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# Hydrogeological Risk and Mining Tunnels: the Fontane-Rodoretto Mine Turin (Italy)

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***Abstract*****—**The interaction of tunneling or mining with groundwater has become a very relevant problem not only due to the need to guarantee the safety of workers and to assure the efficiency of the tunnel drainage systems, but also to safeguard water resources from impoverishment and pollution risk. Therefore it is very important to forecast the drainage processes (i.e., the evaluation of drained discharge and drawdown caused by the excavation). The aim of this study was to know better the system and to quantify the flow drained from the Fontane mines, located in Val Germanasca (Turin, Italy). This allowed to understand the hydrogeological local changes in time. The work has therefore been structured as follows: the reconstruction of the conceptual model with the geological, hydrogeological and geological-structural study; the calculation of the tunnel inflows (through the use of structural methods) and the comparison with the measured flow rates; the water balance at the basin scale. In this way it was possible to understand what are the relationships between rainfall, groundwater level variations and the effect of the presence of tunnels as a means of draining water. Subsequently, it the effects produced by the excavation of the mining tunnels was quantified, through numerical modeling. In particular, the modeling made it possible to observe the drawdown variation as a function of number, excavation depth and different mines linings.

***Keywords*****—**Groundwater, Italy, numerical model, tunneling.

## I. INTRODUCTION

WATER circulation in rocks represents a very important element to solve many problems related to civil, environmental and mining engineering. In particular, the interaction of tunneling or mining with groundwater has become a very relevant problem, as tunnel construction brings two kinds of problems: the first is related to the forecast of water inflow location, and the second is related to the forecast of the drainage processes, flow rate and water table drawdown. Moreover, drained water can interfere with the shallow aquifers and cause water table drawdown, extinction of springs and/or wells, changes in groundwater quality and in the hydrological balance at basin scale [1], [2]. When tunnels are drilled in fractured rock masses, it is difficult to forecast the water inflow location or the drainage processes, because the hydraulic behavior is neither homogeneous nor isotropic and the water flow is controlled by joint features [3]. Such problems increase in the case of mines, because there are many tunnels, generally located at many different levels.

The aim of this study is to know better the system and to quantify the flow drained from the Fontane Mines, located in Val Germanasca (Turin, Italy). This allows to understand the hydrogeological local changes in time and to identify possible solution for restoring natural hydrogeological conditions.

The work has therefore been structured as follows: the reconstruction of the conceptual model with the geological, hydrogeological and geological-structural study; the calculation of the tunnel inflows (through the use of structural methods) and the comparison with the measured discharges; the water balance at the basin scale. Afterwards, to quantify the relationships between rainfall, groundwater level variations and the effect of the presence of tunnels as a means of draining water, a numerical model was implemented through the software Modflow [4].

## II. HYDROGEOLOGICAL SETTING

The Fontane mine is the most important talc mine in Italy. It is an underground mine developed on various levels (Fig. 1). In particular, the study involved two levels no longer used and actually given over a museum: the Paola level (1280 m a.s.l. with a total length of 1375 m) and the Gianna level (1205 m a.s.l. with a total length of 1360 m).

From a geological point of view, the study area consists of pre-Triassic crystalline basements and Mesozoic rocks. In particular the following lithotypes have been surveyed :

1) Meta-igneous rocks, Marbles and Micaschists with garnets and chloritoids having a Carboniferous age;

2) Serpentinites and Calceschists having a Triassic-Jurassic age.

A number of plutons and carbonatic rocks having a Mesozoic age is also present (Triassic Dolomitic Marbles), as Fig. 2 shows.

More in detail, inside the studied mines micaschist and gneiss interbedded with marble and micaschist containing talc mineralization was identified (Fig. 1). These rocks are characterized by a wide water circulation, whose supply derives directly from meteoric recharge and whose discharge is the Germanasca River.

The water circulation is strongly affected by geological and structural setting, and by the mines which act as drains, causing an important water table drawdown.

To reconstruct the water circulation, the structural elements of the area were surveyed both on the surface and in depth. Inside the mining tunnels the structural survey highlighted the presence of a number of faults having main directions NE-

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SW, E–W, NW-SE, and subvertical joint set having direction E-W. The surveys allowed to determine the preferential flow directions and the hydraulic conductivity tensors.

The tunnels inflows in Paola and Gianna levels were monitored through weirs (Fig. 3). The average measured flow rates inside these levels are equal to respectively 0.3 l/s and 3.37 l/s, corresponding to 9,500 m$^3$/y (in the Paola level) and 106,000 m$^3$/y (in the Gianna level).

The hydrogeological balance at the basin scale allowed to highlight how the tunnels inflow amounts, each year, to the infiltration (Table I).

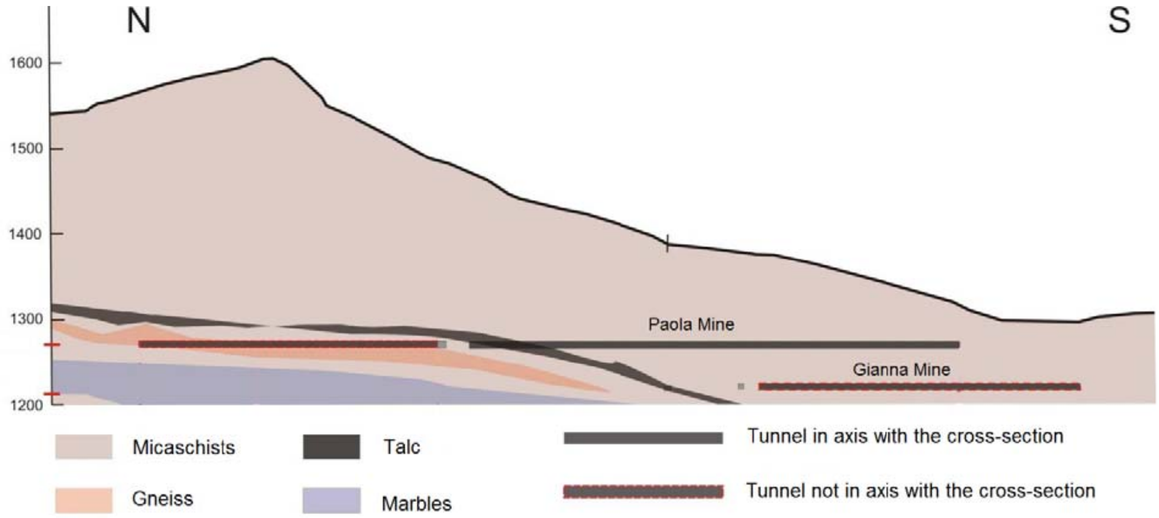

Fig. 1 Cross section of the studied area with two mining tunnels

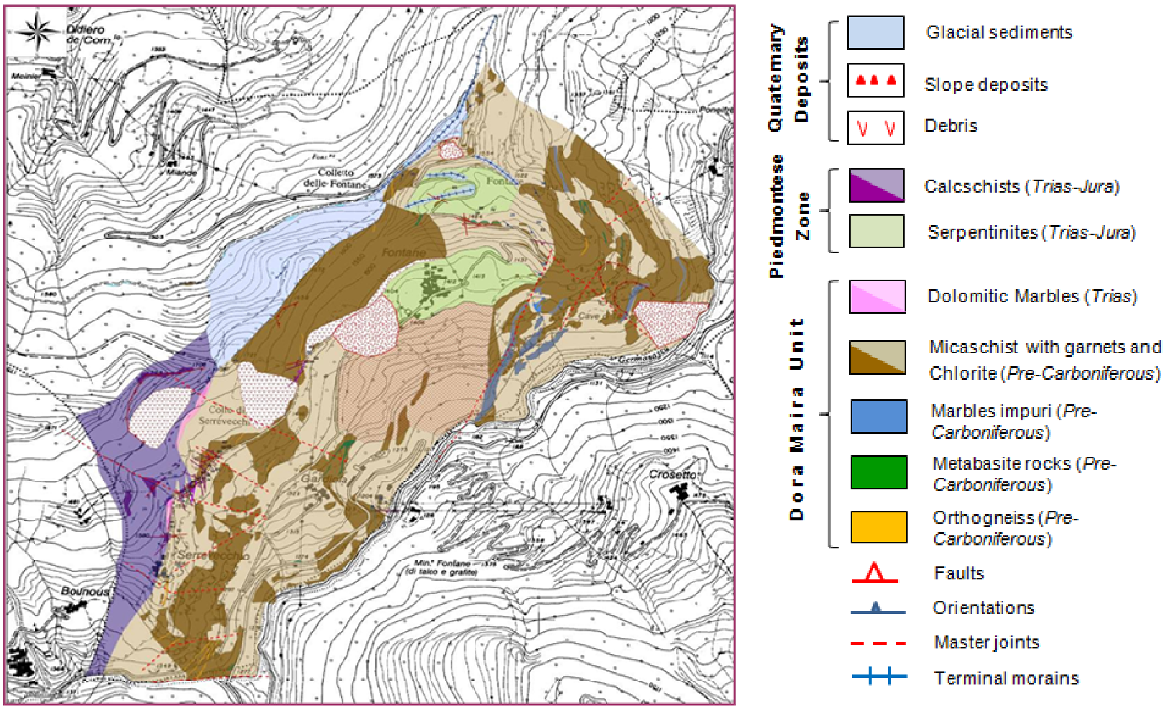

Fig. 2 Geological map of the study area

TABLE I
HYDROGEOLOGICAL BALANCE OF THE STUDY AREA

| Parameter | Value |
|---|---|
| Area | 1,548,259 $m^2$ |
| Yearly average rainfall | 1,055 mm/y |
| Yearly rainfall volume | 1,633,413 $m^3/y$ |
| Yearly average net rainfall volume | 969,764 $m^3/y$ |
| Yearly average recharge | 168,170 $m^3/y$ |

## III. HYDROGEOLOGICAL MODELING

Based on the previously described conceptual model it has been possible to understand what are the relationships between rainfall, groundwater level variations and the effect of the presence of tunnels as a means of draining water. To quantify these effects, a numerical model was implemented through the software Modflow (Harbaugh et al., 2000).

In particular, a domain having dimension equal to 1.2x1.3 $km^2$ was considered, representing the slope from the highest altitude of 1600 m a.s.l. and the foothill river at 1180 m a.s.l.; the cells are squared, with an average dimension of 5x5 $m^2$. Along the vertical direction, 8 layers have been considered having thickness variable according to the geological setting, and generally in between 15 m (i.e the talc and gneiss levels) and 300 m (i.e., for the micaschists).

The hydraulic conductivity values were chosen with reference to the in situ geological-structural surveys (Table II). The recharge was calculated on the basis of the hydrological balance and was considered decreasing with the altitude, from 1E-8 m/s at the highest altitude to 4E-9 m/s along the foothill river. This latter was simulated through a flow dependent boundary condition.

The mines were modeled with two different approaches:

1) As a drain, that corresponds to a boundary condition of flow depending on the hydraulic head, in which the drained discharge D is equal to:

$$D = C_D(h-h_D) \qquad \text{for } h > h_D \qquad (1)$$

$$D = 0 \qquad \text{for } h > h_D \qquad (2)$$

Where $C_D$ is the drain conductance ($L^2T^{-1}$), h is the simulated groundwater head (L) and $h_D$ is the drainage level (L), which for Paola mine is equal to 1280 m a.s.l., whereas for the Gianna Mine is equal to 1205 m a.s.l.; the drain conductance was calculated considering the mines geometry and the hydraulic conductivity of the surrounding rock mass;

TABLE II
HYDRAULIC CONDUCTIVITY VALUES USED IN MODELING

| Litothype | $K_x$ (m/s) | $K_y$ (m/s) | $K_z$ (m/s) |
|---|---|---|---|
| Surface micaschists | 1E-7 | 1E-7 | 1E-8 |
| In depth micaschists | 5E-8 | 5E-8 | 5E-9 |
| Talc | 1E-6 | 1E-6 | 1E-7 |
| Gneiss | 1E-8 | 1E-8 | 1E-9 |
| Marble | 5E-9 | 5E-9 | 5E-10 |

2) As zones having very high hydraulic conductivity, connected to a single drain cell located where the tunnel reaches the topographic surface.

The first approach didn't allow to correctly reproduce the observed tunnel inflow, neither after long calibration procedure. Otherwise, the second approach allowed to reach a good fit between observed and simulated tunnel inflows, by calibrating the conductance of the single drain cell.

The modeling allowed to observe the water table variation from the natural condition (Fig. 4a) to the actual condition. In particular, with the presence of only the Paola Mine (Fig. 4b), only the Gianna Mine (Fig. 4c) and both the Mines (Fig. 4d). As it can be observed, the presence of the only Paola Mine brings about a water table drawdown ranging between 15 and 45 m, whereas the Gianna Mine determines a drawdown in between 10 and 23 m.

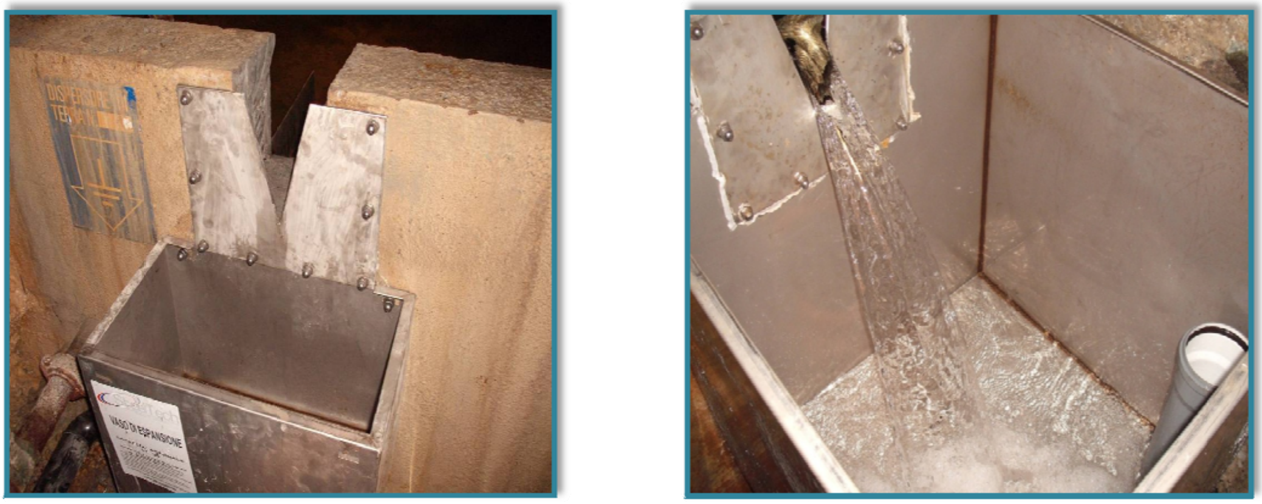

Fig. 3 Weirs used to monitor tunnel inflows

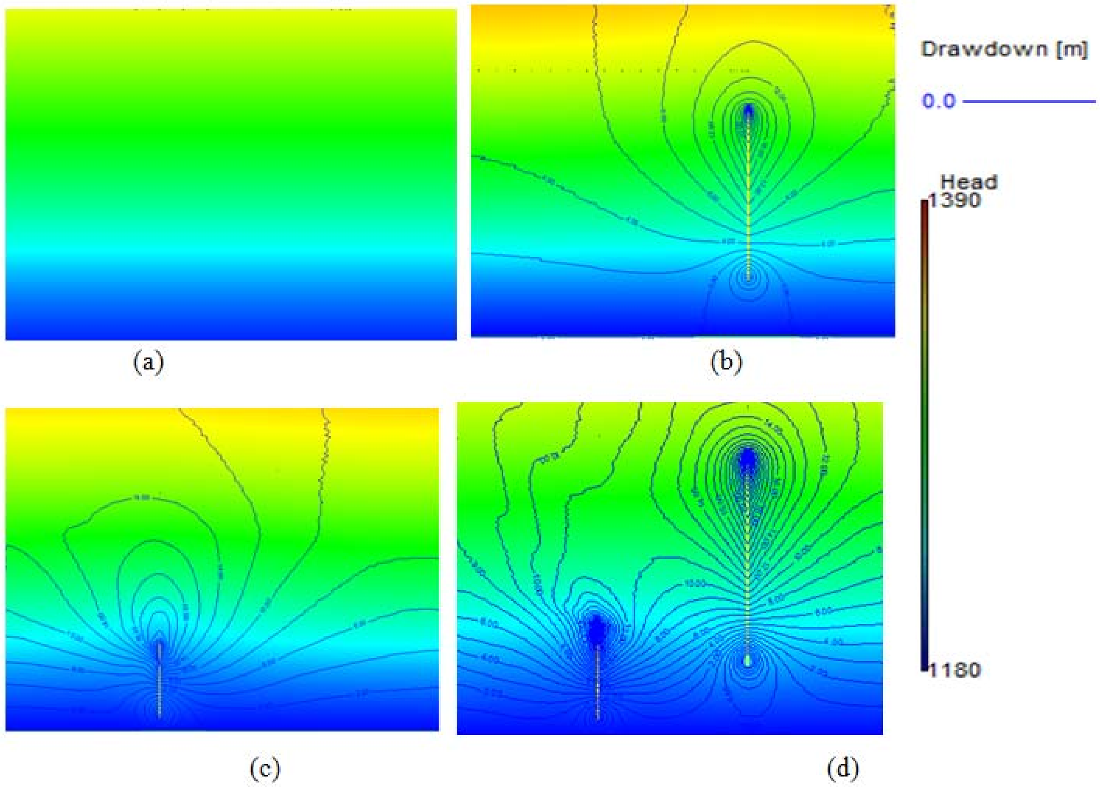

Fig. 4 Simulated hydraulic heads (m a.s.l.): (a) in natural conditions (without mining tunnels); (b) in presence of only Paola Mine; (c) in presence of only Gianna Mine; (d) with both the mining tunnels

Afterwards the possibility of restoring the natural hydrogeological conditions was considered, by reducing the hydraulic conductivity of the tunnel profile. The numerical modeling shows that reducing the hydraulic conductivity from 10-2 m/s to 10-5 m/s it is possible to obtain an acceptable water table drawdown in the order of 20% of the present situation (Fig. 5), corresponding to a tunnel inflow reduction in between 50-80%. Further decreasing in hydraulic conductivity does not produce significant drawdown reduction. This result can be obtained with the shotcrete lining of some mine stretches no longer used.

## IV. CONCLUSIONS

During the years the mining activity in the studied area determined a significant depletion of the groundwater resources, causing a water table drawdown able to dry all the springs present along the slope. This situation arises from the excavation on several levels with the creation of a lot of overlapped tunnels and shafts.

As most of these tunnels are now no longer used the goal of the study was to find a solution for restoring, to some extent, the natural hydrogeological conditions. At this aim the relationships between rainfall, groundwater level variations and the effect of the presence of tunnels as a means of draining water were analyzed and the effects produced by the excavation of the mining tunnels were quantified through numerical modeling.

In particular, it was possible to observe the drawdown and the tunnel inflow variation as a function of the hydraulic conductivity of the mines lining.

On the basis of numerical modeling results to obtain a good restoration of the natural hydrogeological conditions it would be sufficient to realize a shotcrete lining of some mines stretches no longer used.

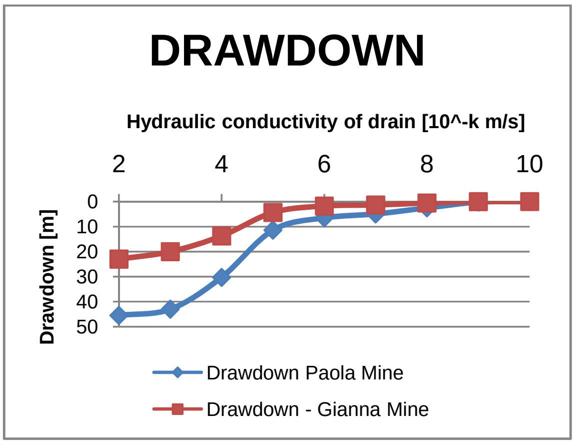

Fig. 5 Drawdown versus the hydraulic conductivity of the tunnel profile (a) Paola Mine, (b) Gianna Mine

## REFERENCES

[1] A. Dematteis, G. Kalamaras, A. Eusebio, "A systems approach for evaluating springs drawdown due to tunneling", in "W*orld Tunnel Congress AITES-ITA*" Vol. 1, Patron, pp 257– 264, 2001.
[2] S. Loew, "Groundwater hydraulics and environmental impacts of tunnels in crystalline rocks", in "*Meccanica e Ingegneria delle rocce – MIR*", Torino, Italy, pp 201–217, 2002.
[3] L. Scesi, P. Gattinoni, *Water Circulation in Rocks*, Springer, 2009, p. 165.
[4] A.W. Harbaugh, E.R. Banta, M.C. Hill, M.G. McDonald, *The U.S. Geological Survey modular ground-water model – User guide to modularization concepts and the groundwater flow process,* Open-file Report 00-92, USGS, Boulder, Co, 121p., 2000.

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