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Rehabilitation of a historic mine with sudden seepage

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Abstract

A mine in South Africa that has been closed for years suddenly developed downstream seepage from the underground. Preliminary investigations showed that it was potentially due to the partial collapse of portions of the board and pillar areas in the underground as well as changes to groundwater levels. There are complicating factors such as no access to the underground, a deep mining horizon and mine plans that are incomplete or unavailable. Current overall stability of the underground is also unknown. The risks to surface water receptors have been mitigated by temporary measures but a long-term permanent solution is the preference. This case study presents the investigations and modelling of the seepage as well as the preliminary plan for plugging the leak points using paste backfill, and the paste recipe development using old onsite dump materials.

Keywords: *paste backfill, case study, water treatment for decant, geochemical modelling*

1 Introduction

South Africa has a long and rich history of mining and has some of the best expertise in the world in applications like coal mining, amongst others. However, the legacy of mining across the country is a liability that is growing. There are several recent examples of historic underground mines that are creating new hazards in today's environment and impacting both water systems and terrestrial ecosystems.

Legacy mines were typically closed to the standards of the day, with little to no consideration for future changes in surface conditions, climate or development (International Council on Mining and Metals 2019). This leaves a large balance of sites that are more and more likely to experience problems in the future with issues like seepage, mine drainage outflows (i.e. water from flooded mine workings emerging at the surface) and structural failure of the underground leading to subsidence (Blowes et al. 2003). These legacy problems have several things in common: they will continue to deteriorate over time, temporary measures will have to be put in place, the risk and liability will continue to grow, and they will end up costing a lot of money.

A typical measure is to institute water treatment to manage output from decant, seepage, etc., but this is only a temporary management tool, not a solution. As a temporary tool it also has its own complications, such as brine management and long-term storage of sludge, which just creates two additional waste streams that require management forever.

Water treatment is a necessary process, of course, to manage impacted streams, but for some sites that are considering water treatment in perpetuity, this means that there is a base case to use for evaluation against options for a permanent solution.

In the following case study, a closed coal mine has recently been shown to have decant emanating from the underground in unexpected locations, e.g. not at specific locations associated with old entries/shafts reporting to surface. The mine is relatively deep and there is no access to the underground anymore, and the mine plans that are available are not comprehensive. There is also no existing infrastructure on the surface but there are additional closure activities happening around capping the fines disposal areas which are far

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removed from the decant areas. The decant areas are on the surface, are not designed for, or permitted to have, discharge locations, and have suddenly appeared after the mine has been closed for many years. The source of the decant is not clear (other than it is coming from the flooded underground) and there are many potential pathways that could be fuelling the decant. In Figure 1, a site plan is shown with the underground highlighted as well as the decant locations (WSP 2024).

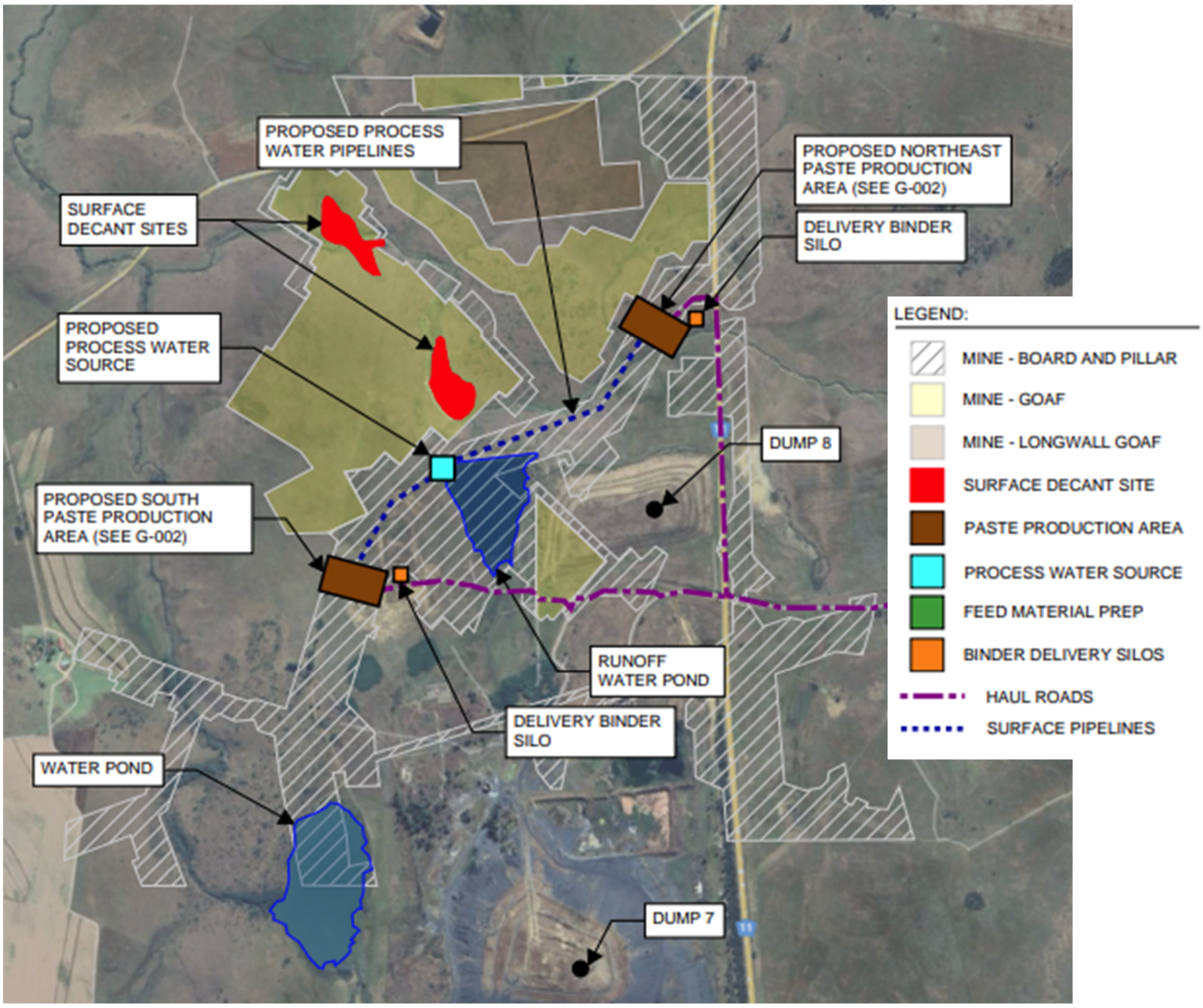

Figure 1 Site plan showing decant panels and preliminary paste production sites on the surface

The mine site follows a board and pillar layout which created substantial voids, though maintenance limitations and incomplete underground plans pose challenges in assessing their current condition as well as general details about the size and spacing of pillars. Key mine compartments show connectivity to surface water features, indicating a potential risk for uncontrolled decanting.

Seepage observed in August 2023 indicated elevated sulphate and total dissolved solids (TDS) levels, with potential risks for watercourse contamination (Singo Consulting 2023).

The scope of the project was to examine the possibility of:

- Injecting the brine products from the temporary water treatment system back into the underground. Although the exact injection rate has not yet been determined – this will be established as part of the ongoing water treatment study – the brine itself is known to have high salinity with elevated levels of total dissolved solids (TDS), sulphates, and chlorides
- Using paste backfill to plug the preferential pathways to eliminate decant production.

To consider these options, an investigation was conducted.

2 Investigations

The investigation addresses the feasibility of utilising underground voids as a temporary storage solution for reverse osmosis (RO) brine, generated from ongoing decant water treatment at the site. Following observations of seepage into nearby watercourses, it was essential to investigate the site's hydrogeology, water quality and potential containment solutions to mitigate environmental impacts during a proposed three-year storage period.

2.1 Overview of key investigative areas

The investigative approach included: (1) site hydrogeology and geochemistry characterisation; (2) brine-mine water compatibility modelling; (3) assessment of containment options; and (4) environmental risk evaluation. This framework provides a comprehensive view of the challenges and mitigation options associated with subsurface brine storage.

2.2 Hydrogeological and geochemical characterisation

2.2.1 Groundwater and surface water dynamics

The site exhibits compartmentalised aquifers with seasonal groundwater variability and hydraulic connections to surface water. Groundwater depths typically average around 24 metres below the surface but fluctuate with rainfall and mine water ingress, impacting containment and seepage risks. Despite the considerable depth, several factors drive the observed discharge.

Underground voids created by the board and pillar mining method alter natural hydrostatic pressure distributions. Partial collapses or changes in void integrity can disrupt pressure gradients, facilitating groundwater movement toward the surface. Additionally, mining activities modify the natural hydraulic gradients within the aquifers; structural changes such as deformations or fractures create pathways that redirect groundwater flow from deeper zones to discharge points. Seasonal recharge and increased rainfall enhance aquifer recharge, raising groundwater levels and pressure. Elevated pressures can overcome geological barriers, driving discharge through pathways established by mining operations.

2.2.2 Geochemical conditions of mine voids

Baseline water quality measured at high TDS and low TDS boreholes indicates saline and neutral drainage, respectively. Dominant geochemical phases include calcite, dolomite and gypsum. These baselines provided important input data for modelling brine-mine water interactions.

2.3 Methodology for reverse osmosis brine interaction studies

2.3.1 Modelling approach

Widely used geochemical modelling software developed by the U.S. Geological Survey simulated the interaction of RO brine with mine water (Parkhurst & Appelo 1999). In this study, pH-redox-equilibrium (PHREEQC) was employed to represent high and low TDS scenarios using data from Borehole 1 and Borehole 2, respectively. The Pitzer database, designed for predicting reactions in high-concentration solutions like brine (Pitzer 1973), was used in the geochemical modelling. These simulations projected geochemical changes over a three-year period, providing insights into expected shifts in key parameters such as sulphate, chloride and TDS. By leveraging PHREEQC, we were able to predict the chemical behaviour of injected brine within the mine voids, thereby informing the feasibility and potential environmental impacts of the proposed brine storage solution.

2.3.2 Data inputs and assumptions

Model inputs included mine water and brine volumes, constituent concentrations and compartment volumes. Key assumptions, such as constant brine composition and excluded trace metals, reflect data limitations while providing a robust initial assessment of brine compatibility within the mine voids.

3 Options development

3.1 Brine storage

For the brine storage component, the focus was to assess the feasibility of using underground voids to temporarily contain RO brine. The following steps outline the approach used to evaluate storage feasibility, containment integrity and associated risks.

Step 1: Volume and capacity assessment

- Part a: assess available storage volume within the mine voids to determine whether current underground compartments can accommodate the expected brine volume over the proposed three-year period.
- Part b: confirm containment capacity, factoring in seasonal fluctuations in groundwater levels and potential changes in underground void space availability.
- Part c: estimate potential brine overflow volumes based on decant rates and expected fluctuations, highlighting any capacity risks if brine volume exceeds void availability.

Step 2: Hydraulic connectivity and migration potential

- Part a: identify potential hydraulic connections between brine storage compartments and surrounding aquifers to assess the risk of brine migration beyond intended containment areas.
- Part b: map existing fractures and fault lines within mine compartments to understand how hydraulic pressure from stored brine might impact these features.
- Part c: assess groundwater flow dynamics in and around the storage zones, determining whether brine containment could be compromised by pre-existing water movement.

Step 3: Brine and mine water compatibility

- Part a: conduct initial geochemical modelling to predict interactions between brine and mine water within the voids, focusing on parameters such as TDS, sulphate and chloride concentrations.
- Part b: evaluate potential changes in brine chemistry due to mixing with mine water, identifying any risks of accelerated mineral scaling, precipitation or pH shifts that could affect containment integrity.
- Part c: determine the likelihood of brine altering mine water chemistry in ways that could lead to secondary contamination, especially with regard to elevated salinity or the mobilisation of metals.

In summary, the brine storage assessment evaluates underground voids for temporary containment, focusing on storage capacity, risks of migration through hydraulic connections and geochemical compatibility to prevent secondary contamination. This approach clarifies potential containment challenges and supports the feasibility of underground storage as a temporary solution.

3.2 Paste backfill

For the paste backfill component, the steps in options development follow.

Step 1: Complete a material survey to see what paste recipe options are available on site.

- Part a: identify feed fine and coarse aggregates.

- Part b: identify available water sources.
- Part c: identify binder type and regional availability.
- Part d: assess the need for admixtures and additional aggregates.

Step 2: Complete an assessment of the underground to understand the hydraulic connectivity between various areas of the mine.

- Part a: identify any obvious locations for flow to the decant pools.
- Part b: identify any secondary locations that have potential for flow paths.
- Part c: assess the overall stability of the underground, particularly near the decant area. This is important to understand the risk for future deterioration of the underground that may prompt additional decant pool development.

Step 3: Complete an assessment of the flow movement in the underground to determine the key performance targets of the plug, e.g. strength, size and hydraulic conductivity.

- Part a: assess volume throughput over time.
- Part b: assess underground water quality at the plug sites to determine if there has been any impact on the paste backfill plug performance, e.g. sulphide attack.

Step 4: Complete a laboratory program for recipe development with consideration of the key performance targets.

- Part a: identify one to three recipes that might be required in different applications in the underground.
- Part b: assess the equipment required to produce the paste backfill recipe.

Step 5: Assess potential for access into the underground to deposit paste backfill for the plug formation.

- Part a: assess the existing access underground for installation of a distribution system.
- Part b: assess the potential for drilling into the underground accurately with large enough boreholes to facilitate paste deposition.

Completing a comprehensive assessment of these components is critical to assess the feasibility of the option. If any of the steps above were not possible or were cost-prohibitive, the conclusion would have been that a paste plug in the underground was not an appropriate solution for this site and situation.

4 Current status

For the brine evaluation component, the water quality analysis and expected trends are discussed below.

4.1 Brine storage

4.1.1 Expected chemical shifts over time

Modelling projected increases in TDS, sulphate, chloride and sodium levels over three years indicated significant chemical alterations, particularly in high TDS compartments (e.g. Borehole 1), where TDS was expected to rise by approximately 34%. In contrast, low TDS compartments (e.g. Borehole 2) exhibited higher proportional changes due to their initially lower baseline concentrations.

As this is a conceptual study, detailed assessments of the proposed brine storage compartments are still underway. Preliminary considerations suggest that the storage compartments may currently contain groundwater, which would need to be displaced by the injected brine. However, exact volumes of existing contained water and the planned brine injection volumes have yet to be determined, pending further investigations into the underground hydrogeological system.

4.1.2 Compliance screening

Model results, screened against national water quality guidelines, showed exceedances in sulphate, magnesium, sodium and TDS from initial conditions through the three-year model period. These findings reinforce the need for consistent monitoring and adaptable treatment strategies to maintain compliance.

4.2 Paste backfill

In this stage of the project for the paste backfill option, each step was assessed to determine feasibility, fatal flaws and risks. The summary of the status is as follows:

Step 1: Material survey

- Part a: an onsite disposal area is available that is not yet capped and could be a source of fine materials. The material is a combination of coal fine rejects, overburden and potentially other aggregate sources from a disposal dump on site. The paste recipe will likely need both fine and coarser aggregate materials to make a low slump, high strength, low flowability material. There has not been a comprehensive testing program yet so the key material characteristics (e.g. particle size distribution, specific gravity and mineralogy) are not yet well understood. The material could potentially be unusable and feed sources would have to be identified from offsite. The preferred option would be to use the 'free' feed material on site, which would also have the advantage of reducing the cap required for the disposal site.
- Part b: there are two ponds on site that have available water sources for the paste backfill.
- Part c: binder is readily available locally and the type would likely be a binder suitable for subaqueous deposition.
- Part d: admixtures and additional aggregate sources would need to be imported to site. This is important since the underground is flooded and will require special considerations.

Step 2: Underground hydraulic connectivity

- Part a: multiple locations were identified for flow paths to the decant pools, with four likely candidates.
- Part b: high potential exists for additional flow paths, depending on the competence of pillars and other underground features, and mine plan accuracy.
- Part c: no stability information is available for the underground. This is required in the next phase.
- Part d: development of preliminary paste plug designs and delivery mechanisms is required.

Step 3: Flow movement in the underground

- Part a: volume throughput over time is based on decant flow estimation.
- Part b: preliminary water quality information is available from the underground but more data is required.

Step 4: Laboratory program

- Part a: no laboratory testing has been completed to date. This is required in the next phase.
- Part b: the equipment required to produce the paste backfill is all standard, readily available mobile equipment in the region.

Step 5: Underground access

- Part a: no access to the underground currently exists.
- Part b: drilling into the underground will be at depths ranging from 200–300 m and trials are currently ongoing to assess accuracy of drilling, along with accuracy of the mine plans. Borehole sizes (150–254 mm) are within the standard range of the drill rigs.

As mentioned above in Step 2, preliminary paste plug designs and the corresponding borehole arrangement have been considered. The key is the pour sequence and borehole spacing must have the ability to tight fill the plug areas to the back and limit/eliminate the downstream flows. A complicating factor is that the likely locations causing the decant flows are in large drifts, so the corresponding plugs are very large as well. In the preliminary design, plug toes have been incorporated to make sure that a sufficient plug width tight to the back is attained. A preliminary sketch of the paste plug is included in Figure 2.

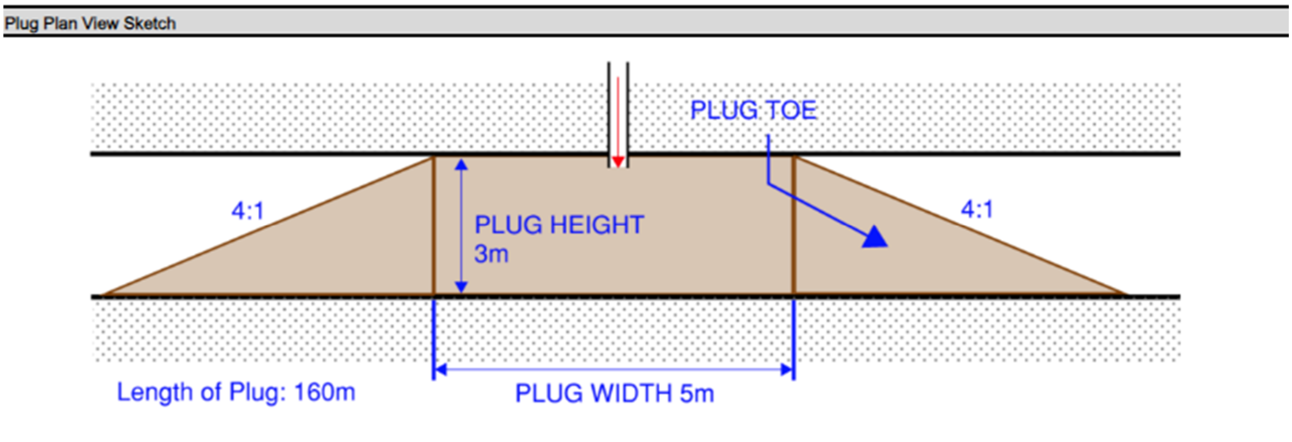

Figure 2 Preliminary paste plug design

5 Risks

Preliminary risks were identified for both the brine and paste backfill options and are discussed in the following.

5.1 Brine storage

The risk assessment for the brine storage option the identified the following three primary scenarios.

5.1.1 Decanting and seepage

Current mine water decanting poses an immediate environmental risk, with elevated concentrations of contaminants impacting local surface water quality. Uncontrolled decanting could continue to exacerbate this contamination, affecting surrounding ecosystems and water uses.

5.1.2 Groundwater contamination from brine storage

Storing RO brine within underground mine panels introduces the risk of contaminating adjacent groundwater resources, particularly if the brine migrates beyond intended containment boundaries. The short-term storage timeline necessitates careful monitoring as brine could infiltrate fractures, increasing salinity in surrounding aquifers and potentially impacting groundwater quality on a larger scale.

5.1.3 Uncertainties and limitations

Several uncertainties could impact the success of the brine storage project:

- Limited data on mine water quality constrains the reliability of geochemical predictions.

- Both the brine panel volume and brine storage volumes are based on theoretical estimates, leading to uncertainties around actual capacity.
- Insufficient hydrogeological data restricts the development of a high-confidence water balance model, complicating predictions of containment stability.
- Model limitations could lead to inaccuracies in predicting chemical interactions, especially over extended periods.

5.2 Paste backfill

The risks attached to the paste backfill option are subdivided into the following three categories:

- feed materials and recipe
- paste backfill delivery
- underground.

At a high level, the main risks associated with the paste backfill feed material and recipe concern any potential for reclassification of the paste as a hazardous waste from a regulatory perspective, along with any permitting or other regulatory requirements for remining the disposal area for feed material. Additional risks include surface water management and spill protection for the water and paste while on the surface.

For paste delivery, the main risk is drilling accuracy to make sure the boreholes are in the preferred locations for the plug. Additional concerns have been documented around borehole flushing and delivery of paste underwater, e.g. using a tremie or free falling through the water column.

For the underground, the major risk is around the location and size of the plugs: Are the mine plans accurately describing the situation in the underground and is the plug sized to withstand appropriate hydrostatic pressures from the flow of water, especially once sections of the mine become plugged? What will the impact of increase pressures be on the plugs and flows? Multiple delivery options have been considered for deposition of the paste to limit/eliminate the paste from simply flowing away from the intended deposition site. This includes using a tremie pipe or installing aggregate/gravel barricades ahead of the paste deposition site to create a barrier of sorts. All these methods depend on an understanding of the flow rates of the water in the underground and the potential impact to paste deposition. That being said, the paste plugs are modelled to have a fairly large footprint to accommodate some flow of material downstream of the deposition point which, while using more material, may be the only way to manage the process.

6 Conclusion

For the brine storage component, initial assessments indicate that underground voids could serve as a viable short-term containment solution. While there are risks related to volume capacity, migration potential and geochemical interactions, these can be managed with targeted monitoring and mitigation measures. Further analysis is required to confirm containment stability, but no issues have emerged as yet to rule out this option.

At this stage of the project it is clear that the use of paste backfill to plug preferential pathways to reduce or eliminate the decant from the underground is a very real option. This would allow for reduction or elimination of the water treatment step, which is a long-term cost and liability. There is additional work to be done to fully assess the option, but currently no fatal flaw exists to rule out using paste backfill.

Acknowledgement

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