Integrating water balance modelling in the economic feasibility analysis of metals mining

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Abstract Realization of mine water management related risks can, e.g., cause temporary shut-downs of mining operations leading to decreased economic returns of metal mining operations. In this paper, a techno-economic system model for metal mines is applied to study this issue. The usability of the model is illustrated with a numerical simulation to analyze the effect of including the additional (unlimited) water storage capacity on the mine profitability and on mine value. The illustrated method allows modeling of water management investments within mining investments, while traditional analyses tend to present water balance modeling and mining profitability as separate issues.

Key words Water balance, Profitability, System dynamic modelling, Simulation, Risk management

Introduction

It is well-known that the feasibility of metal mines may be compromised by inadequate water management policies (ICMM 2012). In the investment decision making process these issues are typically treated as minor matters, which have to be dealt with in order to maintain acceptance of metals mining from the community and the environmental points of view. This is contrary to what we know about the cost of water management in mining, it has been observed that water infrastructure may account for up to ten percent of CAPEX in the mining industry (Fleming 2016). The unremarkable role of water management in profitability analysis may partially be due to the lack of proper techno-economic models for metals mining.

Brown (2010) states that an appropriate mine water evaluation (model) should reflect the full range of possible outcomes of water management. According to Gao et al. (2014) the currently applied engineering models, OPSIM and GoldSim, are not suitable for evaluating long-term water management strategies under a range of climate scenarios. In this paper, we present a novel approach that is different from the purely engineering oriented models found in the literature so far and that combines the technical and economic effects of investments to mine water management to mine profitability, and that is very useful in understanding the size of the added value generated by investments into mine water management.

Metal mining investments are large, irreversible investments with long economic lifetimes. Their profitability is conditioned by several project (geological and technical) and market uncertainties (see discussion in, e.g., Botin et al. 2013; Kenzap & Kazakidis 2013; Park & Nelson 2013). This paper focuses on the water management related uncertainties. Technical analysis of a metal mining project is supplemented with an economic feasibility calculation. Surveys of Bartrop & White (1995); Bhappu & Guzman (1995), and Smith (2002) suggest that mining companies typically apply discounted cash-flow (DCF) based methods, such as the Net Present Value (NPV), or Internal Rate of Return (IRR) to value metal mining projects. For a review of valuation methods we point the interested reader to refer to, e.g., Eves (2013) and Lawrence (2002). The traditional DCF-based methods assume that a metal mining operation is run from the start of the mine, without cessation, until the end of life of mine. In reality, however, metal prices may vary even tens of percent per year, which in turn typically leads to temporary mine closings and re-openings. It has been suggested by Brennan & Schwartz (1985a; 1985b) that a metal could be valued analogically to financial option. In other words, a metal is only mined, when the return of metal sales exceeds the costs of production – and if profitability is not reached, then the mine should be temporarily closed.

Besides the option for temporary closing, metal mining operations usually include also other *real options*. These range from options found in production planning to the option of permanent abandonment of the project. A real option (RO) refers to a possibility, but not an obligation to implement these actions, to steer the profitability of an investment. One of these real options is the option to include water management (investment) in a mine. Reviews of real options in metal mining industry are provided by, e.g., Savolainen (2016b) and Newman et al. (2010).

Trigeorgis (1993) suggest that the value of a real option can be determined by comparing the value of project value with a RO ("expanded NPV") and without it ("Passive NPV") as follows:

Value of Real Options = Expanded NPV – Passive NPV (1)

This simple valuation logic underlies the valuation that is used here in evaluating the difference in value emanating from (optional) investments in to water balance management.
The rest of the paper is organized as follows. Next section introduces the models applied and it is followed by the case example description with simulations. The paper ends with discussion and conclusions.

The model used

In this paper, we run a Monte Carlo analysis on a generic system dynamic feasibility model of metal mining investments, introduced in Savolainen et al. (2017). The model imitates the structure of a real world metal mining investment and consists of several sub-models presenting different aspects of a mining investment. The simulations conducted use a time step of one month. A high level illustrative presentation of the model is visible in fig. 1.

A simple water balance model is created to study the profitability effect of investing in effective water management (see fig. 2), and linked to the production calculation part of the existing techno-economic metal mine profitability analysis model.

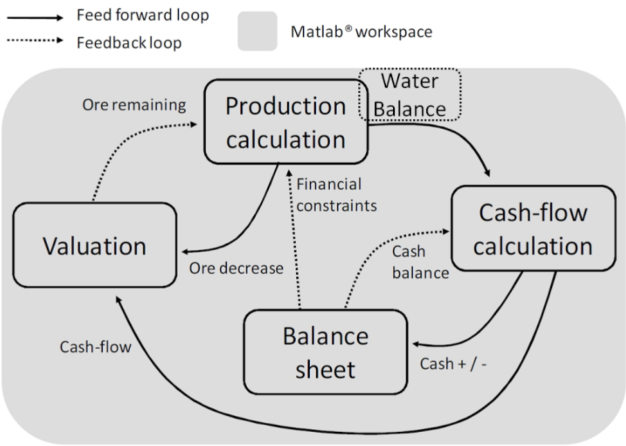

Figure 1 A schematic diagram of a system dynamic feasibility model for metal mining investments. The water balance model is connected to the production calculation and marked with a dashed line

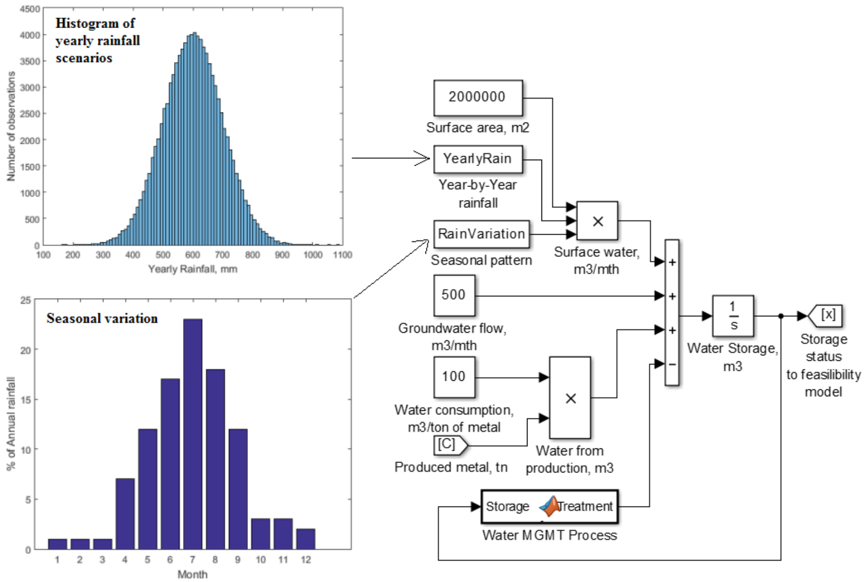

Figure 2 A system dynamic water balance model with randomized yearly rain and seasonal variation is linked into an economic feasibility model

Brown (2010) suggests that some of the major difficulties in mine water evaluations are related to mine inflow predictions and mine dewatering. In the illustrative case (fig. 2) the water balance is dependent on the uncertain yearly precipitation in the mining area, which creates an additional load to the water storage. The evaporation is assumed to be insignificant. The groundwater flow (mine dewatering) is assumed to be fixed. The amount of produced metal is left as a binary control variable, which can be adjusted to steer the overall water balance.

Illustrative case and simulation results

In this paper we are interested in a metal mining project that is under development that would be operating in a high rainfall area. The yearly rainfall is assumed to be normally distributed with a mean value of 600mm and a standard deviation of 150mm. The detailed process description of the water management is not of importance in this paper: it is simply assumed that the final treatment of all waters originating from the mining operation / mining area is done in a centralized purification process, with a fixed capacity. Other key parameters of the project are listed in tab. 1.

Table 1 *List of key variables in the feasibility analysis of the illustrative case example. Modified from Savolainen et al. 2016*

Variable	Unit	Pessimistic	Most Likely	Optimistic	Volatility, %
Reserve size	Tons	72 000	140 000	210 000	-
Metal yield	Tons/month	1 000	1 200	1 400	-
Production ramp	Tons/month	50	100	200	-
Unit cost	EUR/ton	4 000	3 500	3 000	-
Fixed cost	EUR/month	3 000 000	2 500 000	2 000 000	-
Construction time	Months	36	24	12	-
Construction cost	EUR	80 000 000	60 000 000	40 000 000	-
Unit price	EUR/ton	14 000	16 000	18 000	5
Exchange rate	USD/EUR		1,1 (fixed)		-

The project management is facing a decision on the extent to which additional water storage capacity investments are made. It is assumed that in order to regulate the water feed to the water treatment process during periods of high water levels the metal production has to be temporarily stopped. Additional unlimited water storage capacity, above the base case of $1Mm^3$ is the option to be considered for the purposes of this research. Unlimited capacity is studied, because the idea is to understand the "limits" of the needed storage capacity for better adjusting water storage investment size and the profitability effect of such a capacity on the project (how much the closures caused by the $1Mm^3$ vs. unlimited water storage with no closures affect the project value). Fig. 3 presents an illustration of 100 simulated developments of the mine's water balance. The individual simulation runs in fig. 3 (left) are dependent on the realization of uncertainties presented in tab. 1.

The right hand side of fig. 3 shows that the average water storage levels are somewhere close to 2 Mm^3 and indicate that that might be a reasonable size for the initial water storage investment (rather than the planned 1 Mm^3). However, the left hand side of fig. 3 shows that many of the simulated storage levels remain under the initial design of 1 Mm^3, indicating that there is a realistic possibility to consider that the construction of any extra storage capacity could be postponed.

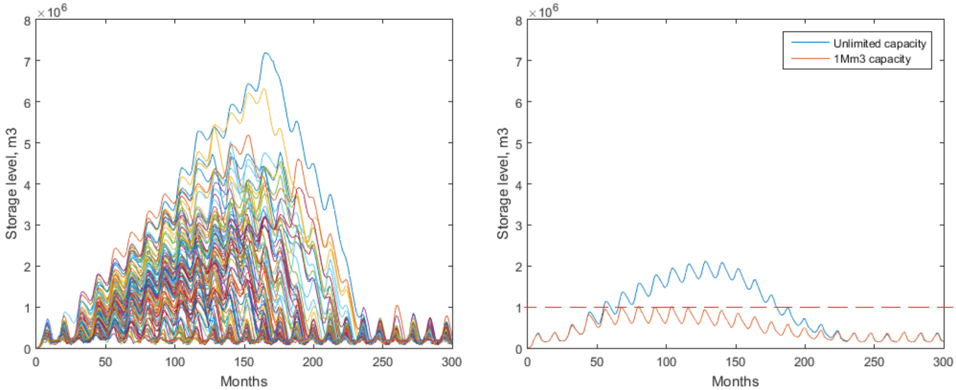

Figure 3 *LEFT: example of 100 simulations of water storage level. RIGHT: average water storage level with and without and with storage constraint*

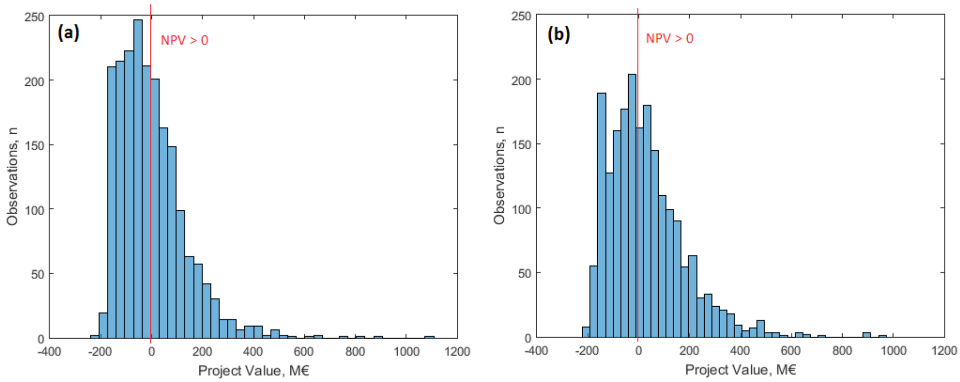

Figure 4 *Histogram of results from 2000 rounds Monte Carlo. Simulated project value (a) with a water storage constraint of 1 Mm3 (b) without storage constraint*

To investigate the economic effect of the water management issue, a 2000 round Monte Carlo simulation is run with the model, while assuming a water storage capacity of 1 Mm^3 and another one assuming no capacity restriction in the water storage. The resulting NPVs are compared in order to determine the value effect. Resulting histograms of these Monte Carlo simulation runs are presented in fig. 3. Tab. 2 summarizes the obtained results.

Table 2 *Project NPV comparison. (*) = real option value of additional water storage capacity*

Value	No storage constraint *„Expanded NPV"*	Storage constraint *„Passive NPV"*	Difference
NPV, mean (M€)	24,47	-1,38	25,85 (*)
NPV > 0, probability (%)	50,8	42,9	7,9

Tab. 2 shows that the NPV of metal mine increases by 25.85 M€ without the water storage constraint, which equals the real option value of Eq. 1. To create a *theoretically* viable operation with NPV=0, the maximum amount that could be spent in the initial design to de-bottleneck the water management constraints is 24.47M€ (25.85M€ – 1.38M€). For example, if the water management constraint could be dealt in the initial design with, say, 10% of most likely initial cost estimate of 60M€, then the expected project value would be ~18.47M€ (24.47M€-6.00M€).

This numerical example illustrates how we can derive better information on the effect and "parameters" of water management investments via a techno-economic model that includes the ability to analyze the economic effects of water management investments.

Discussion and conclusions

This paper has demonstrated the importance of water balance to the overall feasibility of a metal mine by using an illustrative numerical example of a mine operating in a high rainfall area. The illustration has shown that the proposed methodology can be used in gaining a better understanding of the needed water management capacity and of the profitability effects of water management capacity. The used model is generic and it can also be used to model water shortages present in the (semi-)arid areas.

The timing and the cost of water storage investment was left outside the scope of this research. As the building time of extra water capacity is likely to be less than a year, a trigger value for the start of construction could, e.g., be set in the model, which depends on the current water storage level and its rate of change. Furthermore, the construction could be phased in the model to further reduce the risk of over investment. These topics remain issues for further study.

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