Towards sustainable mine water treatment at Grootvlei mine

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ABSTRACT

Approximately 75ML/day of contaminated mine water is pumped from the No. 3 shaft at the Grootvlei Mine near Johannesburg, South Africa. The water is partially treated in a high-density sludge (HDS) plant to remove heavy metals prior to discharge in the Blesbokspruit. The partially treated water still contains significant amounts of dissolved salts, which has to be removed to comply with the terms of the mine's water permit. While it is possible to demonstrate technical feasibility of producing a range of water qualities, economic viability remains elusive, principally due to the high cost of brine and waste disposal. Grootvlei is situated on the East Rand of Gauteng, an area with high unemployment. Consequently, projects that create downstream job opportunities are being evaluated as part of an on-going feasibility study. This paper discusses the main issues and progress on the feasibility study.

INTRODUCTION

Petrex (Pty) Ltd, a subsidiary of BEMA Gold Corporation of Canada operates three gold mines in the East Rand Basin close to Johannesburg: Grootvlei Proprietary Mines Ltd. (Grootvlei), Nigel Mining Company (Pty) Ltd., and Consolidated Modderfontein Ltd. The underground workings in the East Rand mining basin were dewatered from Sallies mine until 1991, when pumping at that point ceased. As a result, large portions of the Main Reef and pockets of the Kimberley Reef are presently flooded. The Grootvlei mining operation is shallower, and in order to gain access to the gold-bearing reefs, the mining basin has to be dewatered. Dewatering started in 1996 by pumping water from 740m below the surface at the No. 3 shaft of Grootvlei.

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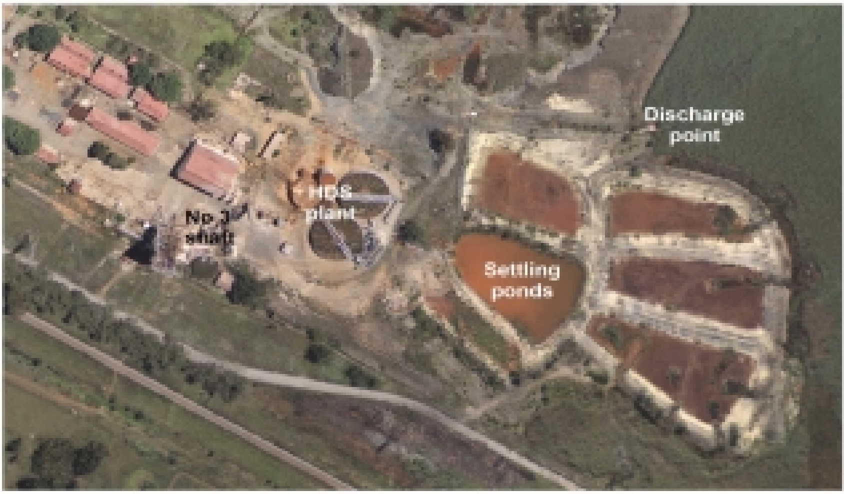


Figure 1. Arial view of Grootvlei HDS Plant

Water is pumped from the underground workings at an average rate of 75 ML/d. Pumping rates vary seasonally, between 30 and 120 ML/d historically. Mine water pumped from underground is treated in a high-density sludge (HDS) plant and discharged into the Blesbokspruit, a part of which has been declared a RAMSAR wetland. Under the current water use license, the mine is allowed to discharge up to 96 ML/d of HDS treated water. An aerial photo of the Grootvlei No 3 shaft, the HDS plant, settling ponds, and discharge point are shown in Figure 1.

ECONOMIC SETTING

Grootvlei Mine is one of the last remaining operating gold mines in the East Rand Mining Basin. Mining has been going on in the East Rand basin for the past 80 years, with the number of active mines peaking in the 1950's. During the 1970's and 1980's, gold mining activities in the area declined and by the 1990's, the majority of the mines in the area closed down. This increased unemployment and hurt the economy of the region.

Based on recent census information, the unemployment rate for the area is 33%. Eleven percent of the people have no education and only 4% have tertiary education. Almost 47% of the population in the area have no income, while 4 out of every 10 households survive on less than R 1 500 per month. These statistics indicate that the prospects for upliftment are currently low and that there is a real need for projects that would promote job creation and social upliftment.

Petrex presently employs some 4000 people at its three operating mines in the area and as such is the biggest single employer there. With the expected life of the mine being approximately 15 years, a water treatment project, with its associated downstream use of treated water and beneficiation of by-products could be aligned closely to the objectives of the Local Economic Development programme. It is therefore the objective of the Mine to develop the treatment of mine water in such a manner that will not only provide an acceptable environmental performance in the short term, but will also establish long-term, sustainable opportunities after mine closure, from which the community could benefit.

CURRENT TREATMENT OF MINE WATER

Treatment at the HDS plant consists of the following major process steps:

- Extraction and pumping of 3125m^3/hr (average) to the surface. Water is pumped from a depth of approximately 780m below the surface;
- In-line addition of pure oxygen to oxidise dissolved iron from the ferrous to the ferric state;
- Addition of 80t/day of lime to increase the pH of the water and aid in the oxidation and precipitation of dissolved iron and manganese;
- Reaction in an aeration basin of 18m diameter and effective hydraulic retention time of 10 minutes. 2300m^3/hr of compressed air is injected to assist with mixing of the resulting slurry;
- Clarification in two parallel clarifiers, each 30m in diameter with an effective volume of 6500m^3. The design surface loading rate is 3.2m/hr. Polyelectrolyte is dosed to assist the clarification process;

A portion of sludge from the clarifiers is returned to the aeration basin, while the remainder is returned to the slimes dams for dewatering.

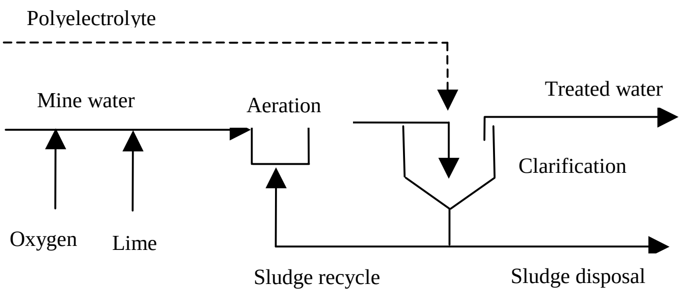


Figure 2. HDS Plant process flow

The cost of pumping and HDS treatment is approximately R1.50/m^3 and the mine presently receives no subsidy for pumping and treatment of the water. No pumping levies are presently charged by DWA&F, although this may change in future, resulting in a substantial increase in dewatering cost.

PRESENT PERFORMANCE OF THE HDS PROCESS

The HDS plant is successful in its intended purposes, which is the removal of iron and manganese (Table 1). Iron is decreased from an average of 135 mg/L to less than 1 mg/L, whilst manganese is decreased from approximately 4.1 to 1 mg/L. It should be noted that iron levels are regularly above 180 mg/L, with a maximum measured value of 210 mg/L during 2002.

Table 1. Performance of the HDS plant – averages for 2002

Component	Unit	Underground Water	HDS Treated Water	Water Permit 2002
pH		6.4	7.52	6.5-8.5
Temp	°C	26.7	26.7	
DO	mg/L	2.5	5.9	>9
EC	mS/m	321.8	315	400
TDS	mg/l	2879	2518	
Cl	mg/L	184	181	210
SO_4	mg/L	1383	1499	2200
Na	mg/L	240	239	290
Ca	mg/L	422	341	
Mg	mg/L	197	117	
Fe	mg/L	135	<1	1
Mn	mg/L	4.1	1.1	1
COD	mg/L	35.4	NA	35
T Hardness	mg/L $CaCO_3$	1520	1165	
Suspended solids	mg/L	41	21	

FUTURE WATER QUALITY REQUIREMENTS

Table 2 compares the present and future water quality requirements specified by the current water use license. It is clear that desalination of the mine water is required, should the mine wish to continue discharging into the Blesbokspruit.

Table 2. Salient water quality requirements from water use license

Component	Unit	Discharge Standards 2002	Discharge Standards 2005
pH		6.5-8.5	6.5-8.5
DO	Mg/L	>9	>9
EC	mS/m	400	45
Cl	mg/L	210	80
SO_4	Mg/L	2200	150
Na	Mg/L	290	70
Fe	Mg/L	1	<0.1
Mn	Mg/L	1	<0.2
COD	Mg/L	35	20

FUTURE MINE WATER VOLUMES

Dewatering will cease in about 15-20 years and present estimates indicate that flooding of the mine basin will take approximately 7-9 years. Decanting is expected to occur some distance away from Grootvlei, near Nigel. While no accurate estimates are available, it is expected that the quantity of decant water will be significantly less than 50ML/day, and the quality should also be improved. Figure 3 compares the conceptual future mine water volumes with the required treatment capacity.

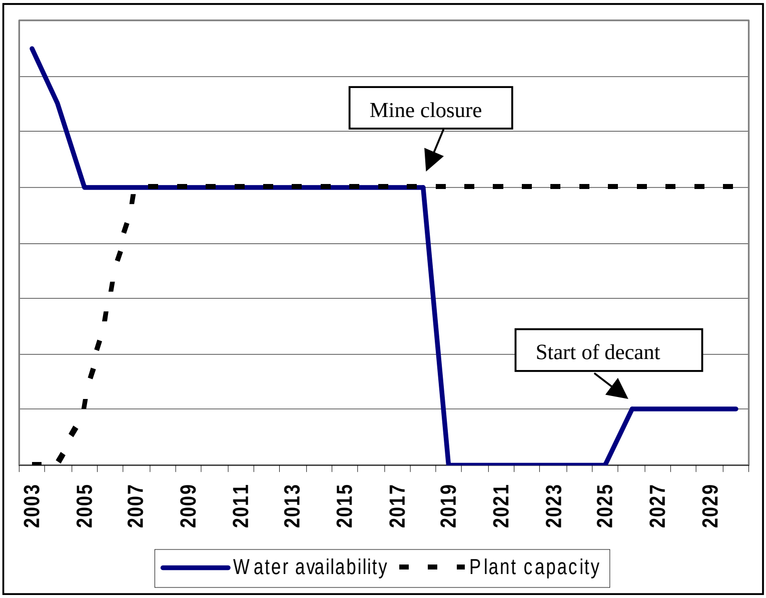


Figure 3. Conceptual model of future mine water flows

In this model, the available mine water is reduced from the present 75ML/day to 50ML/day by various means, such as prevention of surface ingress, etc. At the same time, the capacity of the treatment plant is increased to match the available mine water. At mine closure, say in 2019, pumping from the No. 3 shaft will cease. At this point in time, excess purification capacity will be available. Approximately 7-9 years after mine closure, it is anticipated that less water will be available at the decant point.

The operating life of a desalination plant roughly equals the remaining life of the mine (15-20 years). Thus, after the mine closes, the treatment facility may be scrapped and a new, smaller one erected at the decant point several years later. However, it is likely that dependencies will develop on the available high quality treated mine water. Stopping treatment or pumping at mine closure could therefore result in significant implications; appropriate measures will have to be put in place during the conceptual design phase. Measures to be considered include:

- Continue pumping to prevent discharge at a different physical location and ensure availability of water;

- Provide shortfall from another source, such as river water, treated sewage, potable water, etc.
- Ensure that alternative activities are in place prior to mine closure.

PREVIOUS WORK ON GROOTVLEI DESALINATION OPTIONS

Since 1996, a significant amount of desktop and other research work was done to develop desalination methods for the Grootvlei mine water. In particular, four pilot plants were operated in parallel during 1998 to compare different water treatment technologies. These were:

- Savmin – a novel precipitation technique developed by Mintek;
- Gyp-Cix – a resin based desalination technology developed by Chemeffco;
- Biological sulphur removal as proposed by Rhodes University;
- Reverse osmosis, using selective precipitation techniques as pre-treatment for by-product recovery as proposed by Aqua-K technologies.

The various pilot plants were selected to represent specific technology types, or proposed interesting innovations. The applicability of each process was evaluated in terms of its ability to produce potable water, which could be blended into the Rand Water reticulation network. Operation and evaluation occurred over a two week period, during which regular sampling was performed. By-products were also briefly evaluated, but no significant amounts were produced for extended market testing.

Subsequent to these tests, the Amanzi project was launched to investigate the possibility of treating mine water in the area on a large scale, and supplying the existing distribution networks. Although this was a huge effort, the project was halted for a number of reasons, most importantly:

- Perceived risk in terms of the financial viability of the project on a large scale – particularly in terms of the market acceptability of the by-products;
- Uncertainty in terms of ownership of the water and pumping levies to be charged by DWA&F;
- Uncertainty in terms of the long term environmental liability associated with the mine water from different mines.

The abrupt end to the these efforts, as well as the fact that Grootvlei Mine has changed ownership since then, left a vacuum in terms of the way forward for Grootvlei and other mines in the area.

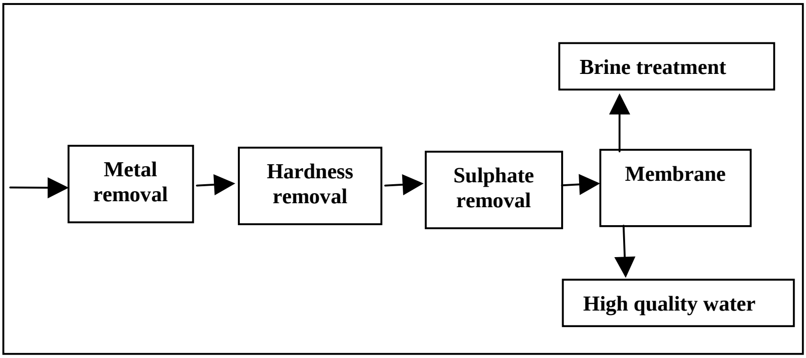
BRIEF REVIEW OF POSSIBLE TREATMENT OPTIONS

A large number of technologies are available for partial or full treatment of the water. These may be classified into two groups:

- Group I: Technologies that remove metals and divalent salts such as calcium and sulphates, but which leave monovalent salts such as sodium and chlorides in the water;
- Group II: Technologies that remove the above, as well as monovalent salts.

Figure 4 illustrates the various treatment steps for metal, hardness, sulphate and monovalent salt removal, as applicable to Grootvlei.

Figure 4. Removal of salts from Grootvlei mine water



The bulk of available technologies do not remove soluble salts such as sodium and chlorides from the water, and so produce relatively brackish water. In order to remove soluble salts, a membrane process (Group II) is typically employed to **concentrate** these salts into a smaller volume. The result is high quality permeate (product) stream and a concentrated brine stream. Disposal of the brine is a major challenge and often requires evaporation to dryness to ensure safe disposal of concentrated salts. The technologies in Group I is typically employed as a **pre-treatment** step to a membrane process (Group II) in order to minimize brine volumes.

A range of by-products can potentially be produced from the salts present in the mine water. Particular details about actual products considered at the moment are confidential, but Table 3 list typical generic salts at each removal stage. Table 4 compares the most frequently considered technologies in terms of Grootvlei's treatment requirements and relatively short time frame to project implementation. When full desalination is required, brine disposal constitutes a major cost element, both in terms of operating and capital costs. Table 5 lists several options.

Table 3. Possible by-products - typical

Process type	Metal removal	Hardness removal	Sulphate removal	Na & Cl removal
Inorganic processes	Me-OH Me-O	$CaSO_4$ $CaCO_3$	$CaSO_4$	
Resin processes	M-OH	$Ca(NO_3)_2$	$(NH_4)_2SO_4$	
Biological processes	Me-S	$CaCO_3$	S	
Membrane processes				NaCl Na_2SO_4

Me-OH: metal hydroxides; Me-O: metal oxides; Me-S: metal sulphides

Table 4. Potential mine water treatment technologies

Technology	Process considerations in terms of Grootvlei's water use licence	
	Positive	**Concerns**
Inorganic precipitation		
Softening	Proven process; Low capital cost.	Sludge generation; Increased TDS.
Barium sulphide	Relatively low operating costs.	Only partial desalination possible.
Fluid bed crystalliser	Pelleted hardness salts; Reduced sludge filtration requirements; Proven technology; Simple operation.	No effect on monovalent salts; Partial desalination only.
Staged chemical precipitation	Potential for by-product recovery; Reduced waste products; Reduced long term liability.	Increased capital costs; Product quality unproven; Increased operator supervision.
SAVMIN	Relatively low capital and operating costs.	No monovalent salt removal; Risk of increased aluminium levels if potable water is produced; Low value gypsum produced.
Ion Exchange		
Gyp-Cix	Removal of radio-activity;	Limited water recovery; Low value by-products.
Fer-IX	Increased by-product value.	Process in development phase.
Biological		
Thiopac	Process proven at relatively large scale.	Partial desalination only.
CSIROSURE	Local experience at coal mines.	Partial desalination only.
BioSure	Combined sulphate & sewage sludge treatment.	Partial desalination only.
Passive systems		
Wetlands	Reduced operating costs; Attractive "walk-away" solution	Applicable to relatively small flows.
Membrane processes		
Reverse osmosis	High quality product water	Brine disposal required.
Nano-filtration	Operating cost slightly lower than that of RO	Lower quality product water; Brine disposal required.
Electro-dialysis reversal	Possible increase in water recovery	Increased operating and capital cost; Brine disposal required.
Electrochemical		
Ecodose Electrochemical	Limited degradation of process equipment	Limited removal of sulphates.
Thermal processes		
Hydrothermal sulphate reduction	Simple unit operations	Limited full scale application No removal of monovalent salts

Table 5. Brine disposal options

Disposal option	Comments
Evaporation ponds	Up to 2500m^3/day of high strength brine will be produced at full capacity. Large evaporation areas will thus be required once full scale production is achieved.
Underground injection	Effects of injection are not well understood at present and this option is not considered viable.
Spreading on unusable land	Mine dumps or other unusable areas may be required. However, the long term environmental liability of the entire area is attracted should this option be pursued.
Ocean discharge	A common pipeline to dispose of brines from a number of inland desalination facilities has been proposed previously. This option is not considered feasible at present.
Inland salt lake discharge	A common inland salt lake may be created to dispose of brine.
Process re-use	Cyanide leaching may be performed at increased TDS values under certain conditions. The brine is thus effectively discharged onto the slimes dams at the end of the process. The effect on groundwater and spillages into rivers has to be carefully considered.
Mechanical evaporation	Brine streams may be evaporated to dryness using mechanical evaporators and crystallisers. This is a proven, but high cost option, although NaCl and Ns_2SO_4 salts may be recovered.
Brine treatment	This option involves recycling of the brine to the membrane plant after precipitation of sparingly soluble salts in a reactor. Whilst the concept is attractive in that very high water recoveries may be achieved, there is an increased risk of membrane fouling.

Table 6. summarises the expected performance of the major technologies currently under evaluation for the treatment of Grootvlei mine water.

Table 6. Expected water qualities from different process options (in mg/L except where otherwise stated)

	TDS	**EC mS/m**	**pH**	**Fe**	**Mn**	**Ca**	**Mg**	**Na**	**Cl**	**SO_4**
Raw water										
Raw water (Average)	2668	296	6.6	221	3.9	337	163	240	184	1524
Final permit requirement	NS	45	6.5-8.5	<0.1	<0.2	NS	NS	70	80	150
Chemical precipitation										
Softening (Lime treatment)	2850	330	8	<0.1	<0.1	6.4	60	240	184	1500
Softening (Lime & soda ash)	2790	358	8	<0.05	<0.05	16	99	745	184	1500
Sequential precipitation	2300	355	7-8	<0.05	<0.05	20	100	750	184	1500
Savmin	800	130	7-8.5	0.1	0.2	55	2	240	184	300
Resin										
Fer-IX	680	100	7.2	0.1	0.1-2.6	50	1.2	240	184	125
Biological										
Paques Thiopaq	670	105	8	<1	<0.5	63.3	50	240	184	200
BioSure			7.5	<1	<0.5			240	184	200
Membrane										
Reverse osmosis	<200	<35	7-8	<0.05	<0.05	<5	<5	<70	<70	<50

PROCESS ECONOMICS

Although detailed cost estimates are confidential at this stage, Table 7 summarises capital and operating cost estimates for a range of treatment technologies for the Grootvlei project. The large variation in pre-treatment costs is indicative of the different process options presently being considered. Cost variation for desalination and brine evaporation sections are significantly less, although these are affected by the efficiency of pre-treatment.

Table 7. First order cost estimates for treating Grootvlei mine water

	Pre-treatment	Desalination	Brine evaporation
Capital cost 10ML/d (R million)	20-60	18-22	40-45
Capital cost 50Ml/d (R million)	75-330	70-80	130-150
Operating cost (R/m^3)	1.00-4.00	1.50-1.80	3.50-4.00

Plant operating costs compare to a retail price for potable water in the area of R2.40 – R4.00/m^3 but exclude: costs of pumping from underground; pumping levies; final filtration & disinfection costs; and distribution costs. These additional costs would significantly impact the viability of treatment.

OPPORTUNITIES FOR SUSTAINABILITY

Economic viability of mine water treatment may be improved by considering a number of opportunities, which are described below.

BLENDING WITH RAND WATER PRODUCT

A major cost component of overall treatment is desalination (Na & Cl removal) with its associated brine evaporation. Significant savings may be achieved if the sodium and chloride in the water can be ignored in terms of treatment. The sodium and chloride content of Grootvlei water is close to SABS Class I potable water specifications (Table 8)

Table 8. Discharge water quality requirements

Component	**2005 Permit**	**SABS Class 0 Potable Water**	**SABS Class I Potable Water**	**SABS Class II Potable Water**	**Rand Water Average**	**HDS plant 2002 average**
EC (mS/m)	45	70	150	370	22	329
Sodium (mg/l)	70	100	200	400	17.3	240
Chlorides (mg/l	80	100	200	600	13.7	184

Rand Water produces a product of very low salinity, primarily due to an excellent raw water source. With a total potable water consumption of approximately 200ML/day in the Ekurhuleni region, blending of a limited amount (10-30ML/day) of partially treated water will have a minimal impact on the overall water quality in the region.

AGRICULTURE

It is known that several salt sensitive crops can be produced successfully, so only partial treatment may be required. Considering the relatively high sodium content in the Grootvlei's mine water, care should be taken not to increase the SAR of the treated water above acceptable levels by removing calcium and magnesium salts (Table 9).

Table 9. Estimated SAR Values for different treatment options

Untreated mine water	2.4
HDS Plant outlet	2.8
Softening	15.2
SAVMIN	8.6
Resin Technologies	9.2
Bio-desalination	5.5

Presently, agricultural water is available at no or very low cost to farmers and this situation is likely to continue in future. Any farming activity based on purified mine water will thus have to compete with an increased cost of crop production. Therefore, while technically speaking, farming activities may be attractive, a clear business plan has to be developed to ensure long term economic viability.

BY-PRODUCTS

In principle, it is preferable to install a treatment process that produces potentially valuable by-products from the contaminating salts. Even if these have to be sold at cost, this approach provides an opportunity to eliminate long term liability from disposed sludge. By-product production will also stimulate downstream job opportunities. However, it should be noted that to date, no major desalination system has been successfully commissioned to produce these by-products at the quantities, quality and consistency required by markets. Considering the volumes and costs applicable to Grootvlei, a phased approach will most likely have to be used in order to limit financial risk and test market acceptability.

CONCLUSIONS

Treatment of the Petrex mine water is necessary from an environmental perspective and the mine is committed to reducing the total salt load discharged. Considering the volumes and composition to be treated, the cost for full stream desalination is daunting. It is therefore imperative that sustainable solutions be found to continue mining in the short term, while an appropriate plan is developed for mine closure. Ideally, treatment methods should benefit the community at large, and efforts in this regard are on-going.