APPLICATION OF COMPUTER MODELING FOR THE DESIGN OF OPEN PIT MINE DEWATERING

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ABSTRACT

The copper-cobalt mines in the Kolwezi area of Shaba, Republic of Zaire have a complex geologic and hydrogeologic conditions. The presence of water bearing strata within the ore-body and in the overburden complicates the open pit mining operation. Pumping of large volumes of ground water from dewatering wells installed within and on the perimeter of the open pits and from pit sumps is necessary at an early stage of mining. Mine dewatering is an important part of mine planning.

Computer modeling with the use of a three dimensional finite-difference ground water flow model was used to simulate dewatering schemes for three open pit mines in an area called Dikuluwe-Mashamba.

This presentation is a continuation of a paper by the same authors entitled "Hydrogeology and Drainage of Copper-Cobalt Mines in the Kolwezi area of Shaba, Republic of Zaire". Included are a description of the computer model, calibration procedures used and the results of simulation of dewatering in several schemes.

INTRODUCTION

In order to determine the requirements for dewatering of the DIMA open pit mines, the flow of ground water both within the DIMA mine area and in an adjacent area surrounding the mines was simulated using the Trescott-Larson 3-D finite difference ground water model. Used by the United States Geological Survey since 1975 in simulating flow of water in extensive multi-layered aquifer systems, the Trescott model allows the hydrologist to simulate the effects of pumping wells on the natural flow system. The procedure which was used in this modeling exercise was first to simulate the steady state hydrologic regime of the area prior to the development of the open pit mine and mine dewatering, and then to replicate the history of the decline of the potentiometric surface in the DIMA area from September, 1974 to

June, 1984 by incorporating the historic pumping in the area into the model.

Although the complex hydrogeology of the DIMA area could not be modeled exactly, through careful adjustment of the boundary conditions, the location and rates of recharge/discharge, and the hydraulic properties of the media, the model was calibrated so as to yield predicted water surface levels which closely matched those actually observed. Great care was taken in the calibration procedure to ensure that agreement between predicted and observed potentiometric surfaces was not achieved at the expense of using boundary conditions and hydraulic parameters which had no physical (hydrogeological) basis.

Brief Description of the Ground Water Flow Model

The computer program which comprises the ground water flow model used in this study was developed by Trescott and Larson of the United States Geological Survey (USGS) in 1975. Subsequently, several modifications and corrections to the model have been made by USGS personnel in order to improve the rate of convergence of the solution routine and to permit the use of head-dependent sources and sinks (Torak, 1982). These changes have been incorporated into the program used in this study. In addition, some modifications to the program were made by the authors of this paper.

In the Trescott model, the spacial domain is discretized into blocks in which the hydraulic properties of the medium are assumed to be homogenous. These hydraulic properties are then assigned to a node located at the center of this block. At each centrally located node, the partial differential equation describing the flow of water is replaced by an algebraic equation in which each derivative is replaced by its finite difference approximation evaluated at the node. This results in one equation for each node at which the value of hydraulic head is unknown. The resulting system of algebraic equations is solved using an iterative method known as the strongly implicit procedure (SIP). When transient problems are simulated, the time domain is also discretized and the system of equations is solved at every time-step.

Each node on the boundary of the flow domain may be treated as either a prescribed head node or as a prescribed flux node. Vertical flow may be modeled by either of two methods. The first method simply solves the 3-D ground water flow equation while the second method, called the quasi 3-D method, solves the 2-D ground water flow equation in each horizontal layer of nodes and then couples the layers by a leakance coefficient to account for vertical flow.

The uppermost layer is treated as an unconfined aquifer while all lower layers are treated as artesian aquifers. In all cases, the bottom of the lowest layer is assumed to be impermeable.

In general, the user must specify the storage coefficient and transmissivity for each node in a confined layer and for the uppermost, unconfined layer the user must specify the specific yield and hydraulic conductivity at each node. The leakance coefficient must be specified for each pair of nodes associated with adjacent layers. The period of time over which a transient simulation is to be performed, and the time interval, must also be specified by the user. The location and pumping rates for wells must be specified at each time interval of the simulation.

Description of DIMA Mines Ground Water Modeling

The horizontal finite difference grid constructed for the DIMA model was centered at Lambert coordinates. The horizontal grid spacing was 100 meters in the center of the grid. Outside of this area, the horizontal grid spacing was expanded by a factor of 1.5 between adjacent block in the X and Y directions as shown on Figure 1.

The initial hydraulic parameters for the model were determined from the results of pumping tests performed on four wells in the DIMA mine area. Maps of transmissivity (or hydraulic conductivity) and storage coefficient were prepared for each layer based on the results of the pumping tests and on basic geological level maps. (A similar map was prepared showing the estimated values of the leakance coefficient between the two layers). From these maps, values of transmissivity (or hydraulic conductivity) and storage coefficient (or specific yield) were assigned to each node in the finite difference grid.

The values of hydrologic parameters (T, K and S) were not available for all geologic strata present within the DIMA area. It was necessary to assume the hydrologic characteristics of the less permeable strata which were not tested. The impact of a potential error in our assumptions of hydrologic parameters for formations less permeable and less capable of ground water storage on modeling would not be substantial.

The boundary of the modeled area was located far enough away from the DIMA area so that pumping in the mine would not effect changes in the water levels on the boundary. Based on estimates of the water surface levels in the modeled area prior to development of the Dikuluwe mine, a steady state simulation of the project area was made. The specified head boundary conditions used for the steady state simulation were adjusted until reasonable agreement between observed and predicted water levels was realized (Figure 2). The constant head boundary conditions specified in the calibrated steady state simulation were then used in the subsequent transient simulations.

Based on other hydrologic studies of the Kolwezi region, (J. Placet, 1975), it was estimated that areal recharge in the modeled area was equal to 5% of the mean annual precipitation (7%

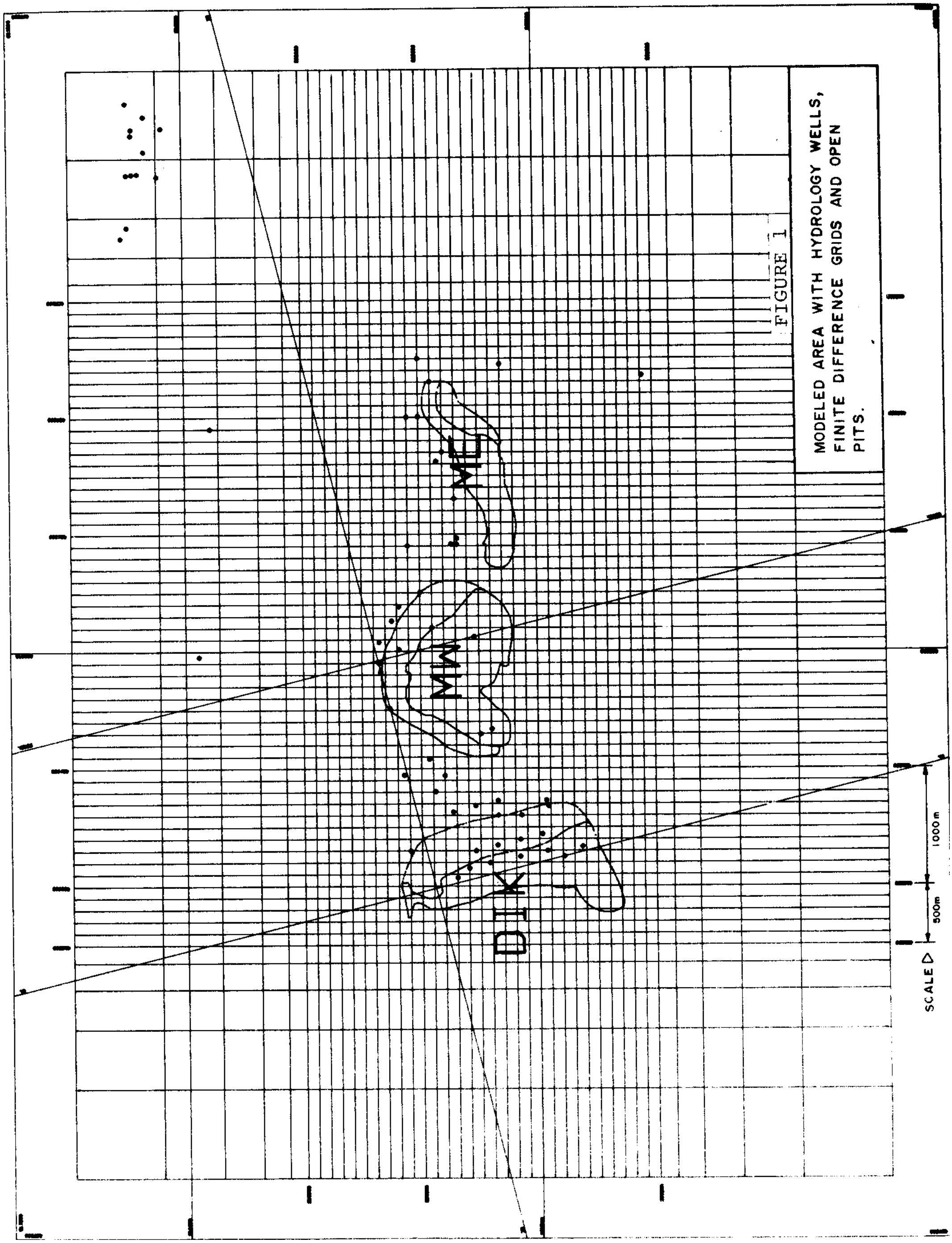

FIGURE 1

MODELED AREA WITH HYDROLOGY WELLS, FINITE DIFFERENCE GRIDS AND OPEN PITS.

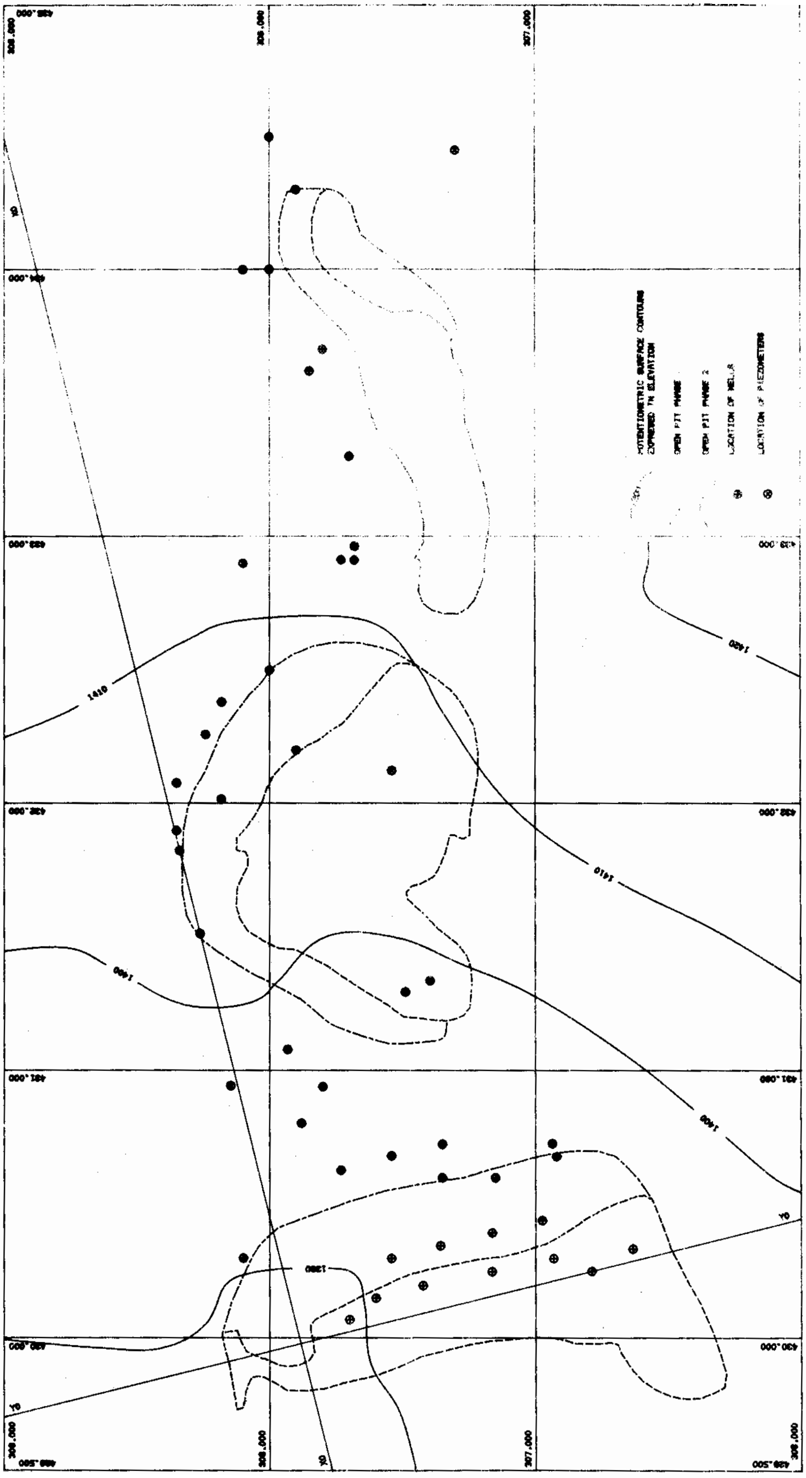

FIGURE 2 POTENTIOMETRIC SURFACE OF GROUNDWATER IN THE PRINCIPAL AQUIFER PRIOR TO MINING - 1974.

on a large hydrologic basin over the Kundelungu Formation, Placet, 1975). This infiltration could be higher at DIMA over barren altered Roan Formations. There are additional sources of recharge in this mine area, for example, the tailings pond located just to the north of the Dikuluwe open pit. Other, also significant amounts of recharge water come from a sinkhole located to the northeast of the Mashamba East area which collects local runoff, and from lake Lac D'Exhaure to the north of the Mashamba East area into which is discharged water pumped from the Kamoto underground mine and from the concentrator. The tailings pond and the lake were both treated as constant head sources with water surface elevations of 1,397 meters and 1,420 meters, respectively. The recharge to the aquifer from the sinkhole was calculated to be at a constant rate of 100 m^3/h and was, therefore, treated as a constant flux source.

Prior to mine development in the DIMA area, the Luilu River is believed to have been a gaining stream along most of its channel which cuts through the project area. The Luilu River was, therefore, a major outlet of water from this subbasin in the natural hydrologic regime. For the steady state simulation, the Luilu River was treated as a constant head boundary. Although the Luilu River has since been dammed upstream of the Dikuluwe mine and its flow diverted completely out of the project area to the Potopoto River. The sections of these rivers where the dams are located were, therefore, treated as areas of constant head at an elevation of 1,400 m.

Calibration of Transient Simulation

When a ground water model is developed for an extensive aquifer system, the hydrologist typically has a relatively small amount of information about the aquifer parameters (T, S, K). The most reliable information is obtained by performing pumping tests on wells located in the aquifer(s). This information is augmented by geological studies which locate and measure the extent of aquifers, aquitards and other important geologic features. The initial set of aquifer parameters used in the model of the DIMA area was developed by combining the information derived from the four pumping tests with geological level maps and cross-sections. In addition, estimates of transmissivity and the storage coefficient were made for areas in which no pumping tests had been performed and for areas in which the water bearing strata were known to be highly impermeable.

The first step of calibration consisted of pumping simulation in wells P-22 and DIK P-1. Short term simulation of pumping was compared with drawdowns achieved during pumping tests in these wells. After reaching a reasonable similarity in pumping tests and modeling results, the second step of calibration was performed.

Using the initial estimates of the aquifer parameters, boundary conditions and location and extent of discharge and recharge areas, the ten-year pumping history was then imposed on the aquifer model, and the simulated potentiometric surface was compared to the observed water surface levels. The procedure used in this study to calibrate the model was to first make adjustments in transmissivity, hydraulic conductivity and leakance values (T, K, TK) and then make small changes in the pumping rates. By adjusting the three hydraulic parameters (T, K, TK), the magnitude of local head gradients could be changed and the overall pattern of head contours from the model could be made to more closely match the observed pattern. This two-step calibration procedure was repeated until the response of the model to the pumping from 9/74 to 12/83 closely approximated the observed decline in the water surface level for this period. Results of this calibration are presented on Figure 3.

On this figure, it is possible to note that the results of the modeling and field water level monitoring are very close in the Dikuluwe and Mashamba East areas. In the Mashamba West area, the drawdown predicted by computer modeling is about 15 m less than measured in the field. This can be explained by the lack of pumping test data from that particular area.

Modeled Cases

The computer simulation was performed for the two basic cases described below.

The pre-pumping situation as developed by a steady-state run (Figure 2) was used as a base for this run. In the period of time between 1974 and December, 1983, the simulation of dewatering used the existing pumping rates. After a comparison of modeling results at the end of 1983 with the measurements of water levels in piezometers and pumping wells, a simulation of dewatering for the period of time between 1984 and 1986 was performed. Modeling beyond the end of 1986 was not considered necessary at this time because mining plans, and hydrogeologic parameters (results of pumping tests in newly installed wells) might change.

During 1984, no new wells were added to increase the pumping capacity. During the first half of 1985, the addition of six dewatering wells with a total pumping capacity of 833 m^3/h was assumed. The total pumping capacity by July, 1985 increased to $Q = 2{,}639\ m^3/h$. During the second half of 1985, two additional wells were assumed operational. These two wells have a total pumping capacity of 360 m^3/h.

During the first half of 1986, two additional wells were assumed to be operational. These two wells have a total pumping capacity of 360 m^3/h. The total pumping capacity by July, 1986 increased to $Q = 3{,}359\ m^3/h$.

The results of the modeling for Case 1 are presented in the following figures showing the changes in the potentiometric surface with time: Figure 3, end of 1983; Figure 4, December 1984; Figure 5, December 1986.

The second case modeled assumed that all wells (as per Case 1) would be operational and that the pumping capacity in the DIMA area would be increased. Four wells with a total pumping capacity of 880 m^3/h would be operational by the end of 1985, and one additional well with a pumping capacity of 220 m^3/h would be operational by the end of 1986.

The results of modeling for Case 2 are presented in the following figures showing the changes in the potentiometric surface with time: Figure 6, December 1984; Figure 7, December 1986.

Results of Modeling

The results of modeling in Case 1 were compared with the mining plans through the year 1986. This comparison indicates that, with the existing pumping capacity, the drawdown would be slower than required by mining plans for all three open pit mines - Dikuluwe, Mashamba West and Mashamba East. A more detailed analysis for these three mine follows.

Dikuluwe

The average water level within the Dikuluwe pit area at the end of 1983 was between the elevations of 1,320 and 1,330 m. With the effective pumping capacity (actual pumping rates) of about 2,300 m^3/h in the Dikuluwe area, the drawdown would proceed at an approximate rate of 9 meters per year (26.8 meters between December, 1983 and December, 1986). The following table presents a comparison of predicted average drawdown with mining elevations (mine sump elevations).

TABLE 1

PREDICTED WATER LEVELS AND PLANNED MINE SUMP LEVELS

DIKULUWE PIT - PROJECT 1240

	ELEVATIONS (m)				
	1983	1984	1985	1986	NOTES
Average WL Elevations	1320	1311	1302	1293	End of indicated year is considered.
Mine Sump Elevation	1320	1280	1280	1270	
Difference	0	-31	-22	-23	

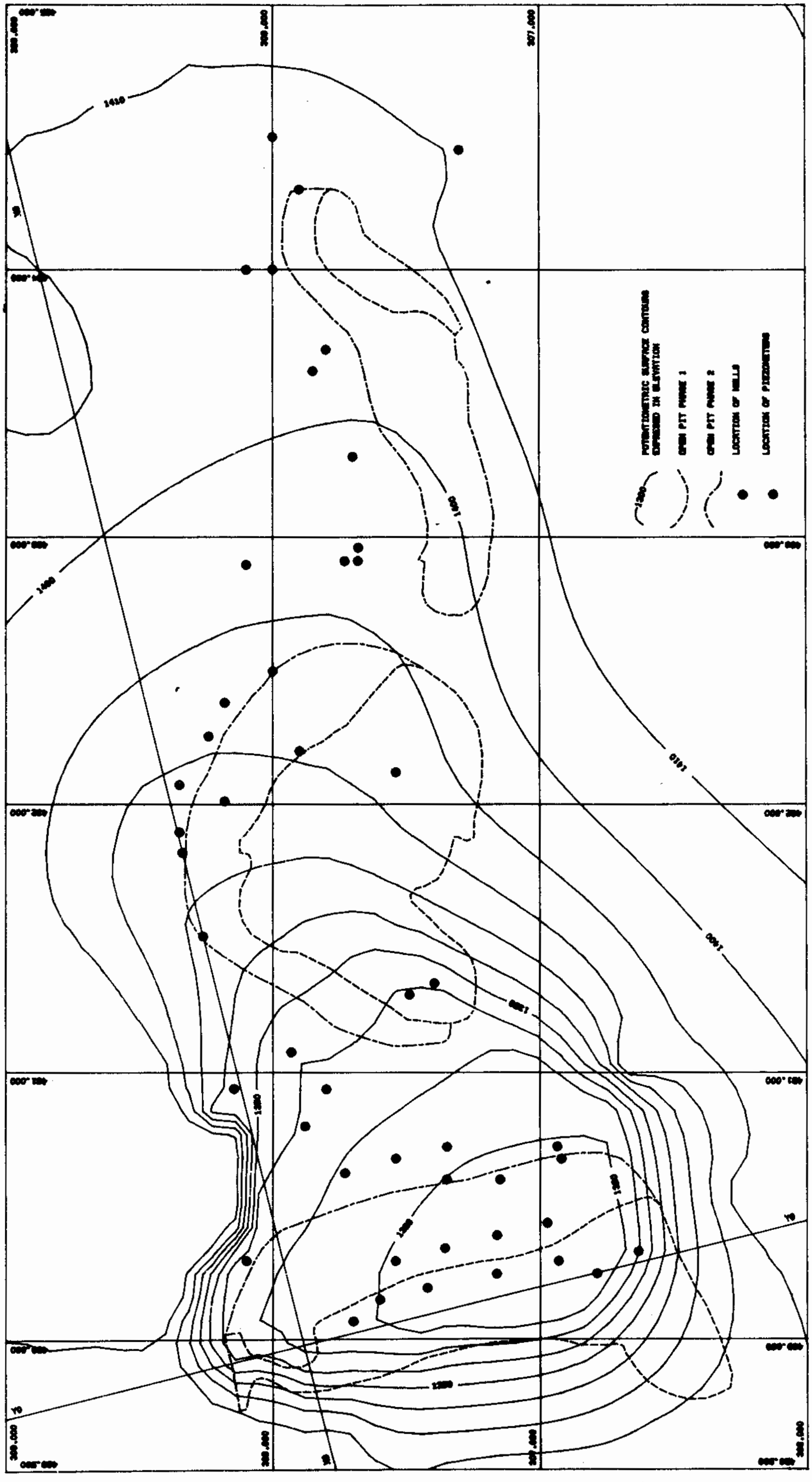

FIGURE 3 MAP OF POTENTIOMETRIC SURFACE AFTER 9 YEARS OF DEWATERING - 1983.

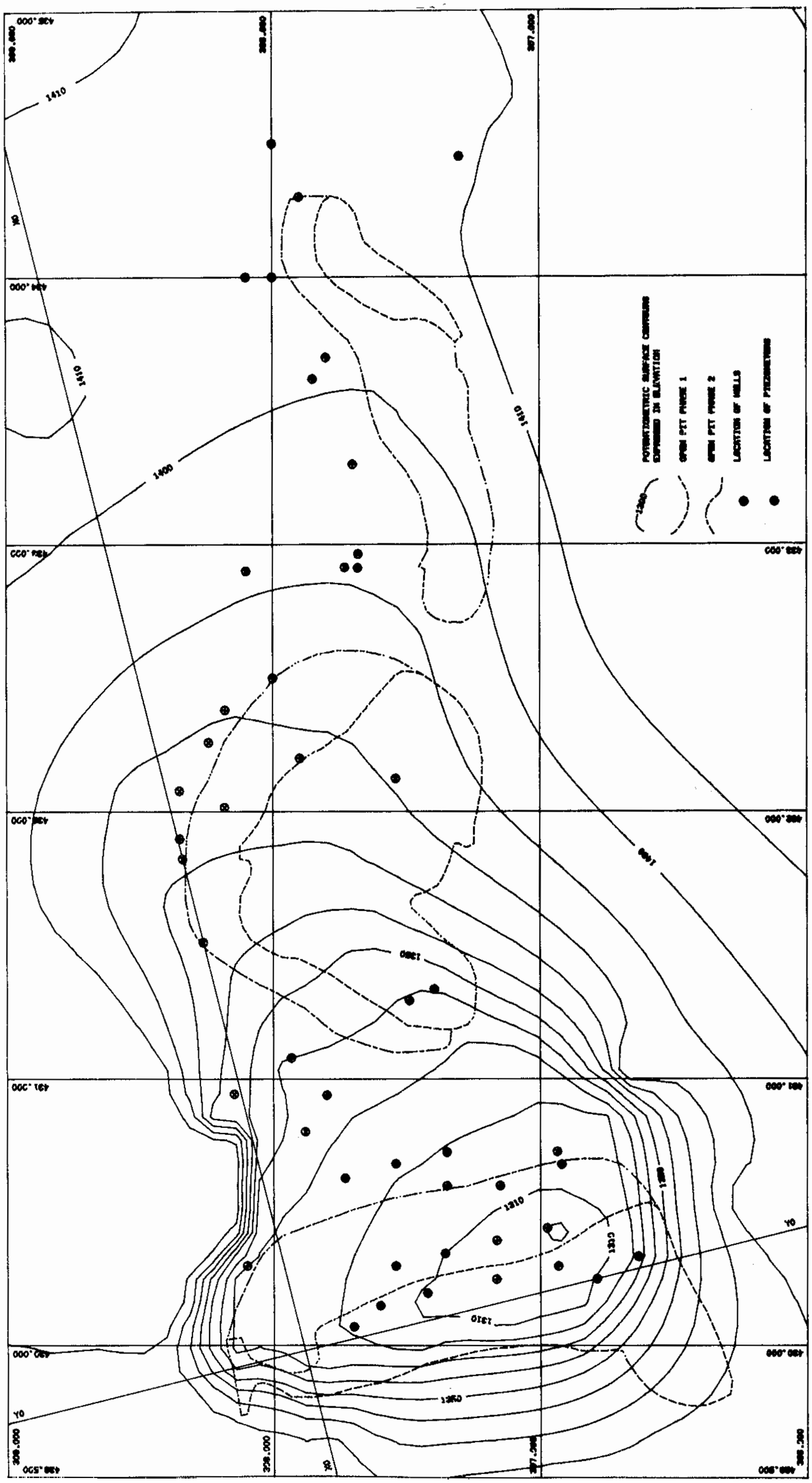

FIGURE 4 CASE I - MODELING DECEMBER 1984.

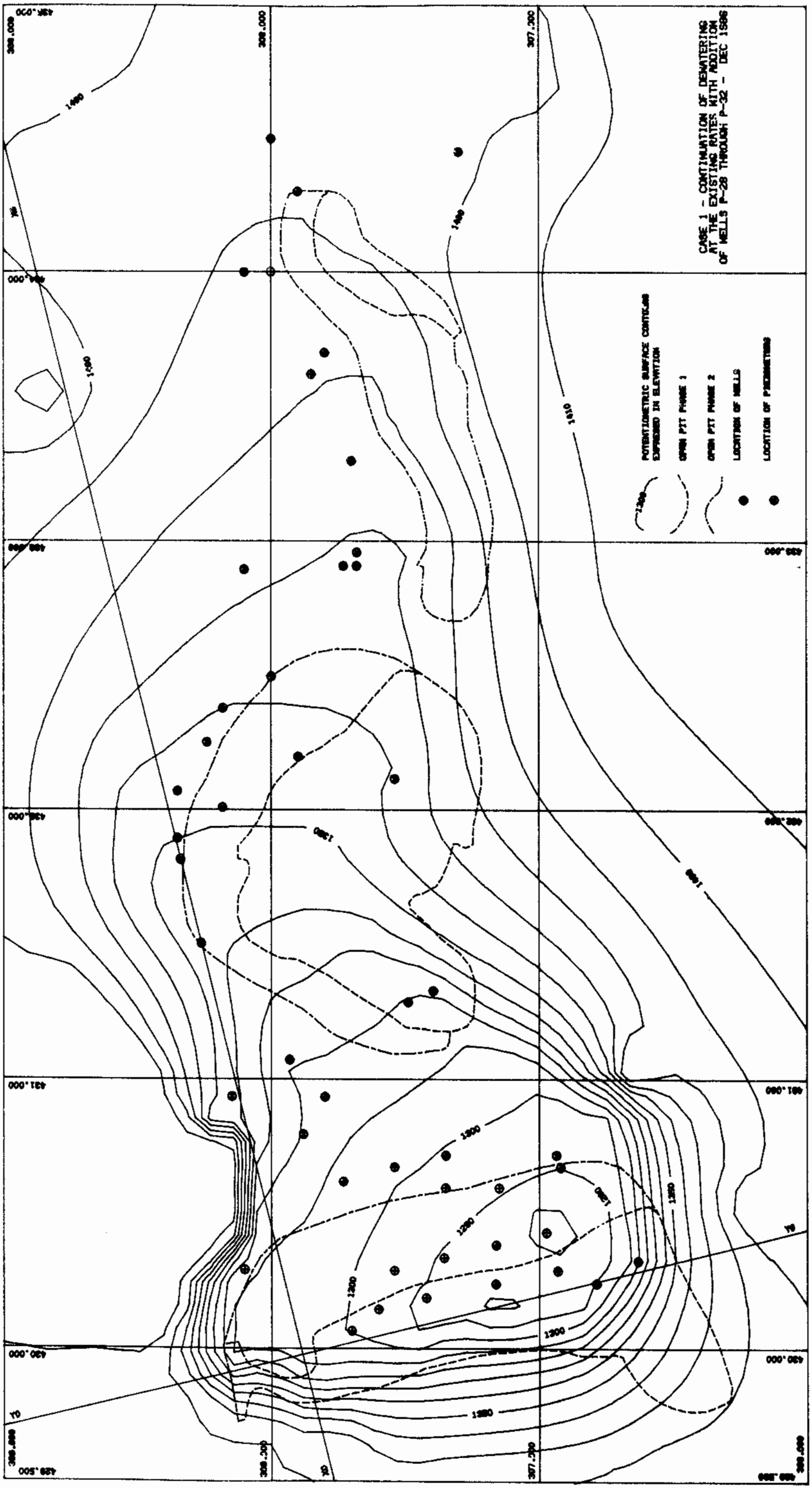

FIGURE 5 CASE I - MODELING DECEMBER 1986.

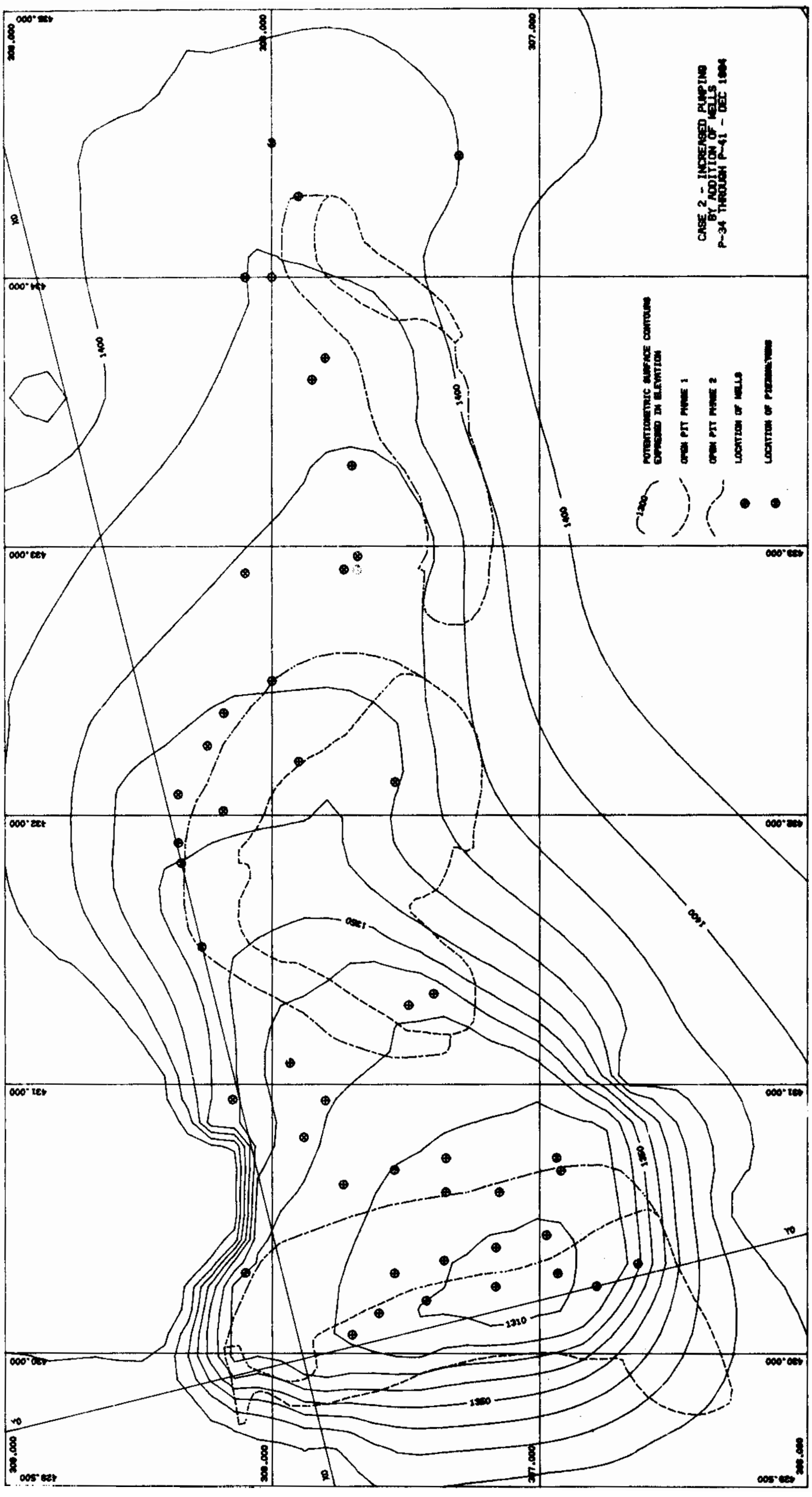

FIGURE 6 CASE 2 - MODELING DECEMBER 1984

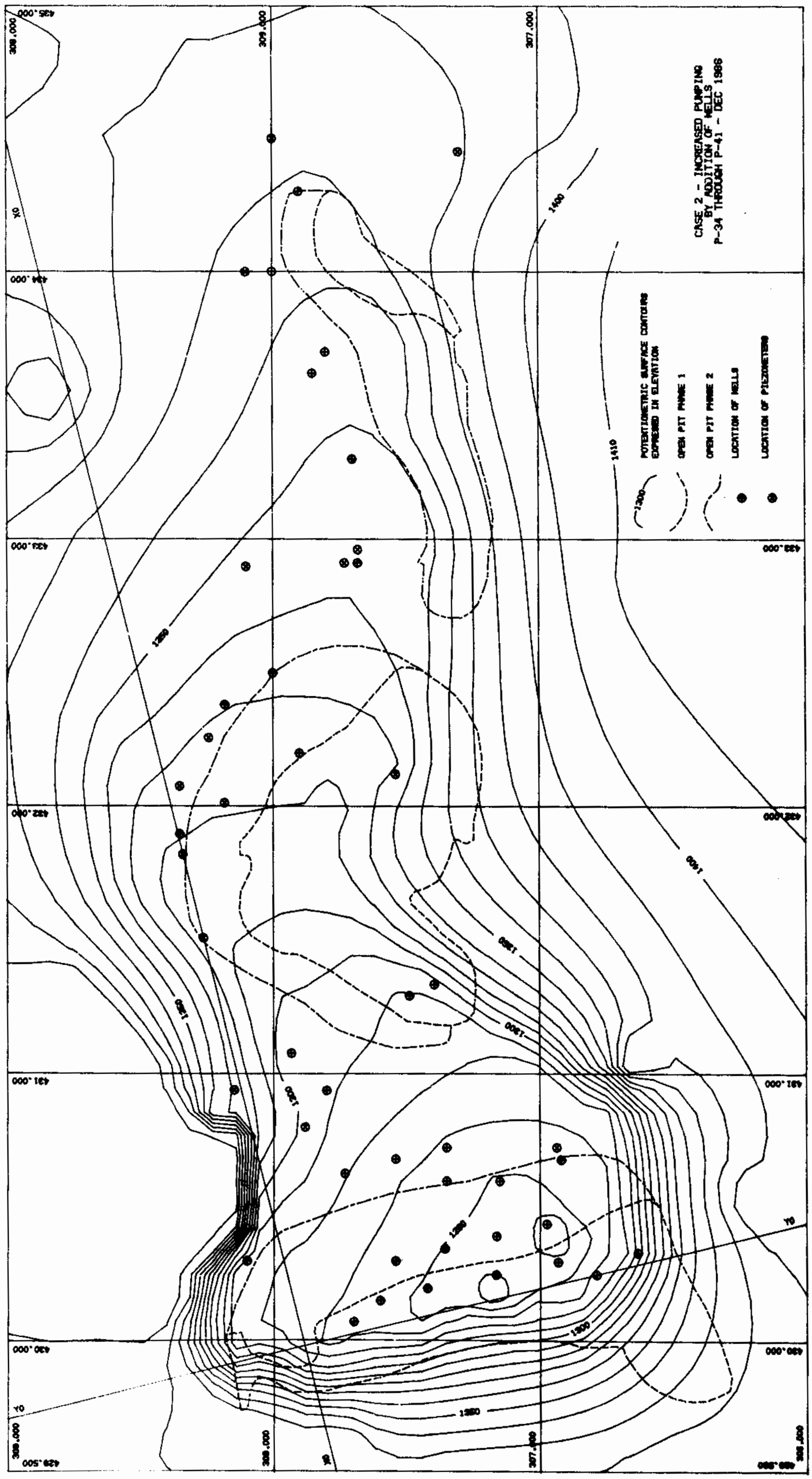

FIGURE 7 CASE 2 - MODELING DECEMBER 1986.

It is concluded that the dewatering progress at the actual rates cannot satisfy the requirements of the mining plans. The difference between the water level elevation and mining progress would be most critical at the end of 1984, when the proposed mining progress is about 31 meters ahead of dewatering. Therefore, if the downward progress of mining in the Dikuluwe pit is faster than about 10 meters per year, the pumping capacity should be increased.

Mashamba West

The average water level within the Mashamba West pit area was, at the end of 1983, at about an elevation of 1,360 m. The pumping rate for this area was very low, only about 360 m^3/h. This rate should increase to about 955 m^3/h by the end of 1984 if the proposed new wells are installed. With the increased dewatering effort, the water table should be dropping by about 7.6 m per year (22.9 m between 1983 and 1986). The following table presents a comparison of the predicted average drawdown with mining elevation (mine sump elevations).

TABLE 2

PREDICTED WATER LEVELS AND PLANNED MINE SUMP LEVELS

MASHAMBA WEST PIT - PROJECT 1300

	ELEVATIONS (m)			
	1983	1984	1985	1986
Average WL Elevations	1360	1352.4	1344.8	1337.2
Mine Sump Elevation	1370	1360	1330	1310
Difference	+10	+7.6	-14.8	-27.2

It is concluded that the dewatering progress at the existing rates cannot satisfy the requirements of the mining plans in 1985 and 1986. If the mining were to progress at a pace more than approximately 8 meters per year, the pumping capacity should be increased.

Mashamba East

The average water level within the Mashamba West pit area was, at the end of 1983, at about an elevation of 1,360 m. At this time, there is no pumping well in the Mashamba East pit area. The existing well (DIK P - 1) should be set in operation as soon as possible (Q = 140 m^3/h). By the end of 1985, the pumping capacity should be, if the planned wells are installed, about 925

m^3/h. With the indicated pumping capacity, the water table should be dropping by about 6.6 m per year (19.8 m between 1983 and 1986). The following table presents a comparison of predicted average drawdown with mining elevation (mine sump elevations).

TABLE 3

PREDICTED WATER LEVELS AND PLANNED MINE SUMP LEVELS

MASHAMBA EAST PIT - PROJECT 1320

	ELEVATIONS (m)				
	1983	1984	1985	1986	NOTES
Average WL Elevations	1390	1383.4	1376.8	1370.2	End of indicated year is considered.
Mine Sump Elevation		1410	1370	1360	
Difference	0	+26.6	-6.8	-9.2	

It is concluded that the dewatering progress, if four new wells are installed during 1985 and 1986, would be satisfactory for the existing mining plans by the first half of 1985. After that, the mining progress would be greater than the drawdown.

CONCLUSIONS AND RECOMMENDATIONS

The computer modeling of ground water flow performed for the DIMA area indicated that the progress of dewatering (with the addition of 9 wells by the end of 1985) would not be satisfactory for the existing mining plans. From mid 1984 through the end of 1986, the problem would be most pronounced in the Dikuluwe and Mashamba West pits.

It will be necessary to increase the pumping capacity and/or decrease the recharge capacity into the aquifer. An increase of pumping capacity could be achieved in the following ways:

- increase of pumping rates in the existing wells;
- installation of new wells, or;
- installation of horizontal drains.

An increase of pumping rates in the existing wells would be possible by installing more powerful Peerless pumps in particular wells, or by the acquisition of submersible pumps. Another option is to repair some of the existing wells which are not used for pumping.

The installation of horizontal drains is considered a supplemental means of dewatering. It is most appropriate for strata not easily drained by vertical wells (low permeability, perched aquifer, vertical fracture systems, etc.). They are useful in improving slope stability in problem areas. However, horizontal drains can substantially increase the drainage rates for a particular mine.

The option of installing additional wells was the subject of the modeling in the second case. For this case, three additional wells were located in the Dikuluwe pit area. The addition of these three wells would substantially improve the dewatering capacity. The progress of dewatering (to include three new wells in the Dikuluwe pit area, one new well in the Mashamba West pit area and one new well in the Mashamba East pit area) is shown on Figure 6 (1984), Figure 7 (1986) and is summarized in the following tables:

TABLE 4

DEWATERING RESULTS WITH ADDITIONAL WELLS

(CASE 2 COMPUTER MODELING)

DIKULUWE PIT

	ELEVATIONS (m)		
	1984	1985	1986
Average WL Elevations	1310	1280	1260
Mine Sump Elevation	1280	1280	1270
Difference	-30	0	+10

This table indicates that, with the addition of three wells, dewatering progress would be satisfactory for the proposed mining schedule, with the exception of the year 1984. Therefore, it is recommended that deepening of the pit in the second half of the year 1984 be slowed if increased inflow and slope stability problems develop.

TABLE 5

DEWATERING RESULTS WITH ADDITIONAL WELLS

(CASE 2 COMPUTER MODELING)

MASHAMBA WEST PIT

	ELEVATIONS (m) 1984	1985	1986
Average WL Elevations	1360	1340	1320
Mine Sump Elevation	1360	1330	1310
Difference	0	-10	-10

In this pit, the dewatering effort would be sufficient on the western slope of the pit and not quite satisfactory on the eastern pit slope. Supplementary horizontal drains on this side of the pit should probably solve the problem. The paucity of indicative hydrologic data is thought responsible for model results that indicate slower dewatering rates than those actually measured (specific to this part of the DIMA pit).

TABLE 6

DEWATERING RESULTS WITH ADDITIONAL WELLS

(CASE 2 COMPUTER MODELING)

MASHAMBA EAST PIT

	ELEVATIONS (m) 1984	1985	1986
Average WL Elevations	1390	1370	1360
Mine Sump Elevation	1410	1370	1360
Difference	+20	0	0

In this pit, the addition of one well would sufficiently increase the dewatering capacity and the water table would be lowered in coordination with the proposed mining schedule.

Case 2 of the computer modeling indicated that the addition of three wells in the Dikuluwe pit area and the addition of one well in each of the Mashamba pits, should allow dewatering efforts to keep pace with mining progress.

Decreasing the recharge potential into the aquifer is another option to improve drawdown without the installation of all of the recommended wells. As discussed previously, the DIMA area geology and topography has a great potential for increased recharge into the principal aquifer. It was assumed that only about 5% of an average year precipitation will infiltrate into the ground water system. However, due to the presence of sink holes, rivers, tailing ponds and discharge of waste water into the Lac D'Exhaure, the overall recharge rate into the aquifer is much higher than 5% of the precipitation.

It is believed that substantial recharge into the aquifer occurs through the Lac D'Exhaure and therefore, it would be possible to reduce this recharge by eliminating discharge into this sinkhole. Another option would be to dry this lake and to line its bottom with clay or an artificial liner. By eliminating the discharge into this lake, great improvement in the water quality in the Mashamba area would be achieved.

Reducing the seepage and the recharge to the aquifer from the tailings pond and dams on the Luilu and Kabulungu Rivers would be more expensive and more technically difficult. Monitoring of runoff into existing sinkholes in the DIMA area is suggested. Should this data indicate that the runoff infiltrates rapidly into the ground water system, sealing of the dolinas should be undertaken. This would increase the evaporation and decrease the infiltration rates.

Computer modeling for the DIMA area will be repeated in the near future with the addition of the newly obtained hydrologic characteristics into the model.

ACKNOWLEDGEMENTS

The authors wish to thank the managment of Gecamines in Lubumbashi, Republic of Zaire for permission to publish this paper. Special thanks is expressed to Dr. R. Kvapil, President of Geomines, Inc. in Tucson, Arizona for his suggestions and contributions during the entire project. Contributions from the Geomines, Inc. staff, who performed the computer modeling and illustrations are gratefully acknowledged.

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