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Improvement in Big Gossan paste hybrid reticulation system design to optimise gravity flow: a case study

I Febritirtana *PT Freeport Indonesia, Indonesia*

D Kuswanto *PT Freeport Indonesia, Indonesia*

D Putra *PT Freeport Indonesia, Indonesia*

Abstract

Big Gossan mine is one of PT Freeport Indonesia's active underground mines in Papua, Indonesia. The mine began operations in 2010. It is operated using the open stope method with paste fill. The current production capacity is 7,500 tonne per day. The Big Gossan paste plant, located at 3100L, has been delivering an average of 4,000 m^3/day of paste. To ensure continuous distribution of paste to stopes at the production level, it utilises a hybrid reticulation system, which consists of gravity and pump flow rather than only by gravity or pump system. The hybrid reticulation system enhances paste productivity by providing flexibility on distribution, depending on the stope's location and priorities.

Given the dynamic mining sequence, the paste reticulation system needs to be adaptable to changing circumstances. This paper aims to examine the design of the hybrid paste reticulation system and its improvement for the Big Gossan mine, especially focusing on optimising gravity flow instead of relying on pump flow, because gravity flow has shown to be more productive in delivering paste fill.

Keywords: *Big Gossan, hybrid, paste fill, gravity, pump*

1 Introduction

Big Gossan is one of the active underground mines within the PT Freeport Indonesia Grasberg mining district in Papua. Distinctively, it is the only mine in the area that utilises open stope mining, a method that contrasts with the block caving techniques predominantly used in the surrounding mines, as shown in Figure 1.

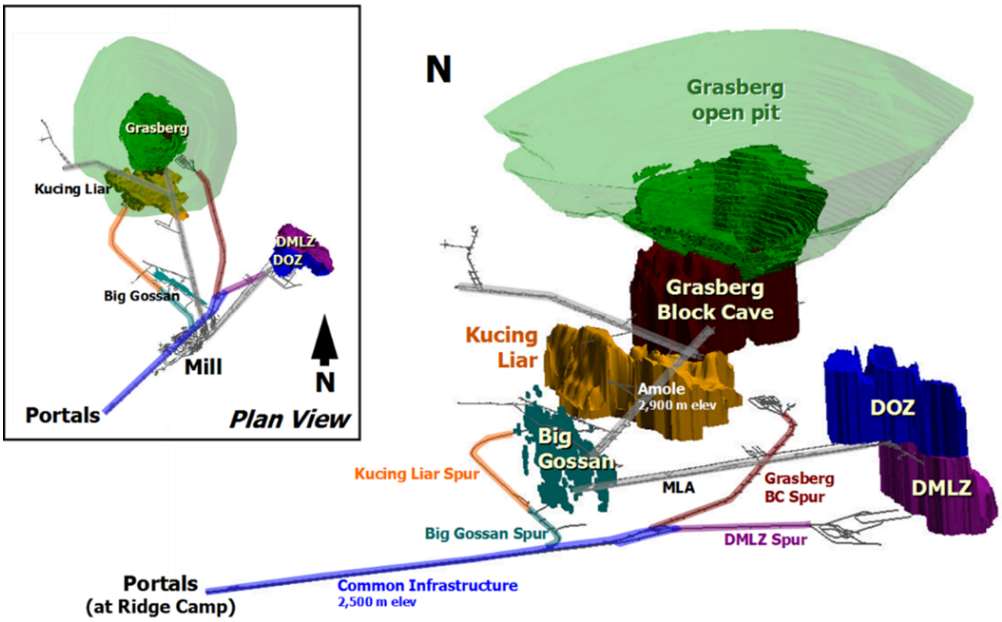

Figure 1 Freeport Grasberg mining district (source: PT Freeport Indonesia)

At present, Big Gossan has reached an average production rate of 7,500 tonne per day and the number has increased over the years, as shown in Figure 2. A critical aspect of its mining operations is the use of paste fill which plays a dual role in the mine's production sequence. Firstly, the paste fill serves as a method for confining empty stopes, effectively allowing for the safe and efficient continuation of mining activities. Secondly, it provides a stable platform for miners and heavy equipment, which is essential for the ongoing production processes (Freeport-McMoRan 2005)

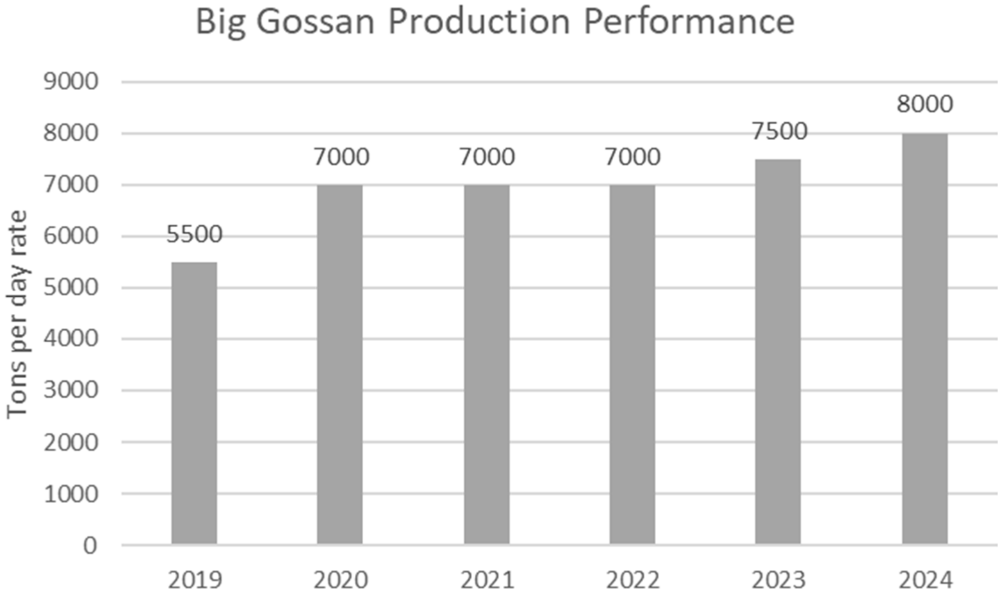

Figure 2 Big Gossan mine production performance

The production sequence at Big Gossan is a primary-secondary sequencing pattern within multiple stoping blocks. This methodical approach is created to maximise the extraction of high-grade ore while maintaining operational safety and efficiency. The combination of selective mining, high-grade ore, and continuous paste fill operations justifies Big Gossan's significant contribution to the PT Freeport Indonesia mining operations.

Big Gossan is operated using the open stope mining method, with paste fill to ensure its sustainable safe production. The effective operation of the paste backfill is crucial for ensuring uninterrupted mining operations and achieving the desired production targets. This is particularly true for underground mines, like Big Gossan, where the reliance on the performance of paste backfill is significant.

A key challenge arises when there is an increase in production goals. In such scenarios, the targets for paste fill must be adjusted to match the increased production demands as indicated in Figure 2. This escalates a focus on the paste reticulation system, which is essential for efficiently delivering paste fill to the stopes within the production zones. The performance of this system is critical, as it directly impacts the effectiveness and consistency of the paste fill operation which influences the overall mining productivity of Big Gossan mine.

2 Big Gossan paste plant

Big Gossan paste plant, a fixed facility for paste production, is on the top level of the Big Gossan mine at 3100 L. Paste fill produced at the Big Gossan paste plant is a combination of tailings, cement, and water. Its production process consists of:

- Tailings filtration
  - Around 240 tonnes per hour of tailings is sent from mill facilities on the surface, with an average percent solid of 65%. Big Gossan paste plant has three-disc filters, and those are used to reduce the moisture content in the tailings by up to 81% percent solid as per the mix design requirements.

- Batching process
  - The paste consists of 76 wt% tailing, 4.6 wt% cement, with the remaining being water. These components are mixed in a batch mixer. This stage is called the paste batching process. These materials are mixed and released after the final product reaches the power draw target.
- Paste distribution
  - After the batching process is done, the paste will be sent to the stopes on the production levels. This distribution method is done through gravity flow or pumping.

The paste plant schematic is shown in Figure 3.

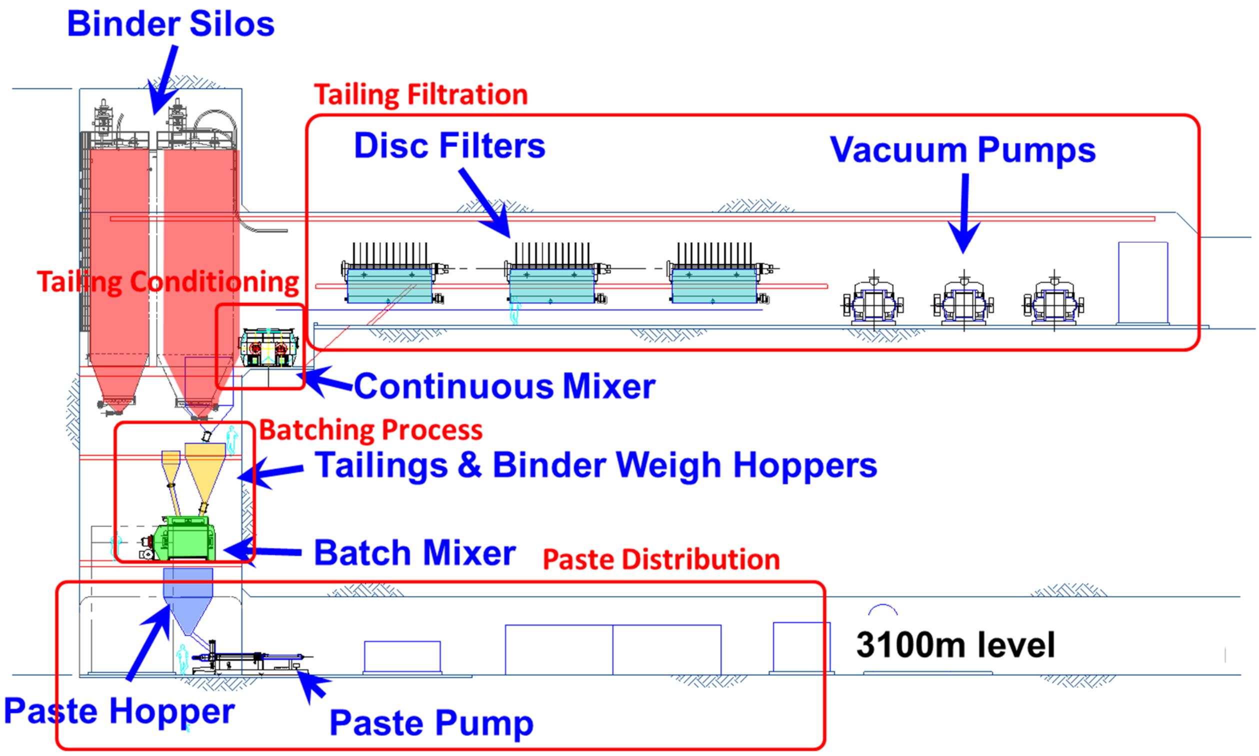

Figure 3 Big Gossan paste plant schematic (source: PT Freeport Indonesia)

The reticulation system of Big Gossan paste plant consists of two methods or a hybrid system: gravity flow and pumping. This hybrid system provides the advantage of flexibility for paste distribution, allowing the choice of which method is suitable for filling the empty stopes. The option to choose a distribution method is based on calculated flow modelling to prevent the head pressure being below the total pressure drop when the paste flows inside the pipe. This condition can lead to operational inefficiencies and potential blockages in the system.

3 Gravity versus pump flow in paste fill Big Gossan mine

The use of gravity and pump flow in the reticulation system at the Big Gossan paste plant highlights two distinct approaches to paste distribution, each with its own set of characteristics. Both methods have been used to send the paste to the stopes. The differences of two methods have been identified and analysed. The goal of this analysis is not just to improve paste distribution, but also to align the paste performance with the productivity objectives of the Big Gossan mine. Effective paste distribution directly impacts the efficiency of stope filling and overall mining operations. By optimising this aspect of the mining process, the Big Gossan can achieve higher productivity levels, maintain operational efficiency, and meet its production targets more effectively.

The comparison between gravity and pump flow are provided in the Table 1.

Table 1 Comparison between gravity flow and pump flow in Big Gossan paste fill

Gravity flow	Pump flow
Utilises gravity force or natural energy to move paste material	Utilises a pump or mechanical force to move paste material
Uses 10 inch diameter nominal pipe size (NPS)	Uses 10 inch diameter NPS
Produces unstable and intermittent flow	Produces stable and consistent flow
Limits range of paste distribution	Provides larger range of paste distribution
Lowers operational costs	Results in high cost of pump utilisation and maintenance
Creates 4,000 m^3/day flow rate (calculated when the plant was running smoothly and no downtime)	Creates 3,000 m^3/day flow rate (calculated when the plant was running smoothly and no downtime based on real performance, not from pump specification)

From the table, we can see clear differences between two methods. Gravity flow has a higher flow rate and lower costs because it uses natural force but has limited range on paste distribution distance. Pump flow itself has a wider range of paste distribution, but the flow rate is lower and produces a high cost on setup and ongoing operational maintenance. The higher flow rate is a key factor in boosting productivity in paste fill operation, as it allows for more material to be moved in a shorter amount of time. In mining operations where productivity and cost-effectiveness are crucial, gravity flow is preferred over pump flow.

4 Reticulation design improvement

Considering the unique geological and structural aspects of the mine, the mine's production is organised into three primary zones: west, central, and east. These zones are closely aligned with the mine's operational sequence, indicating a methodical approach to the progression of mining activities. Such zoning is crucial for efficient resource management and maintaining a structured mining process. These three zones are shown in Figure 4.

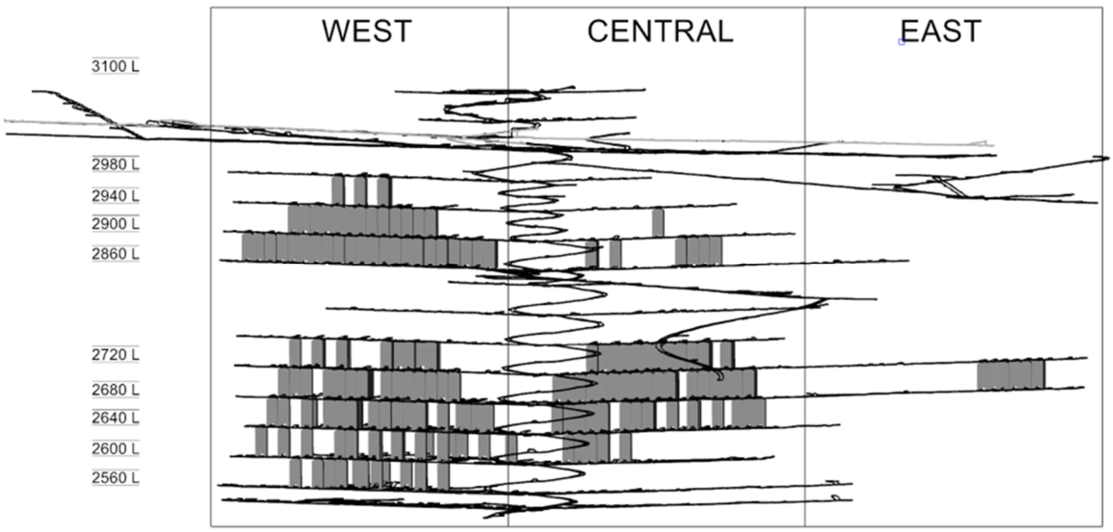

Figure 4 Production zones in Big Gossan mine

The design of the original paste reticulation system was created to cover three specific zones, utilising both gravity and pump flow. The original design of Big Gossan reticulation is shown in Figure 4. Several stopes in west and east areas are not covered by gravity flow because it is outside gravity distribution cone. To determine the gravity distribution zone, pressure drop formula will be used:

$$\Delta P = \frac{P_1 - P_2}{\Delta L} \tag{1}$$

where:

L = pipe length or the distance between two selected locations which are P_1 and P_2 (Yang et al. 2020)

ΔP = pressure drop between P_1 and P_2 at the 1 m/s velocity.

The data of pressure drop is provided in the Table 2.

Table 2 Slump number versus pressure drop at 10-inch pipe diameter (Golder Paste Technology Ltd 2005)

Slump (inch)	Pressure drop (kPa/m)
5	7.8
6	6
7	5
8	4.1
9	3.6

Using the given pressure drop data, total head pressure in the west and east location can be calculated using Equation 1. The paste plant area will be determined as $P_{1,}$ while the west and east zone will be determined as P_2. A 6-inch slump is used on the calculation, as this number is most suitable slump in paste fill mix design. Flow modelling based on pressure drop calculation as shown in and Table 3 and Figure 5.

Table 3 Maximum distance can be reached by gravity flow on original plan

Level	Maximum horizontal L to west and east zone	Note
2980	135 m	
2940	175 m	
2900	305 m	
2860	460 m	
2760	0 m	Not designed yet
2720	755 m	
2680	835 m	
2640	880 m	
2600	950 m	
2560	1100 m	

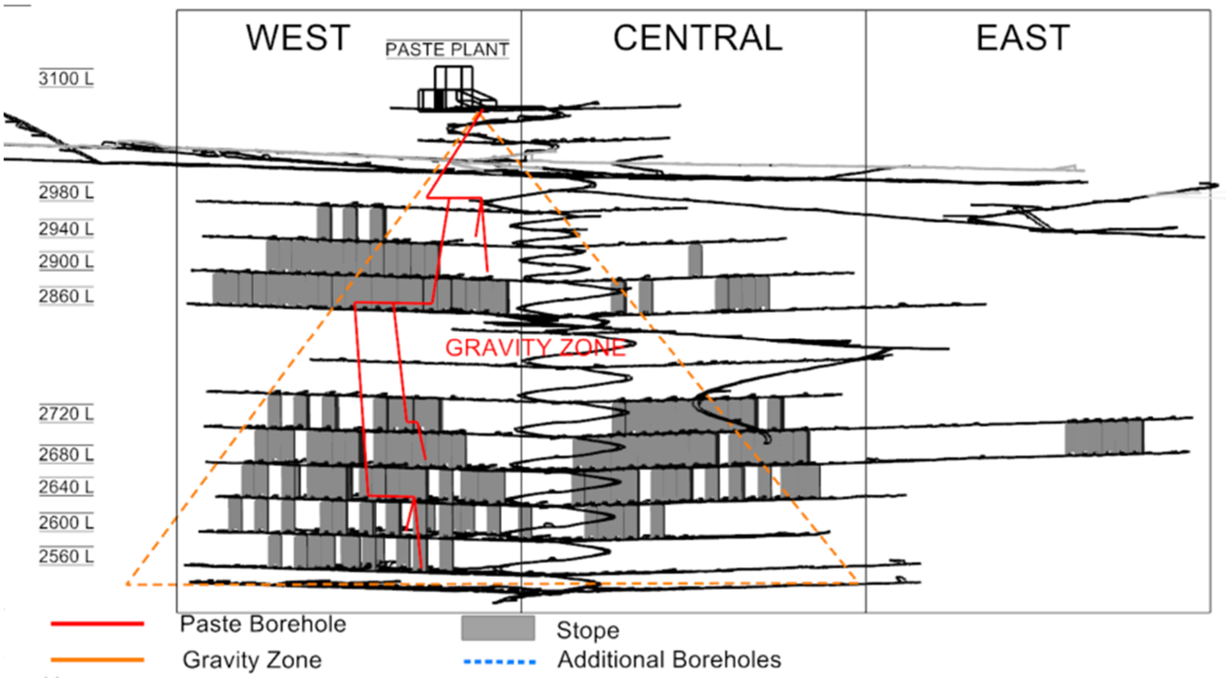

Figure 5 Original paste boreholes location and gravity zones

There are several key considerations when the objective is to optimise paste distribution:

- Paste plant location
  - The location of the paste plant is critical in a gravity flow system. Ideally, it should be placed at a higher elevation in the mine. This higher positioning of the plant leverages the force of gravity, allowing the paste to flow downstream more efficiently. The strategic placement of the plant can significantly influence the effectiveness and range of the gravity flow. A higher placement means a larger area can be covered, as the gravitational force can carry the paste further.
- Pipe dimension and installation
  - Larger diameters in pipes result in increased flow rates, yet this also leads to higher costs. Choosing the appropriate pipe diameter can enhance the efficiency of paste distribution. In terms of pipe installation, it incorporated two types: vertical and horizontal. The vertical pipes are positioned through boreholes, a method used to reduce the overall length of the pipes while achieving the required elevation. Meanwhile, the horizontal pipes are installed in the footwall, linking from the base of the vertical pipes straight to the stopes.
- Pressure drop
  - Pressure drop is the difference in pressure between two selected locations. Pressure drops on paste flow is occurring when it enters the piping system at one point and exits at other points or designated points (Panja 2023).

The decision to prioritise gravity over pump flow in the paste reticulation system marks a significant shift in the operational strategy, particularly in the context of the paste productivity. This change solidifies the fact that utilising gravity for paste movement is not only more efficient but also potentially more productive. To implement this new approach, the original reticulation system needed substantial improvement.

In the pursuit of achieving substantial improvements, there are multiple scenarios that must be considered. Each of these scenarios presents its own set of possibilities and challenges, and the choice of which path to follow depends on a careful evaluation of several key factors. Firstly, the timeline is a crucial aspect, and understanding the duration required for implementing each scenario is vital. It’s not just about how quickly a solution can be put into place, but also about the longevity of its impact and any potential disruptions it might cause during the implementation phase.

Secondly, the difficulties or efforts needed for each scenario cannot be underestimated. This involves assessing the technical complexities, the level of manpower required, the need for specialised skills or knowledge, and the overall feasibility of executing the plan. It's important to gauge whether the organisation has the necessary resources and expertise to handle these challenges or if additional support needs to be sourced.

Finally, cost estimation is a critical component in the decision-making process. This goes beyond the initial financial outlay and encompasses a comprehensive analysis of long-term financial implications, including maintenance costs, potential savings, and return on investment. The selected scenario should justify its cost not only in terms of monetary value but also in terms of value adding to the project or operation.

The scenarios are:

- Pipe specification change
  - When a decision is made to modify pipe specifications to enhance paste productivity, it typically involves enlarging the pipe diameter to boost the flow rate (Pomelo 2023). Given that the paste pipes installed in the Big Gossan mine are over 10 km of length, replacing the entire pipeline would be time-consuming and costly. Additionally, during this replacement period, paste fill operations would need to be temporarily halted due to the unavailability of the reticulation system.
- Increase slump number
  - The slump number indicates the fluidity of paste. Increasing the slump number leads to a reduced pressure drop, which might appear as an easy solution requiring minimal effort. However, the consequences of increasing the slump number are quite complex. To increase slump number, more water needs to be added to the paste (Luan et al. 2021), resulting in an extension on curing times in the stope and decreased the paste strength. Such a delay can disrupt the mining sequence, ultimately leading to decreased productivity in mining operations.
- Additional vertical or boreholes pipe installation
  - Installing extra borehole pipes in specific areas are necessary to expand the zones influenced by gravity flow. This approach can be implemented concurrently with ongoing paste fill operations. Moreover, the expense involved is less compared to the cost of replacing the existing pipes.

Among the three available options, the installation of additional vertical or borehole pipes emerges as the most favourable scenario for implementation. This strategy stands out for several reasons, primarily due to its lower risk profile and its potential to yield the highest productivity compared to the other alternatives. Another critical aspect of this choice is that it does not disrupt the current paste fill operations. Unlike some other options that might require a temporary shutdown or a slowdown of operations for implementation, the addition of vertical or borehole pipes can be carried out alongside the ongoing activities. This parallel implementation ensures that there is no significant halt or decrease in productivity during the upgrade process. The continuity of operations is vital for maintaining the workflow and meeting the project timelines.

The utilization of pressure drop data, as outlined in Table 2, plays a crucial role in determining the strategic placement of new paste boreholes. This process involves a detailed assessment and calculation to identify the most effective locations for these boreholes. This information is essential in making informed decisions about where to position the new boreholes to optimize the gravity flow within the mine.

Several potential locations for these additional boreholes are identified. These locations are carefully selected based on their ability to enhance the efficiency and coverage of the gravity flow system. Once these locations are determined, the plan for the installation of the new boreholes is executed according to a predefined timeline. This timeline is critical to ensure that the additions to the system are made in a timely and efficient manner, without causing significant disruptions to ongoing operations or the production plan that has been made. Adhering to this timeline is vital for maintaining the productivity and efficiency of the mine's operations.

In addition to the details provided in the textual description, a visual representation of these new borehole locations and the expanded coverage of the gravity zones is available in Table 4 and Figure 6. This figure offers a clear and comprehensive overview of the enhancements being made to the system. It visually depicts the new boreholes' placement and illustrates how these additions will expand the gravity flow coverage within the mine.

Table 4 Maximum distance after additional boreholes

Level	Maximum horizontal L to west and east zone	New distance after additional boreholes
2980	135 m	–
2940	175 m	325 m
2900	305 m	455 m
2860	460 m	–
2760	0 m	620 m
2720	755 m	–
2680	835 m	–
2640	880 m	–
2600	950 m	–
2560	1,100 m	–

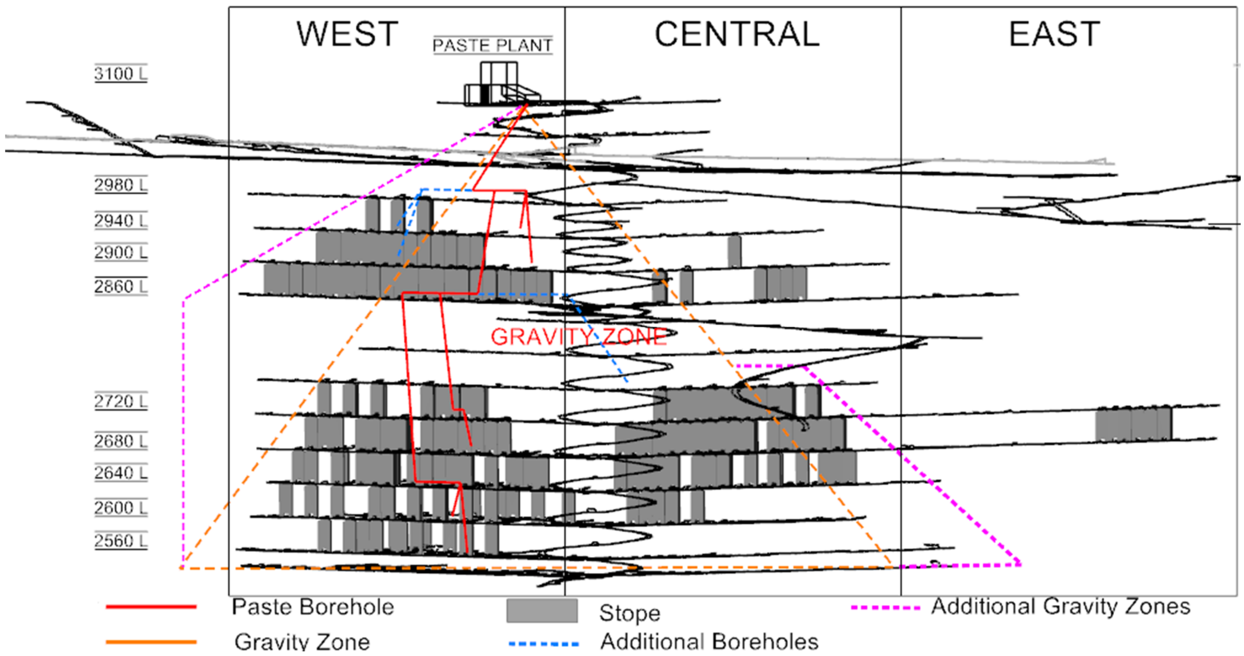

Figure 6 Additional paste boreholes in the new reticulation design

5 Paste production

The integration of additional paste boreholes into the existing reticulation system marked a significant advancement in the project executed between 2020 and 2021. This strategic move involved connecting the new boreholes' pipes to the current system, enhancing its overall functionality and efficiency.

In 2019–2023 period, calculated paste volume that require pump flow in the existing paste reticulation system was estimated at 220,000 m^3. This figure was based on initial calculations and assessments of the stope volume that needed to be filled based on mining sequence. However, the implementation of the new reticulation system brought significant reduction in this requirement.

The actual data gathered after the system improvement was implemented was only 66,000 m^3 of the paste volume needed to use pump flow, a significant decrease from the initially projected volume of pump flow. This drastic reduction highlights the effectiveness of the new system that optimised the reticulation system using gravity flow.

Over the past five years, the reticulation system has seen a remarkable level of productivity, with approximately 2,800,000 m^3 of material successfully delivered to the stopes compared with a projected 2,530,000 m^3 of paste using only the reticulation design without improvement as shown in Figure 7. This achievement is not just a matter of surpassing the projection operational targets, it signifies a substantial increase of the projected numbers by an impressive 265,426 m^3 or 110% higher. This achievement is directly attributable to the improvements made in the original reticulation design. The improvement not only enhances paste productivity but also has a direct impact on maintaining the production rate in line with the designated mining sequence.

The improvement on the paste delivery not only enhances paste productivity but also has a direct impact on maintaining the production rate in line with the designated mining sequence. It ensures a more consistent and reliable paste filling activity to empty stopes, therefore minimising the bottleneck on mining operational activities.

In summary, the past five years have demonstrated the benefits of redesigning and improving the reticulation system, setting a strong foundation for future growth and efficiency in the mine's operations. The data reflects a system that has not only met but exceeded expectations, paving the way for continued advancements and higher productivity in the years to come.

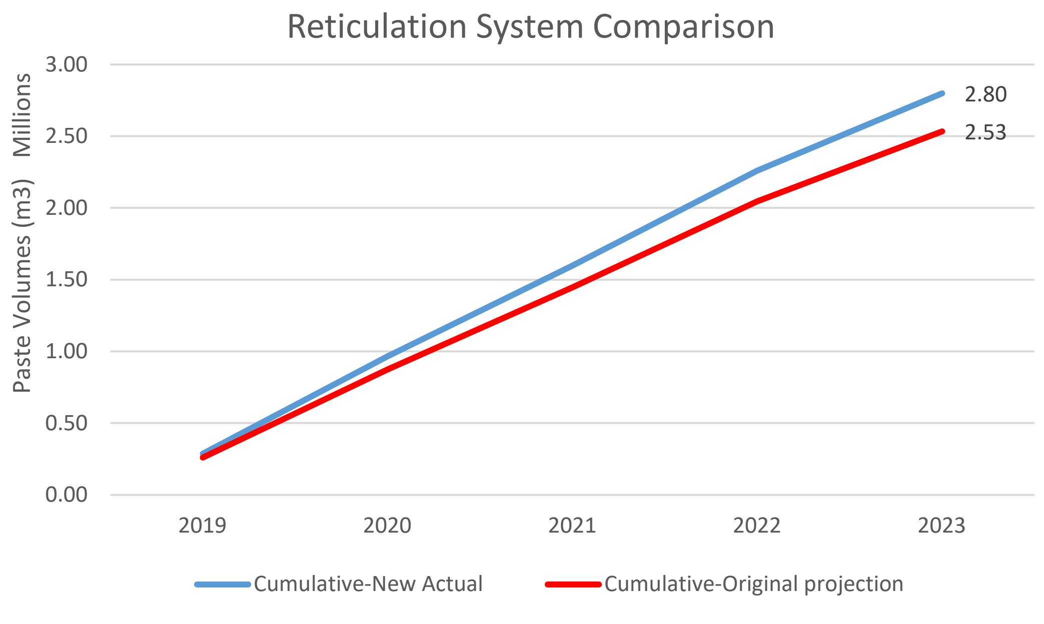

Figure 7 Paste fill achievement at the 2019-2023 period

6 Conclusion

The modification of the reticulation design in the case of the Big Gossan mine has demonstrated significant improvements, leading to enhanced productivity in the paste fill operations. This positive change can be attributed to a strategic shift from relying primarily on pump flow to several far distance stopes to leveraging gravity flow, which has proven to be more efficient.

The successful implementation of this improvement was based on the strategic placement of additional boreholes. By thoroughly analysing available data, key insights were gained into how the paste was moving through the existing system and where the potential bottlenecks or inefficiencies lay. This analysis allowed for the identification of optimal locations for the new boreholes to maximise the effectiveness of gravity flow and without creating disruption of the paste fill operation.

Acknowledgement

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