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EARLY COPPER DELIVERY VERSUS ULTIMATE RECOVERY IN A SMALL-SCALE SUBLEVEL CAVING SCHEDULE

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Abstract

This study extends a previous PCSLC assessment of the T4 orebody by examining how draw strategy influences copper delivery and material-handling requirements. Two extraction strategies were compared using schedule-based model outputs while maintaining the same mine geometry and sequencing concept. The results show that higher ultimate recovery does not necessarily provide earlier or more mass-efficient copper delivery because increased extraction also promotes dilution and additional material handling.

Keywords: *sublevel caving, draw strategy, copper recovery, dilution, production timing*

1. INTRODUCTION

Sublevel caving (SLC) performance is governed not only by the amount of ore available, but also by the sequence and draw strategy. Recovery and dilution evolve together as extraction expands draw columns, increases recovery between levels and mobilises material outside the original ring inventory [1,2,3,4]. These effects are particularly important in small and irregular orebodies, where the distance between production rings and waste-producing boundaries is limited and where local overdraw cannot be averaged across a large footprint [1,2].

A previous study of the T4 orebody at the Jama Bor mine developed a three-level primary cave sublevel caving (PCSLC) model and compared alternative extraction targets while retaining the same physical layout [1]. The conservative strategy produced 77-79% copper recovery and approximately 39% dilution, whereas increased extraction raised recovery to 87% and dilution to approximately 51% [1]. Those endpoint indicators describe the final recovery-dilution trade-off, but they do not show when copper is delivered or how much additional material must be handled to obtain the final recovery increment. The objective of this paper is therefore to provide a schedule-based extension of the earlier analysis. Monthly model outputs are used to compare cumulative copper delivery through time, recovery at approximately equal total material draw, and the incremental mass and dilution associated with the higher-recovery endpoint. The intention is not to identify an economic optimum, but to demonstrate why ultimate recovery should be interpreted together with production timing and material-handling intensity.

2. EXPERIMENTAL

2.1. Model and draw strategies

The analysis uses the same T4 PCSLC model described in [1]. The modelled in situ ring inventory comprises 171.53 kt at an average grade of 6.411% Cu, corresponding to 10.996 kt of contained copper. The compact layout includes the -30, -45 and -60 m production levels, seven drifts and 140 rings. Geometry, ring inventory, flat-front sequence, swell assumption and external dilution source were kept unchanged so that the schedule response could be attributed to the draw rules rather than to a different mine design [1,5].

Two cases were evaluated. In the conservative case, the extraction targets at -30 and -45 m were both 30%, while the -60 m level was controlled by a grade-based shut-off criterion. In the increased-extraction case, the targets were raised to 40% at -30 m and 80% at -45 m levels, with the same shut-off logic at -60 m level. Figure 1 summarizes the comparison.

Each schedule period represents one month. The total schedule comprises 33 monthly periods in the conservative case and 43 in the increased-extraction case; the previously reported 23 and 31 month values refer to the approximately stable production windows within those schedules.

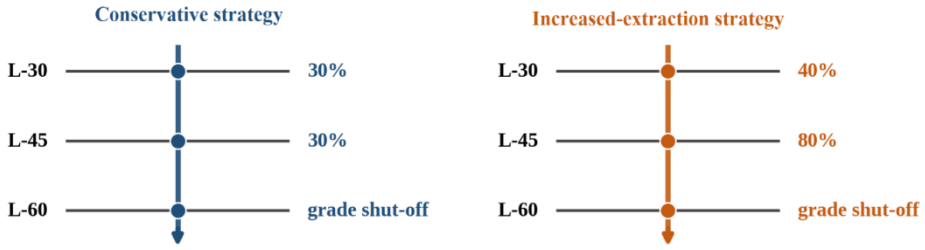


Figure 1. *Draw rules used in the schedule comparison*

2.2. Schedule-based indicators

For each schedule period i, depleted tonnage T_i, copper grade g_Cu,i and dilution fraction d_i were read from the two model workbooks. Period copper metal, cumulative copper recovery and dilution mass were calculated as:

$$m_{Cu,i} = T_i g_{Cu,i}/100 \quad (1)$$

$$R_n = 100 \cdot \Sigma_{(i=1\ldots n)} m_{Cu,i}/M_{Cu,0} \quad (2)$$

$$D_i = T_i D_i \quad (3)$$

where $M_{Cu,0}$ is the in situ copper metal contained in the modelled rings. The conservative schedule terminates at period 33. This period was therefore used as the common-horizon comparison point. At this common horizon, cumulative material draw was 219.87 kt in the conservative case and 220.23 kt in the increased-extraction case, a

difference of only 0.16%. A scenario-incremental grade was also calculated from the difference in final copper metal divided by the difference in final material drawn.

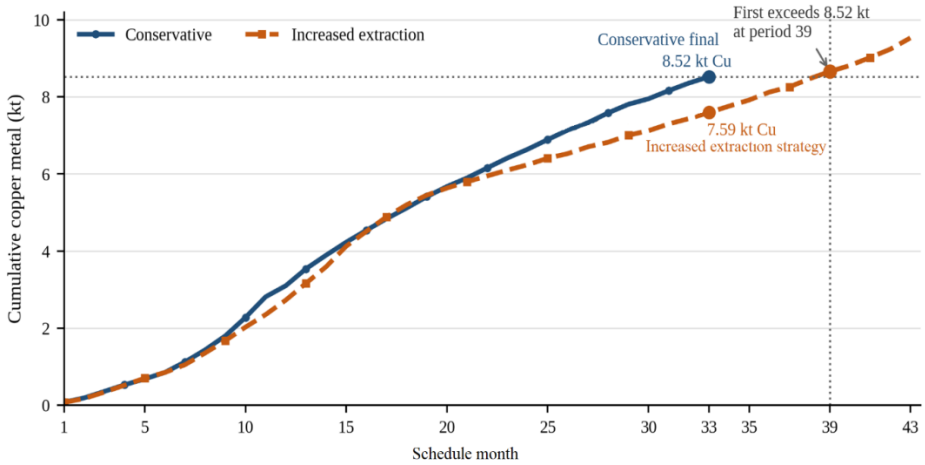


Figure 2. *Cumulative copper delivery by schedule month. The increased-extraction strategy first exceeds the conservative final copper output at period 39*

3. RESULTS AND DISCUSSION

3.1. Copper delivery through time

Figure 2 shows that the two strategies follow a similar cumulative copper trajectory during the early schedule, but their later responses diverge. The conservative schedule terminates at period 33 after delivering 8.520 kt Cu, equivalent to 77.5% recovery.

At the same period, the increased-extraction schedule has drawn 220.23 kt, almost identical to the conservative total of 219.87 kt, but has delivered only 7.592 kt Cu, or 69.0% recovery. At almost the same total draw, the conservative case had therefore recovered 0.928 kt more copper. The difference is consistent with the higher cumulative grade and lower dilution observed in the conservative case at this stage of the schedule.

The increased-extraction case continues for ten additional periods and first exceeds the conservative final copper output at period 39. At that point it has drawn 270.26 kt of material and accumulated 133.94 kt of dilution. The final endpoint at period 43 reaches 9.529 kt Cu and 86.7% recovery. Thus, the strategy provides more ultimate copper, but part of that benefit is delayed and depends on extended draw after the conservative schedule has already reached its endpoint.

Table 1. *Comparison at approximately equal drawn mass and at the final increased-extraction endpoint*

Parameter	Conservative strategy P33	Increased extraction strategy P33	Increased extraction strategy P43
Schedule month	33	33	43
Cumulative material drawn, kt	219.87	220.23	303.70
Cumulative Cu metal, kt	8.52	7.59	9.53
Cu recovery, %	77.5	69.0	86.7
Cumulative average Cu grade, %	3.875	3.447	3.138
Dilution mass, kt	86.76	100.39	154.79
Dilution, %	39.5	45.6	51.0

3.2. Recovery per unit of material drawn

At the common-horizon comparison point, the increased-extraction strategy had already entered a stronger dilution regime: cumulative dilution was 45.6%, compared with 39.5% in the conservative case. Consequently, its cumulative average Cu grade was lower, 3.447% versus 3.875%. More aggressive draw ultimately recovered more metal, but recovered less copper per unit of material drawn during the common production horizon.

The mass-based comparison in Figure 3 reinforces the timing result. At approximately 220 kt of cumulative draw, the conservative strategy achieves 77.5% recovery, compared with 69.0% for the increased-extraction strategy. Higher extraction targets mobilize more upper-level ore, but they also increase level interaction and the entry of dilution into the active draw system. Consequently, additional tones do not produce a proportional increase in copper metal.

Relative to the conservative endpoint, the increased-extraction endpoint requires an additional 83.83 kt of total material to recover an additional 1.009 kt Cu. The corresponding scenario-incremental grade is 1.20% Cu.

This value is derived from the difference between the two model endpoints and should not be interpreted as the grade of a physically separable production stream. The difference in modelled dilution mass between the two final endpoints is 68.03 kt, equivalent to 81.1% of the total difference in drawn mass. The average schedule grade therefore decreases from 3.875 to 3.138% Cu even though final recovery increases by 9.17 percentage points.

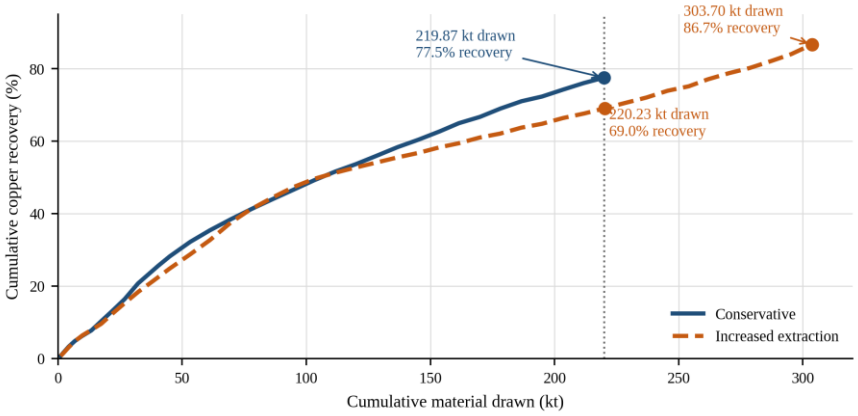


Figure 3. *Cumulative copper recovery versus cumulative material drawn*

These results do not imply that the conservative strategy is universally preferable. The increased-extraction strategy expands the recoverable metal envelope and extends the stable production window reported in [1] from approximately 23 to 31 months. Its suitability depends on whether the processing system, haulage capacity and economic cut-off can accommodate the additional low-grade and dilution material. The results instead show that a strategy selected only by final recovery may conceal delayed metal delivery and a substantial material-handling burden. Intermediate extraction targets should therefore be tested before defining an operating strategy.

4. CONCLUSION

Schedule-level analysis provides information that is not visible from final recovery and dilution values alone. At nearly equal cumulative draw of approximately 220 kt, the conservative strategy delivered 0.928 kt more copper and achieved 8.5 percentage points higher recovery at the same schedule horizon. However, the increased-extraction strategy continued production, surpassed the conservative final copper output at period 39, and ultimately recovered an additional 1.009 kt Cu. The two strategies therefore represent different operating trade-offs: the conservative case favours earlier copper delivery, higher grade and lower dilution, while the increased-extraction case provides higher ultimate recovery and longer production life. Selection between them should depend on company objectives, processing capacity and economic conditions. Further work should include intermediate draw cases, site calibration and economic evaluation.

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