DEWATERING OF THE PICO DE ITABIRITO IRON MINE: AN ENVIRONMENTAL RECLAMATION CASE STUDY

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ABSTRACT

The focus of the present paper is the planing of the dewatering and the environmental impact reclamation of Pico Iron Mine. The monitoring of the dewatering, as well as the geological and hydrometeorological information, generated a database to use a numeric groundwater model, Modflow. The calibration of the model by steady state and transient approach favoured to study of several dewatering wells arrangement and to identify hydrologic impacts generated.

The main impact identified was the flow rate reduction of two springs that discharges groundwater from iron formation aquifer. After several simulations aimed at optimising the future environmental recovery, the selected option of this study contemplates the simultaneous back filling of the ultimate pit with waste and barren rocks of another mines, as well as rainwater. It is expected that the aforementioned springs will recover around 70% of their minimum initial flow, after a period of twenty years from the end of the dewatering operations.

INTRODUCTION

The Pico de Itabirito iron ore mine is located some 6 km to west-northwest of the town of Itabirito and approximately 50 km to south of the city of Belo Horizonte, the capital of the State of Minas Gerais, Brazil (Figure 1). Its facilities as well as its mining area are located at the southeastern border of Itabirito ridge, around 1,400 meters height. MBR - Minerações Brasileiras Reunidas, a Brazilian mining company that owns this world class mine, is enhancing its production to 11 million tons of iron ore concentrates per year and to achieve his target has started, in 1994, the exploitation below the water table, that at that time was situated at the level 1,350 meters. Thus, it was drilled two wells within the mine pit, starting lowering the water table. Now a days, there are four wells in operation that produce a monthly volume flow rate around 180 thousands cubic meters of water.

This paper focuses the activities developed for planning the mining dewatering till the 2007 year when it will finish the mining bellow the water table as well as the planning for recovering the environmental impacts generated by the aquifer over-exploitation. After the definition of the conceptual hydrogeological model for the area giving the due support to the simulation of dewatering operations with the objective of minimising the environmental impact and also trying to diminish the necessary period for area recovery.

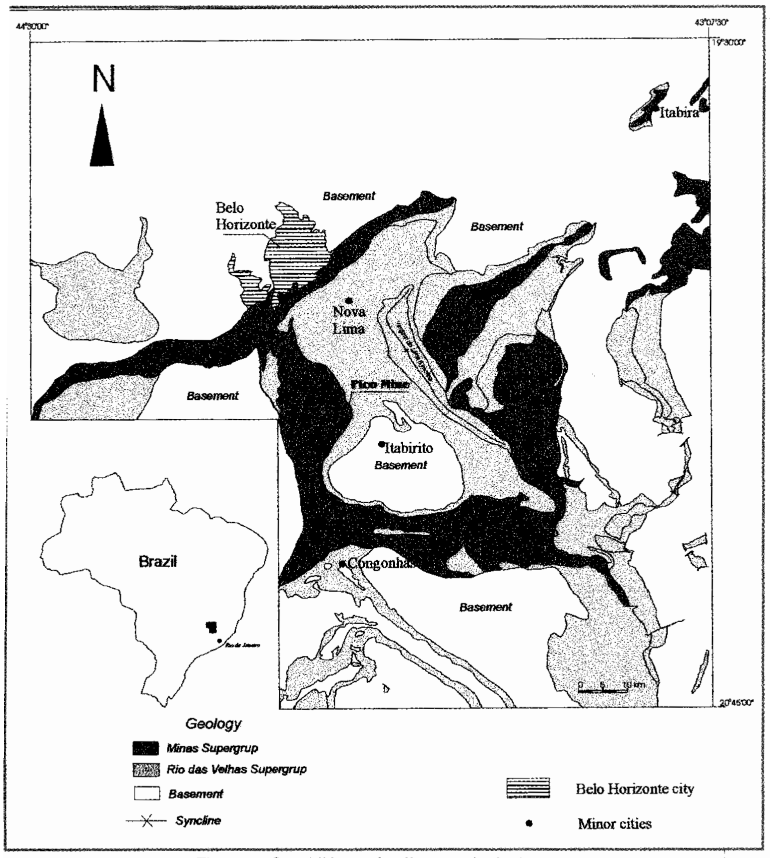

Figure 1. Quadrilátero Ferrífero geological map.

GEOLOGY

The region (Figure 1) is located within the mineral province called Quadrilátero Ferrífero (Iron quadrilateral) that comprehends various mountain ridges, bearing iron ore deposits, arranged as a four-sided polygon that occupies and area roughly equivalent to 5,000 km^2. The orogenesis that has erected these mountains is linked to the tectonic-metamorphic events acting over Proterozoic sediments, generating big continuos synclinal structures and disrupted thrust faults, further eroded. The Mina do Pico do Itabirito (or simply Pico Mine) is located over one of these mega-structures, the Moeda Syncline, occupying its southeastern border. The flank of this syncline is locally inverted, with layers presenting strong dip to east and an N-S strike (Figure 2).

In stratigraphycal terms, the Mina do Pico is inserted within the Proterozoic metasediment sequence belonging to the Minas Supergroup. Walking from east to west, that in stratigraphycal terms means going from the basis to the top, one can find the following litostratigraphies for the referred Minas Supergroup.

- Moeda Formation, is the basal unit of the Minas Supergroup and sustains the ridge beam line from the Itabirito range border, constituted by intercalation of quartz-rich, sericitic, and sometimes, conglomeratic meta-sandstones. These meta-sandstones are generally denominated quartzites and films, laminas and layers of metapelites, generally called phylites intercalate them;
- Batatal Formation, overlying the Moeda Formation quartzites, is constituted by sericitic phylites that grade for dolomitic phylites with chert intercalations, representing the transition of a clastic environment to a chemical one;
- Cauê Formation, are essentially the iron ore mineralizations. This formation is constituted by banded ironstone, mainly composed of siliceous itabirite with subordination of argylous and carbonated itabirite and some hard hematites. The weathering action over these rocks has provoked a supergenous enrichment generating soft and medium, hematite ore bodies and itabirites rich in iron;
- Gandarela Formation, representing carbonated rocks, predominantly dolomites. This formation also bears quartz-phylites, graphitic-phylites, dolomitic phylites and some subordinated itabirites.

The Itabira Group (comprising Cauê and Gandarela formations) is overlaid by the Piracicaba and Itacolomi groups, stratigraphic units that contains schists, phylites and quartzites that are not important within the context of this work.

After the deposition of Minas Supergroup, there were magmatic intrusions of basic character, also submitted to the same metamorphic events that affected the Minas Group sediments. So it is interesting to put in evidence this class of rocks.

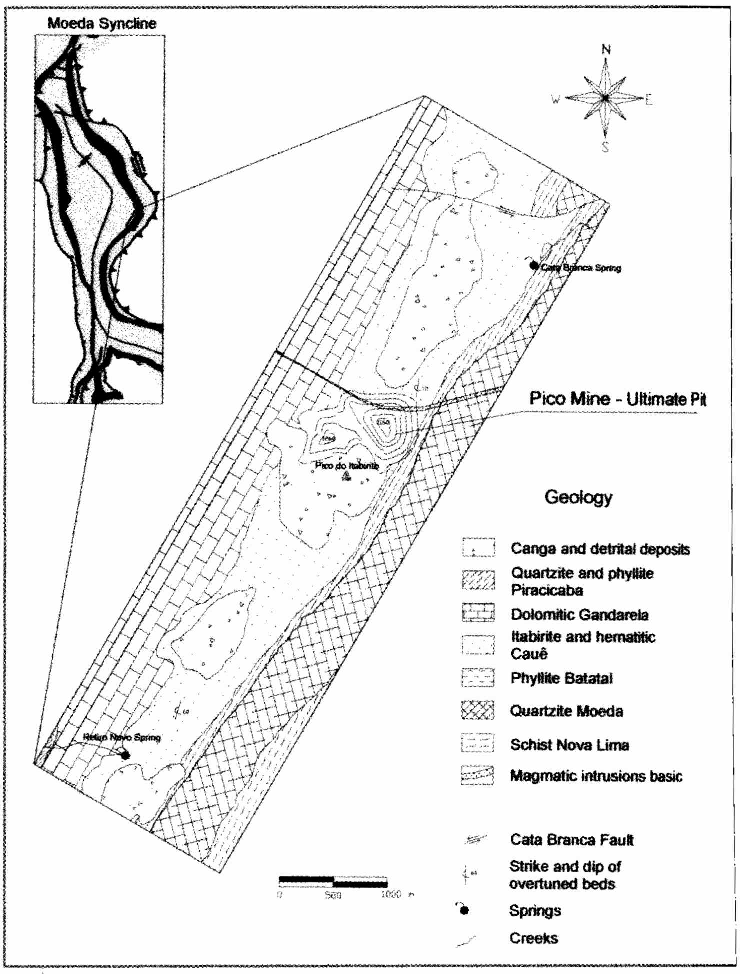

Figure 2. Pico Mine geological map of model area.

- Metabasic Rocks, constituting dikes of basic mineralogy composition. These dikes cut the metassediments and were exposed to the same tectonic events that have affected the Minas Supergroup. It is known, in the region of Mina do Pico, just one metabasic body, located at the northern portion of the hematites occurrences.

During the Cenozoic occurred some small but important and conspicuous sedimentary deposits. These deposits are generally described as follows:

- Detrital ("rolados") deposits, are sedimentary deposits, related to the flux of detritic materials, basically constituted of hematites and itabirites blocks and fragments that were dislocated to basins, probably generated at the Miocene epoch.
- Cangas", are rock types constituted of rich weathered product, covering practically all the extension of the iron ore formation. Generally, cangas are formed by colluvionar material derived from iron ores formations, represented by hematites pebbles and blocks, as well as, some fragments of itabirites, strongly cemented by iron hydroxides.

CONCEPTUAL HYDROGEOLOGICAL MODEL

The hydrogeological units that exist in the area are essentially related to the geological units previously described. The main aquifer is the Cauê Formation that refers to the proper iron formation. The hydrogeologic behaviour of this unit is related to a porous type or intergranular aquifer with the permeability and storage increasing according to the weathering degree. The best conditions to water circulation and storing are encountered within the iron ore formations, when submitted to the processes of supergene enrichment. In fact, the dissolution of silica and carbonate layers pertaining to the itabirites enhances the underground water storage and transmission. The specific storage of these aquifers generally varies in between 0.002 to 0.15 and their permeability is normally in the interval 0.1 to 3 m/day. Nevertheless, in areas of compact and fractured hematites and itabirites the rock permeability can achieve 10 m/day, a very high magnitude.

The iron ore aquifer occupies locally an extent strip of terrain measuring 800 meters wide and having a subvertical attitude. Toward the depth, the aquifers extends to the interior of the Moeda Syncline, where it is not known the real condition of the aquifer, because its characteristics varies accordingly to the degree of the decomposition of its rocks. The aquifer is limited to east by the phylites of Batatal Formation and to west by the impervious argylous materials. related to the weathered products of the carbonate rocks. belonging to the Gandarela Formation. At the northern border of the pit. the aquifer is truncated by a dike of weathered metabasic rock that behaves like an aquiclud (impervious) to aquitard.

The cangas and detritic deposits are highly permeable sedimentary overburdens that do not store water locally, but constitute fundamental pieces for the recharging the Cauê aquifer. The aquifer recharge is also favoured by the regional climate that has a notable rainy season with excess of water. Due the behaviour of the sedimentary overburden, the waters related to Cauê aquifer have a low salt content, due the quick infiltration and a small interaction with the soil.

The climate is characterised by hot and humid summers with precipitation in between 1,000 to 2,000 mm yearly. as well as, dry and mind winters. The relationship between precipitation and evaporation presents a water excess of 1,300 mm in the rainy season and a deficit of 183 mm in the dry period. As the water table of the aquifer is deep the evaporation action within the aquifer is practically absent and the waters are generally fresh chlorinated-bicarbonated sodic to mixed water associated to an electrical conductivity around 10 to 20 μSiemens.

There are two natural springs close to Mina do Pico (Figure 2). The first of these springs is located approximately 2 km to NNE of the operating mine and corresponds to the high Cata Branca creek. The second spring is located at the opposite extreme, around 3 km SSW from the mine faces and refers to the Retiro Novo creek fountainhead.

NUMERICAL MODEL

The numerical modelling was performed with the help of Modflow Program, implemented through the Software Visual Modflow for Windows, version 2.62. The investigated domain has an area of 7.2 km extension by 2 km wide. It was discretized as a grid containing 36 rows, 67 columns and 4 layers.

The north and south limits corresponds to the Cata Branca and Retiro Novo creeks fountainheads. The east and west limits are the Batatal and Gandarela formations, associated to a zero flow rate. This environmental impact study has considered the aquifer in between both fountainheads as the responsible to all volume of water, disregarding inflows, from north and from south.

The geologic characteristic was discretized into five groups, in the model, comprising itabirites, compact and fractured hematites and itabirites, anfibolitic itabirites, soft hematites and metabasic rocks. The blocks discretization, layer by layer, was performed with the help of the previous horizontal sections, exported to the Visual Modflow as dxf files, with the help of the Mining Software DATAMINE (Figure 3).

The numerical model was initially calibrated as steady state, supported by the piezometric, fluviometric, rates of springs and precipitations related to the hydrological year of 1991/1992 that precedes the mine dewatering. The fountainheads behaviour were simulated as constant heads and the water control for the springs are measured through the Budget Zone. The maximum calibration error in steady state regimen was 1,6 % and the value of the calibrated effective recharge was 270 mm/year that corresponds to 16,4 % of the precipitation in the hydrologic year of 1991/1992.

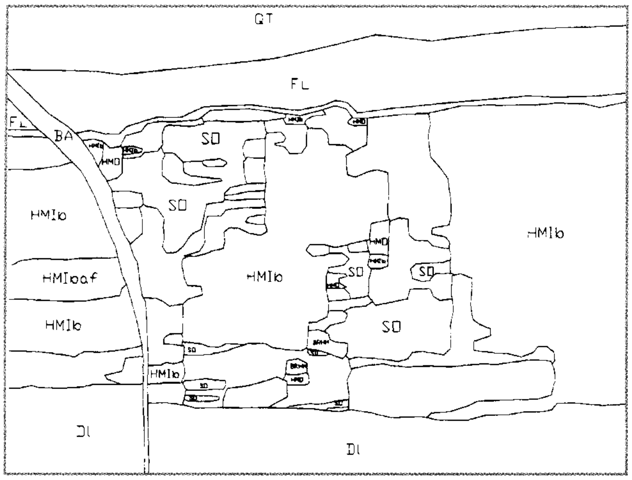

Figure 3. Data mine, horizontal section at 1240m level.

After the steady state calibration, the numerical model were calibrated under the transient regimen, based on the data collected during the operation of the wells, within the period from 1994 to 1998, comprising a total of 1,481 days. Under the transitory approach, the fountainheads were represented as drains associated to the conductance between 1000 to 800 m^2/day.

As the piezometric levels are deep into the terrain, the evapotranspiration was not taking into account. Thus, the sole consideration was associated to the recharge of 16,4 % during the period. The Figure 4 presents the calibration curve under transitory regimen.

DEWATERING SIMULATION

Surpassing the phase of defining a well-calibrated numerical model under transient regimen, the next step of the study was to perform several computer simulations covering several possible future situations with new wells located at strategic places and choosing a response compatible with the minor impact at the fountainheads. It was abandoned the common procedure of designing just one well battery operating for the biggest possible period and lowering the water level to its maximum. The solution achieved to promote the necessary mine dewatering and simultaneously minimising the impact over the fountainheads was to design four batteries or group of wells operating under different volumetric flow rates at distinct periods. The period simulated was from April 1998 to December 2007.

The ultimate pit for the Pico de Itabirito Mine presented two bottom pits (Figure 5). One of this bottom pits is called Mina Velha and is situated at the 1,260 meters level. The second bottom pit is denominated Mina Nova and is located at the 1.160 meters level. It was designed two wells (MVP5 and MVP6) in addition to the four existing ones (MVP1 to MVP4) configuring one sole battery, in order to lower the Mina Velha water table. To lower the Mina Nova water table it was designed two sets of four wells batteries MNB1P1 to MNB1P4 and MNB2P1 to MNB2P4. Another group comprising two wells was also designed to lower the water table level at the north of the metabasic rocks with the purpose of avoiding geotechnical instabilities.

The Table 1 presents the time scheduling and the yield related to the exploitation of this group of wells.

The Figure 6 and 7 presents the hydraulic potentials for the investigated areas at the specific dates: March 1998 and December 2007. The Table 2 shows the totals pumped from the dewatering wells at the correspondent fountainhead volumetric flow rates.

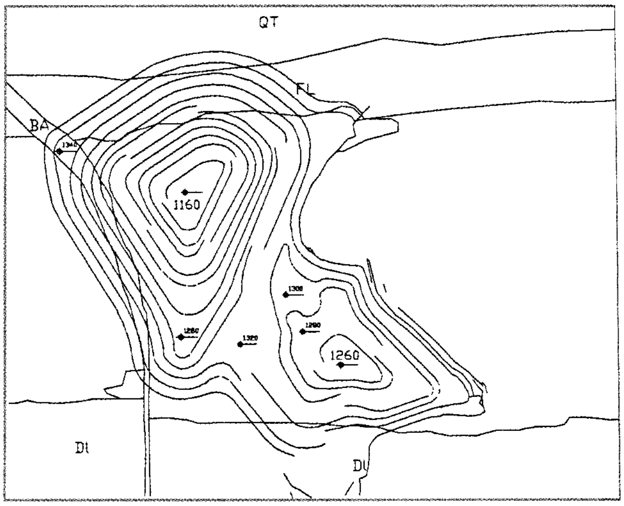

Figure 5. Pico Mine ultimate pit.

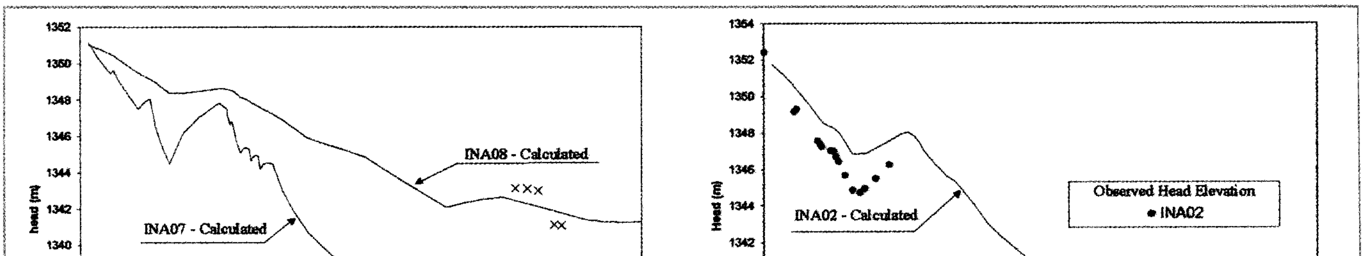

Figure 4. Observation and calculated head.

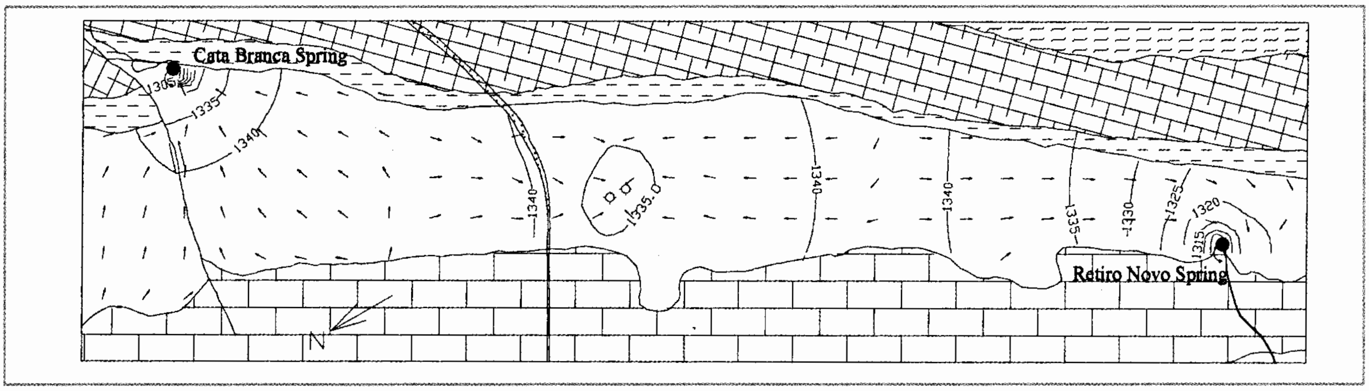

Figure 6. Head equipotentials contours, March, 1998

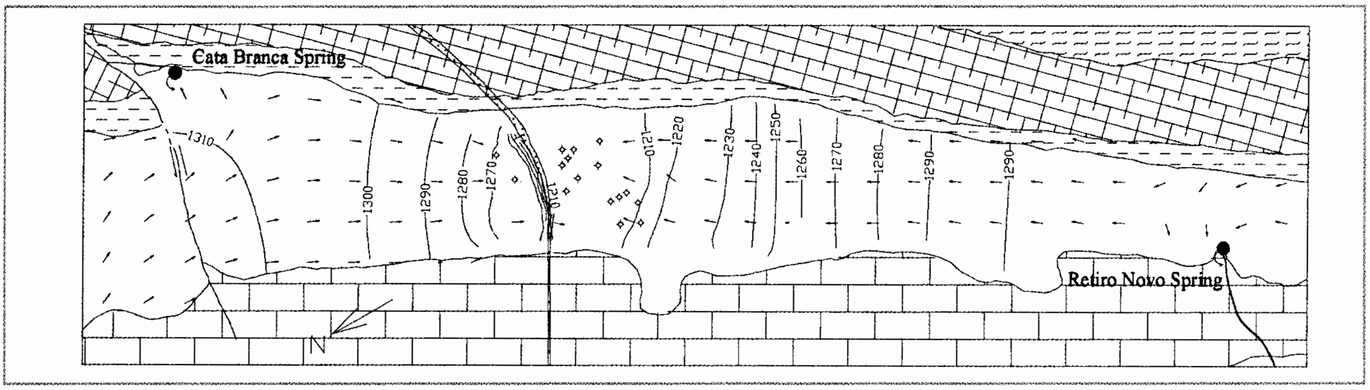

Figure 7. Head equipotentials contours, December, 2007

Period	Yield by well in cubic meter by day							
	MVP1	MVP2	MVP3	MVP4	MVP5 a MVP6	BPI e BP2	MNB1P1 a MNB1P4	MNB2P1 a MNB2P4
1/4/98 a 31/5/98	-3984	0	0	0	0	0	0	0
1/6/98 a 30/6/98	-4800	0	0	0	0	0	0	0
1/7/98 a 31/12/98	-4800	-3600	0	0	0	0	0	0
1/1/99 a 30/6/99	-3600	-2880	-120	-750	-2400	0	0	0
1/7/99 a 31/12/99	-3600	-2880	-120	-750	-2400	-1920	0	0
1/1/00 a 31/12/00	-3600	-2880	-120	-750	-2400	-1920	0	0
1/1/01 a 31/12/01	-3600	-2880	0	0	-2400	-1920	-2880	0
1/1/02 a 31/12/02	0	0	0	0	0	-1920	-2880	0
1/1/03 a 31/12/06	0	0	0	0	0	0	-2880	0
1/1/07 a 31/12/07	0	0	0	0	0	0	-2880	-4200

Table 1. Yield from dewatering wells.

Year	Springs			Total wells pumping	Total wells and springs
	Cata Branca	Retiro Novo	Total		
	(m^3/day)	(m^3/day)	(m^3/day)	(m^3/day)	(m^3/day)
1,999	4,029	2,060	6,089	12,150	18,239
2,000	3,807	2,034	5,841	15,990	21,831
2,002	3,405	1,957	5,362	15,990	21,352
2,003	2, 952	1,836	4,788	26,640	31,428
2,004	2,460	1,666	4,126	15,360	19,486
2,006	1,253	846	2,099	11,520	13,619
2,007	1,021	669	1,690	30,720	32,410

RECLAMATION SIMULATION

The mining activities at the Mina do Pico are expected to be finish by 2007 when it will be also initiated the reclamation of the aquifer and the volume flow rate of the impacted springs. Initially, it was simulated the back filling of the ultimate pit with the rain water considering a contribution area equivalent to 1,4 km^2 and forming a lake situated at 1,350 meters level.

The necessary rainwater to fill the lake was evaluated in more than 70 million cubic meters. It will take 30 years or more to fill the lake with only rainwater. It is known that the aquifer will recover at least some of its initial characteristics when filling the lake. So the investigated lake will fill very slowly and, due his reason, this hypothesis was abandoned.

As MBR owns other mines to be exploited, after the year 2007, around Mina do Pico, according the corporation long term development plan, it will be possible to fill the ultimate pit of Pico Mine, not only with rain water, but also with the waste and tailings generated by these associated operations. This will speed up the process of filling the lake and will simultaneously promote a better recovery of the aquifer water level.

According to MBR, the mines close to Pico de Itabirito are scheduled to produce after 2007, approximately 1,5 million cubic meters of waste and 2 million cubic meters of tailings per year. So, taking into account these products, the Mina do Pico ultimate pit will fill, achieving the 1,340 meters level, by the end of the 2016. Thus, from 2008 to 2017 the mine pit will receive total volumes equivalent to 20, 15 and 19 million cubic meters of tailing, waste and water respectively.

The use of tailings and waste to construct the lake will speed up the raising of water level and the pit fulfilment till the level 1,340 meters. The lamina of this lake will be a little bit less than 10 meters in average, such a way to permit the existence of high recharges taxes during the period of aquifer recovery.

Essentially, this project contemplates the construction of a 0,5 km^2 lake that will behave as an artificial recharge struc-

Year	SPRINGS			
	Cata Branca		Retiro Novo	
	(m^3/day)	Recovery	(m^3/day)	Recovery
2009	564	14%	341	17%
2011	411	10%	155	8%
2015	680	17%	315	15%
2017	864	21%	471	23%
2019	1320	33%	707	34%
2021	1903	47%	1060	51%
2025	2655	66%	1606	78%
2027	2883	72%	1889	92%

Table 3. Recovery evolution of springs yield rates.

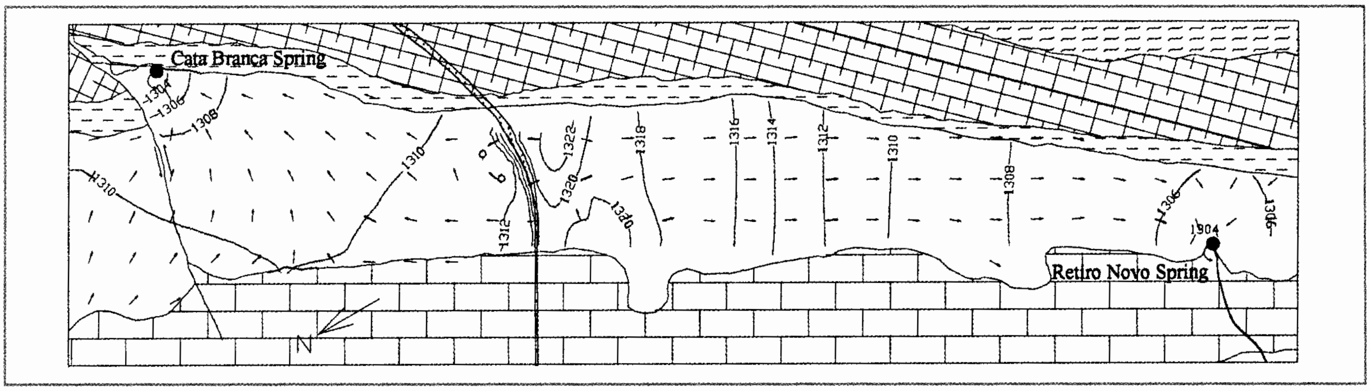

Figure 8. Head Equipotentials contours, December, 2017

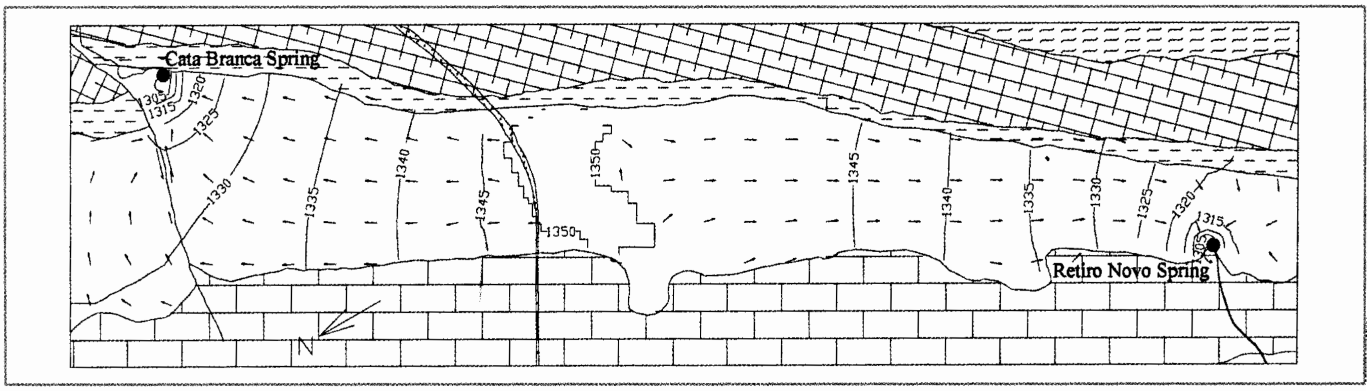

Figure 9. Head Equipotentials contours, December, 2027

ture, representing a water inflow if 3,800 mm/year. It was simulated 20 years of recovering the Mina do Pico dewatering, a period necessary to establish 70% and 92% of the original volumetric flow rate of the fountainheads. The Table 3 summarises the evolution of the recovery of the volumetric flow rate of the springs at the period from 2008 to 2027. The Figures 8 and 9 presents the hydraulic potentials for the investigated areas at the specific dates: December 2017 and December 2027.

CONCLUSIONS

Man depends on minerals to survive a condition, long established, will continue indefinitely. Requirements of technological progress and necessities of modern civilisation are placing increasing demands upon the mineral industry to produce more and greater quantity of minerals. There is no other way of producing minerals, base of our technology and economy, unless mining.

Nevertheless, mining is becoming a very questionable economical activity because it is not usually possible to extract minerals from earth without changing the environment in some way. A mine requires access roads, power and water. Mine site shall provide space for processing facilities, shops, offices, change houses and store facilities. The waste and tailing material produced by the mine and processing operations must be disposed of. Mines also cause severe impacts in water resources.

There is a great urgency of better understanding and emphasise the roles of ecology, environmental control and management if water resources at the down of this third millennium. Now a days, companies must realise that too much change of the environment will put them out of business and that it is possible to mine and produce the ores that population needs respecting the environment. As a result of this philosophy, many mining companies, all over the world are working and developing new techniques to reduce the impact in the immediate environment.

One of the main challenges that Brazilian iron ores are facing is to mine economically below the water table and simultaneously to manage the water resources. MBR and other important iron ore companies in Brazil are succeeding in this challenge through the application of modern hydrogeological investigation techniques, numerical modelling and computer simulation of underground water movements.

ACKNOWLEDGEMENTS

The authors wish to thank their colleagues of MBR engaged in Pico do Itabirito operations, specially Mr. Júlio Nery that have encouraged us to develop this study and Mr. Wayne Raymond Mader for his assistantship in preparing this paper. The permission of MBR, represented for Mr. Oscar Tessari and Mr. José Maurício Ramos, and MDGEO for publication of this paper is appreciated.

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