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# Underground paste fill reticulation management of system flow-loss

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## Abstract

*An underground paste fill system will inevitably experience a system flow-loss event during its operational life. In a flow-loss event, the underground reticulation design, flow-control hardware, instrumentation specification and system recovery methods can greatly impact the time taken to safely and effectively achieve a full system clearance and recommence backfilling activities.*

*In addition, the learnings and methods discussed in this paper minimise the opportunity cost of using valuable underground work crew resources to rectify the blocked pipe work and the associated paste plant downtime. This deficit of paste filling will further impact the mining production schedule by increasing mining activity interaction and disrupting the extraction sequence. Direct costs of a blockage may include piping replacement and work crew labour as well as an increased risk of injury and equipment damage during a time-critical activity.*

*The management of a flow-loss event must consider each of the following three flow-loss conditions experienced:*

- *System blockage.*
- *System stalling.*
- *Reticulation failure.*

*A case study (Scenario 1) is presented to demonstrate the management of a flow-loss event, which includes system blockage and stalling due to insufficient available head pressure being overcome by system segmentation. Segmentation highlights the advantages of the ability to carry out safe and effective system isolation from underground in a time-critical situation.*

*Reticulation failure response is also discussed in this paper, with an explanation of the recovery method and the requirement of an adaptive approach as the flow-loss condition can transition from one type to another during the recovery effort.*

**Keywords:** p*aste fill, reticulation blockage, recovery, flow-loss event, dump diverter, surface borehole*

## 1 Introduction

The three flow-loss conditions discussed in this paper are system blockage, system stalling and reticulation failure of the underground paste delivery reticulation pipe work. Underground reticulation fits into the overall paste production system, which is divided into paste plant (wet and/or dry feed), surface borehole and underground reticulation system. This relationship is shown in Figure 1.

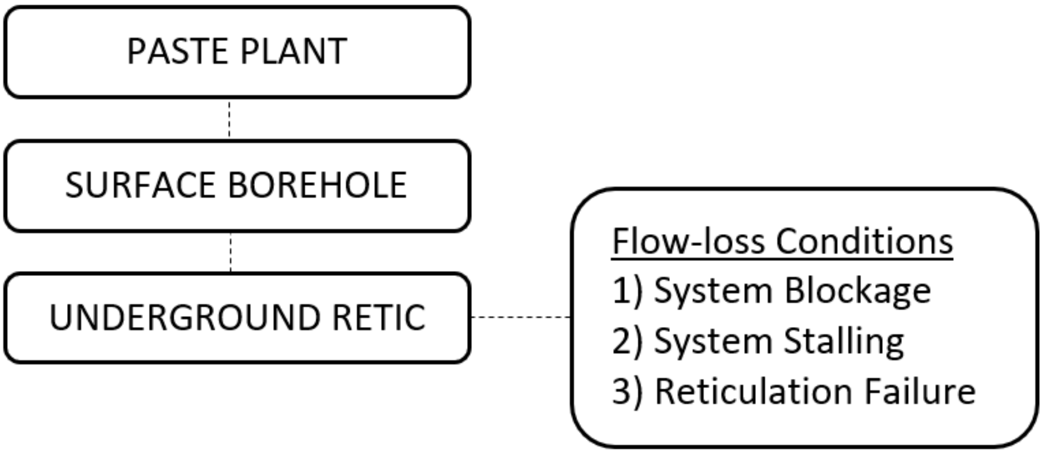



**Figure 1 Main paste operational areas**

## 1.1 System blockage

System blockage is defined as a point restriction within the paste reticulation pipe work. This may be caused by rock borehole failure, foreign material in the paste mixture, a dry lump of binder/tails or cured paste mixture in a stagnate region re-entering the flow stream. The paste mixture upstream and downstream of the blockage is initially in a liquid state and can flow until the curing paste mixture begins to solidify.

## 1.2 System stalling

System stalling occurs when the pressure required to deliver the mixture is greater than the pressure available due to elevation change in the system. One cause of stalling in an operating system is when the consistency of the paste mixture increases gradually, resulting in increasing friction-loss of the paste mixture (often expressed as kPa/m). This friction-loss is a function of the rheological parameters of the paste mixture and is indicated by the slump and yield-stress measurements in operational sample testing. This increased resistance occurs throughout the entire pipework wherever full pipe flow occurs and is not confined to a local point in the system.

Scale and rust forming on the inside of the pipe will also increase the friction-loss (kPa/m) of the system; however, the scouring effect of the abrasive paste mixture will remove this build-up to expose the pipe material.

## 1.3 Reticulation failure

Reticulation failure is defined as a dramatic loss of system pressure at a local point within the underground pipe work system. A reticulation failure is often due to an event such as a pipe wall failure or a coupling failure. It results in paste mixture escaping from the pipe work into the mine workings. This failure point divides the system into an upstream segment and a downstream segment. The repair of this failure and clearing of the downstream segment of the reticulation is a time-critical activity.

## 1.4 System flow-loss response

Responding to a flow-loss event with an overall objective of safely and effectively clearing the entire paste delivery system will enable the operator to treat each of the three conditions progressively. It is likely that rectifying a blockage condition may result in reticulation failure, and once this is rectified, the operator may then be required to treat a system stalled condition. Conversely, reticulation failure may result in a downstream blockage due to curing paste mixture, which needs to be treated after the reticulation failure is rectified. This flow-loss condition transition is represented in Figure 2.

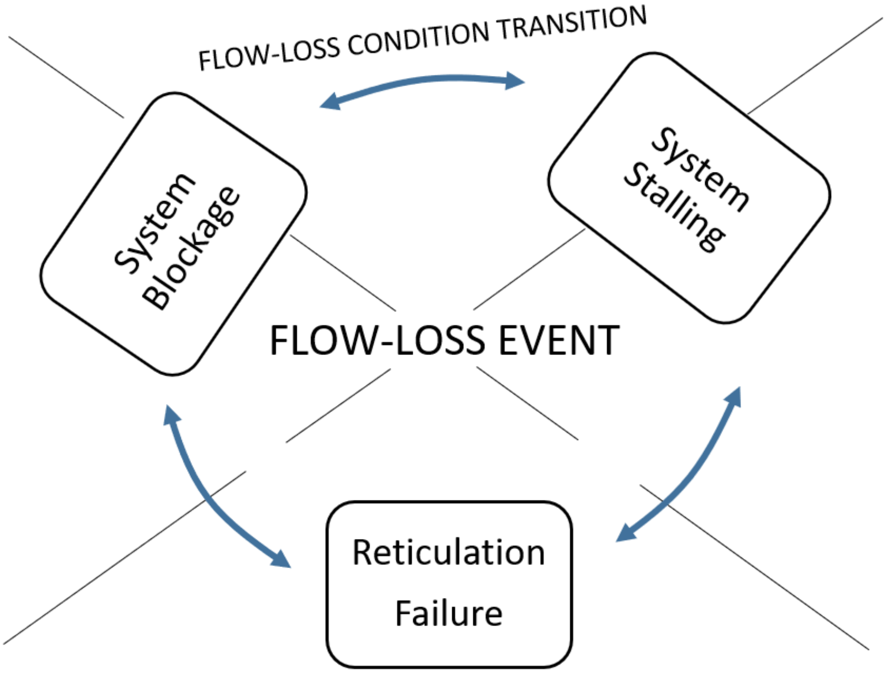



**Figure 2 Flow-loss condition transition**

System recovery can only be achieved in an effective timeframe if flow-control equipment and instrumentation is integrated into the underground paste delivery system. The instrumentation will assist in identifying the location and type of flow-loss event, and the flow-control equipment enables the safe and effective clearing of the entire system.

Working from the surface down, each section that is cleared ensures that the maximum flushing pressure is available to the next downstream segment. The intent is that applying the maximum available pressure will overcome the frictional resistance of paste mixture to be cleared. Such an approach is reliant on the ability of the incorporated hardware to divert the full pipe flow of each segment of reticulation to be cleared.

A method of system triage may also be incorporated to focus the recovery efforts to initially clear critical infrastructure such as boreholes (surface and inter-level), installed flow-control equipment and instrumentation, then steel pipe work, and finally the high-density polyethylene (HDPE) segments. This approach will typically be guided by the financial cost and/or time associated with the potential loss of each section of the underground paste reticulation system.

Further benefits are realised with reliable remote operation and monitoring of this equipment, including flow-control hardware, flow and pressure instrumentation and cameras from the paste plant control room. A well-designed and maintained underground fibre optic/communications network and process control system support is critical to realising these benefits.

These measures can only be achieved through the incorporation of fit-for-purpose mechanical equipment and electrical controls, which form a fundamental part of the paste system operating philosophy, while the physical aspects of the response should be complemented with a trigger action response plan and associated training of responsible personnel.

## 2 Operational case study for the management of system flow-loss

The Independence Group NL (IGO) Nova Mine is located in the Fraser Range, Western Australia (Figure 3), about 380 km northeast of the port of Esperance. The underground nickel/copper mine uses open stoping with a paste backfill mining method.


**Figure 3 IGO Nova Mine location in Western Australia**

The Nova paste plant has an average production rate of 85 $m^3$/h feeding the surface borehole. The surface borehole configuration is a NB250 SCH40 (nominal 250 mm diameter, schedule 40) outer casing with a hanging wear casing. The wear casing is a threaded coupling oil/gas well casing and consists of a lead-in 12 m length of 7 inch casing (internal diameter (ID) 157.07 mm, wall thickness 10.365 mm) into a 4.5 inch casing (ID 88.9 mm, wall thickness 12.7 mm). The Nova paste surface borehole length is 230 m.

The underground main reticulation pipe work is NB150 SCH80 steel pipe (ID 146.36 mm, wall thickness 10.97 mm). The main joining method is Victaulic HP70-ES couplings, though ANSI #600 flanges (ideally lap joint; however, welded neck are acceptable) are used for selected elbows within the system. The system is rated to a maximum operating pressure of 10 MPa.

Figures 4 and 5 show the Nova orebody and the paste delivery system incorporating flow-control hardware, flow and pressure instrumentation and cameras. A fibre optic communications network to the underground workings enables remote monitoring and function of the underground equipment from the surface paste control room.

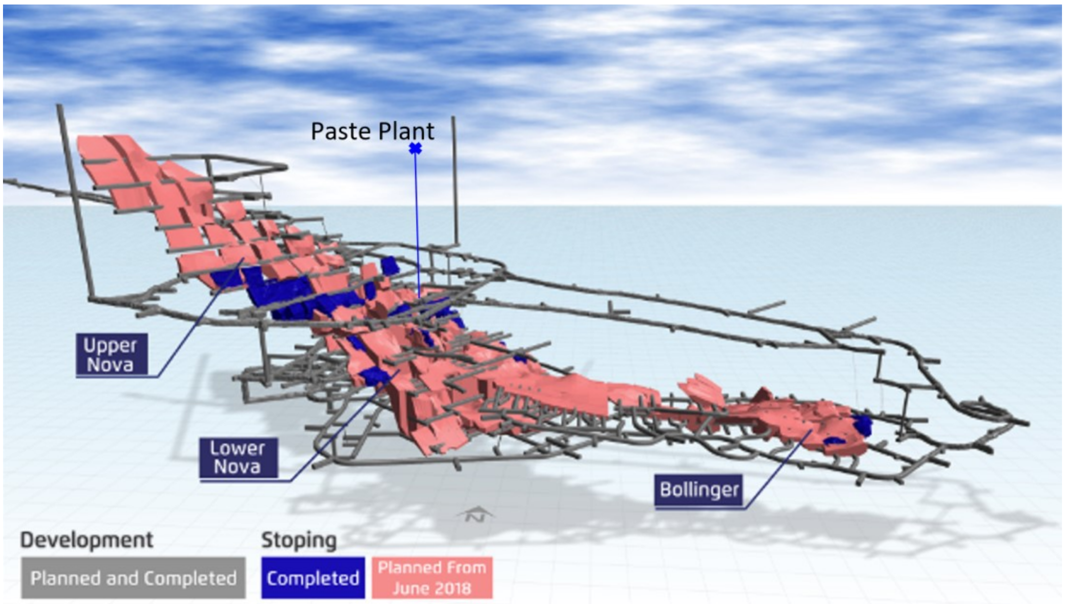



**Figure 4 IGO Nova Mine layout**

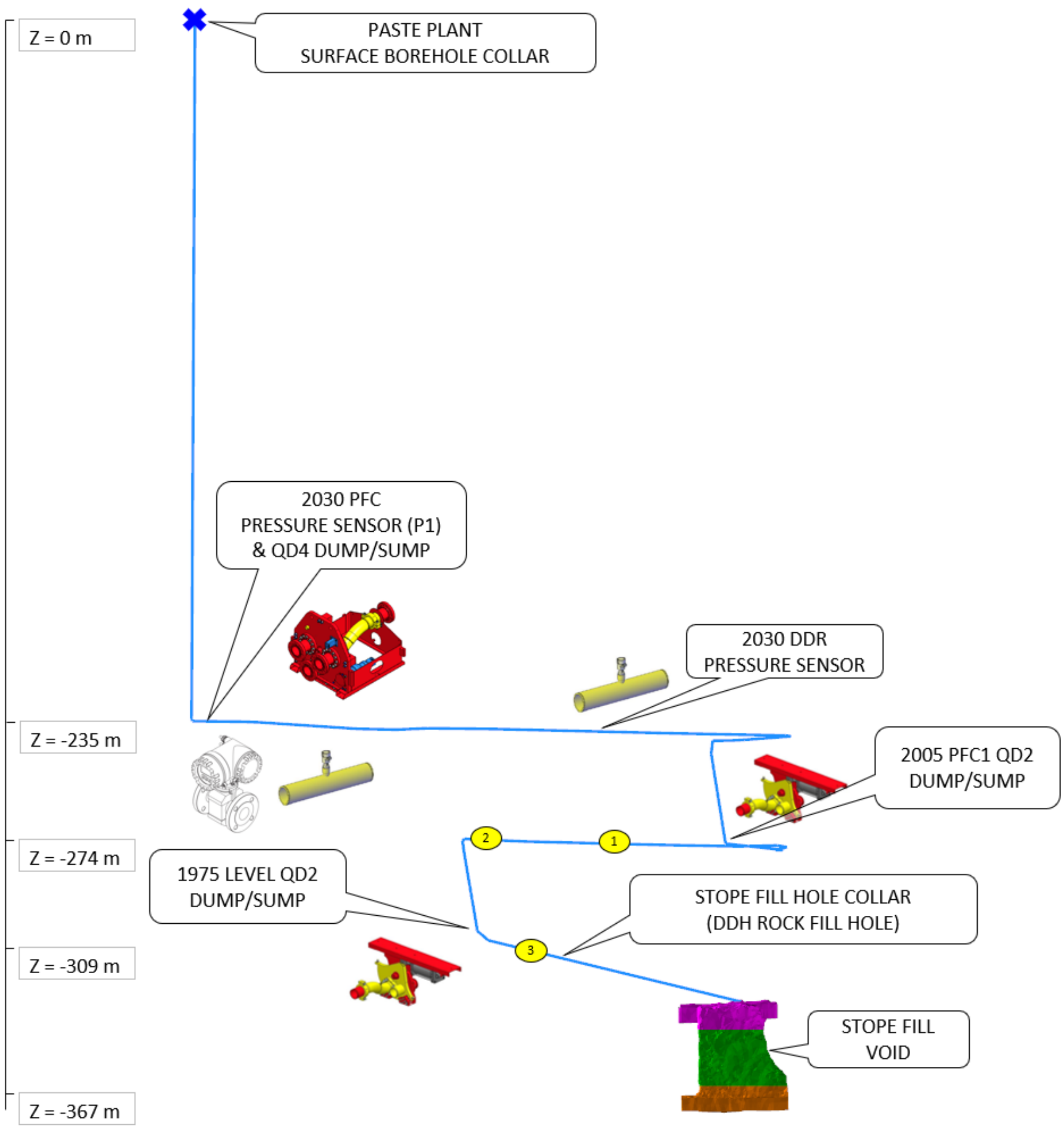



**Figure 5 Paste delivery system**

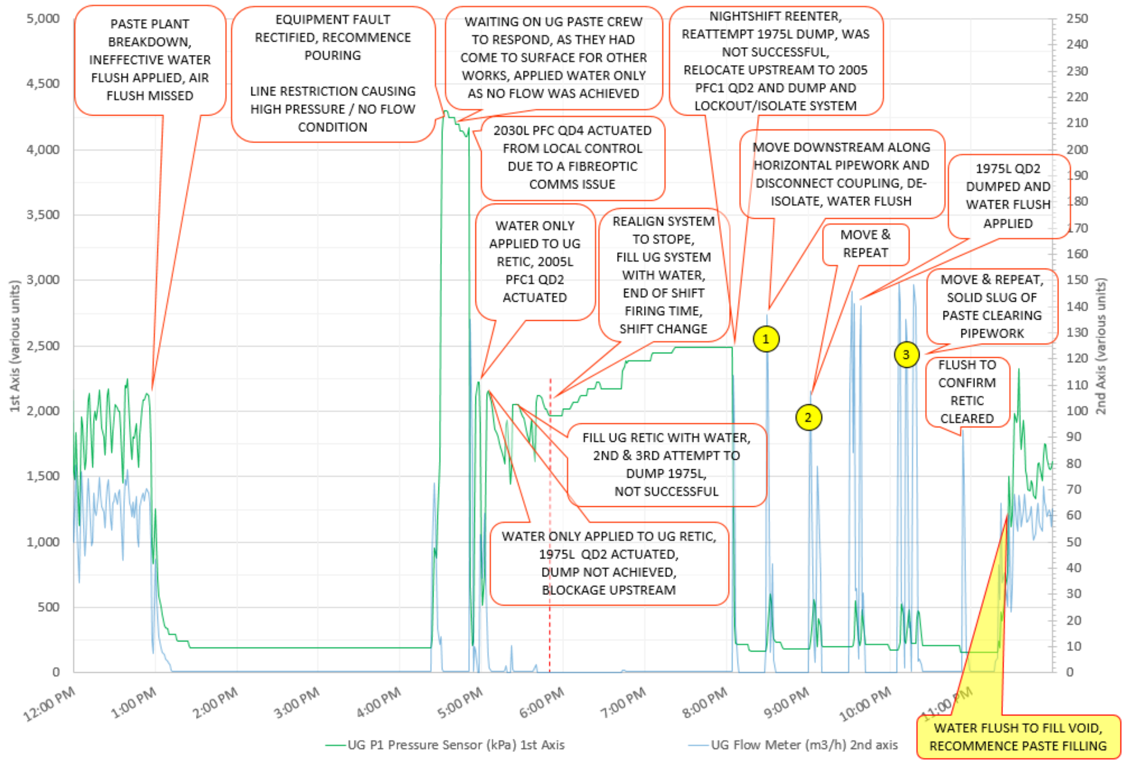
The paste fill delivery holes are often up to 100 m in length and are drilled using a diamond drillhole (DDH) rig of HQ size resulting in a rock hole with an inside diameter of 96 mm. The DDH collar is reamed to enable a steel pipe insert spigot to be grouted in place. The system overview shown in Figure 5 presents the three main interaction points accessed during the system flow-loss event recovery. Symbolised by the yellow numbered circles, the corresponding sequence of system interactions progress in a downstream direction and is explained in the text below.

## 2.1 Flow-loss event

In this scenario, a flow-loss event occurred towards the end of the day shift (Figure 6). Leading up to the event, a stope swap had been conducted and a paste plant clean had been completed. After restart, the paste was consistently poured to the stope for 1.5 hours when the paste plant tripped out due to an equipment fault. During the initial crash stop response, the underground reticulation was flushed with water, and no air flush was applied (this water-only flush was later found to be ineffective). A normal flush sequence includes water and compressed air to reliably clear the reticulation system.


## Figure 6 Paste operations running data

Figure 7 shows the blockage response steps with the pressure and flow data plot, the intervention points are labelled as locations 1, 2 and 3, and are the same as in Figure 5.




## Figure 7 Pressure and flow data during flow-loss event recovery

## 2.2 Flow-loss event response sequence

Each phase of the response sequence is described and evaluated to determine performance and where opportunities might exist for improvement:

- **1:00 pm**

  Paste plant tripped out due to an equipment fault; water-only flush was applied to the underground reticulation.

- **4:30 pm**

  Upon recommencement of paste pouring to the underground, the 2030L PFC P1 pressure sensor peaked at 4,300 kPa (static), with an expected average operating pressure (dynamic) during pouring to this stope of 1,800 kPa. This was accurately identified as a blockage condition, and filter feed/borehole delivery was stopped. The backfill engineer was notified as part of the blockage escalation process.

  It was reiterated during a brief discussion, that only water was to be used to apply pressure until the paste mixture was remobilised, as indicated by the underground flow meter. Once the paste mixture mobilised, air flush then could be applied to clear the reticulation pipe work. Experience has shown that the application of a compressed air flush with the paste mixture in a static state further compacts the mixture and potentially removes the paste mixture moisture, exacerbating the blockage situation.

- **4:35 pm**

  Attempts were made to remotely activate the 2030L Paste QD4 diverter to dump the surface borehole paste mixture. However, due to a network communication fault, the QD4 was required to be operated from the local control panel.

- **4:50 pm**

  Once the underground paste crew arrived at the 2030L PFC and rotated the QD4 to the dump position, the surface borehole was flushed with water, and then air. The dumped paste mixture and then clear water was visually confirmed using the paste camera in the dump sump. This time delay highlighted the importance of a reliable underground communications network. It also showed the value of a competent underground paste crew available to support the recovery effort if network communications are not available or prove unreliable.

- **4:55 pm**

  The QD4 was realigned to the blocked reticulation pipework and water was again applied. The system was filled with water to continue to apply a hydrostatic pressure to the blockage, and the system pressures were monitored.

- **5:00 pm**

  The paste crew was required to attend the 2005L Paste QD2 diverter, as remote capability had not yet been configured. The QD2 was activated from the local control and the paste reticulation system was cleared to the 2005L QD2. A water and air flush was applied to the 2005L dump sump.

- **5:10 pm**

  The paste crew attended the 1975L QD2 diverter. Once rotated to the dump position, the paste mixture failed to clear the reticulation pipework. This indicated the blockage was located in-between 2005L and 1975L. Several attempts were made to apply hydrostatic pressure to the blockage by filling the system with water and dumping at the 1975L QD2, with no success.

- **5:50 pm**

  As it was the end of the day shift, and the charged stopes were ready to be fired at end-of-shift, the paste crew realigned the reticulation pipe work to the stope delivery point and travelled to the surface. This realignment was to contain any discharged paste mixture or flush water, or both, in the stope void. The paste reticulation system was then filled to the surface with water to maintain a hydrostatic pressure against the blockage paste mixture.

- **7:00 pm**

  Following the mining crew pre-start meeting, the incoming paste crew attended the paste plant. After a brief discussion of the recovery efforts to date, a sketch-out of the proposed plan was completed. The night-shift paste crew immediately travelled underground to assist as directed. The importance of this direct personal communication (face-to-face meeting in the paste control room is preferred) cannot be overstated, as each flow-loss event will be slightly different each time and an adaptive approach will be required to successfully recover the entire system.

- **7:45 pm**

  The paste crew went directly to the 1975L QD2 and functioned the diverter. No paste mixture or water was dumped, indicating the blockage of paste mixture was upstream, between 1975L up to the 2005L QD2.

  The following steps show the advantage of safely and effectively segmenting the underground reticulation to enable the maximum available head pressure to be applied to the aligned downstream segment to be cleared. This can only be safely and effectively carried out by mechanically isolating and locking out the reticulation system with the upstream flow-control equipment, isolating the energy from the downstream segment to be worked on.

- **8:05 pm**

  The 2005L QD2 was functioned to dump the surface borehole and upstream reticulation pipework. The QD2 was isolated and locked out to enable work on the downstream pipe work. The on-level (2005L) pipe work segment was separated in half and the discharge area was barricaded.

- **8:20 pm**

  The paste crew de-isolated and realigned the QD2. Water flush was applied from the paste plant to allow water pressure to be applied to the paste pipe work. A very thick/curing paste mixture was evacuated to the barricaded area (Figures 5 and 7 – yellow circle 1).

  2005L QD2 was again isolated and locked out to enable work on the downstream pipework. The on-level (2005L) pipe work length was then disconnected near the top of the downstream inter-level borehole (2005 down to 1975) and the discharge area was barricaded.

- **9:00 pm**

  The paste crew de-isolated and realigned the QD2 to allow water pressure to be applied to the paste pipework. A very thick/curing paste mixture was again evacuated to the barricaded area (Figures 5 and 7 – yellow circle 2).

- **9:30 pm**

  The paste crew relocated down to 1975L and awaited the paste plant instruction. Once the paste reticulation was filled with water, the 1975L QD2 was functioned to the dump position, evacuating further paste mixture.

  The 1975L QD2 was then isolated and locked out.

- **10:10 pm**

  The on-level reticulation length was divided and barricaded. Water was then applied from the paste plant, evacuating further paste mixture and flush water (Figures 5 and 7 – yellow circle 3).

  The last portion was found to be clear, using a combination of tapping the reticulation and cracking the couplings and visual confirmations.

- **10:50 pm**

  The reticulation was then de-isolated and aligned to the stope fill point. A water and air flush was applied through to the stope void. The installed flow meter, pressure sensors and breather hole indicated that the flush was successful and full reticulation recovery had been achieved.

- **11:30 pm**

  The paste plant was restarted and paste filling of the void recommenced.

  This process took 7 hours from the high pressure reading at the 2030 PFC P1 pressure sensor, indicating a full blockage until the recommencement of pouring paste mixture to the fill void.

  The 1,000 m of reticulation, including a 230 m fully cased surface borehole and two inter-level rock boreholes, had been cleared and reinstated. The downtime that would likely be caused by a blocked and cured reticulation system that would require manual clearing could be several weeks. This manual recovery intervention could also have a high potential of disrupting the mine production schedule.

## 2.3 Flow-loss event discussion

Two critical benefits of incorporating flow-control equipment and instrumentation in the underground paste reticulation that have been highlighted here during the flow-loss event recovery were:

- The ability to apply the maximum available head pressure to a shortened segment of blocked reticulation using system segmentation to overcome the system friction-loss and clear the segment.
- The timely response time by the underground paste crew was enabled by using a safe and effective mechanical isolation and lock-out of the reticulation segment to be worked upon.

These two critical benefits are also of upmost importance in the event of a reticulation failure, where the upstream portion of the reticulation system can be effectively flushed to the failure point. However, the downstream segment will contain curing paste mixture. As mentioned above, it is likely that a blockage condition can then result in a reticulation failure, and once this is rectified, it may then require treatment as a system stalled condition. Conversely, a reticulation failure may result in a downstream blockage due to curing paste mixture. This blockage would need to be treated once the reticulation failure is rectified.

If the preferred approach of repairing the reticulation failure – realigning the system and applying a full water flush – is not successful, an alternative recovery method maybe used, requiring the use of a flushing head unit. This unit is connected immediately below the reticulation failure; and water and air pressure can be applied from the mine's water/air services to flush the downstream reticulation. To be effective, this must be applied in a timely manner and further highlights the advantage of being able to isolate the reticulation directly upstream of the failure point.

An added point to be noted is that the inclusion of flow-control equipment and instrumentation will increase the maintenance requirement of the paste fill reticulation system. Like all equipment used in the underground environment, regular servicing and function checks are required to enable reliable operations, especially in a flow-loss event and associated recovery efforts. However, the cost-benefit of a successful blockage recovery will far outweigh the slightly increased system operating costs inherently associated with a more sophisticated paste fill delivery system.

# 3 Conclusion

Using currently available technology in a holistic manner gives the paste operational team a range of options to be implemented during a flow-loss event such as discussed in this paper. The benefits of considering this technology during the design phase include:

- Protecting the surface and inter-level boreholes and underground reticulation pipe work by providing a means of clearing the direct upstream portion of the underground reticulation system by dumping the problematic paste mixture.
- Minimising the opportunity cost of using valuable underground work crew resources to rectify the blocked pipe work and having the paste plant shutdown. This deficit of paste filling will further impact the mine production schedule through increased mine activity interaction and extraction sequence disruption.
- Providing a safe and effective isolation and lock-out method for the underground work crews in a time-critical situation by enabling a mechanical means of physically separating the upstream energy source from the personnel working on the pipe work downstream.
- Isolating the upstream energy source by switching the entire stream of flow to a dump or isolated position, not only achieving upstream system pressure relief but also full upstream isolation.

Learnings from this flow-loss event discussion include:

- The importance of a reliable fibre optic/communications network and regular function testing of system hardware in local and remote settings to ensure the flow-control equipment can be reliably used once a flow-loss condition is identified.
- Recognise the value of experienced paste operational personnel and ongoing training and mentoring involving the engineers, coordinators, paste plant operators and the underground paste crews as each flow-loss event will have slight differences that may not be captured within the procedure to the detail required for a successful system recovery.
- Have a clear escalation process and initial response procedures in place. These include a duty-card process with instructions for each role in the paste operational team.

The risk of paste fill system blockage is somewhat inherent in mining operations due to the variability of the input feed parameters, location of the delivery point in the underground workings and the nature of delivering a high-yield paste mixture using a gravity-powered system. Incorporating the methods and learnings discussed in this paper will assist in achieving successful system recovery in a safe and effective manner. Recognising the value of underground reticulation design, flow-control hardware selection, instrumentation specification and system recovery methods is crucial in achieving reliable filling operations for the ongoing success of the mine’s production.

# 4 Acknowledgement

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