Salsigne Gold Mine Water Flow Modeling

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Abstract
The Salsigne gold mine was closed in 2004, with cessation of water pumping leading to a gradual inundation of the workings. Fears of pollution are linked to the probability of water level rise and subsequent release of minewater to surface streams. From the data gathered since closure, a simple hydraulic model was developed to describe the behaviour of the water reservoir in the abandoned mine workings. The model successfully describes the observed phenomena and confirms the absence of immediate pollution risks. The possibility of a gradual closing up of the hydraulic linkages with surface streams is one of the important factors to be further studied.

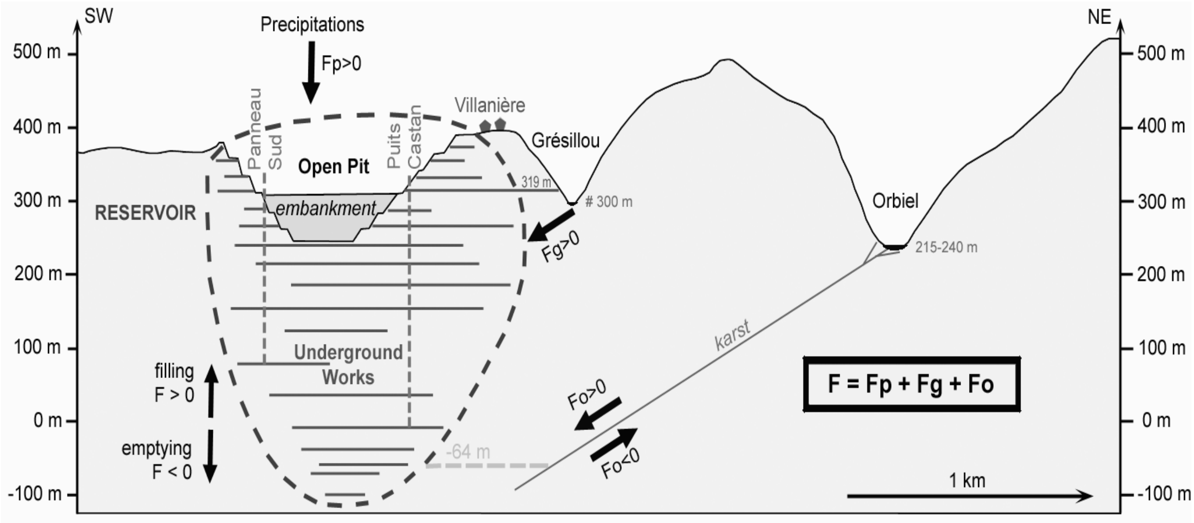
Key words: karst, minewater, modeling, Salsigne gold mine

Introduction
With the closure of operation of the Salsigne gold mine in France in 2004, pumping of groundwater ceased in August of that year. In addition to regular releases to a nearby stream, the Orbiel, there is the possibility also of subsequent discharge of groundwater from an abandoned gallery at level 319 m asl which, by passing over ground historically contaminated, could lead to pollution of another nearby stream, the Grésillou.
Since the cessation of pumping, the minewater has been regularly monitored. This shows a stabilization of level around 250-260 m asl, lower than the predictions of previous studies (ANTEA 2003, Combes - ENSMP 2005).
This study proposes a new hydraulic model to better predict the likelihood and risks of possible discharge and pollution of the environment. The model was first tested in the field at the end of 2006, with careful observation and follow-up during the subsequent year.

Methodology
The behaviour of the subsurface waterbody in the mine workings is based on a simple model combining one or more two-way hydraulic connections in the underlying karsts, with also ingress of surface drainage from the disused open-pit workings. It is assumed that there is no significant natural groundwater reservoir with which the minewater interacts.
The volume of the water reservoir is determined (Combes - ENSMP 2005) by the voids left unfilled in the underground workings and the space in the disused open pit (in part filled in). Water inflows are modelled on the basis of weekly measurements of surface water levels as influenced by pluviometric data from several stations near the site. Data from August 2004 to December 2006 have been used in the first instance to establish this model. The model has been tested against the actual evolution of mine water level and inferred discharges, and is believed to now give a realistic representation of the dynamics of water flows in the mine. Water flows have been combined with contamination levels in the mine to also estimate the impact on stream quality where discharges have, and are likely to continue to, occur.

Hydraulic exchanges between the mine and the environment
The calculation of water flows is based solely on the factors of rainfall and direct flow exchange with two neighbouring streams, Orbiel and Grésillou. The different flow elements have been individually calculated and combined in the model in order to compare the predictions with actual observations.
Possible water losses from the mine have been identified at around 300 m asl for the Grésillou and between 215 and 240 m asl for the Orbiel (ANTEA 2003). The hydraulic link with the Orbiel passes via an opening in the karst substrata around level -64 m asl. This linkage had already been directly observed while the mine was still active. This study is therefore based on the exchanges shown in Figure 1.

Figure 1 *Schematic representation of hydraulic exchanges between the mine and the environment*



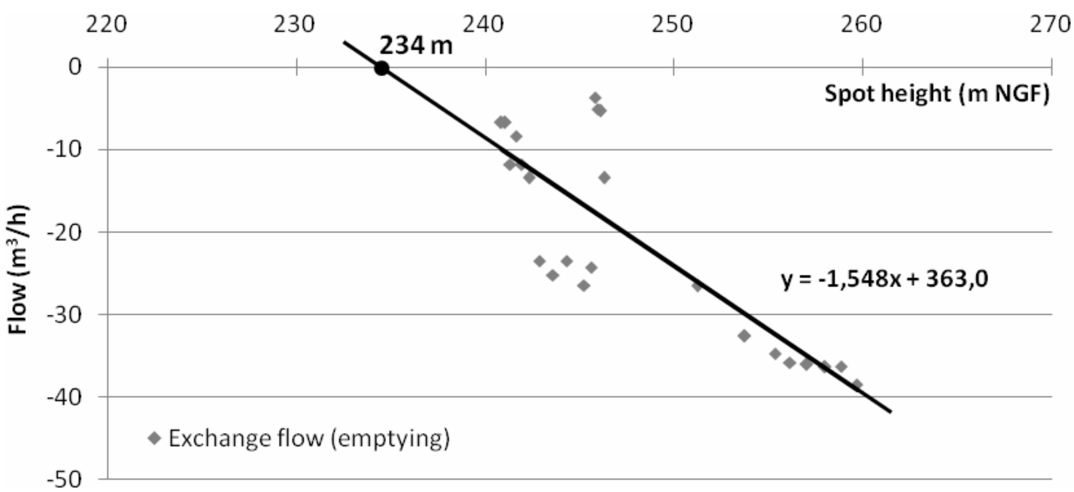
F: total flow
Fp: flow of precipitation (supply)
Fg: flow of Grésillou stream (supply)
Fo: flow of Orbiel stream (supply>0, emptying<0)

Exchange between the mine and Orbiel stream

Considering the periods of low or zero flow in the Grésillou in the absence of rainfall, we can assume that the hydraulic exchange between the mine and the Orbiel represents the only actual discharge for the mine. This exchange is shown on Figure 2.

The graph of the discharge (Fo) as a function of the height of water in the mine (z) gives a linear equation Fo = -1,548*z + 363, with an equilibrium at 234 m asl, which represents the average discharge of the Orbiel into the mine.

Figure 2 *Hydraulic exchange between the mine and the Orbiel stream*



Influence of rainfall

For the model, we consider the catchment surface to be the open-pit of the mine, with an infiltration efficiency coefficient that is seasonally dependent. The effective precipitation is then:

Fp = C*(P/1000)*S/(Δt*24) with C = coefficient of efficiency, P = precipitation (mm), S = surface area affected (m²), Δt = number of days of rainfall at P.

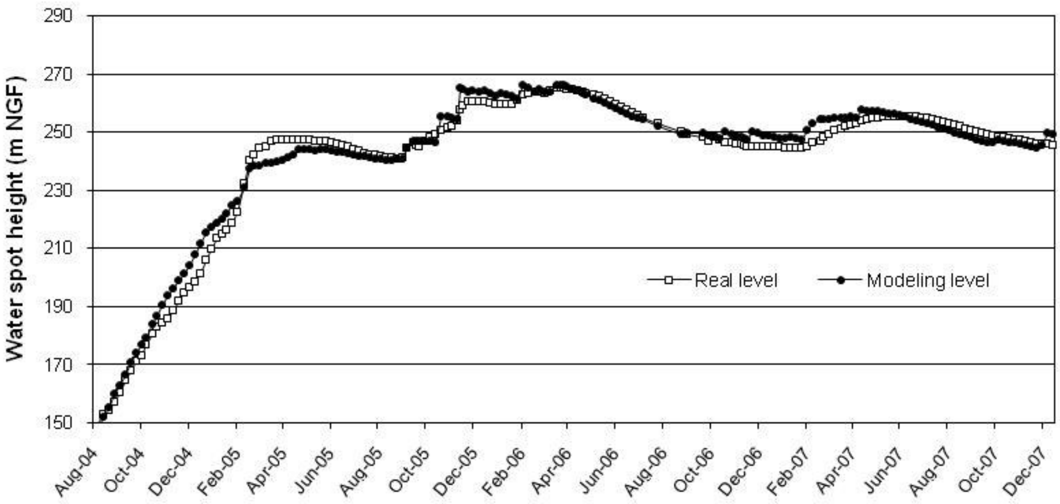
Exchange between the mine and the Grésillou

This is assumed to depend only on exchange at the level of 300 m asl between the mine and the stream. If we suppose the flow of the Grésillou (Fg) to have a linear relationship with height (z), as measured at two points [300 m - 0 m^3/h] and [-60 m – 85 m^3/h] (ANTEA 2003), we obtain the equation Fg = - 0,24*z + 71.

Calculation of water level

From the three simple formulas established above – for the Orbiel, the Grésillou and rainfall – we can calculate the evolution of the water levels in the mine. During the period when the mine was filling with water, i.e. between August 2004 and December 2006, we obtain a curve very similar to that actually observed, as shown on Figure 3.

Figure 3 *Comparison between observed and calculated water levels*



The curve gives an indication of the reliability of the model: 93% of the calculated levels are within +/- 7 m of observed values. The standard deviation between the curves is 3.5 m with an average variation of 0.97 m. Despite its simplicity the model predicts the water fluctuations in the mine quite well, using only the three input/outflow parameters discussed earlier. This result allows us to put aside the possibility of other significant inputs and outflows.

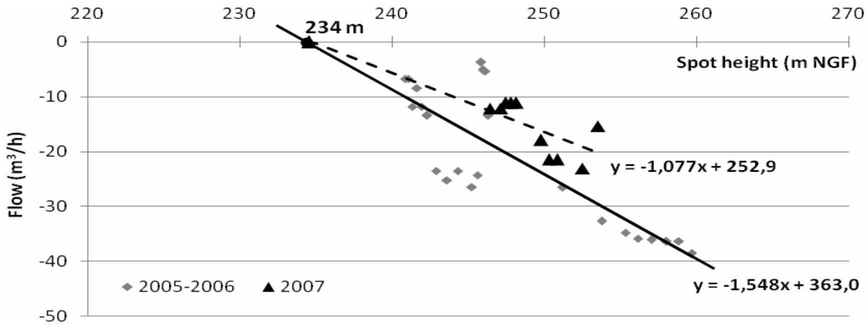
When the model is applied retrospectively to the mine in its past operational state, the calculated figures for discharges are of the same order as were observed between 1990 and 2003 (ANTEA 2003). The model is thus also valid for this operational period.

When a simulation is carried out for future years 2008 – 2011, and pessimistically assuming a period of higher rainfall, an oscillating pattern of flow is predicted over the seasons, with the winter/springtime inputs being subsequently released into the Orbiel at dryer times of the year via the hydraulic communication through the karst. Under these conditions, the water level remains much below the level of the gallery at 319 m asl, which would overflow into the Grésillou. The highest level observed is 285 m asl, and we can infer that the risk of pollution to the outside environment is minimal.

Further refinement of the model

The preceding simulation is based on a stable scenario as far as the hydraulic connections are concerned. However a calculation of the exchange flows during dry periods of the Grésillou using 2007 data shows a slow reduction in exchange with the Orbiel. This leads to the hypothesis of a possible gradual blocking of the connections in the karst at the bottom of the mine.

Figure 4 *Changes in water exchange with the Orbiel stream*



A new simulation for future years 2008 – 2011 with the gradual reduction in exchange flows shows a predicted rise in the water level in the mine. This evolution is a factor to be further studied and followed up in more detail.

Mine water quality

The hydraulic model allows us to study additional factors to simple water level fluctuations. In particular, the water discharge to the Orbiel has elevated levels of arsenic and sulphates. Together with measured concentration levels in mine water, the volume calculations allow us to predict likely pollution risks. The model predicts a dilution factor of between 400 and 1300, depending on seasonal fluctuations, of the mine water discharged to the Orbiel. The impact of mine water discharge on the Orbiel is thus likely to be very small.

This is confirmed by on-site measurement. Despite high levels of arsenic around 300 µg/l in the mine water, the levels measured in the Orbiel show no detectable increase below the discharge point. The same is true for sulphates which are about 380 mg/l in the mine but only 30 mg/l in the Orbiel. The stream thus maintains a water quality rated good to very good for all classes of use.

Conclusion

Following the cessation of pumping of minewater at Salsigne in August 2004, a hydraulic model was developed for the mine and its riverine environment. The model considers the mine, two nearby streams – the Orbiel and the Grésillou – and rainfall data to calculate the water levels in the mine under a variety of circumstances and seasons. The model predicts both present and past observed levels with a high level of accuracy, giving confidence also for its use as a forecasting tool for future years. A hydraulic linkage deep within the mine with the Orbiel stream limits water fluctuations within the mine to safe levels as far as risk of overflow through the 319 m asl adit into the Grésillou is concerned.

An analysis of 2007 data nevertheless reveals a gradual diminution of exchange flows with the Orbiel, giving rise to speculation of a progressive blocking of the karst channels with sediment from the mine. It will be important to study this phenomenon further in order to predict with greater precision the future flows that would result from such a scenario. In case this scenario is confirmed, further studies should be designed so to also shed light on possible interventions that could prevent water levels to reach 319 m asl, as such level would mean an overflow into the Grésillou with subsequent heavy pollution.

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