Minimizing Life Cycle Costs at High Flowrates

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ABSTRACT

Open pit mining can require large dewatering operations at high flowrates. When this dewatering water is required to be treated prior to discharge back to the environment or reinjection, the resulting life cycle costs can be significant and can impact mine operations. A confidential mine in Nevada, USA was faced with such a problem, requiring it to treat greater than 8,500 m3/hr (37,500 gpm) of water from dewatering wells to remove arsenic. Typical arsenic treatment technologies such as adsorption, ion exchange and coagulation/microfiltration have been shown to be effective removing arsenic; however, the associated capital costs would be prohibitive at such high flowrates. Therefore a conventional ferric hydroxide precipitation followed by clarification process was selected as a capital cost-effective alternative; at approximately 50% the cost of other arsenic removal technologies.

Several process configurations were investigated, but the two main configurations considered involved either settling ponds or clarifiers for solid/liquid separation. Additionally, two different site locations were considered, and due to the high flowrates, small differences in elevation resulted in vastly different pumping conditions. In order to determine the “best” configuration, the design team performed a Life Cycle Value Analysis that included monetary factors such as capital and operating costs; but also included non-monetary factors such as Reliability, Complexity, Flexibility, Land Requirements, Risk, Maintenance, among others. This approach allowed all factors that were important to the mining company to be considered appropriately.

Interestingly, this approach yielded a result that the clarifier alternative was preferred over settling ponds, despite it having a higher capital cost. Operational costs over the life of the facility tilted the analysis toward the site location at a higher elevation despite the need to build a 2,150 m^3/hr (9,500 gpm) pump station in order to get some of the water to that elevation.

Keywords: Life Cycle, Water Treatment, Arsenic

INTRODUCTION

A large combination open-pit and underground mine in Nevada, USA has a sophisticated dewatering well system surrounding the mine works to allow extraction of ore from both the pit and the underground mine. Currently, this equates to 6,400 m^3/hr (28,200 gpm) of water in the dewatering system. After a thorough analysis of current dewatering water the current arsenic levels in the mine complex were determined to be approximately 0.020 mg/L. Future wells will increase the total dewatering flowrate to 8,500 m3/hr (37,500 gpm) and likely will have higher arsenic concentrations. These concentrations exceed the Nevada Division of Environmental Protection (NDEP) Profile I arsenic reference value of 0.010 mg/L. Since the arsenic concentration is similar from well to well, the mine will be required to treat arsenic from all of the water prior to infiltration and irrigation. A new Water Treatment Plant (WTP) must be constructed and be able to achieve high reliability of treatment.

To determine the WTP design requirements, the dewatering flowrate was modelled based on the water production from different well production zones as shown in Figure 1.

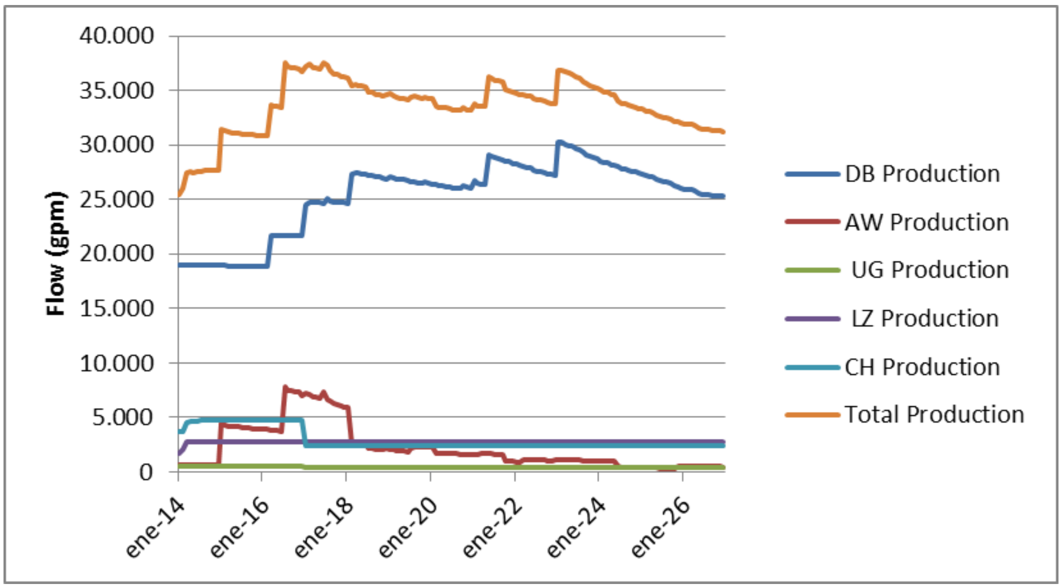

Figure 1 Dewatering Flowrate Projection by Production Zone

Finally, arsenic concentrations from each dewatering well were flow weighted to create a total projected arsenic concentration (mg/L), as presented in Figure 2. Average arsenic loading is important to understand for long-term chemical consumption when determining the operating costs; but peak arsenic values are also important for sizing chemical feed equipment and determining sludge handling alternatives. Therefore, three different sets of arsenic loading values were determined, the average, 85^{th} percentile and the 95^{th} percentile.

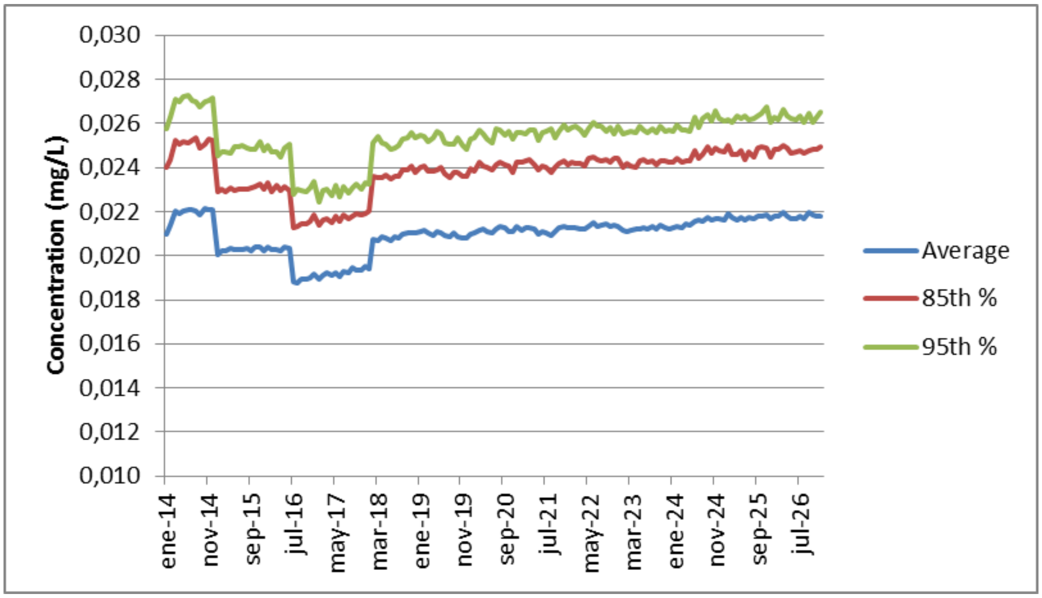

Figure 2 Projected Arsenic Concentration into the new WTP

Due to the high flowrates at the new WTP, mine staff's familiarity, and the cost effective nature of treatment, it was determined to utilize ferric hydroxide precipitation as the preferred method for arsenic removal. This process works by adding a ferric iron source (typically, ferric sulphate or ferric chloride) which forms a ferric hydroxide floc particle, as shown in Equation 1, which has an overall positive charge.

$$Fe_2(SO_4)_3 + H_2O \leftrightarrow Fe(OH)_2^+ \qquad \text{(at pH < 7.3)} \qquad (1)$$

Dissolved arsenic (V), or arsenate, has a net negative charge under most all pH conditions and adsorbs to the ferric hydroxide to form a precipitant that can be removed from the water solution.

$$H_2AsO_4^- + Fe(OH)_2^+ \rightarrow \text{Precipitant} \qquad (2)$$

During bench-scale testing, it was found that a portion of the arsenic present in the dewatering source was in the arsenic (III), or arsenite, form. Dissolved arsenic (III) has no net charge associated with it, and hence, cannot be removed via ferric hydroxide precipitation. Approximately 1.8 mg/L of hypochlorite bleach was added to oxidize all the arsenic to the arsenic (V) state so that it could be removed in the ferric precipitation step.

The project team desired to compare the life cycle costs of constructing a WTP utilizing settling ponds versus using clarifiers to settle this precipitant.

Additionally, there were two different site locations to evaluate. The "boneyard" site was at the bottom of a valley and allowed all the water from the dewatering wells to flow to that site without any modifications to any wells or without any additional booster pump stations. The second site, the "waste rock" site, was at a higher elevation on an old waste rock pile. Most of the dewatering zones could be pumped to the waste rock site without any additional modifications; however, one production zone required a booster pump for 2,150 m^3/hr (9,500 gpm) to get all the water to the WTP.

In order to evaluate which of the two different WTP processes and which of the two different site locations was best for this project, the team performed a Life Cycle Value Analysis (LCVA) on the alternatives. This paper will discuss how the LCVA process was used to quantify both monetary and non-monetary factors to make the best decision for this particular application.

METHODOLOGY

The LCVA approach combined monetary factors such as Capital Cost and Operation Cost (both Level 4 cost estimates at this stage of the project) as well as non-monetary criteria. The "non-monetary" criteria are summarized in Table 1. Monetary factors are easy to quantify; however, non-monetary factors are much more difficult to quantify. In order to accomplish this, each factor was given a weighting factor to determine how important each criterion was to that particular mine, which helped engage mine staff in the decision process. The "non-monetary" criteria developed by the mine were weighted as shown in Table 1.

Table 1 Non-Monetary Criteria Weighting Factors

Non-Monetary Criteria	Weighting Factor (1-4)
Reliability	4
Operational Complexity	2
Flexibility / Adaptability	3
Maintenance Requirements	1.5
Labour Requirements	2
Land Requirements	1
Risk / Liability	3
Truck Traffic	1
Redundancy	2

These criteria and weighting factors were input into the LCVA tool and each of the alternatives were scored on these particular "non-monetary" criteria on a scale of 1 to 5 with a score of one meaning that the particular alternative was not well suited for that particular criterion. The alternative score was then multiplied by the weighting factor to determine an overall score for each alternative for each non-monetary criterion. The scores for all non-monetary criteria were then added together to determine an overall "non-monetary" score for each alternative. These scores were used to quantify how well each alternative performed on criteria that were important to the mine other than just costs.

Finally, the monetary costs were normalized by dividing each cost by the lowest cost alternative, and the "non-monetary" scores were normalized by dividing each score by the lowest score. A simple monte-carlo analysis was conducted to compare the alternatives based on the scenarios in Table 2.

Table 2 LCVA Scenarios

Scenario	Monetary Weighting	Non-Monetary Weighting
1	30%	70%
2	50%	50%
3	70%	30%
4	100%	0%

RESULTS AND DISCUSSION

Solid / Liquid Separation Process

The two solid/liquid separation processes that were evaluated were double-lined earthen settling basins and standard circular clarifiers. The results of the non-monetary criteria for the solid/liquid separation process are summarized in Figure 3.

		Basins		Clarifiers	
	Weighting Factor	IS	WS	IS	WS
Reliability	4	2.0	8.0	4.0	16.0
Operational Complexity	2	3.5	7.0	3.5	7.0
Flexibility/Adaptability	3	1.5	4.5	3.0	9.0
Maintenance Requirements	1.5	2.0	3.0	4.0	6.0
Labor Requirements	2	3.0	6.0	3.0	6.0
Land Requirements	1	1.0	1.0	3.0	3.0
Risk/Liability	3	2.0	6.0	4.0	12.0
Truck Traffic	1	3.0	3.0	3.0	3.0
Redundancy	2	3.0	6.0	3.0	6.0
Overall Score			44.5		68.0
Alternative Ranking		**2**		**1**	
Relative Ranking		1.55		1.00	

Figure 3 Non-Monetary Evaluation for the Solid / Liquid Separation

The biggest "non-monetary" differences between the two alternatives in this study were Reliability, Flexibility and Risk. Settling basins, as configured for this project, were designed for sludge to be continuously removed from the basins with a stationary sludge pump. Many people on the design team expressed concern that this may not effectively remove sludge from everywhere else; leading to excessive buildup of sludge elsewhere in the pond. Therefore, there was an inherent Risk associated with the settling basin alternative. There were also questions about how clear the effluent water from the settling ponds would be if/when sludge build-up in the pond began to increase, so the system's Reliability to treat water consistently throughout the year came into question.

The simple monte-carlo analysis for the solid/liquid separation is summarized in Table 3.

Table 3 Final LCVA Analysis for the Solid / Liquid Separation Process

Alternative	Cost Rank	Weighted Cost Rank	Process Rank	Weighted Non-monetary Rank	Total Weighted Rank	Final Rank
Weighting		**30%**		**70%**		
Settling Basins	1.05	0.31	1.55	1.08	1.40	2
Clarifiers	1.16	0.35	1.00	0.70	1.05	1
Weighting		**50%**		**50%**		
Settling Basins	1.05	0.52	1.55	0.77	1.30	2
Clarifiers	1.16	0.58	1.00	0.50	1.08	1
Weighting		**70%**		**30%**		
Settling Basins	1.05	0.73	1.55	0.46	1.20	2
Clarifiers	1.16	0.81	1.00	0.30	1.11	1
Weighting		**100%**		**0%**		
Settling Basins	1.05	1.05	1.55	0.00	1.05	1
Clarifiers	1.16	1.16	1.00	0.00	1.16	2

At the start of the project, the mine operations and the engineering team felt that settling basins would be significantly less expensive and that the clarifier option would be prohibitively costly. Much to the team's surprise, when the LCVA process was completed it turned out that the clarifier option was the preferred alternative when the non-monetary criteria were weighted at 30% of the decision or higher, as shown in Table 3. The more weight the "non-monetary" criteria were given, the greater the LCVA analysis favored clarifiers.

Site Location Selection

The two different site locations that were evaluated were the "boneyard" site and the "waste rock" site. The results of the non-monetary criteria for the site location selection are summarized in Figure 4.

		Boneyard		**Waste Rock**	
Weighting Factor		IS	WS	IS	WS
Reliability	4	3.0	12.0	3.0	12.0
Operational Complexity	2	4.0	8.0	4.0	8.0
Flexibility/Adaptability	3	3.0	9.0	3.0	9.0
Maintenance Requirements	1.5	4.0	6.0	4.0	6.0
Labor Requirements	2	3.0	6.0	3.0	6.0
Land Requirements	1	3.0	3.0	3.0	3.0
Risk/Liability	3	4.0	12.0	3.0	9.0
Truck Traffic	1	3.0	3.0	3.0	3.0
Redundancy	2	3.0	6.0	3.0	6.0
Overall Score			65.0		62.0
Alternative Ranking		**1**		**2**	
Relative Ranking		1.00		1.05	

Figure 4 Non-Monetary Evaluation for the Solid / Liquid Separation

There was little difference in the non-monetary criteria between the two different site locations. The only real difference was that the waste rock site sat on an old waste rock pile that had settled over time, and a geotechnical evaluation of the site indicated that certain engineering design measures had to take place to account for differential settling across the site. Therefore, there was some associated Risk with this site over the virgin ground at the bone yard site. The engineering measures necessary to account for differential settling were taken into account in cost of building at that site.

The simple monte-carlo analysis for the site location selection is summarized in Table 4.

Table 4 Final LCVA Analysis for the Site Location

Alternative	Cost Rank	Weighted Cost Rank	Process Rank	Non-monetary Rank	Total Weighted Rank	Final Rank
Weighting		**30%**		**70%**		
"Boneyard"	1.05	0.31	1.00	0.70	1.01	1
"Waste Rock"	1.00	0.30	1.05	0.74	1.04	2
Weighting		**50%**		**50%**		
"Boneyard"	1.05	0.52	1.00	0.50	1.02	1
"Waste Rock"	1.00	0.50	1.05	0.53	1.03	2
Weighting		**70%**		**30%**		
"Boneyard"	1.05	0.73	1.00	0.30	1.03	2
"Waste Rock"	1.00	0.70	1.05	0.32	1.02	1
Weighting		**100%**		**0%**		
"Boneyard"	1.05	1.05	1.00	0.00	1.05	2
"Waste Rock"	1.00	1.00	1.05	0.00	1.00	1

Overall, the LCVA analysis showed very little difference between the two site locations. It indicated that the waste rock site was preferred when non-monetary criteria were weighted 50% or less, but not by a wide margin; and conversely, the bone yard site was preferred marginally higher when non-monetary criteria were weighted over 50%.

CONCLUSION

The Life Cycle Value Analysis procedure was proved to be a helpful tool for the mine team to make a decision regarding the preferred solid / liquid separation processes and the preferred site location. This procedure quantified everything that the mine felt was important to them, including monetary and non-monetary factors. The selected alternative from this analysis was to design the clarifiers for the solid / liquid separation process because it was decided that the non-monetary factors accounted for at least 30% of the decision with all the uncertainly related to the settling pond implementation. The waste rock site was selected as the best location since the LCVA showed that there was little difference between the alternatives based on the non-monetary criteria, so this decision could be made based on which alternative offered the most cost-effective approach.

The LCVA process can be applied to many different types of decisions at a mine site, especially when non-monetary criteria weigh heavily, such as with environmental measures. Through this process, it was critical that the appropriate team members are engaged in the process from the beginning.

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