Mine Scheduling Considering Hydrologic Scenarios

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ABSTRACT

Water plays an important role in the mining industry because it must be used for ore processing and in the case of open pit mines it is used for irrigation of haul roads. Due to changes in climate conditions, water availability should be considered in mine plans during the whole life of mine. For example, in the particular case of central Chile, it is important to mention that a persistent rainfall deficit has prevailed since 2010 to date leading to a market decline in water reservoirs among other effects, which particularly affected water supply of a mining operation in central Chile.

The purpose of this work is to show the differences in the mine plans in terms of the net present value (NPV) considering water availability constraints for a mine operation located in central Chile with its water supply provided by a nearby river. There were 4 hydrological scenarios evaluated in the first 10 years of the mine plan, considering 3 cases of different capacities for the processing plant.

The main conclusions of this work is that NPV shows a decreasing tendency as more in the future the hydrologic scenario takes place, because the water required for some months is greater than the water available. Also, in this case study, there is no convenience for increasing the processing plant capacity in relation to case 1, due that the CAPEX is greater than the discounted profits.

INTRODUCTION

In this introduction chapter two topics are going to be discussed: mine planning and the role of water in mining.

The mine planning process in open pit mining begins with a geologic block model that contains ore and waste. After introducing parameters such as slope angles, costs, prices, and the metallurgical recovery, the final pit is obtained as a result. The final pit limits defines what is economically mineable from a given deposit. It identifies which blocks should be mined and which ones should be left in the ground (Dagdelen, 2001). The mining program schedule may extend over many years and involve a lot of capital expenditure and risk (Lerchs and Grossman, 1964). Therefore a correct definition of the ultimate pit and its phases is relevant to maximize the value of the mining business. The final pit or ultimate pit is divided in a series of interim pit phases that reflects successive cutbacks (Williams et al., 2009). Since economic scenarios, as well as geologic and geotechnical data change in time, the mine planning process is dynamic.

Water plays a major role in the mining industry. In the operation it must be used for the ore processing and in the case of open pit mines it is used for the irrigation of haul roads. The issues and concerns is about the quantity of water consumed by mining activities, and impacts in water quality (which, in turn, often affect water availability). In fact there has been an increasing focus on mining and water issues leading to more regulations in water rights and responsibilities, and more attention to water management and potential environmental impacts associated with mining (Mudd, 2008). As described, it is possible to figure out the importance of water for the mining business. This implies that it must be incorporated in the mine planning process. Just to show the important role of water in the mining industry, it is useful to mention that in year 2015 an ore processing plant located at Los Bronces Mine in central Chile, suffered a stoppage of 29 days regarding water scarcity (Minería Chilena, 2015) which certainly impacted its business.

It is worth mentioning that changes in climate conditions must be considered in mine plans. For example a persistent rainfall deficit has prevailed in central Chile since 2010 to date, leading to a market decline in water reservoirs among other effects. The observations in central Chile indicate a regional mean precipitation trend of -3.7% decade^{-1} between 1979 and 2008 and a trend of -7.1% decade^{-1} between 1979 and 2014 (Boisier et al. 2016) (**Figure 1b**). This so called megadrought has no precedents in local records and contributes to a long standing dry trend in the region (Boisier et al. 2016). It is also important to point out that glaciers in central Chile has shown a significant ice-mass reduction with an accelerated trend in recent decades (Carrasco et al., 2008). This megadrought combined with the ice mass lost certainly affects basins which supply water that is used in mining, energy, and agriculture.

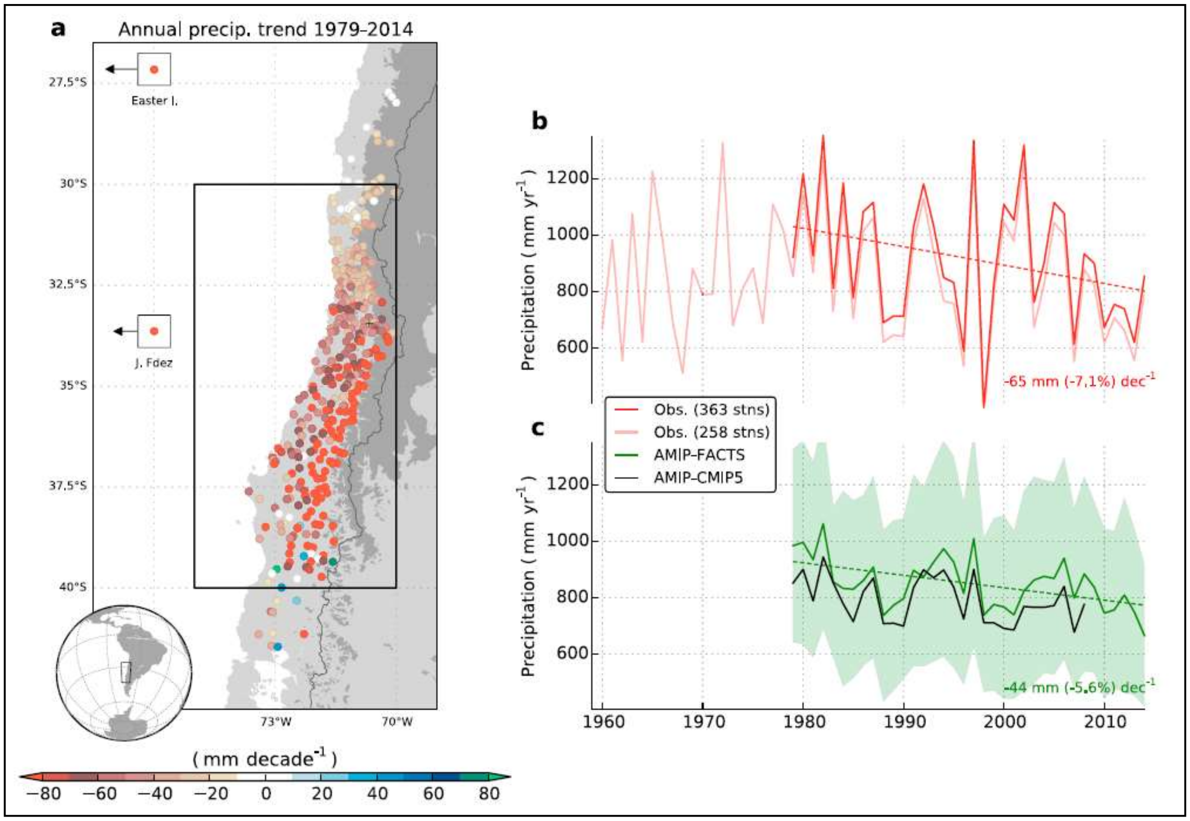

Figure 1 (a) Trends of annual precipitation observed in rain gauge stations in Chile between 1979 and 2014. Time series of annual mean precipitation in central Chile based on (b) rain gauge observations and (c) SST-forced GCM simulations. Dashed lines indicate the corresponding linear precipitation trend from 1979 to 2014. Box in Figure 1a shows domain used for regional average (Boisier et al. 2016).

Based in the facts stated in this introduction chapter, the objective of this study is to evaluate the impact of hydrologic scenarios in mine planning for a mine located in central Chile. In particular, it is focused on how water supply has impacts in the economics of a project in terms of the net present value (NPV).

METHODOLOGY

The methodology to undertake the present work is as follows:

1. Select a case study based on an ore deposit. This deposit will be located in a basin that will supply water for the operation.
2. Determine the water consumption for ore and waste.
3. Determine the water availability of the river from the basin that supplies water to the deposit.

4. Undertake and evaluate three cases of mine schedules in terms of NPV for the first 10 years of the mine plan. In the first case, all the material movement and the processing of ore can be carried out by the water available. The second case considers a processing plant 2 times bigger than the capacity of the first case, and the third case considers a processing plant 3 times bigger than the capacity of the first case. Cases 2 and 3 are affected by the water availability.
5. The three cases described will be evaluated considering 4 different hydrologic scenarios: the first scenario has no restriction on water availability, the second one considers water availability for periods 2006 to 2015, the third and fourth scenarios corresponds to hydrologic scenarios for years 2026 to 2035 and 2046 to 2055 respectively.

CASE STUDY

The case study consists of a regular block model from a real copper ore deposit. Due to a confidentiality agreement, the name and location of this deposit cannot be disclosed. The characteristics of this block model is as follows:

- Regular blocks of 10 metres x 10 metres x 10 metres.
- East-West length: 1600 metres.
- North-South length: 1650 metres.
- Depth: 1500 metres.

Each block has copper grades as information. In this case study, only two destinations for blocks are considered: a processing flotation plant for ore and a waste dump otherwise.

The optimization stage for obtaining the final pit limits and the scheduling is going to be undertaken using a direct block scheduling (DBS) approach because it incorporates blending constraints, including water availability, which must be satisfied because the efficiency and many times the feasibility of the plant process depends on the attributes of the combination of blocks that are processed at a given period. (Espinoza et al. 2013)(Morales et al., 2015).

The economic parameters, metallurgical recovery, and slope angle shown in **Table 1** are going to be used as inputs in this case study.

Table 1 Economic parameters, metallurgical recovery, and slope angle to perform the open pit optimization.

Copper price [US$/lb]	2
Mine cost [US$/mt]	1.8
Processing cost [US$/mt]	13
Metallurgical recovery [%]	85
Smelter and refining costs [US$/lb]	0.65
Discount rate per year [%]	10
Slope angle [°]	45

For the present work, a capital expenditure (CAPEX) for the processing plant of USD 12,000 per daily metric tonne of ore is going to be used. This information is based on empirical data from year 2014 (Parra, 2015). The annual discount rate to determine the NPV will be of 10%.

In this case study, the water consumption for ore processing in this operation is 0.72 m^3/t. This amount of water will be fed totally by a nearby river that supplies water. Streamflow data close to the mine was recollected from a gauge station belonging to the DGA (Chilean national water department). Between years 2006 to 2015, the minimum average streamflow per month was 0.2 m^3/s in March 2011. This streamflow corresponds to 518,400 m^3/month, which allows to process 720,000 t/month. Annually, this number is equivalent to 8,640,000 t/year. In order to avoid being affected by the availability of water for past periods and future hydrologic scenarios, for case 1 a processing capacity of 7,700,000 t/year was chosen. The capacities of the processing plants for cases two and three, which are 2 times and 3 times bigger in relation to the first case, can be appreciated in **Table 2**.

Table 2 Processing plant capacities for each case.

Processing plant capacity t/year	Case
7,700,000	1
15,400,000	2
23,100,000	3

For future hydrologic scenarios considered in this case study (2026 to 2035 and 2046 to 2055) ,the water availability projections were obtained by applying a proportional reduction (-7.1% $decade^{-1}$) in the average of the streamflow, assuming that the reduction in the streamflow is the same as the decrease in the precipitation rate.

The monthly average streamflow for different periods and the monthly water consumed by the processing plant for different capacities can be appreciated in **Figure 2**.

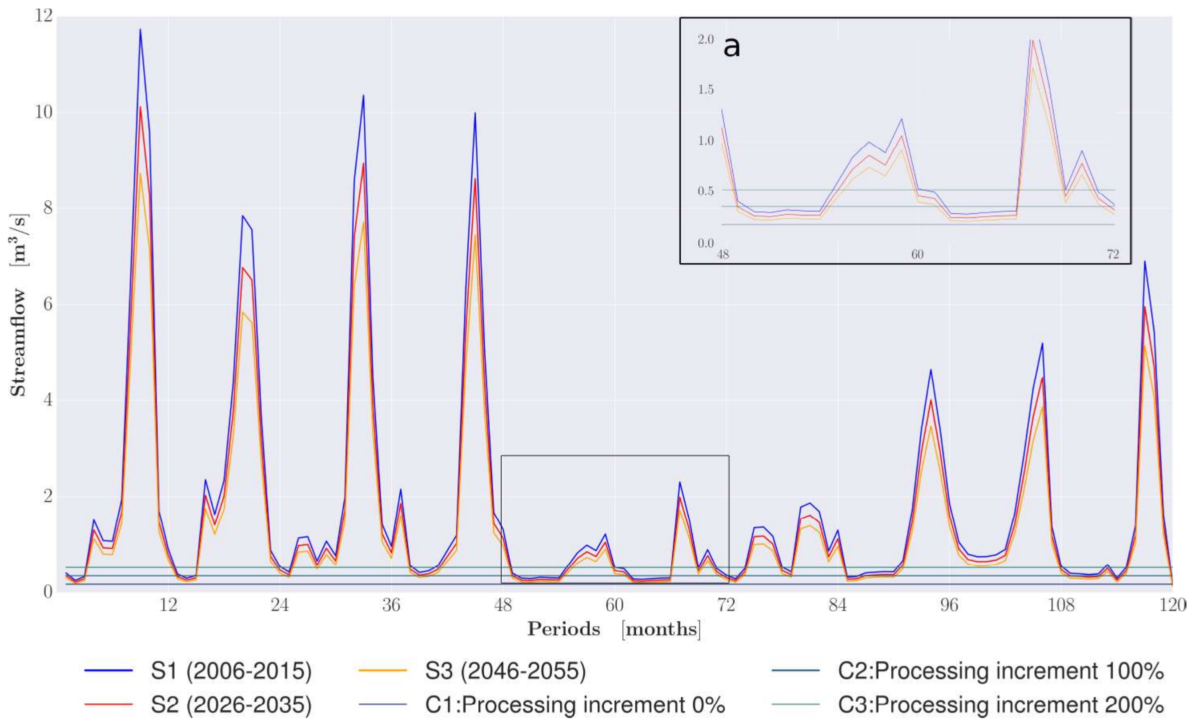

Figure 2 Monthly average streamflow for hydrologic scenarios belonging to years 2006 to 2015, 2026 to 2035, 2046 to 2055, and monthly water requirements for cases 1, 2, and 3. **(a)** Zoom in the area of the periods belonging to periods 48 to 84.

As can be appreciated in **Figure 2a**, the water requirements for cases 2 and 3, in relation to case 1, are greater than the streamflow for certain months (especially in the enlarged zoom area of the graph). The implications for the mine plan and its economic value will be analysed in the results and discussion chapter.

RESULTS AND DISCUSSION

In this chapter, two main results are going to be shown and discussed: mine schedule and the effect of water availability on mine plans in terms of the NPV.

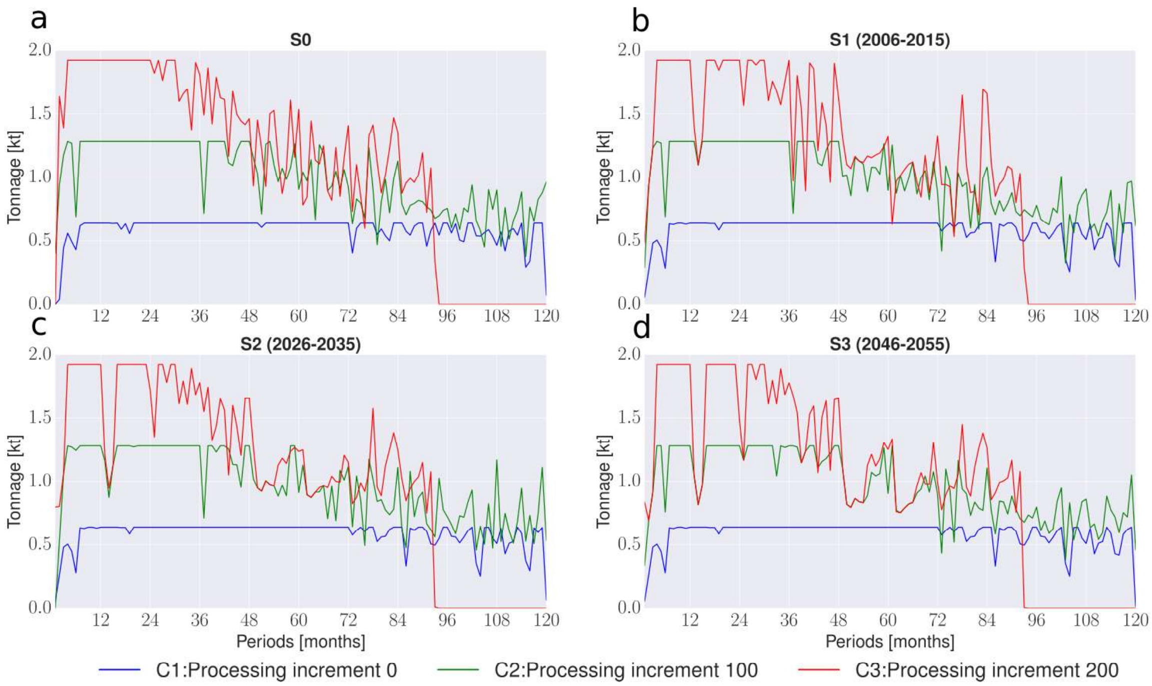

Figure 3 Tonnage of ore sent to processing plant considering different cases of capacities. **(a)** No availability constraints. **(b)** Hydrologic scenario considering years 2006 to 2015. **(c)** Hydrologic scenario considering years 2026-2035. **(d)** Hydrologic scenario considering years 2046 to 2055.

As can be appreciated from **Figure 3**, as more in the future a hydrologic scenario belongs, the less is the amount of ore sent to the processing plant for some months. This is especially true for periods going from months 48 to 84. For example, in the cases belonging to the hydrologic scenario 3, which goes from years 2046 to 2055, the ore sent to the processing plant tend to be less for some months in relation to the ore sent to the processing plant for scenarios 0 to 2, due to the fact that in future periods the water available decreases. It is interesting to see that in case 3, for periods that go beyond the 96th the ore sent to process is 0. This happens because all the ore form the pit shell has been extracted.

Also, as the capacity of the processing plant increases, the variability of ore sent to the processing plant increases, because the amount of required water is directly proportional to the processing plant capacity, and in some periods the required water is more than the water available, making impossible to send all the ore that the plant can process.

Figure 4 shows the NPV results in relation to the NPV of the 1st case.

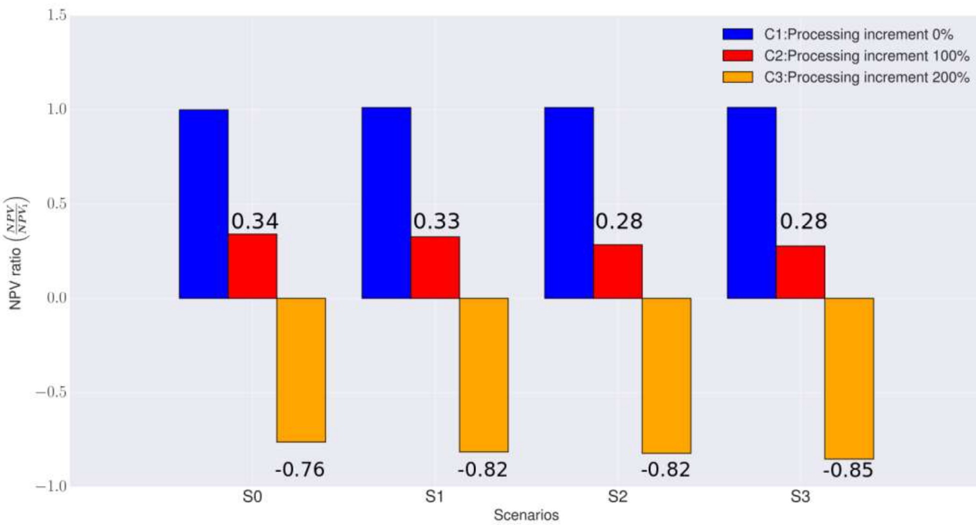

Figure 4 NPV ratio for different cases considering scenario 0 (without water constraints), scenario 1 (water availability for years 2006 to 2015), scenario 2 (water availability for years 2026 to 2035), and scenario 3 (water availability for years 2046 to 2055).

As can be appreciated from **Figure 4**, NPV for cases 2 and 3 show a decreasing tendency as more in the future the hydrologic scenarios take place, because the water available also has a decreasing tendency. For case 1 this tendency cannot be appreciated because, as it was stated in the methodology of the present work, in case 1 all the ore processed is not affected by the water availability. For case 3 the ratio is negative because the NPV is also negative. This has to do with the fact that the CAPEX for this last case is greater than all the discounted profits during the mine schedule.

It is also possible to conclude that there is no convenience for increasing the processing plant capacity in relation to case 1, due that the CAPEX is greater than the discounted profits.

CONCLUSIONS

In this work we did an analysis regarding the impacts of hydrologic scenarios in cases of mine plans, especially when there is not enough water available to process all the ore that the plant can process. It is worth mentioning that this work was focused on a single case study of an ore deposit located in central Chile.

The following conclusions were obtained:

- NPV for cases 2 and 3 shows a decreasing tendency as more in the future the hydrologic scenarios take place, because the water available also has a decreasing tendency.
- In this case study there is no convenience for increasing the processing plant capacity in relation to case 1, due that the CAPEX is greater than the discounted profits.

- As more in the future a hydrologic scenarios belongs, the less is the amount of ore sent to the processing plant for some months. This is especially true for periods going from months 48 to 84.
- As the capacity of the processing plant increases, the variability of ore sent to the processing plant increases, because in some periods the required water is more than the water available, making impossible to send all the ore that the plant can process.

As future work, it should be necessary to include a predictive hydrologic model for future periods in the case study. In this opportunity, only projections based on empirical past data was taken into account. Also, studying alternatives such as a desalination plant or an artificial reservoir should be included in the analysis to determine if they are economically convenient to implement when there is no raw water availability.

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