

Managing water in the transition from open-pit to underground mining, Grasberg – GBC: Challenges and strategic approaches

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ABSTRACT

Grasberg mine, located in the remote highlands of Papua, Indonesia yielding substantial reserves of copper and gold, has long been synonymous with open-pit mining. However, with the completion of the open pit, the mine has embarked on a monumental transition toward underground mining. Located in high rainfall rate area, this transition presents a unique set of water management challenges due to altered environment.

This paper provides an overview of the water management challenges and strategic approaches associated with the Grasberg Block Cave (GBC) transition, based on industry practices and development. The transition to underground mining requires a comprehensive understanding of the mine hydrogeological condition as the groundwater dynamics change, potentially leading to increased water ingress into underground workings. Controlling water inflows is paramount to ensure safety and efficiency of underground mining operations. Challenges in water management include controlling groundwater level, seepage, underground drainage, and surface water infiltration into underground areas. Excessive water ingress can pose safety risks and hinder mining operations. Strategies for effective water management during this transition encompass hydrological modelling, dewatering systems, surface – underground drainage management and sustainable practices. PT Freeport Indonesia has been working diligently to address these challenges and implement sustainable water management practices. Successfully reducing 250 l/s of water inflows from production areas, probability of reducing wet muck spills, controlling 1,250 – 3,200 l/s of mine drainage and reuse 315 l/s - 630 l/s for mill operation. This transition serves as a notable case study, illustrating the evolving strategies required to adapt to changing mining environments.

1 INTRODUCTION

Grasberg, one of the world's largest gold and copper mines has reached the completion point and embarked on monumental transition toward underground mining (Figure 1). Located in remote highlands of Papua ranging from 2900 – 4500 m above mean sea level (AMSL) elevation, the area is characterized by rugged topography and extreme relief contribute to a climate that conducive to heavy and frequent rain showers. This consistent precipitation offers benefits to the mining and mineral processing activities. However, with the transition from open pit to underground, a unique set of water management challenges were appeared.

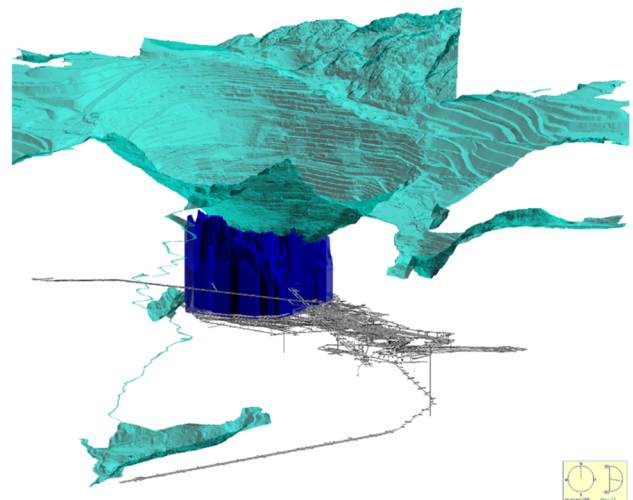


Figure 1 Grasberg final pit and Grasberg block cave mine.

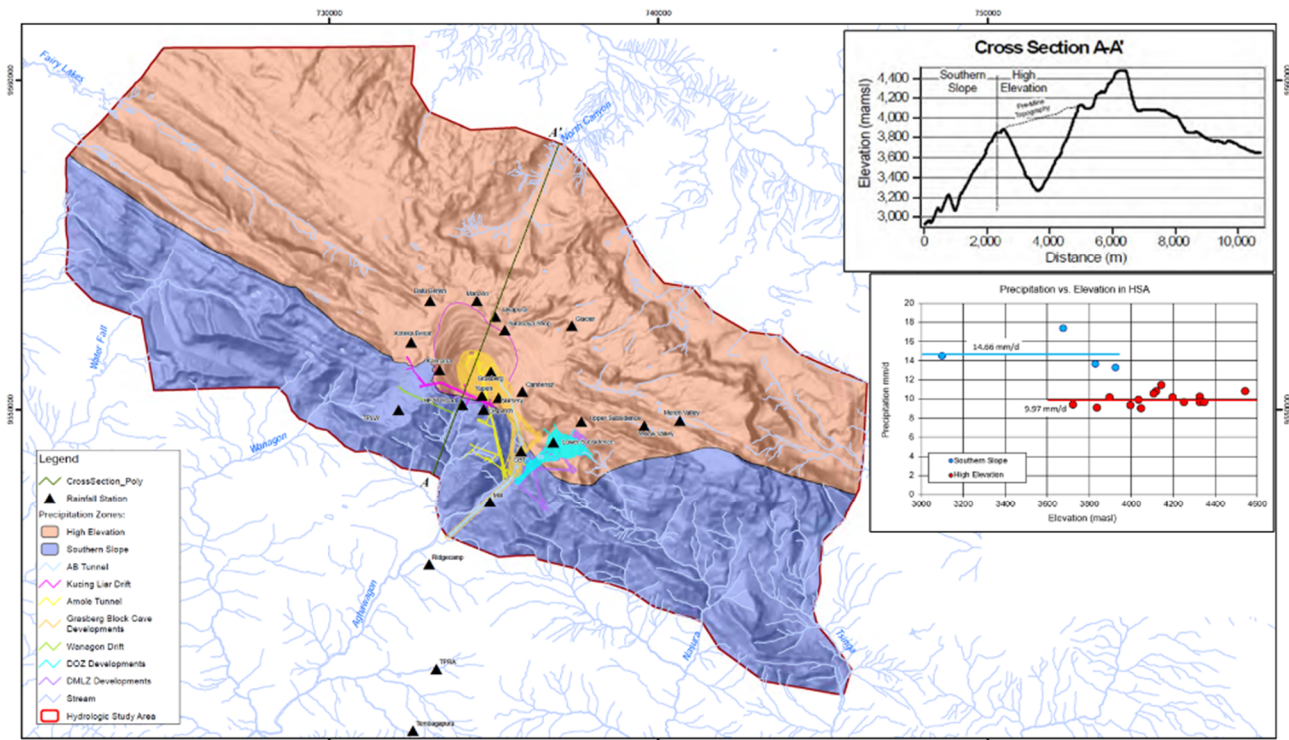


Figure 2 Map of rainfall station and distribution of precipitation zones.

1.1 Hydrology of Grasberg

The mine is situated in the area with a relatively high rainfall. There are 19 rainfall stations located around the Grasberg mine. Based on the different precipitation rates, the rainfall monitoring areas were divided into two major areas e.g., southern slope and high elevation (Figure 2).

The data from the southern slope stations are available since 1982, meanwhile data from the high elevation stations are available from 1995, with different stations having different periods of measurement.

- High elevation – above GBT elevation (15 stations) with average precipitation ranging from 9.0 to 11.4 mm/day (long-term average rate of 9.9 mm/day)
- Southern slope – below Mill elevation (4 stations) with average precipitation ranging from 13.2 mm/d to 17.3 mm/day (long-term average rate of 14.6 mm/day).

The distribution of average precipitation per month indicates that the “wettest” conditions occur in December through April and “relatively dry” conditions occur in May through August (Figure 3).

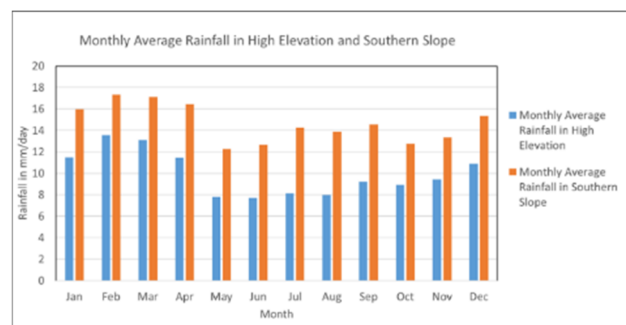


Figure 3 Long-term monthly average precipitation.

1.2 Geology of Grasberg

The main geological formations in Grasberg open pit and GBC mine comprise a sequence of folded sedimentary rocks of Mesozoic and Tertiary ages including limestones, sandstones, and siltstones. The fold axes trend west-northwest to east-southeast (WNW-ESE). The Grasberg porphyry is a major intrusion comprising diorite and andesitic volcanic and hosts the major Grasberg copper-gold orebody. Related mineralization formed high grade skarn deposits including the Ertsberg, East Ertsberg and Kucing Liar orebodies.

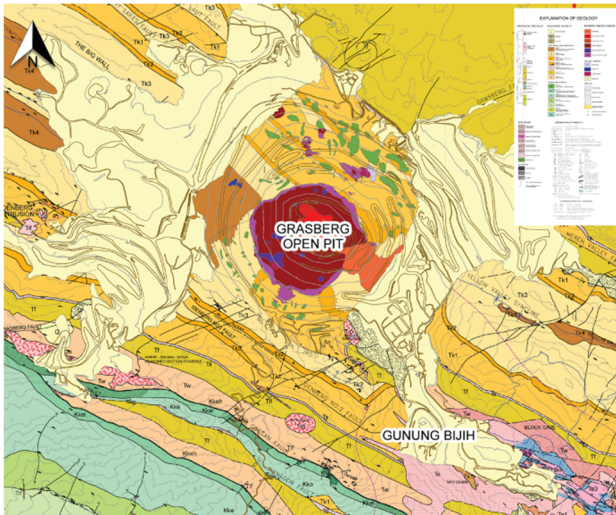


Figure 4 Regional geological map of Grasberg mineral district.

Numerous faults cut across the folded rocks. Steeply dipping faults, which includes the Idenberg, Fairy Lake and Meren Valley faults, are oriented along the main WNW-ESE axis. Another set of faults with a WSW-ESE axis, include the Carstenz Valley and the Grasberg faults (Figure 4).

1.3 Hydrogeology of Grasberg

Previous work by Hydrologic Consultants, Inc (1997-2008) and SRK (2018) described the conceptual hydrogeological setting of the

Grasberg area as five concentric rings around the Grasberg Intrusive Complex (GIC) (**Error! Reference source not found.**) which truncated by the Kali intrusive from the southeast consisting of:

- The Heavy Sulfide Zone (HSZ)
- An inboard contact zone between the GIC and the HSZ
- The outboard contact zone between the HSZ and adjacent marble
- Marble
- Limestone

The GIC consists of three major hydrogeologic zones (SRK, 2018):

- Poker Chip Zone (PCZ) is a multi-lobed zone of relatively high hydraulic conductivity around the central stockworks that occurs from ground surface down to an elevation of approximately 3,600 m AMSL (currently mined out)
- Less conductive intrusive rock below the PCZ to an elevation of approximately 3,300 m AMSL
- Very tight intrusive rock below approximately elevation 3,200 m AMSL, with two more permeable zones known as Softzone and Gajah Tidur Stockwork.

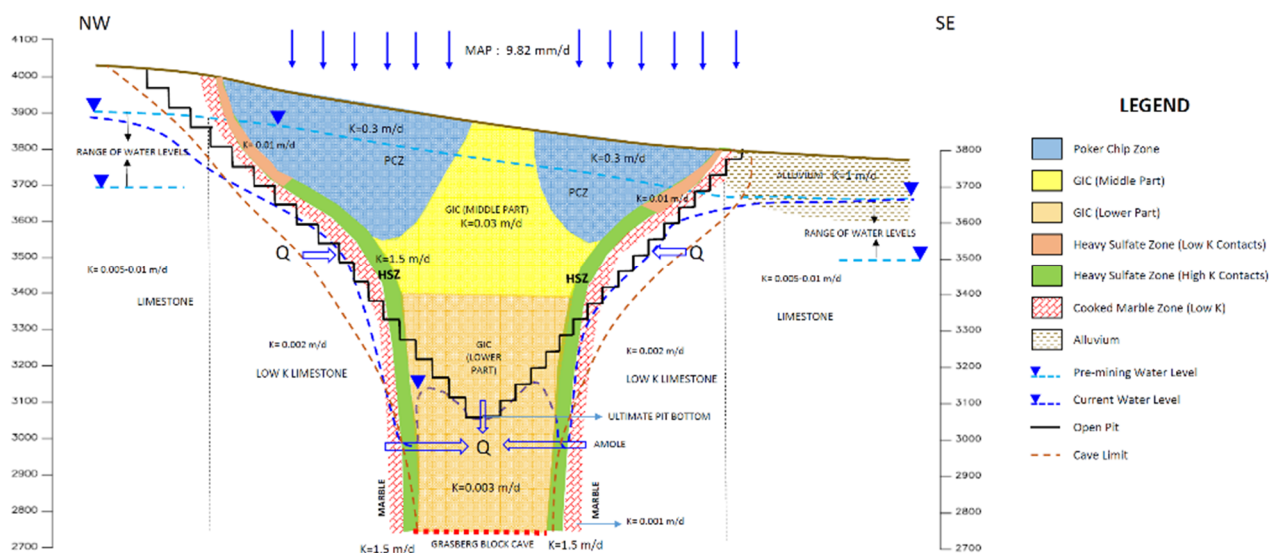


Figure 5 Conceptual hydrogeologic model of Grasberg area (SRK, 2018).

The HSZ is an essentially continuous zone of very low hydraulic conductivity ranging from 10 to 125 m in width. Conversely, the inboard and

outboard contact zones of the HSZ are transmissive between elevations of approximately 3,650 and 2,800 m AMSL. Above

an elevation of approximately 3,650 m AMSL, these contact zones appear to be less transmissive. The outboard marble zone and limestone units around the GIC have low hydraulic conductivity and appear to form barriers to groundwater flowing toward the GIC. Although not well defined, structures locally breach the marble and limestone shell.

A series of the permeable faults and associated fracture zones (Grasberg, Fairy Lake, Merren Valley, Idenberg#1, and Karume) surrounding the GIC are major groundwater conduits into the Grasberg mine area (Figure 6).

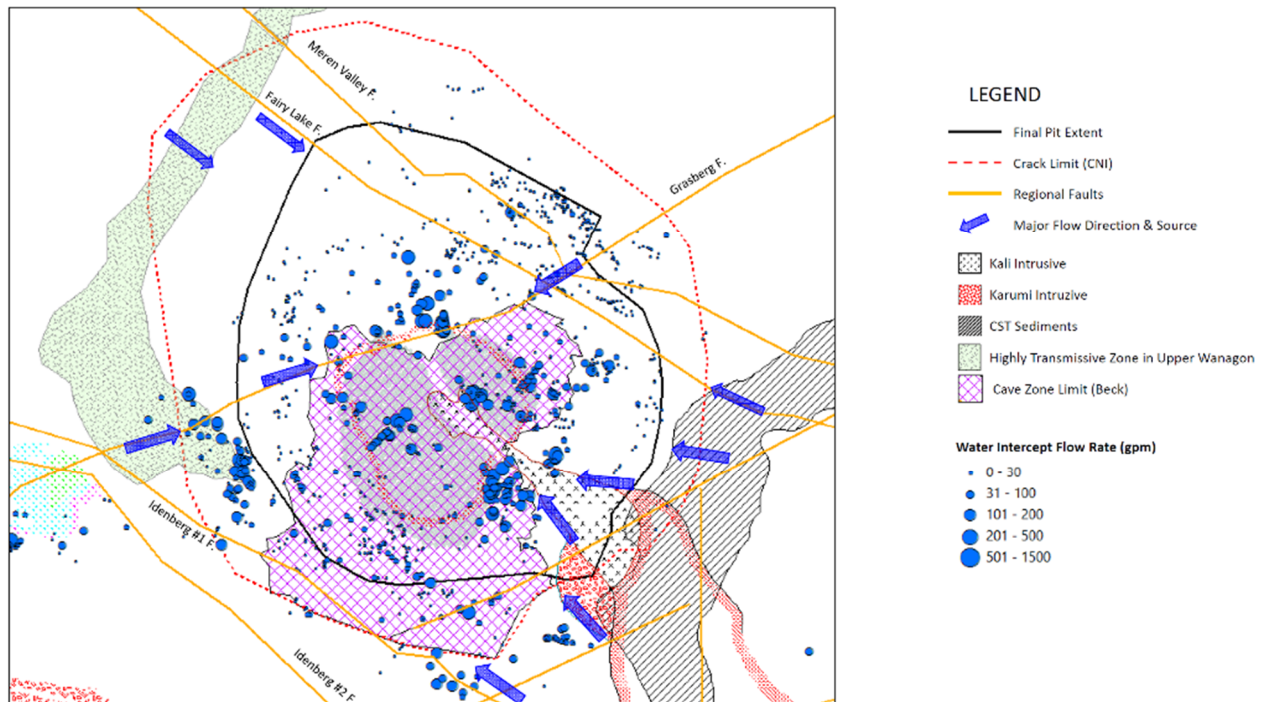


Figure 6 Conceptual hydrogeologic model of GBC in plan view (SRK, 2018).

2 WATER MANAGEMENT

2.1 Grasberg Open-Pit Era

Grasberg open pit era focus on Surface water management and dewatering, during excavation of the open pit is essential to keep the slope dry and manage or control the accumulation of surface water towards the pit bottom. There are several factors that affect the design of the drainage system including rainfall, catchment area and infiltration rate. The Grasberg pit drainage system consists of sumps with drop drain pipelines between benches, connecting ditch networks on benches, sumps with pumping systems, main drainage ditches on the road, culvert, control box, sediment pond, and vertical drain holes.

2.1.1 Ditch Network

The ditch network follows the road access to capture water runoff from roads and adjacent benches. The maximum flow rate capacity of each ditch network is different depending on its geometry and the estimated flow from its catchment area. Ditches on the benches are lined with a different lining material. Depending on the geological and geotechnical considerations concrete lining, HDPE liner/geo-membrane lining or conveyor lining may be applied. Ditches along the road are not lined as the velocity of flow will reduce infiltration to slope below and because it will restrict access for maintenance.

2.1.2 In-Pit Pumping

The in-pit pumping system operates to reduce runoff water entering the pit bottom during a

rainfall event. Due to capacity constraints, in-pit pumping can only be operated from the area above elevation 3,565 m AMSL. Water is pumped from several sumps installed beside the haul road to a peripheral ditch system (Figure 7),



Figure 7 Grasberg sump and pump condition.

then through several stages to the perimeter of the pit where water can then flow by gravity below the 3565 m AMSL elevation is discharged directly to UG mine either using the pump or directly into the vertical hole. Approximately 40 pumps operate in the Grasberg pit, of which 36 units are diesel pumps and 4 units are electric pumps.

2.1.3 Pit Dewatering System

Pit dewatering was done with the objective to lower the ground water table to prevent significant ground water flow into excavation and ensure stability of the slope.

There were several KPI for Grasberg dewatering system while the excavation progressed.

- Ensure the poker chip zone was dewatered.
- Control the middle GIC unit water level that has low pore pressure.
- Ensure the limestone was dewatered.
- Ensure the saturation 50 m behind the pit wall.

All dewatering holes were drilled based on systematic used of conceptual hydrogeology, series of piezometer were also installed on or

near several important point such as fault and lithological contact (Figure 8).

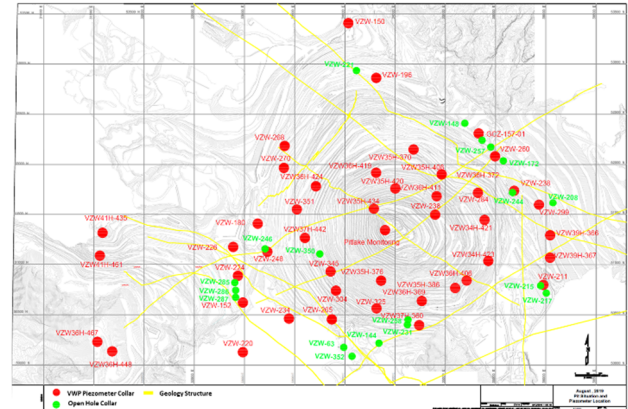


Figure 8 Grasberg surface monitoring piezometer.

There were three types of dewatering systems that PT Freeport Indonesia (PTFI) had in Grasberg.

1. In pit horizontal dewatering drilling
2. Vertical dewatering drilling
3. Semi horizontal dewatering drilling from underground dewatering drift (Amole - Kucing Liar).

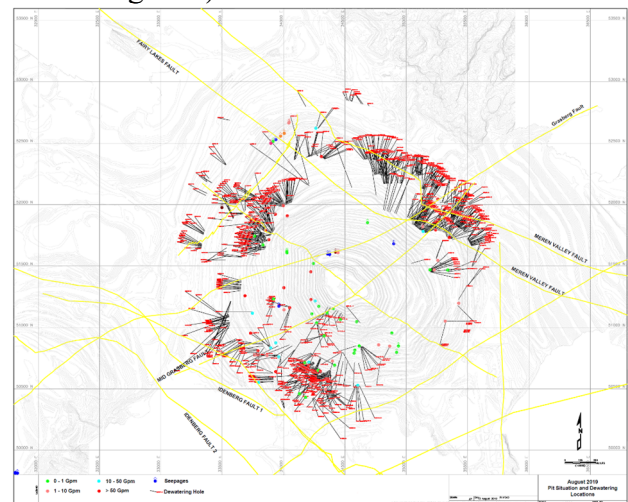


Figure 9 Grasberg horizontal dewatering.

In pit horizontal dewatering was aimed to depressurize local pit wall for pit stability and optimization at the later stage (Figure 9), meanwhile the vertical dewatering drilling were conducted especially for dewatering the poker chip zone. To increase the effectivity of dewatering drilling, PTFI constructed a dewatering drift (Amole - Kucing Liar) below the Grasberg open pit, semi horizontal dewatering drill hole and Amole - Kucing Liar

dewatering drift function as the main dewatering system that utilize gravity to dewater the open pit (Figure 10).

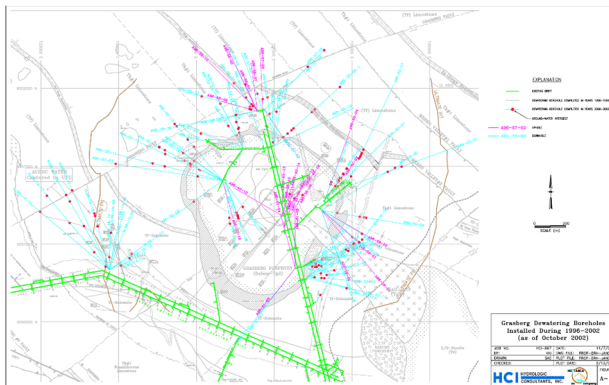


Figure 10 Grasberg semi horizontal dewatering drilling from underground dewatering drift (Amole – Kucing Liar) (Hydrologic Consultants, Inc, 2003).

With this configuration in Grasberg open pit era, PTFI successfully performed an efficient mine dewatering that proven can prevent or reduce pit lake formation and maintain the slope stability, beside that Amole dewatering drift also provided a significant amount of water for mill operation that helped PTFI to become one of the low-cost copper and gold mining operation in the world.

2.2 Grasberg – GBC Transition

The transition from Grasberg open pit into GBC underground mine bring a lot of new challenges, the controlled surface drainage area is decreased due to the increasing subsidence zone of GBC cave. The connectivity between Grasberg open pit and GBC underground mine needs to be managed appropriately without proper surface and underground water management. Direct infiltration can cause a lot of problems in GBC such as water inrush, wet muck, and depleting water supply for Mill operation.

Water management in Grasberg – GBC transition era can be divided into two parts, first is before the GBC production cave breakthrough to Grasberg pit bottom and second after the GBC production cave breakthrough to Grasberg pit bottom. The cave will break through to the Amole drift first and the bottom of the pit

eventually, and the cave and fractured zones will propagate out into the walls of the Grasberg pit, the breakthrough itself was modeled and based on that model the changing nature of groundwater inflow to the GBC as the block cave develops can conceptually be described in four stages. The four stages are shown sequentially in Figure 11.

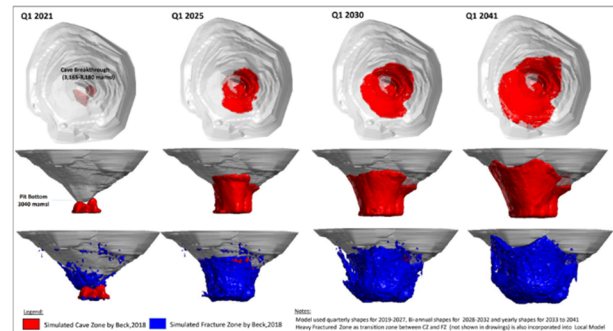


Figure 11 Simulated GBC cave and fractured zones model (Beck, 2018).

- | | |
|---------|--|
| Stage 1 | No cave; inflow only from structures with relatively low transmissivity to the supporting drifts. |
| Stage 2 | A cave develops within the GIC, and inflow begins from more transmissive features encountered by the cave (specifically interpreted as Mid Grasberg Fault). |
| Stage 3 | The cave reaches the bottom of the ultimate Grasberg pit, but remains within the GIC, and additional inflow comes from direct precipitation and seepage from the pit wall within the carbonate rock. |
| Stage 4 | The cave and fractured zones propagate through the HSZ and additional inflow to the cave material comes from carbonate rocks, sediments, Kali and Karume intrusive (whose upper portion might be sufficiently permeable to yield some water), and major water-bearing faults (e.g., Grasberg Fault, and potentially, Fairy Lake and Merren Valley Faults). |

2.2.1 Pit Bottom – Amole Dewatering Drift Breakthrough

With the transition draw near all the new challenges become real and to resolve that condition at the early stage of GBC PTFI decide to increase the depth of the Grasberg open pit until its breakthrough Amole Dewatering drift. This decision was taken to prevent the occurrence of an unmanageable pit lake forming at the bottom of the old pit bottom, which poses high risk to the underground operations. Ponding water at the base of the pit has the potential to create catastrophic inrush to underground mine workings. Based on the 2018 subsidence model (Beck, 2018), the cave will breakthrough to base of the pit around July-August 2022.

The model also forecasted that the surface breakthrough might be gradual with additional highly permeable pathways evolving throughout the process. First location to be impacted by the breakthrough were Amole XC#28 in 2019, the forecast was coming true on January 2019, following pit benching (mining) at elevation 3035 m AMSL the wall broke through the Amole at XC#28 (Figure 12)

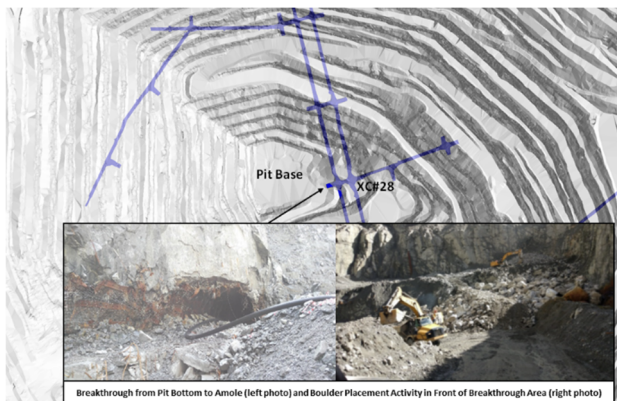


Figure 12 Grasberg pit bottom breakthrough to Amole dewatering drift.

Any surface water ponding above 3035 m AMSL freely drains to the Amole. The elevation of final pit bottom is about 8 to 10 m below the Amole level. An estimated maximum 51,000 m³ of water is stored (no material filling the bottom of the pit) under the 3035 m AMSL and the final pit bottom elevation. That water cannot be drained, to monitor this condition a piezometer was installed in the bottom of the pit (**Error!**

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The breakthrough window acts as a drain way for the lake in the Grasberg pit bottom. During the storm event, which eventually occurred in March 2019, the water flowing through this drain way peaked up to 3200 lps with average flow about 1050 lps.

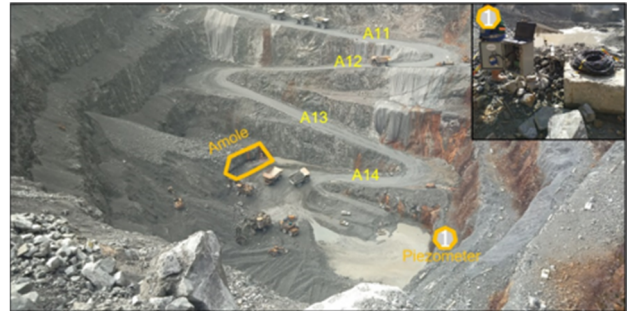


Figure 13 Piezometer location at Grasberg pit bottom.

This kind of flow can report to the GBC extraction level when the cave zone breaks through the Amole drift where it will create a conductive connection.



Figure 14 The condition of Grasberg bottom pit with amole drift during the storm event.

2.2.2 GBC Production Cave - Amole Dewatering Drift Breakthrough

During mid of May 2020, flow monitoring on Amole dewatering drift start showing decreasing trend even when the piezometer at the bottom pit was showing water level that exceeded the breakthrough level. This phenomenon was interpreted as decreasing permeability of the

Amole breakthrough. At the end of May 2020, sudden flow drops were recorded and based on the inspection small crack were found in XC25 Amole. The crack happened due to the PB West Cave that reached Amole level (Figure 15).

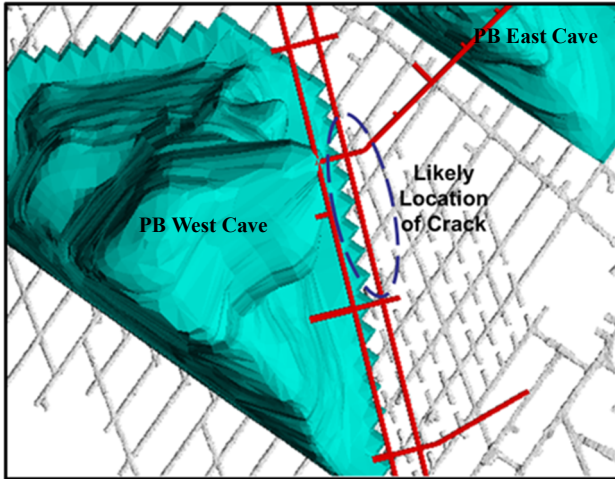


Figure 15 PB West Cave breakthrough to Amole dewatering drift.

Since then, the flow at Amole continues to decrease until it was gone completely. This milestone signaled a direct connection between Surface – Amole – GBC which led to an increased water discharge flow at the draw points located near GBC cave – Amole breakthrough area.

On mid December 2020, a significant water flow was reported at the middle access of Undercut level (Figure 16). Water chemical properties analysis showed the water had same characteristic with the water that was found in Amole.

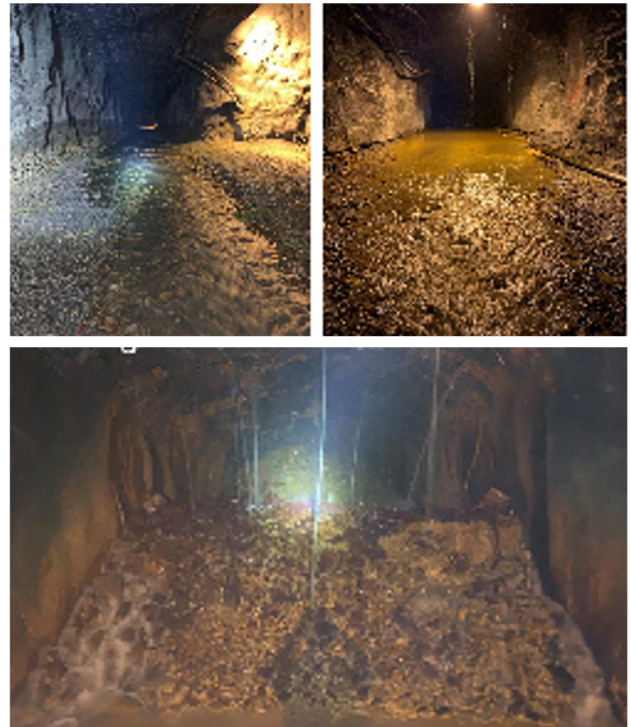


Figure 16 Significant water flow at Undercut middle access.

The finding was reinforced by cave shape analysis using HOD, Tomography and Elexon cave monitoring beacon that also shows the same conclusion that PB East Cave had already reached Amole level at 3005 m AMSL since the end of October 2020. (Figure 17).

The monitored water discharge from GBC Extraction level shows increasing flow (Figure 18), at first the increasing flow was observed at PB West draw points but after PB East cave reach Amole level, PB west draw points water starting to decreasing meanwhile the PB East draw points water started to increase.

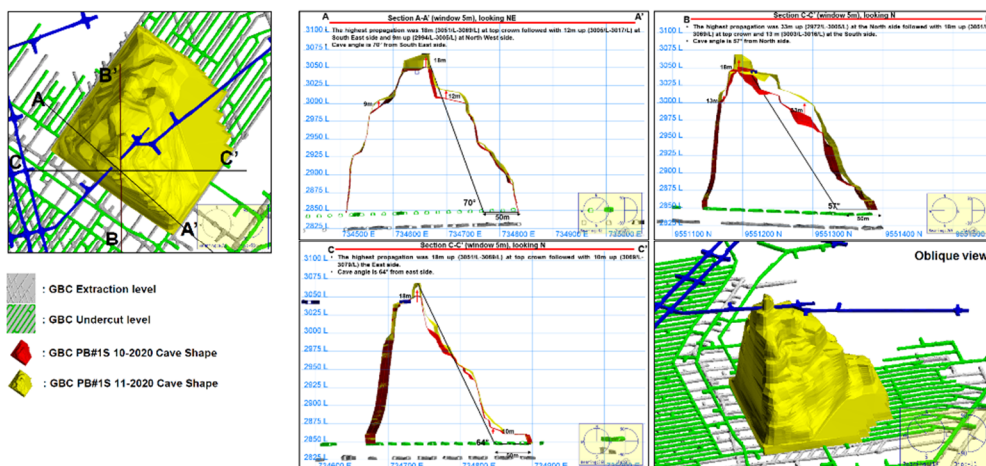


Figure 17 PB East Cave breakthrough to Amole XC25 to east access.

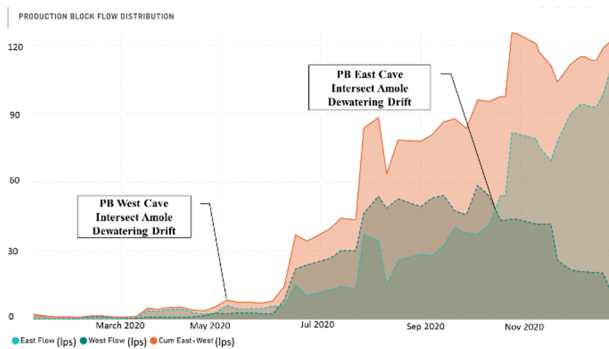


Figure 18 Production block flow graph when production Cave breakthrough the Amole dewatering drift.

The high-water inflow in draw points could lead to potential critical risk at production area such as:

- **Wet muck**
When a significant water continuously recharged the cave and mixed with the in-situ fine materials, wet muck material would be formed and would pose a risk to production and operational activities within the extraction area.
- **Flooding and sudden water inrush**
As Amole and Grasberg pit has been connected, the water from bottom pit that influenced by storm will eventually flow to GBC and flooding risk occur along the drainage route. Moreover, amole water that used to go to the mill to support the mill operation is now gone to the cave zone.

To handle the risk in high water in-flow area work is conducted remotely and TARP is applied.

2.2.3 GBC Water Flooding Trigger Action Response Plan

Trigger action response plans (TARP) are important tools used to manage risk. A TARP defines a set of trigger levels related to a particular hazard, along with the associated responses to be initiated when that trigger level is reached.

Not long after the production block cave breakthrough to Amole PTFI composed the first

GBC Flooding TARP, this TARP was composed only based on the maximum rainfall water that can be held by Grasberg Sump before it overflows into bottom pit (3.5 mm/hr) and the highest recorded of rainfall after production cave breakthrough the amole dewatering drift (15 mm/hr), since high rainfall event that happen on February 1st, 2021 GBC Flooding TARP were revised. The revised TARP was composed based on the re-arranged rainfall hyetograph and maximum drainage capacity of AB1 Tunnel.

The hyetograph is made from 129.4 mm/24-hour rainfall that was recorded in Yapen station in 31 Jan – 1 Feb 2021, the re-arranged hyetograph then being calculated for percentage of rainfall every hour to estimate the shape of hyetograph from a total 90 mm/24-hour rainfall. The 90 mm/24-hour rainfall was chosen as Amole run off flow that recorded in 2020 has reach 1900 lps with 90 mm rainfall.

The 90 mm/24 hours hyetograph has peak intensity at 10th hour, with peak intensity 6.4 mm/Hour. The runoff flow was assumed to peak at extraction level two (2) hours after rainfall peak (at 12th hour) and cumulative rainfall that has the same peak time with the flow is four (4) hours cumulative rainfall.

By then, a threshold then decided using 4 hours cumulative rainfall as high as 8.7 mm/4 hours to trigger TARP alert level 2. This threshold is inferred to have run off flow associated with it as high as 500 lps (Figure 19). Meanwhile the Probable part of this flow has been started feeding pump system in Grasberg pit and being pumped. Meanwhile 15 mm accumulation of rainfall in four hours was chosen as the upper alert of the TARP.

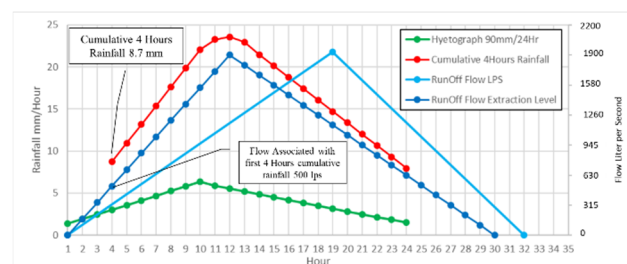


Figure 19 Rainfall Hyetograph.

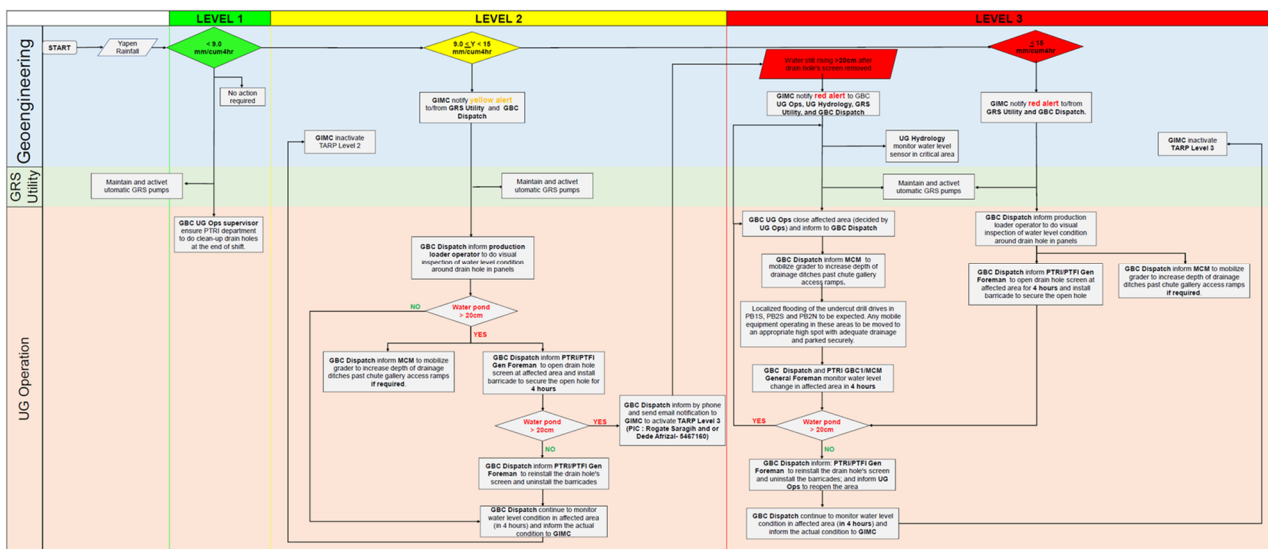
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Considering the maximum capacity of the AB1 Tunnel, which is around 2500 lps, an extra TARP parameter was included for the lower-level part

of GBC using measured flow in Lower Pump Station (LPS) Level. With 1900 lps for alert level 2 and more than 2200 lps for alert level 3. This extra parameter helps the team to do a better preparation for incoming flood in AB1 Tunnel. The 4 hours cumulative rainfall will be an indication of rainfall increase, in case the rainfall decreases, the alert will need 4 hours to back to level 1. The TARP activate protocols at several area in GBC and Grasberg that requires a series of action from several department (**Error! Reference source not found.**).

TARP Protocol Workflow in GBC Production Area



TARP Protocol Workflow in AB Tunnel Area

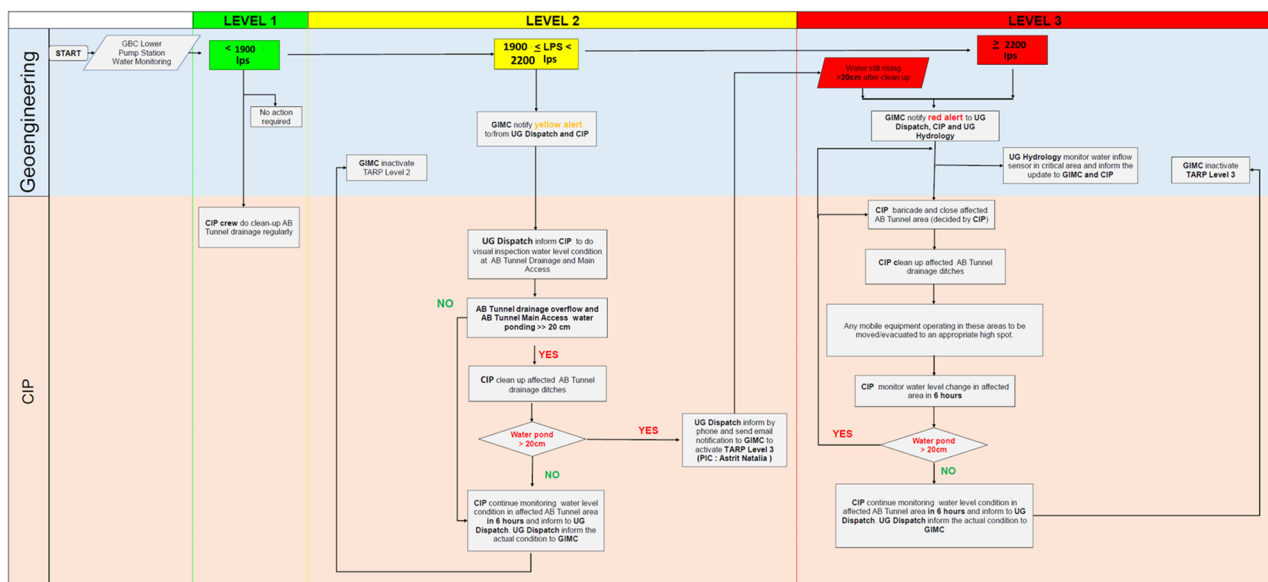


Figure 20 GBC Trigger action response plans protocol workflow

2.2.4 Amole Diversion Project.

Amole diversion project were conducted as a mitigation to resolve the high-water inflow situation that happen inside the production cave and extraction draw points.

The diversion was designed to be conducted from undercut level targeting two big water accumulation point in Amole XC27 and XC30. Drilling to Amole XC30 was meant to intercept water flowing from northern Amole that came from past drilling projects either dewatering or exploration holes.

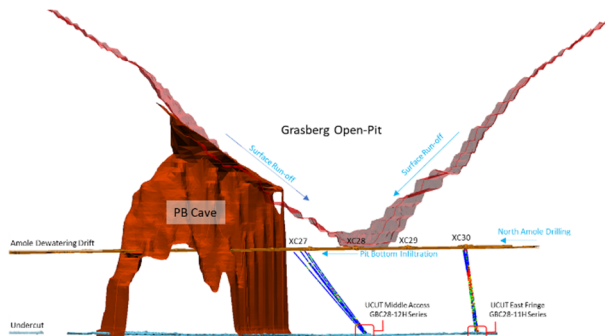


Figure 21 GBC Undercut – Amole XC27 and XC30 drilling design.

Meanwhile, drilling to Amole XC27 was meant to intercept water that infiltrated from pit bottom through Amole-Grasberg breakthrough around XC28 (Figure 21). Both drilling was aimed to

intercept all the water before flowing into the GBC cave.

Using diamond drill rig with HQ drill size, ~259 m drill depth and +49 ° for XC27 and ~195 m drill depth and +82 ° Inclination for XC30 drilling. With small target size ± 5 m wide a high degree drilling accuracy were needed, to do this PTFI with help of Major Pontil decided to limit the drill rate, using hexagonal chrome barrel and conducted a maxibor for every 50 m depth.

Resulting with 170 lps of water diverted from XC30 in 5 drill holes and 100 lps of water diverted from XC27 in 4 drill holes, that successfully reducing water inflow to GBC production cave and keeping it to be less than 100 lps (Figure 22 and Figure 23) and probability to reducing wet muck spill.

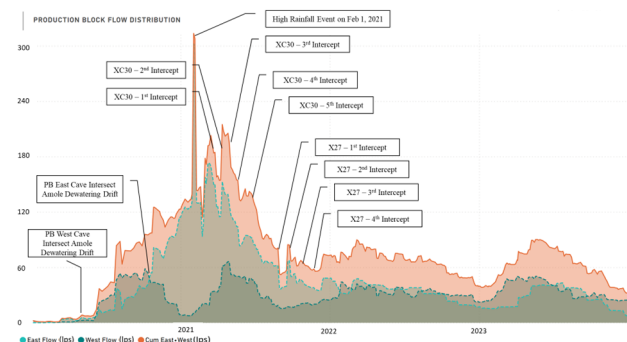


Figure 22 Amole diversion project implication to production block flow.

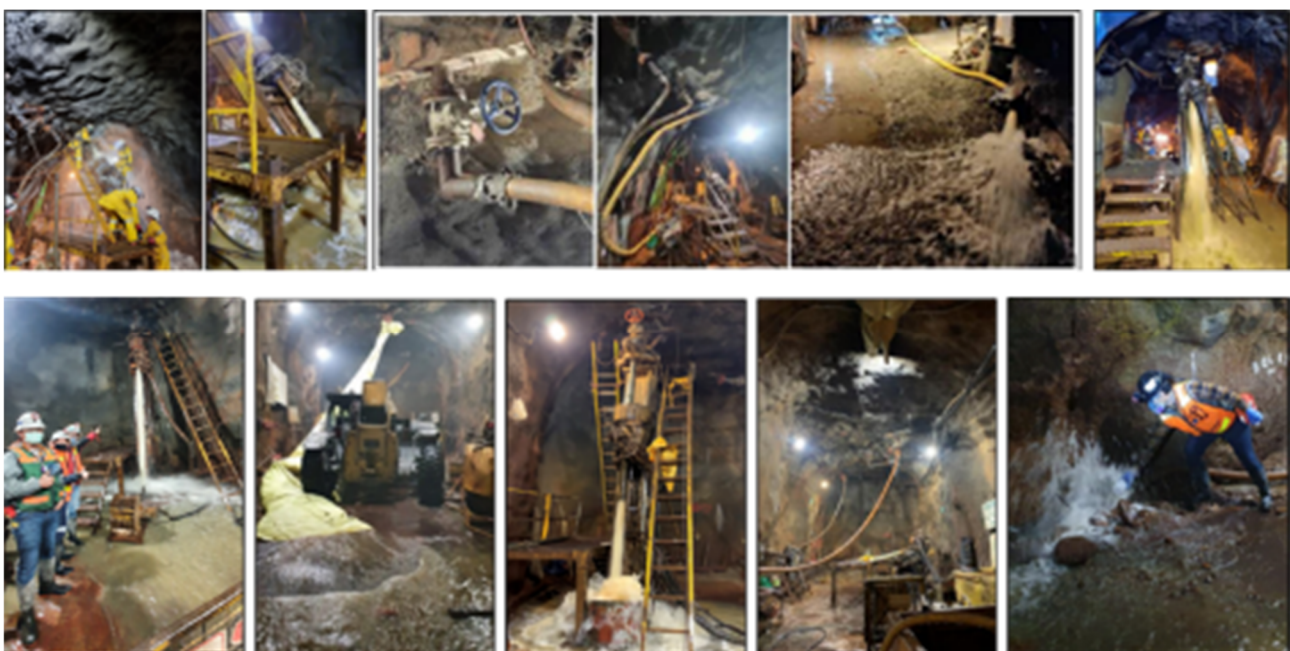


Figure 23 Drilling to Amole XC30 and XC27 result.

2.2.5 GBC Water Management.

GBC mine located directly below Grasberg open pit, and since the transition to the underground mining was going on, the connection to the bottom pit continued to increase GBC water. Therefore, water management were focus on controlling surface water infiltration into underground, groundwater level, seepage, and underground drainage.

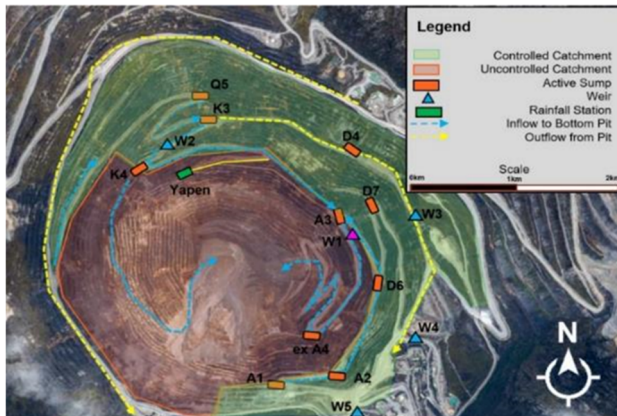


Figure 24 Surface drainage control structure.

Surface water run off control was still managed using a series of ditch network and in Pit pumping system(**Error! Reference source not found.**), but due to the development of the cave that trigger the subsidence and instability at the Grasberg open-pit, only 48% run off area of Grasberg open pit can be controlled by pumping and the rest 52% of surface run off directly went to GBC, to control the area PTFI utilize 25 pumps with capacity around 1600 lps to pump the surface water from the managed catchment.

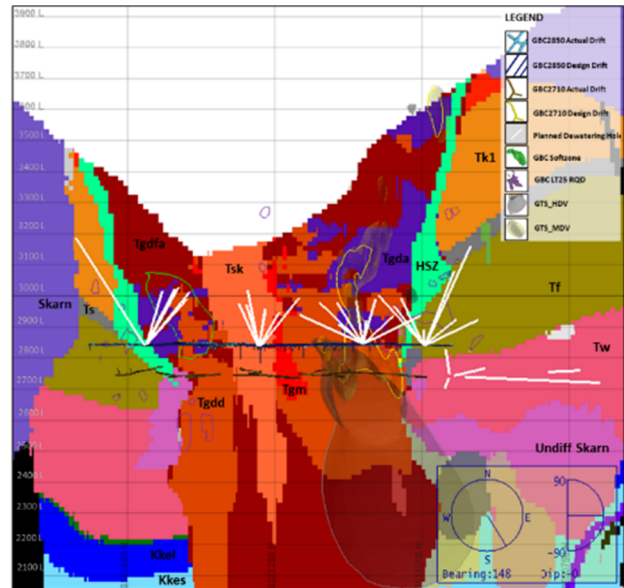
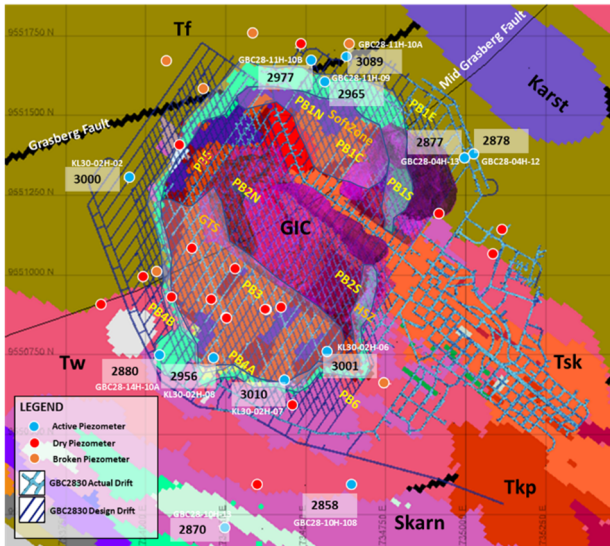


Figure 25 Geological section of GBC with dewatering drilling hole trace.

Groundwater level and seepage were controlled using a systematic dewatering from Undercut and Drainage levels. Both levels were chosen because of the geological setting of GBC mine which like ring with horizontal layered sedimentary/limestone formation on the outside of the deposit, meanwhile inside the deposit aquifer were compartmentalize and scares in multilevel format (Figure 25).

Since 2015, 246 dewatering holes had been drilled and initially produced 1600 lps of water that was utilized by operation team to support the production and development of GBC mine. To date most of the aquifer had been dewatered and only left several spots that cannot be reached by diamond drill due to bad ground or where development have not reached that area.



GBC Haulage Water Level Monitoring System

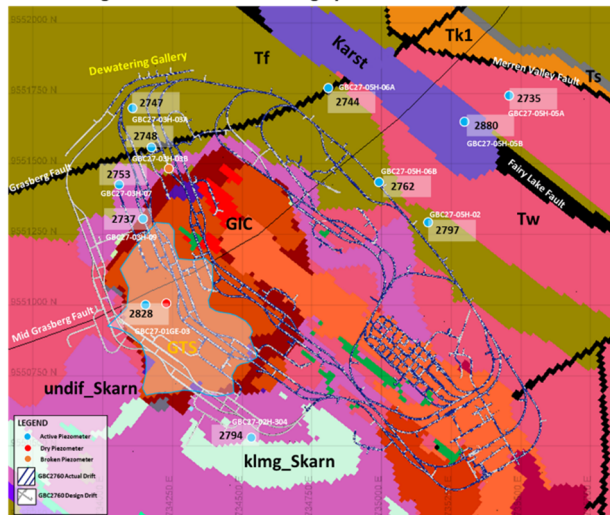


Figure 26 GBC Water level monitoring system.

Dewatering project is continuously audited every year based on the water level data (Figure 26) that is acquired from online GBC water level monitoring system using Vibrating wire piezometer and actual groundwater (seepage) condition in the drift.

The waters that were produced by underground dewatering system need to be handled properly, this water should be away from the extraction level as it was intended to reduce the flow to extraction level.

The ground water that still available as flow in the extraction level are due to groundwater seepage, direct infiltration and run off that still pass the dewatering and diversion system. This flow is classified as ‘residual passive inflow

(RPI)’ and a subject in ground water modeling result (Figure 27)

The drainage layout of extraction level of GBC mine is designed to collect this flow (RPI) at the center of the panels and divert the water by vertical drain holes to service level (exhaust drift). On the extraction level, the elevation difference from drain holes to middle access is 5m and to fringe drift is 3m.

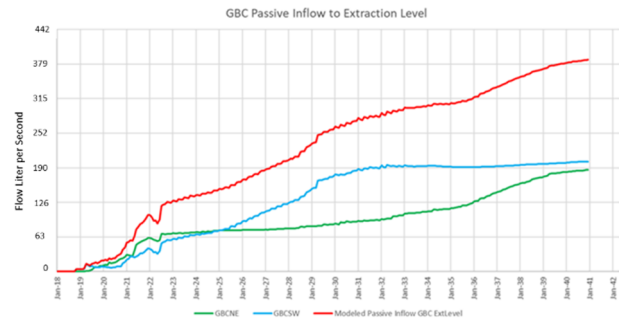


Figure 27 Predicted Inflow to GBC Mine – Long-Term Average Rainfall.

Before cave breaks through the pit bottom, the inflow rate to the GBC cave zone is forecasted to increase to about 120 lps in year of 2022 (Figure 27), where the current groundwater around GBC flowing (dewatering holes and drift seepages) as much as 700 – 750 lps. A network of dewatering holes is being installed ahead of the cave front on the undercut levels to help dewater the GBC mine. The rest of inflow will be entering the draw points and captured by the existing drainage system.

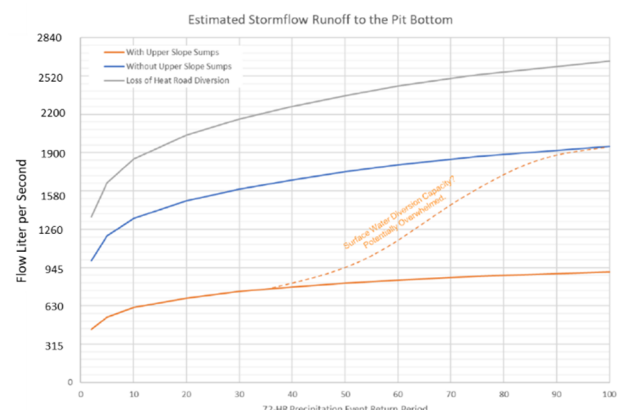


Figure 28 Estimated Stormflow Runoff to the Pit Bottom (Piteau, 2018).

It is estimated, when the cave breakthrough to the pit bottom is achieved, maximum inflow into extraction level during storm rainfall event (100-

year return period and 72-hour rainfall event) could reach 1,950 lps (Piteau, 2018) (Figure 28). On the extraction level, 1 m and 30 cm diameter drain holes have been constructed to anticipate the peak flow from pit and Amole tunnel.

Maintaining the effectiveness of drain holes is essential to prevent adverse ponding and flooding events in mine workings. Solid material carried by water will potentially block drain holes intakes, particularly in the panel where heavy traffic is observed. Regular clean-up must be conducted to ensure the drain holes are free flowing.

When the GBC cave broke through the pit bottom in July-August 2022 major changes to the surface water flow occurred. With the occurrence of the collapse material filling the bottom pit, some part of the rainfall runoff will no longer be drained into the Amole from the existing Amole/pit breakthrough at XC#28 (and then be dealt with the underground water management system by middle access diversion drain hole) but will start reporting to the PB2N cave through the newly connection made with the pit bottom.

Water will report to the GBC extraction level and handled by the established drainage system. Underground drainage and pumping capacity are designed to provide adequate capacity for extreme storm events to prevent flooding.

Based on calculations, the drainage system designed for GBC can handle water reporting

through the cave during normal rainfall. The system is designed to divert water at a rate of 299,772 m³/day (3500 lps). The two main components which facilitate this water management include the Lower and Upper Pumping Stations system respectively located at 2,700 m AMSL and 2,960 m AMSL and an overflow system to AB Tunnel drainage system at 2,535 m AMSL. The designed pumping capacity to the mill level is 109,008 m³/day (1260 lps), while the designed capacity for AB1 Tunnel ditch is 218,039 m³/day (2520 lps).

The actual flood peak on the GBC extraction level will be controlled by the extent to which flow pathways develop through the fragmented cave material and how sediment acts to reduce the permeability of the preferential flow zones. With time, the magnitude of the flows reaching the GBC extraction level is expected to attenuate because of fragmentation in the pit walls, which creates a longer pathway for the water to reach the extraction level.

The rate at which the flood water dissipates will depend on the number of drainage holes in the panel. The routing model shows that up to 1m diameter drain holes would be required for each panel to control maximum water inflow. This is considered important, particularly if cave intersects the Amole tunnel and a concentration of water inflow occurs in one or several panels.

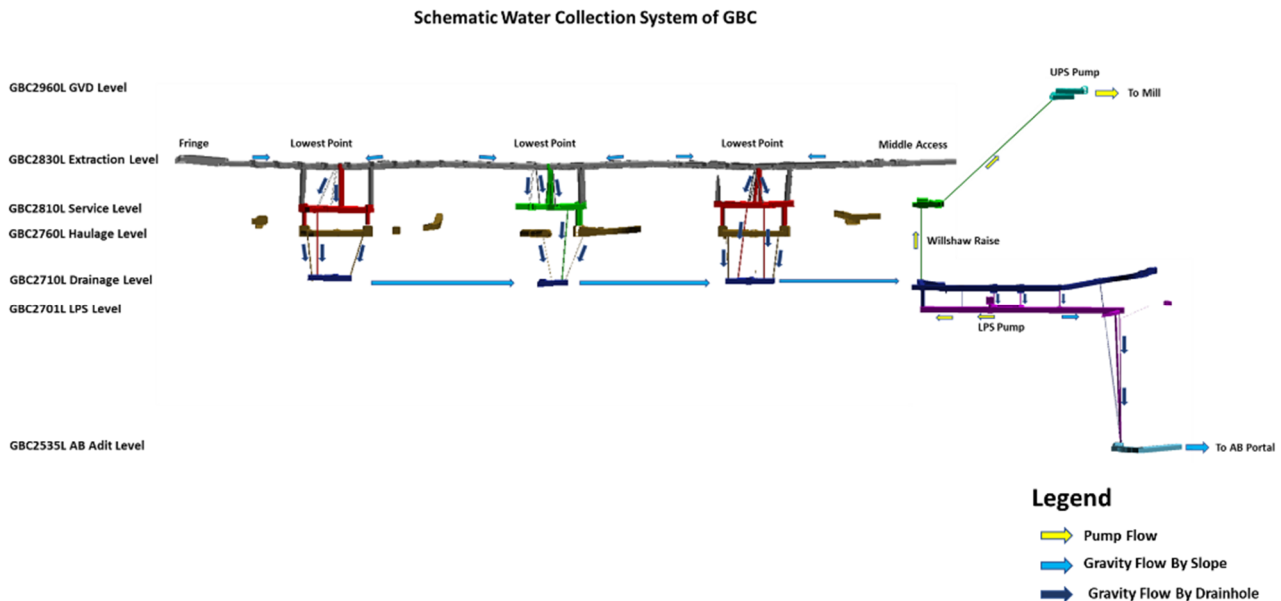


Figure 29 Schematic water collection system of GBC.

The production levels have 1m diameter drain holes installed to handle potential high inflows. The large diameter drains holes connected to service level and then series of small drain holes feed to a dedicated drainage level that collects the water. Water is then directed to the Lower Pump Station (LPS) and pumped to Upper Station (UPS) and then pumped to the mill via the Amole tunnel. Any water more than the pumping capacity will gravity drain down to the AB tunnel and out to surface (Figure 29).

To date LPS and UPS pump normally working in 315-630 lps range with 2 of 3 pump running, in the future 4 pump will be available to support the operation, with the reuse of GBC drainage water for mill operation, PTFI is a step further in implementing sustainable water management practice.

3 CONCLUSION

The transition from open pit to underground mining bring a change into groundwater dynamic present significant challenge for water management such as water inrush, wet muck and depleting water supply, this condition necessitates effective strategies. Through hydrological modeling, comprehensive monitoring, diversion project, intensive dewatering and proper surface and underground drainage management Grasberg open-pit

operation successfully transitioned into GBC underground mining operation.

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