MINE WATER AND ENVIRONMENTAL PROTECTION
THE SOMINCOR CASE

J F Nunes *, D G Richards **, H A Gama **

* Hidroprojecto, Portugal, ** Somincor, Neves-Corvo Mine, Portugal

INTRODUCTION

The Neves-corvo mine is situated in southern Portugal 230 Km south of Lisbon and is operated by Somincor-Sociedade Mineira de Neves-Corvo. It is an underground mining operation producing 1.6 million tonnes per year of copper and copper-tin ores from depths of 250 to 550 meters. The mine and copper concentrator were commissioned in 1988, and a tin concentrator was completed early in 1990.

The water which is used in the transport and deposition of tailings at Neves-Corvo, and the rainwater runoff from oxidised and acidified pyrite waste dumps, are potential contaminants for the surface waters of the Oeiras River catchment and for the regional groundwaters.

To avoid the contamination of surface waters, the Cerro do Lobo tailings dam and the pluvial water dam have been constructed; the first for storage of tailings from the concentrators, with zero discharge; the second in order to store temporarily surface runoff water from the pyrite stockpiles which, after suitable treatment, is discharged into the Oeiras River.

Proper lining of the Cerro do Lobo lagoon, and the zero-discharge condition, would prevent the possible contamination of surface waters.

In order to ascertain the permeability characteristics of the dam foundations, suitable geological and geotechnical explorative studies were carried out. These consisted essentially of reconnaissance trenches following the dam axis, and exploratory boreholes accompanied by Lugéon water absorbtion tests.

These studies were carried out under the control of CEGÊ - Consultores para Estudos de Geologia e Engenharia Lda.

To establish the permeability of the floors of the two lagoons, and the influence of possible seepage on underground flow regimes and underlying groundwater quality, a detailed hydrogeological study was carried out. This was supported by the installation of a series of piezometers, several of which were later used as sampling points in a study using tracers. These studies were carried out by Geoestudos.

TAILINGS DAM (CERRO DO LOBO)

Typical Cross Section

Given the morphology of the valley, the foundation characteristics, and the construction materials available, a profile was selected as shown in Fig. 1, consisting of a central clay core with upstream and downstream stabilising shells. At the interface between the downstream shell and the core there is an inclined filter leading to a drainage mat in contact with the foundation which extends to the toe of the downstream wall. A drainage trench was constructed at this point, leading to a pumping well.

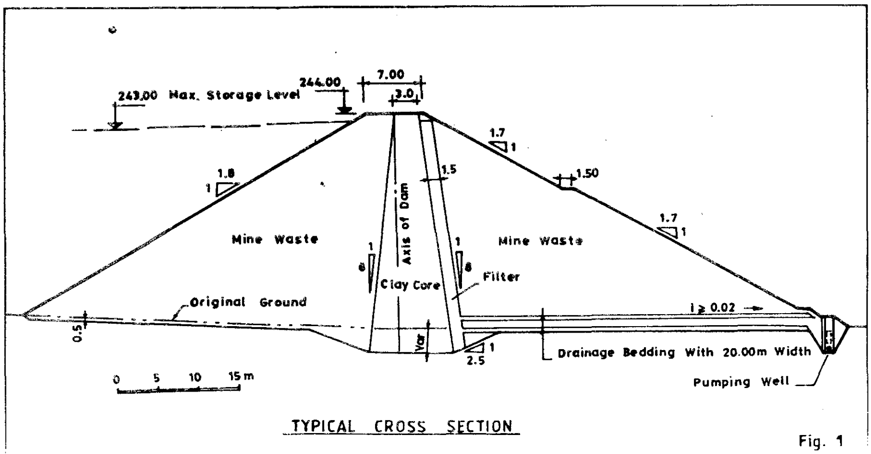


Fig. 1

In the first phase the dam wall reached a height of 28 m above the foundation, and a crest length of 415 m. In a second phase, currently being studied, the dam will reach 40 metres above foundation with a crest length of 1200 m. Two small saddle dams were also constructed in the first phase.

PERMEABILITY OF THE FOUNDATION ROCK-MASS

During the geotechnicall investigations, Lugéon water absorbtion tests were carried out in all boreholes at 5 pressure levels, and at pressures of 1, 2, 4, 2, 1 Kgf cm^{-1} down to 15 metres, and 2, 4, 8, 4, 2 Kgf cm^{-1} for depths greater than 15 metres.

The results which were obtained allowed the rock-mass to be zoned by permeability into the following 3 zones:

Zone 1 - Down to an average depth of 25 m, with absorbtions greater than 0.5 VA (5×10^{-5} cm sec^{-1}).

Zone 2 - Only defined at the margins, with an average thickness of over 5 m, with absorbtions between 0.3 VA and 0.5 VA ($3 \times 10^{-5} < K < 5 \times 10^{-5}$ cm sec^{-1})

Zone 3 - Located below zone 2, with absorbtions below 0.3 VA ($K < 3 \times 10^{-5}$ cm sec^{-1}).

The relatively high permeabilities determined for the foundation rock-mass suggested that the construction of a grouted curtain to seal the dam foundations could reduce the volume of any seepage and largely avoid the contamination of the aquifer. To test this possibility, Somincor commissioned a study, bearing in mind the future build-up of deposited tailings. This study was carried out by LNEC, and concluded:

a) The influence of the accumulating tailings, which was thought to be beneficial, is not significant;

b) The construction of a grout curtain would reduce the volumes draining through the dam and foundations by a factor of ~9 in the central zone, but would increase the volume of the lagoon which would contaminate the aquifer by 23%;

c) From the point of view of of aquifer contamination, the construction of a grout curtain is not reccommended, since the waters would normally drain through the foundation of the dam above the aquifer;

d) The total drainage in any of the cases is not high.

HYDROGEOLOGICAL STUDY

Regional Hydrogeology

In 1985, Fernandez-Rubio and Associates established a hydrogeological model for the Neves-Corvo area, which included a surface system, an intermediate system, and a deep system.

Surface System

This would include the zone of decompression of the rock-mass to a depth of approximately 30 to 50 metres, and the alluvial deposits of watercourses.

This system would be highly dependent on direct recharge by rainfall and on inflow from water courses. The water table would follow local topography, and its evolution will reflect seasonal variation and the development of mine workings.

The directions of flow would be towards the Oeiras River, with the exception of the zone of influence of the mine.

The permeability of this aquifer would be relatively low and, according to a BRGM study (1983), would vary between 2×10^{-3} cm sec^{-1} and 1.8×10^{-3}cm sec^{-1} for alluvium, and 1×10^{-5} cm sec^{-1} for fractured rock.

Intermediate System

This system would act purely as a water transfer zone from the deep system to the surface system, or from the later to the deep system.

According to the BRGM the permeability of this system would be of the order of 10^{-6} cm sec^{-1}, and storage coefficients would be extremely low.

Deep System

The deep system, before being affected by mine workings, would have been a confined aquifer with a high hydraulic load, which would have caused vertical ascent of water along decompression areas. The intense fracturing around the orebodies would lead to high fracture permeabilities.

The development of the mine workings caused a drow down of the water table, local changes in the direction of underground flows, and an increase in the influx of water into the tunnels and access ramp.

Thus, the opening of the access ramp and other underground excavations disturbed the hydraulic balance between the three systems. As a consequence, the three aquifers began to drain into the underground workings.

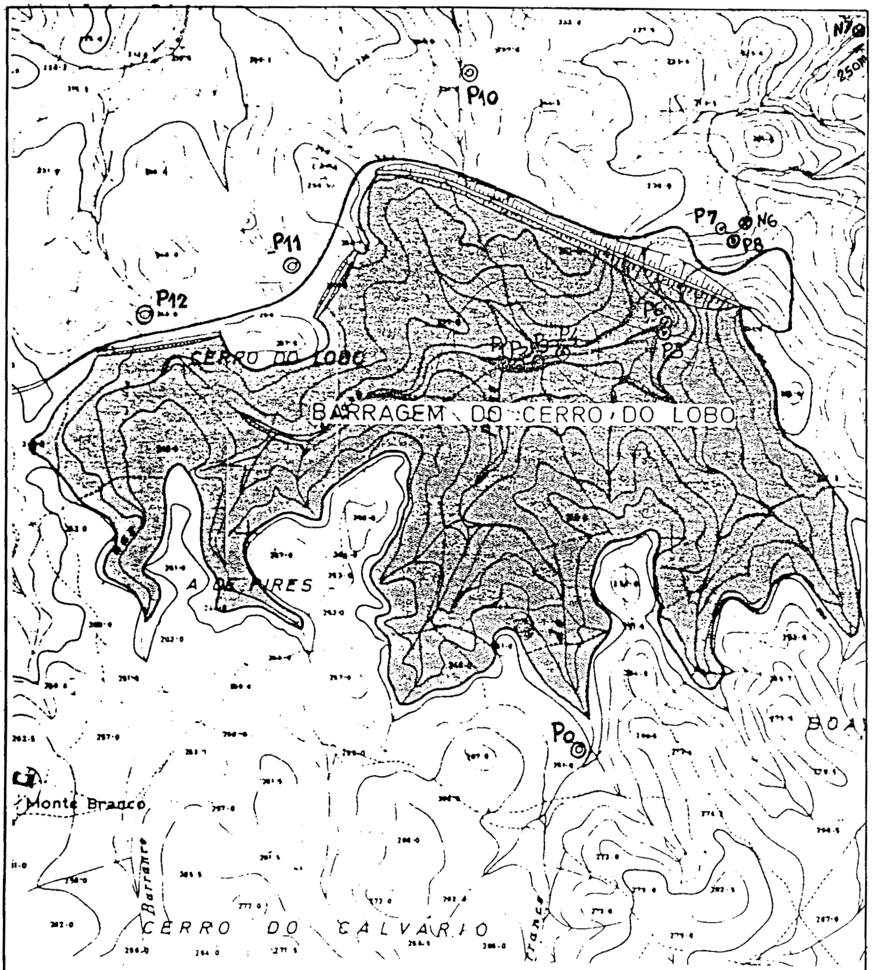
LOCAL HYDROGEOLOGY - CERRO DO LOBO AND WATER DAMS

Cerro do Lobo Dam

In order to know the prevailing hydrogeological conditions in the lagoon area of the dam, 9 boreholes were drilled, at the locations shown in Fig. 2. Six of these were whithin the dam limits, and three downstream of the dam wall. These boreholes were equipped as piezometers. The details of these boreholes are shown in the following table:

TABLE: Characteristics of the Boreholes

DATA	P1	P2	P3	P4	P5	P6	P7	P8	P9
Start of Drilling	13/9/87	14/9/87	15/9/87	16/9/87	18/9/87	19/9/87	22/9/87	31/10/87	------
Collar Elevation	224.60	224.30	223.00	222.00	218.00	217.00	217.00	214.00	214.00
Hole Depth	18.50	20.20	20.30	20.60	20.00	20.00	20.00	55.00	55.00
Depth of Aquifer	13.80	14.70	12.50	11.35	11.50	10.00	16.50	16.50	------
Depth to water table	2.00	2.30	----	1.80	5.00	4.70	5.00	5.00	------
Piezome-tric Quota	222.60	222.00	----	220.00	213.00	212.30	209.00	209.00	------



LOCATION PLAN SHOWING CERRO DO LOBO DAM
AND PIEZOMETERS USED FOR MONITORING

Fig.2

The boreholes showed the presence of a confined aquifer with its ceiling at a depth of 10 to 16 metres, which has a positive artesian head of 0.20 metres during the rainy season. However, the prevailing hydrogeological model for the remainder of the area has not been established.

The water table roughly follows the land surface, creating a hydraulic gradient of approximately 2.5%. This gradient changes abruptly between piezometers P6 and P7/P8, which are respectively upstream and downstream of the line of the dam wall.

Pumping tests carried out in the piezometres allowed the following calculations for this aquifer:

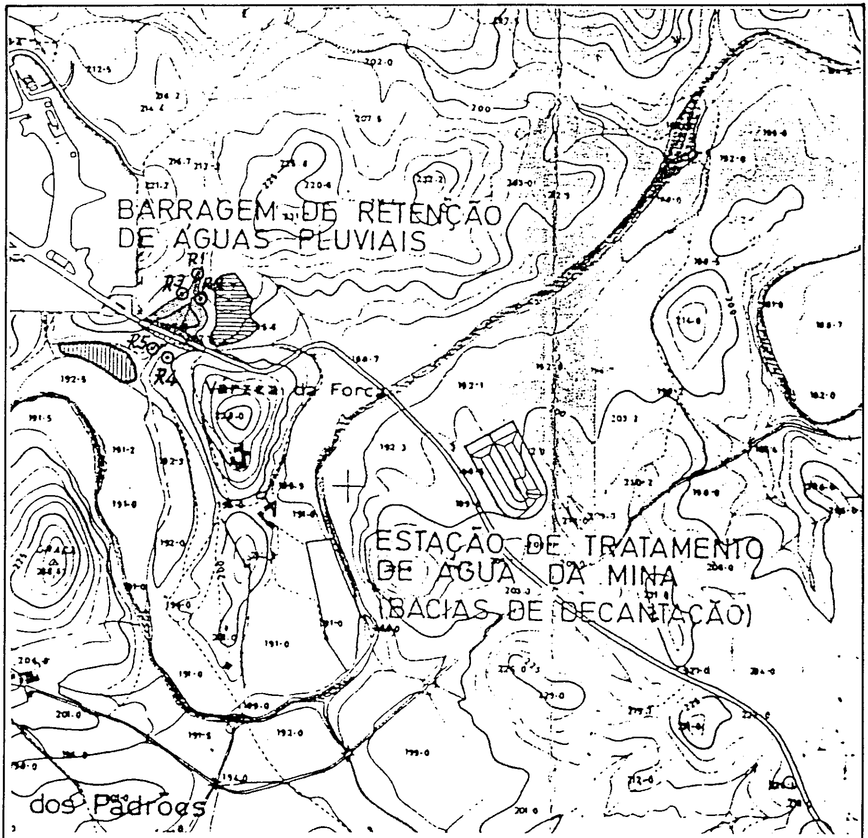
Transmissivity (T) = 6 m^2 /day
Storage Coefficient (S) = 4.9×10^{-8}
Permeability (K) 1m/day = 1.16×10^{-3} cm sec^{-1}

PLUVIAL WATER DAM

In this dam 5 boreholes were drilled, which were subsequently equipped as piezometers. Their location is given in Fig. 3, and a summary of their details is given in the following table:

TABLE: Characteristics of the Drillings

DATA	R1	R2	R3	R4	R5
Start of Drilling	30/10/87	29/10/87	28/10/87	27/10/87	26/10/87
Elevation	215.00	215.20	218.00	210.00	212.00
Depth	55.00	52.50	52.00	42.00	42.00
Depth of Water 10/87	40.00	38.00	38.00	30.00	30.00
Table 5/88	46.76	48.39	No water	38.34	48.55



LOCATION PLAN SHOWING PLUVIAL WATER DAM
AND PIEZOMETERS USED FOR MONITORING

Fig. 3

The influence of the cone of depression created by drainage into underground workings clearly extends to this area, so that the water table in piezometers R4 and R5, close to the Oeiras River, is below the level of the river. The confined aquifer detected beneath Cerro do Lobo dam was not detected in this area, thus the conceptual model appears to be confirmed.

TRACER TESTS

The test consisted of introducing 1 Kg of uranine (chemical formula $C_{20}H_{10}Na_2O_5$) into piezometers P1 (Cerro do Lobo Dam) and R1 (Pluvial Water Dam), and the collection of water samples for tracer detection from the remaining piezometers and from sampling points in the mine. The detection of the tracer would be made more difficult by the presence of fluorescent material in the piezometer water.

Sampling continued for a period of 193 days, but the results, which are shown in the following tables, were not anomalous.

From the small amount of data obtained, flow-rates of 5 metres per day for Cerro do Lobo and 7 metres per day for the Pluvial Water Dam could be calculated. No uranine whatsolver was detected in any underground water samples.

ANALYSIS OF RESULTS

Watertightness of the Cerro do Lobo Dam

The study carried out by LNEC for Somincor, based on the geological/geotechnical studies and hydrogeological studies, concluded that, in a situation without a grout curtain, 0.03 litres per second per meter width of dam wall would flow through the foundations and under the body of the dam. These volumes would be gathered in the drainage trench leading to the collection well.

For a dam width of 415 metres, a flow of 44.82 m^3 . hr would arise. Considering that the influence of the water contained in the dam would be principally in the zone corresponding to the bed of the stream, an average width of 200 metres could be assumed for the purposes of calculation, giving a volume of 21.0 m3 hr .

The average flow pumped from the collection well in 1990 varied between 4.8 m3 hr in February, March and April, and 1.1 m^3 hr in the months of May, June and July (1). These values are clearly much lower than those estimated in the study.

The differences between the flow pumped in the first three months and the last three will be due, amongst other reasons, to the contribution of precipitation, and to improved watertightness from settling of slimes, by the variation of pH, or a combination of the two.

Evolution of the Chemical Content of Groundwaters

A comparative study of groundwater chemistry from samples taken in piezometers N6 and N7 before and after the commissioning of the works allows the following conclusions:

a) Variation in pH (graph 1)
Before the commissioning of the dam, the pH of water in the downstream piezometers was, respectively:

N 6 - pH = 7.46
N 7 - pH = 6.89

During 1989, the pH of piezometers N6 and N7 remained practically constant, with values between 7.45 and 7.29. From January to June 1990 the pH of these holes was also steady, with values between 7.6 and 7.3.

b) Metal Ions (graphs 2 and 3)
Comparing the concentrations of these metals before commissioning, when the contents were, respectively:

Cu^{++} - 0.039 ppm in N 7 and 0.05 ppm in N 6
Zn^{++} - 1.030 ppm in N 7 and 0.700 ppm in N 6

(1) The piezometer that is located next the dam and also next the colector well was producing in August a flow of 4 m3 hr with this, the total average flow that can be obteined is 5 m^3 hr .

With those observed during 1989 and 1990, it can be concluded that:

b1) Copper (Cu^{++})
The average concentrations in the two years were:
1989 - N 6 = 0.07 ppm; N 7 = 0,04 ppm
1990 - N 6 = 0.03 ppm; N 7 = 0.04 ppm

b2) Zinc (Zn^{++})
The average concentration in the two yeras were:
1989 - N 6 = 0.01 ppm; N 7 = 0.03 ppm
1990 - N 6 = 0.01 ppm; N 7 = 0.03 ppm

CONCLUSIONS

From this analysis the following conclusions can be made:

Tightness of the Dam Wall

Flows seeping through the foundations and through the body of the dam are so small that these structures can be considered to be practically sealed.

Tightness of the Lagoon

Having confirmed that pH and concentrations of metal ions commonly found in the ore have been effectively constant throughout 1989 and 1990, it can be concluded that the dam reservoir and the dam wall foundation have behaved as sealed structures, confirming the predictions of the studies which took place. (It is thought that an analytical error is responsible for the level of Zn^{++} determined in 1987).

Pollution of Surface Waters and Groundwater

The sealing of the reservoir, dam wall and foundations ensures that contamination of surface water or groundwater downstream of the dam need not be feared.

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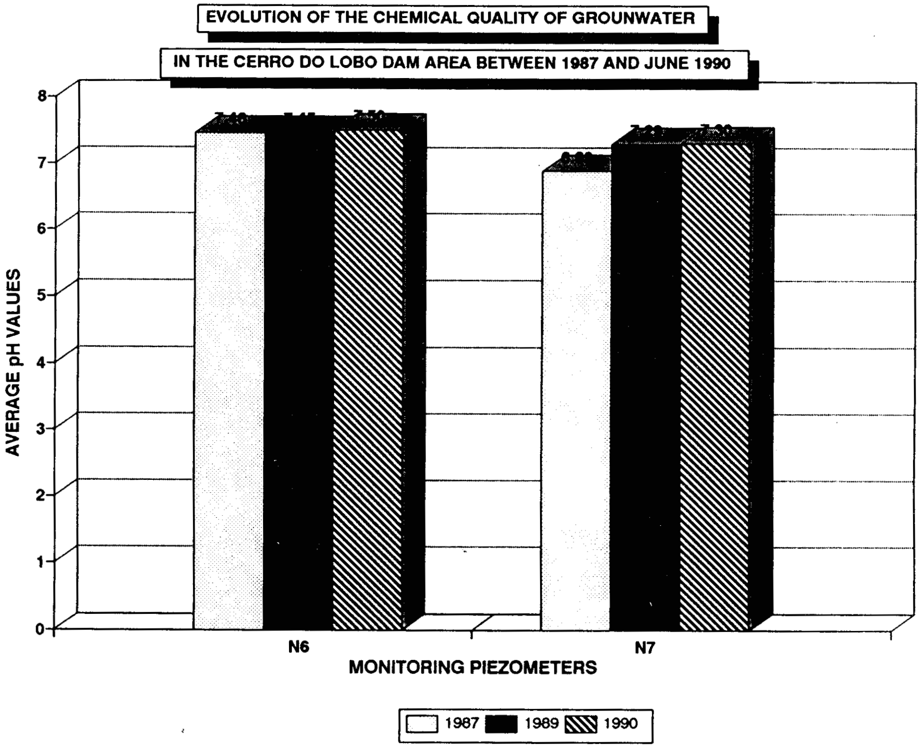
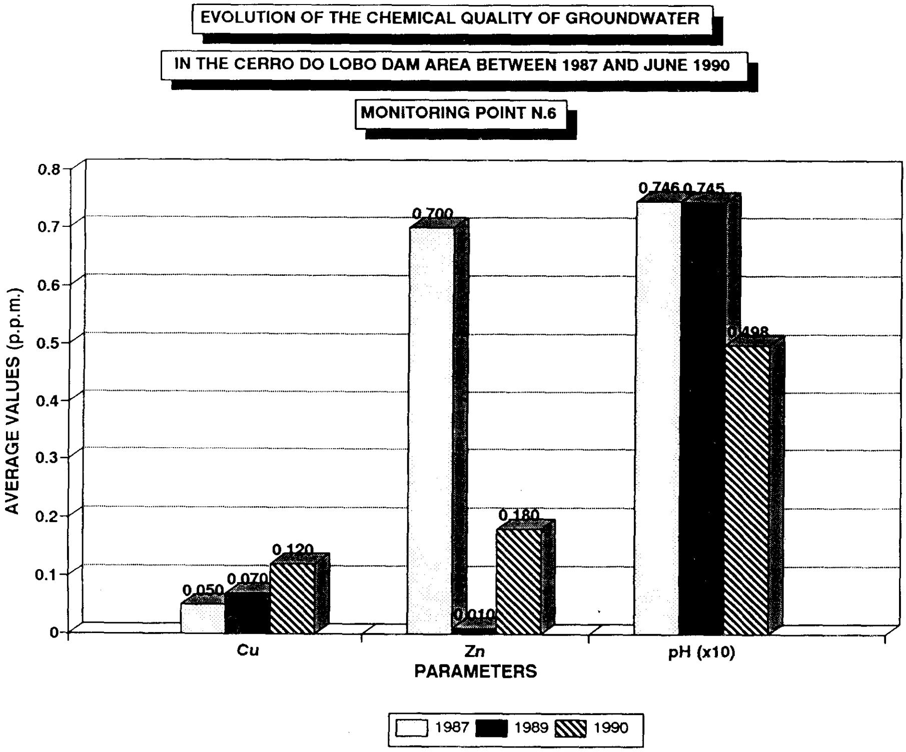
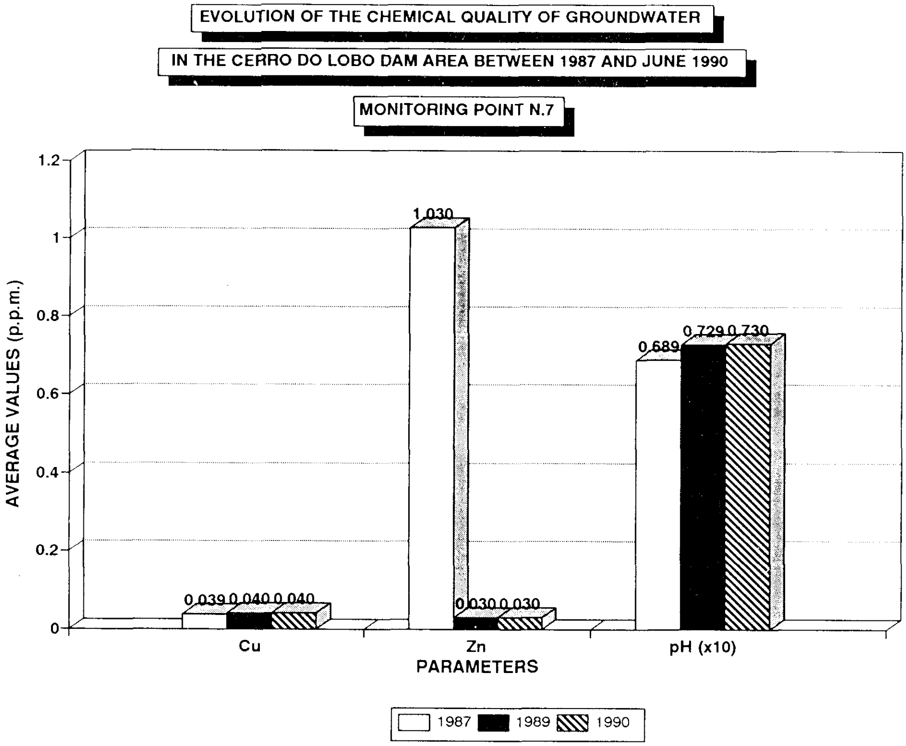

EVOLUTION OF THE CHEMICAL QUALITY OF GROUNWATER
IN THE CERRO DO LOBO DAM AREA BETWEEN 1987 AND JUNE 1990
AVERAGE pH VALUES
0
1
2
3
4
5
6
7
8
N6
N7
MONITORING PIEZOMETERS
1987
1989
1990

GRAPHIC NR.1


EVOLUTION OF THE CHEMICAL QUALITY OF GROUNDWATER
IN THE CERRO DO LOBO DAM AREA BETWEEN 1987 AND JUNE 1990
MONITORING POINT N.6
AVERAGE VALUES (p.p.m.)
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0.050
0.070
0.120
0.700
0.010
0.180
0.746
0.745
0.498
Cu
Zn
pH (x10)
PARAMETERS
1987
1989
1990

GRAPHIC NR.2

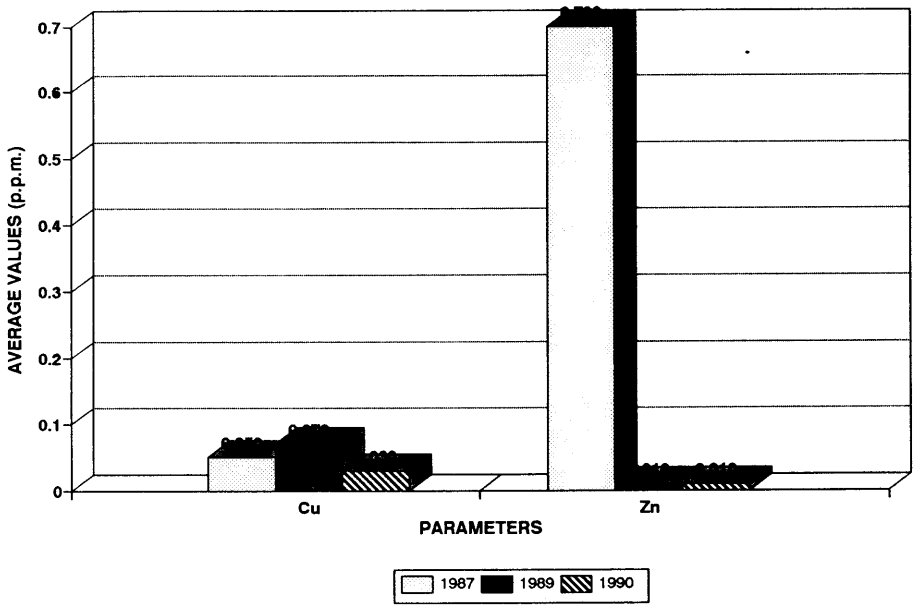

EVOLUTION OF THE CHEMICAL QUALITY OF GROUNDWATER
IN THE CERRO DO LOBO DAM AREA BETWEEN 1987 AND JUNE 1990
MONITORING POINT N.7
AVERAGE VALUES (p.p.m.)
1.2
1
0.8
0.6
0.4
0.2
0
0.039
0.040
0.040
1.030
0.030
0.030
0.689
0.729
0.730
Cu
Zn
pH (x10)
PARAMETERS
1987
1989
1990

GRAPHIC NR.3

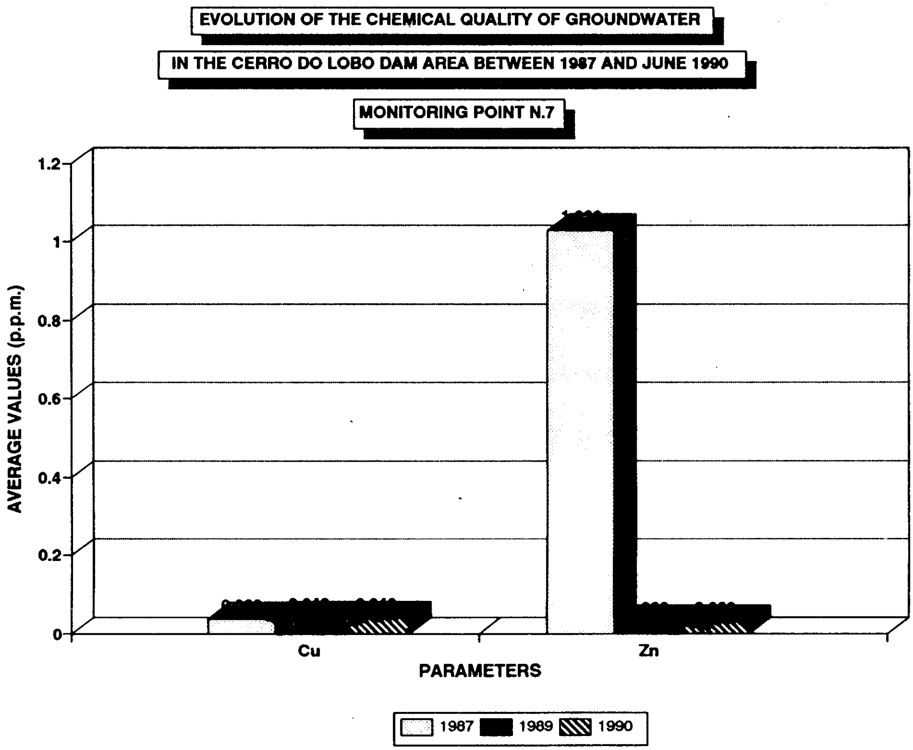
EVOLUTION OF THE CHEMICAL QUALITY OF GROUNDWATER

IN THE CERRO DO LOBO DAM AREA BETWEEN 1987 AND JUNE 1990

MONITORING POINT N.6



GRAPHIC NR. 4


EVOLUTION OF THE CHEMICAL QUALITY OF GROUNDWATER
IN THE CERRO DO LOBO DAM AREA BETWEEN 1987 AND JUNE 1990
MONITORING POINT N.7
AVERAGE VALUES (p.p.m.)
1.2
1
0.8
0.6
0.4
0.2
0
Cu
Zn
PARAMETERS
1987
1989
1990

GRAPHIC NR.5