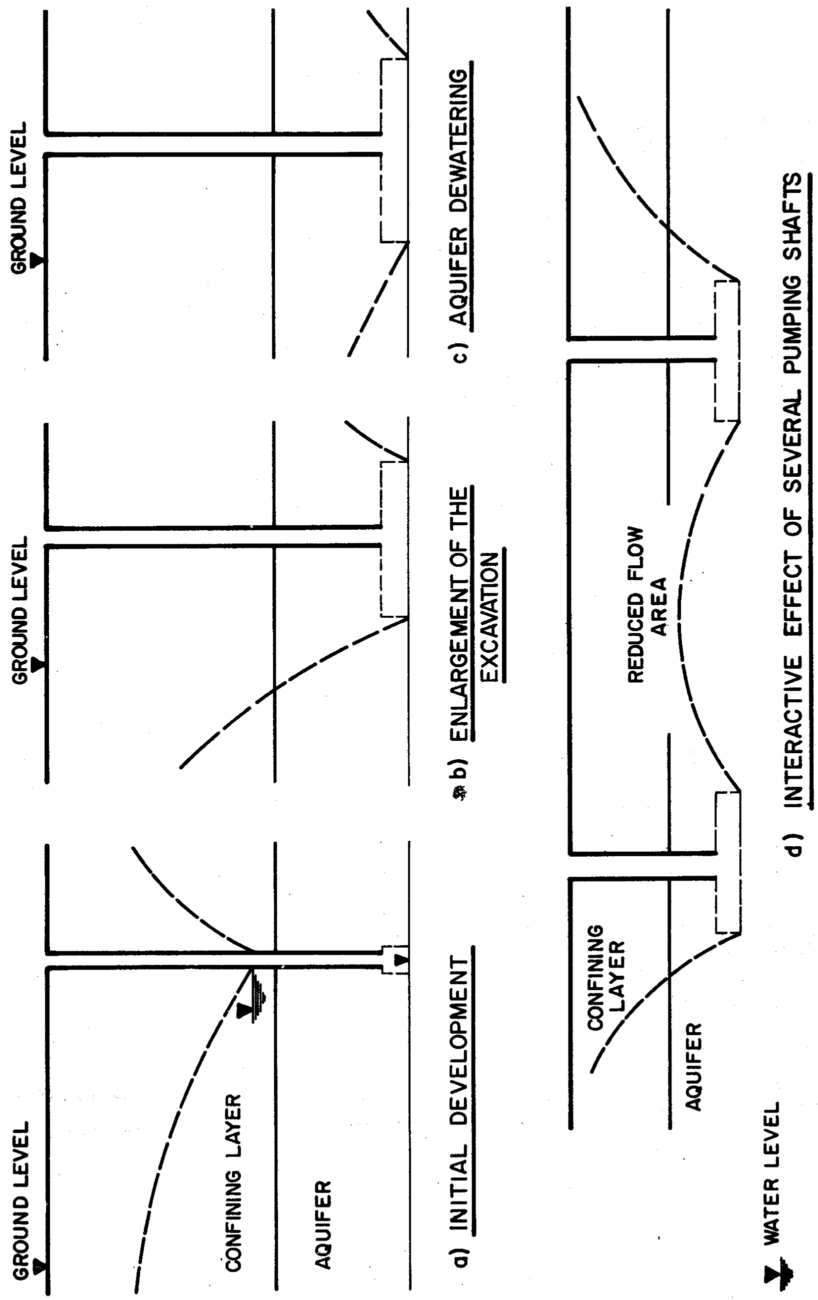
Drawdown caused by pumping water from a borehole has two components:

- laminar flow component proportional to the pumping rate
- turbulent flow proportional to a certin power of the pumping rate. This component varies with the geometry and the size of the intake area of the borehole.

3.2 Dewatering process

The dewatering process of a mine in a confined aquifer can be divided in 4 successive phases, as illustrated in Fig 2 (a to d):

- Initial development of the excavation: high turbulent flow component caused by the small intake area. Pumping rates can be relatively low with inefficient drawdown characteristics.


GROUND LEVEL
CONFINING LAYER
AQUIFER
a) INITIAL DEVELOPMENT
GROUND LEVEL
b) ENLARGEMENT OF THE EXCAVATION
GROUND LEVEL
c) AQUIFER DEWATERING
CONFINING LAYER
AQUIFER
REDUCED FLOW AREA
WATER LEVEL
d) INTERACTIVE EFFECT OF SEVERAL PUMPING SHAFTS

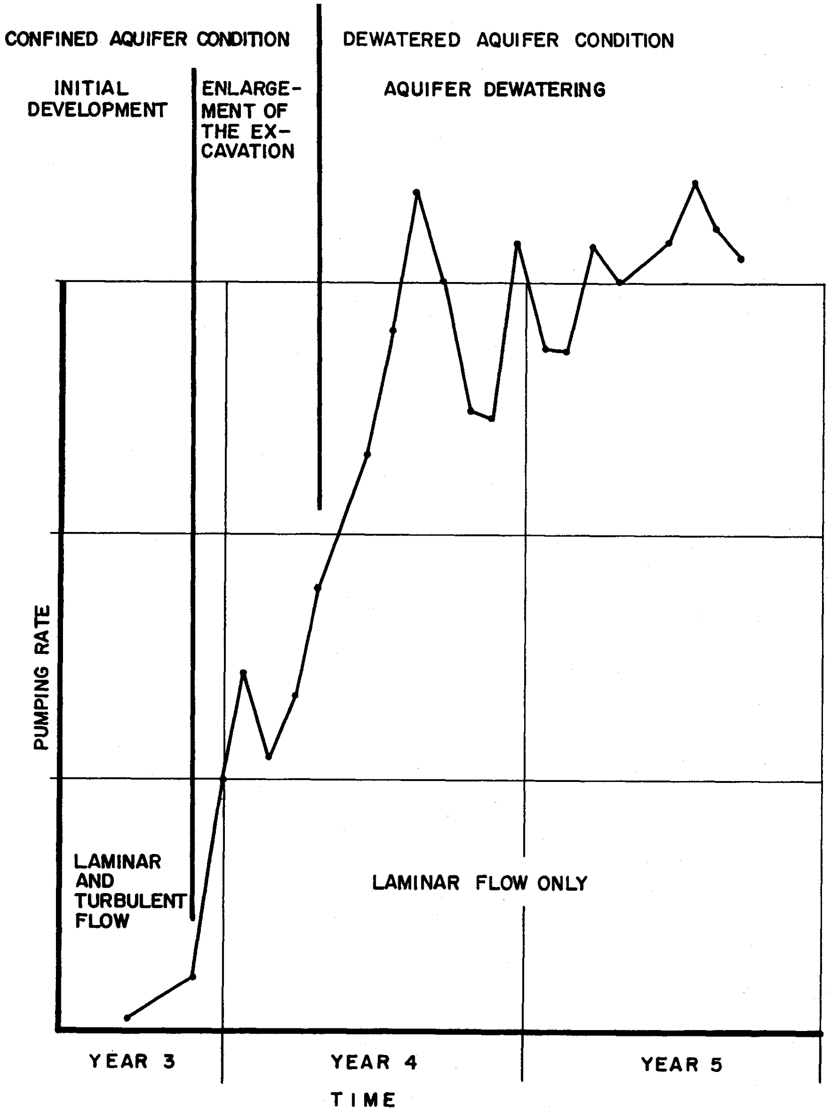


FIG 3 MINE DEWATERING PHASES IN TYPICAL GOLD MINE

- Enlargement of the excavation: the turbulent flow decreases and inflow increases consequently. This is the phases of a rapid increase in inflows.

- Aquifer dewatering: The piezometric surface drops below the confining layer resulting in a change of the storage coefficient into a specific yield. Additionally, the transmissivity decreases with the saturated thickness of the aquifer. Inflows continue to increase but at a slower rate.

- Interactive effect of several pumping shafts: When several mines are operating at close range, each of them diverts some part of the flow that would otherwise reach the other mines, resulting in a reduction of the inflow.

  Fig 3 shows a typical inflow record from an underground gold mine in the Orange Free State, in which the first three phases can be identified. Phase 4 is described by Venter (1986).

In general the rate of inflow to a mine is seen to behave in a non-linear fashion. Inflows are noted to decrease after reaching a certain peak. This seems to occur approximately 8 to 12 years after the start of mining.

4 INFLOW EQUATION

Several theoretical inflow models are available. However, the most appropriate seems to be the non-linear radial flow model developed by Schmieder (1978a, b, 1979) and Perez-Franco (1982) and summarised by Singh and Atkins (1984). The analytical solution based on unsteady flow condition requires the following parameters:

- Aquifer characteristics

  Transmissivity can be deducted from test pumping and packer testing results. Storage coefficient can be obtained from test pumping. Regional values of the aquifer characteristics can also be back calculated using historical piezometric data.

The drawdown to be obtained is the difference between the mine lower level and the initial static water level. Historical piezometric fluctuation records are also useful in calibrating the aquifer characteristics.

- Aquifer geometry

  The drawdown created by the pumping in the mine depends on the aquifer geometry, ie the presence of lateral boundaries as well as the presence of a confining or semi-confining layer over the aquifer.

- Mine geometry

  The inflow equation requires the water level be lowered down to the lower level at the edge of the mine. Some simplification of mine geometry is required to convert the actual geometry into a circular geometry centred around the bottom of the shaft.

INFLOW PREDICTION METHOD

When the required data listed in the section above are available, it is theoretically possible to predict the inflow rate during the life of the mine. But if historical pumping and piezometric data also exist, it may be possible to test the validity of the inflow prediction. Two computer models working interactively can be used for this purpose:

- an aquifer model: using historical piezometric data, the aquifer model will calibrate the regional aquifer characteristics and the aquifer geometry. In the second stage, it will predict the long term piezometric fluctuation under certain pumping conditions.

- an inflow model : using the regional aquifer characteristics calibrated by the aquifer model, the inflow model is calibrated by back calculating the historical pumping rates. In the second stage, it will predict the long term inflow rates to the mine and for specific levels.

The interactive process is schematically presented in the flow chart of Fig 4.

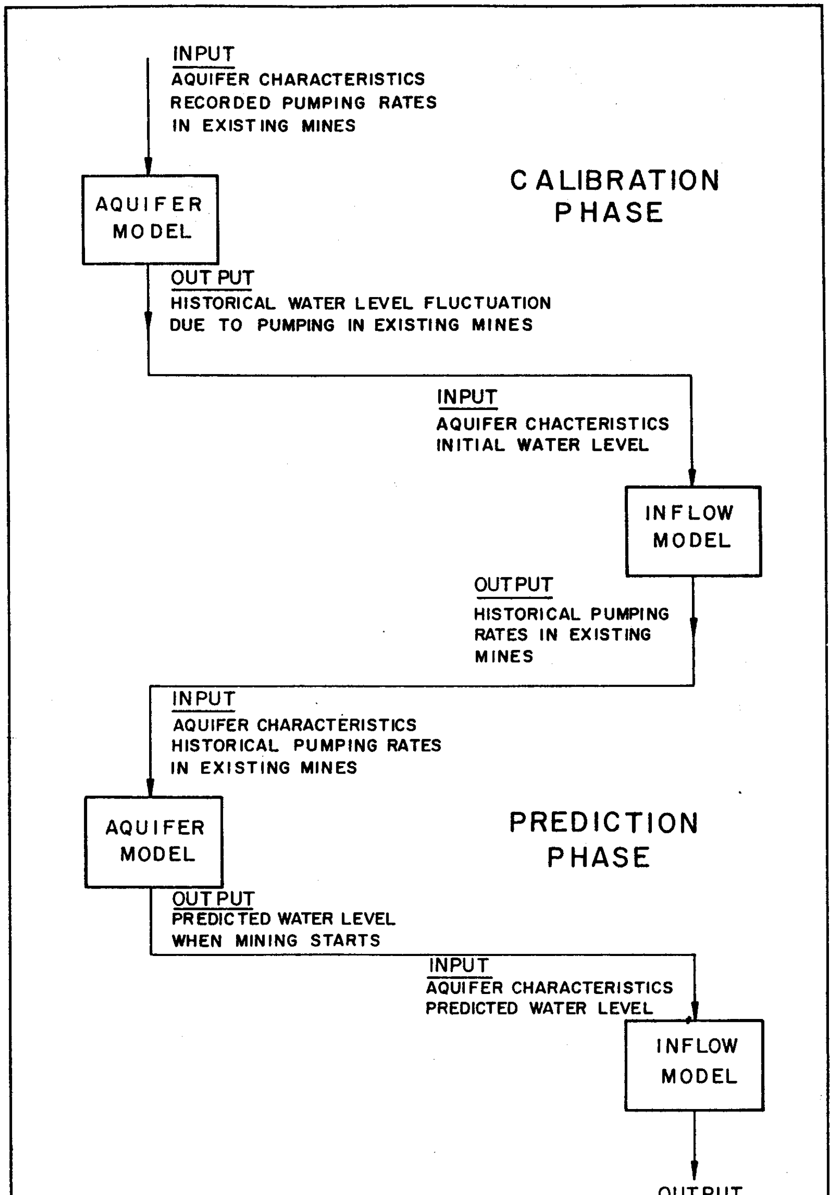


FIG 4 INFLOW PREDICTION MODELLING FLOW CHART

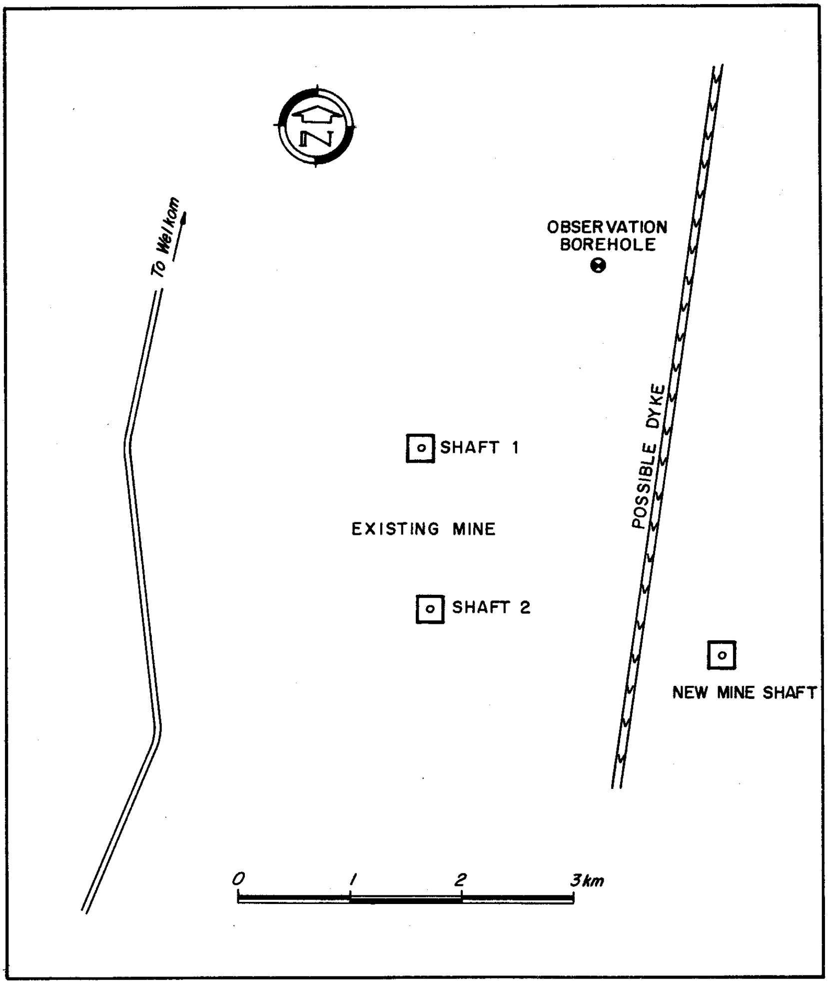


FIG 5 LOCATION MAP

6 APPLICATION

The method described above was used to predict the ground water inflow rate in a new gold mine in the Orange Free State (Fig 5). In this particular case, an adjacent mine had been operating for the last few years with the consequences that:

- historical pumping and piezometric data were available
- the pumping from two shafts of the existing mine has influenced the water level in the area of the new mine. This had to be taken into account in estimating the drawdown required to dewater the new mine.

The aquifer consists of the faulted and folded Ventersdorp and Witwatersrand Supergroup, overlain by the semi-confining Karoo Sequence. The average permeability obtained from packer testing results is 0,016 m/day. The initial static water level was about 110 m below ground level in 1980. Due to the influence of the dewatering in the operating mine and possibly of other mines further away, the water level has dropped, and this drop has been monitored in an observation borehole marked OB on Fig 5. Historical pumping data were also available for the existing mine (Shaft 1 and 2 on Fig 5).

4.1 Aquifer model

The aquifer model is a finite element model with 164 elements and 177 nodes. It covers an area of about 10 km in radius around the new shaft (Fig 6).

A no-flow boundary condition was set on the northern boundary of the model to represent the influence of past pumping from distant mines. A constant head condition was set on the eastern, southern and western boundaries to represent the extension of the aquifer over a long and unknown distance in these directions.

The mesh of the model was shaped to represent a possible dyke effect, should it be required, although no such effect has yet been identified.

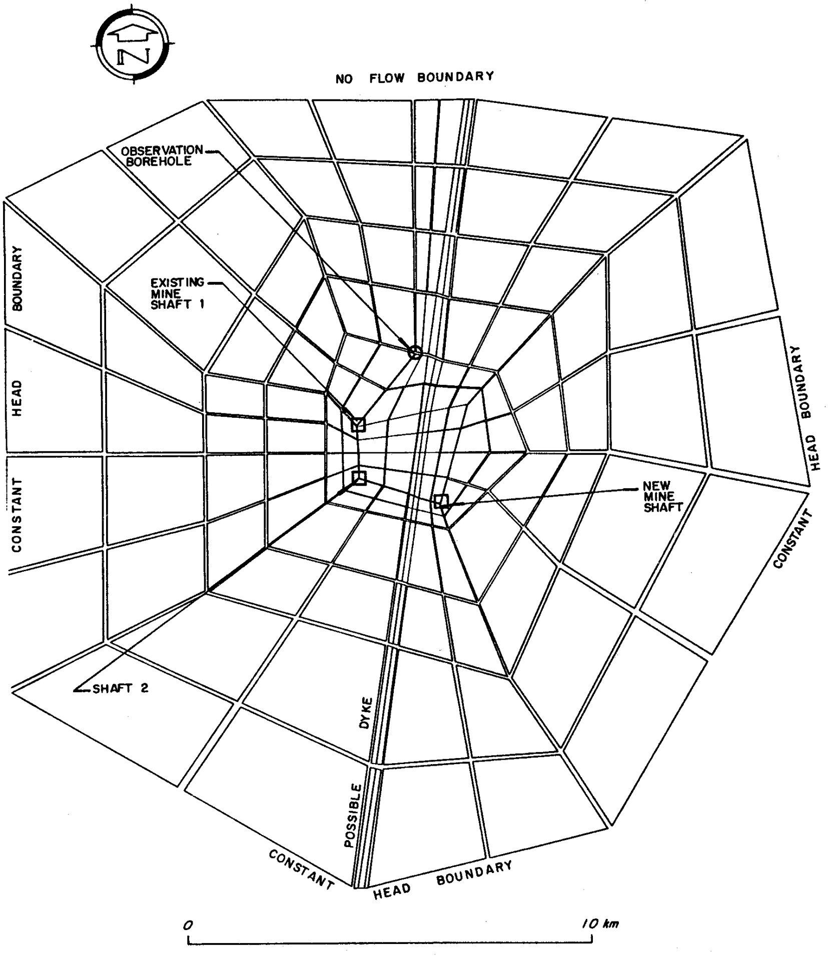


FIG 6 FINITE ELEMENT GROUND WATER MODELLING

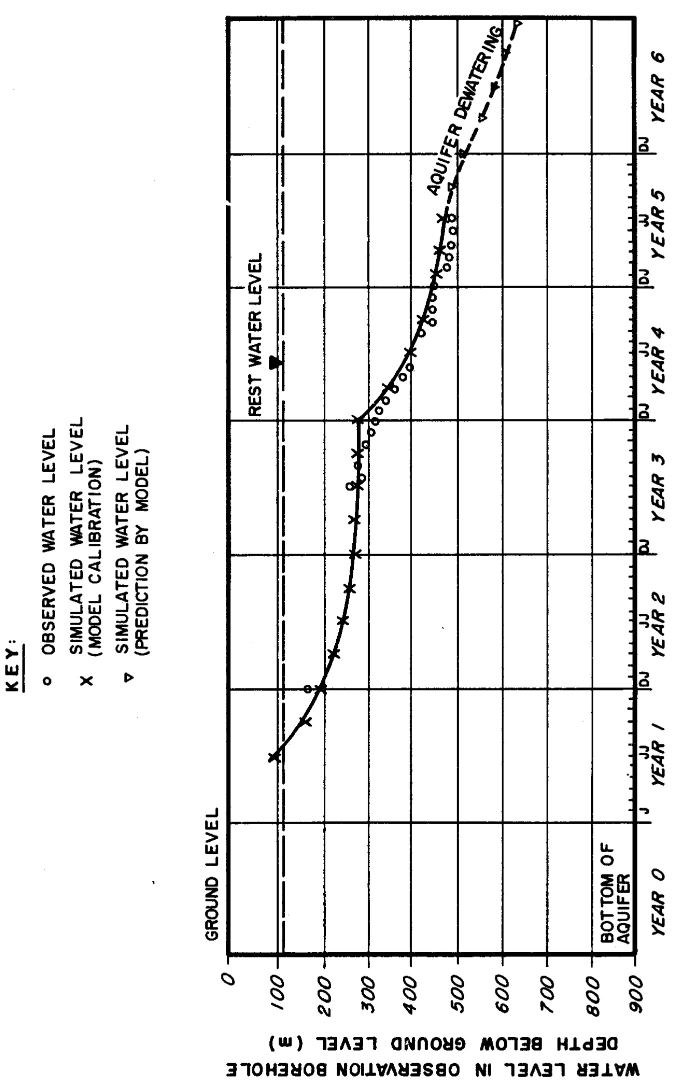


FIG 7 CALIBRATION OF FINITE ELEMENT GROUND WATER MODELLING

PREDICTED PIEZOMETRIC SURFACE
JANUARY YEAR 6

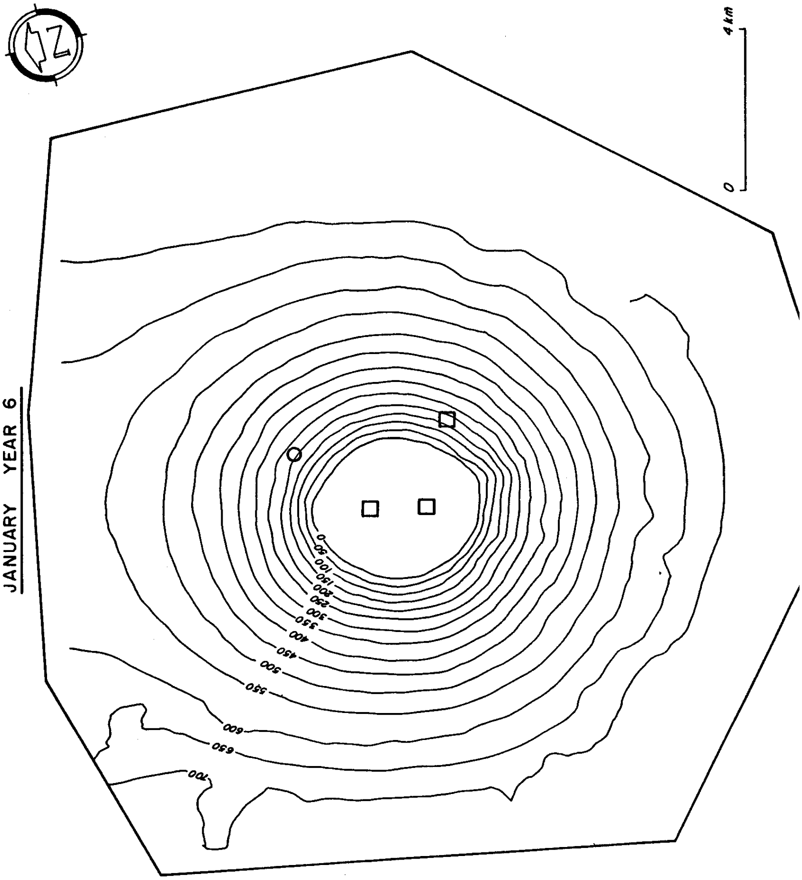


FIG 8

The aquifer consists of 250 m of Ventersdorp Supergroup and the top of the Witwatersrand Supergroup, semi-confined below 650 m of Karoo sequence.

The original rest water level was set everywhere at 110 m bgl.

The aquifer model was calibrated using the following parameters assigned to every element:

- permeability : 0,024 m/d
- transmissivity : 6 m2/d
- storage coefficient : 0,0001
- unconfined storage coefficient : 0,001
- vertical permeability of the confining layer : 0,00011 m/day

A permeability of 0,016 m/day obtained from packer testing was initially entered in the model. This value was then increased up to 0,024 m/day until a good fit was obtained between calculated and observed water level in the observation borehole (Fig 7).

The aquifer model was then used to generate the predicted piezometric contours at the time when the new shaft would start operating (Fig 8).

6.2 Inflow model

The inflow model calculated the inflow rate at a certain time given the drawdown to be obtained at the edge of the mine, the aquifer characteristics and the mine radius. The model was developed in such a way as it can calculate the inflow under:

- laminar and turbulent flow conditions
- laminar flow only

It was calibrated using the historical pumping data from the operating shafts of the existing mine (Fig 9).

a) initial development: laminar and turbulent flow, confined aquifer
b) enlargement of the excavation: laminar flow only, confined aquifer

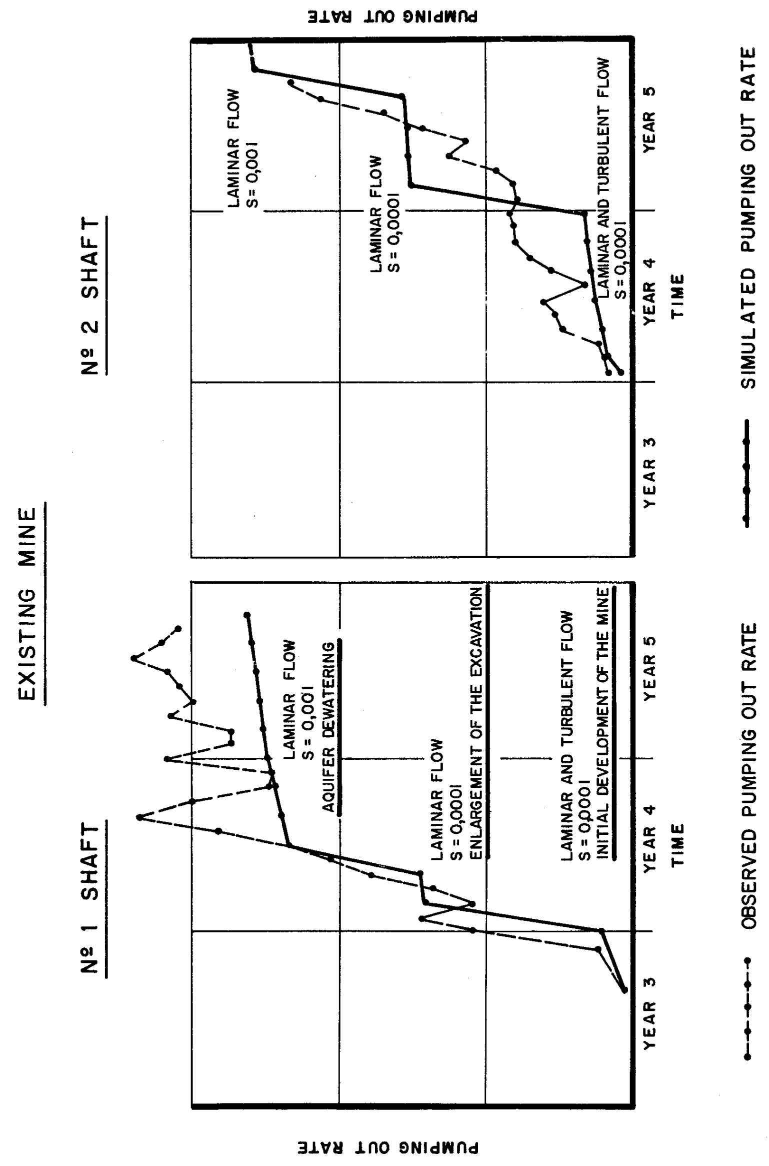


FIG 9 CALIBRATION OF INFLOW MODEL

c) aquifer dewatering : laminar flow only, but the aquifer becomes unconfined as the water level dropped below the confining Karoo Sequence.

The inflow model was later on used to predict the inflow rate when the new shaft starts operating. According to the piezometric plan predicted by the aquifer model, it was deduced that the level of ground water above the bottom of the mine was about 350 m.

The inflow was therefore calculated assuming:

- a drawdown of 350 m
- laminar and turbulent flow conditions during the first 3 months of operation
- laminar flow after 3 months
- pressure flow in a confined aquifer during the first 6 months
- aquifer dewatering and gravity flow afte 6 months

The predicted inflow curve is given in Fig 10.

7 DISCUSSION

The interactive mode of operation of the aquifer model and the inflow model would result in a great confidence in the prediction as the parameters required by the modelling were cross-checked using both models. Furthermore, the validity of the prediction theory was also checked by the calibration of the inflow model.

However, the reliability of the method depends heavily on the quality of the available data. In this particular case, the available data were sufficient to develop the models and test the method, but their weakness should not be underestimated:

- water levels were observed regularly in only one borehole. If several observation holes had been available, it would have been possible to deduce any anisotropy or heterogeneity in the aquifer and obtain a better regional transmissivity map.

- The water level was measured in the observation borehole since only June of year 3. Beforehand, the water level was measured only once in December of year 0 resulting in the following assumptions:

  - the initial rest water level is believed to have been at 110 m bgl

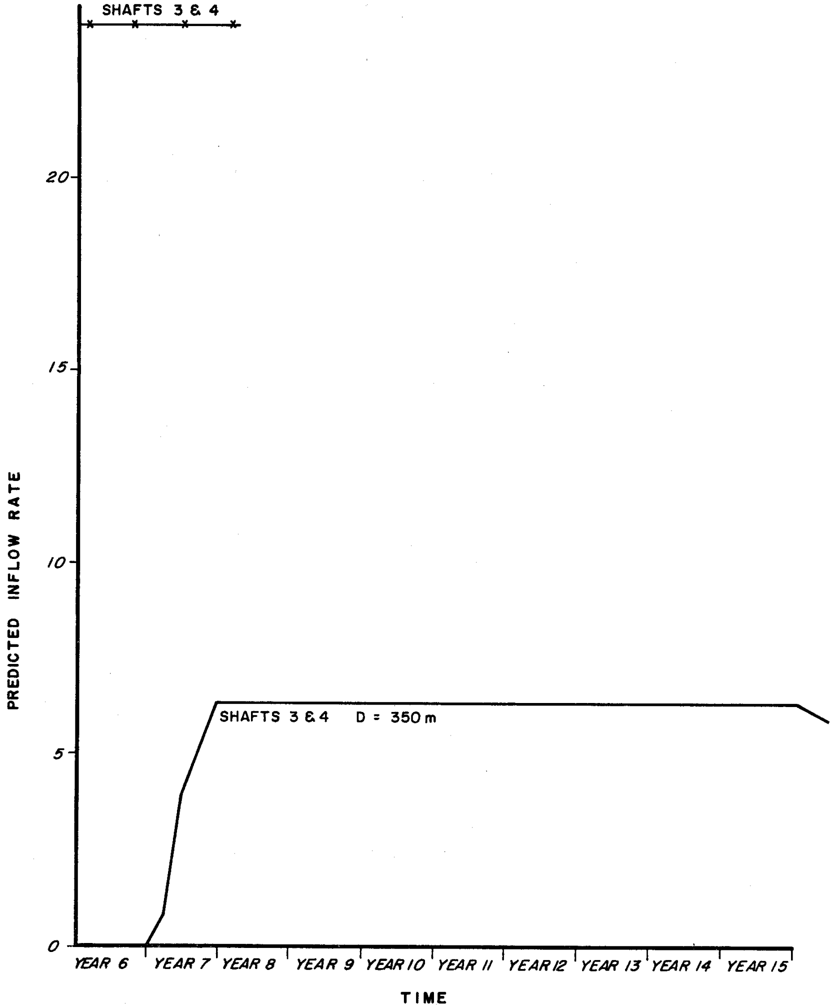


FIG 10 PREDICTED INFLOW RATE

- it was necessary to assume a certain pumping history during the shaft sinking period

- If the water level measured in year 0 is wrong, then the model prediction could change dramatically:

  - the initial water level would be set at about 270 m bgl
  - no pumping during shaft sinking would be required
  - the transmissivity to reproduce the water level drawdown in the observation borehole would be much greater and consequently, the predicted inflow would also be higher.

8 CONCLUSION

Accepting the assumptions given, the following conclusions can be drawn:

- The computer technology and the software available to date allow the generation of sophisticated and rational methods to simulate aquifer behaviour and predict the impact of ground water on mining. By careful calibration of the models, a high degree of confidence in the validity of the prediction can be obtained.

- The condition "sine qua non" to implement this technique is that reliable data on the history of piezometric levels before and during mining activities be available. Most of the required data could be obtained from monitoring the water level in the exploration boreholes, for which purpose it is necessary to equip the exploration holes with a proper casing to prevent their collapse and to seal off the upper less important aquifer (Karoo).

- The method provides mine management with guidelines for initial underground pumping requirements as well as ongoing dewatering requirements and assists management to design ways of minimising impacts and costs of dewatering.

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