Water Quality and Compliance Monitoring of Treated Underground and Surface Water at the Grootvlei Proprietary Mines and the Blesbokspruit Wetland, Springs, South Africa

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Abstract During 1996, Grootvlei Mine in Springs, on the East Rand Basin, Witwatersrand, discharged severely contaminated water into the Blesbokspruit Wetland. Subsequently, a HDS (High Density Sludge) plant had to be constructed to remove Iron and Suspended Solids to less than prescribed concentrations. Monitoring of the quality of the HDS effluent consisted of daily sampling and analyses of pH, Electrical Conductivity, Iron and Suspended Solids (SS). Compliance analyses to required standards showed the plant, over a period of approximately 3500 days, to achieve 83.4 % compliance for Iron, 80.8 % for SS, and 99 % for both pH and Electrical Conductivity.

Keywords Mine Water; Treatment; Monitoring; Compliance

Introduction

Acid Rock Drainage (ARD) is a major contributor of environmental degradation worlwide. This is also applicable to the pyrite (FeS_2) containing Witwatersrand gold-ores which have been mined for more than a hundred years in South Africa. Acid mine-water is the consequence of the oxidation of iron-pyrites with the subsequent formation of sulphuric acid (Unz & Dietz 1986). Consequently, effluents and seepage waters with high levels of metals, salts and sulphate are able to reach the aquatic environment. Various authors describe the relevant chemical reactions involved in the oxidation of pyrite into dissolved iron, sulphate and hydrogen (*e.g.* Wittmann & Förstner 1976; Johnson *et al.* 1979; Thompson 1980; Murray 1987; Usher *et al.* 2003).

Release of untreated ARD from the Grootvlei Mine No 3 Shaft into the Blesbokspruit, necessitated the construction of a HDS (High Density Sludge; van Staden 1979; Osuchowski 1992; Craddock 1997) plant (Fig. 1 in electronic attachment) to treat the contaminated undergroundwater, and reduce the concentrations of Iron and Suspended Solids being released into the Blesbokspruit wetland. Treatment of contaminated undergroundwater was achieved by the addition of oxygen which converted ferrous (Fe^{2+}) to ferric (Fe^{3+}) iron. Precipitation of the ferric hydroxide sludge was achieved through the addition of lime as neutralising agent. Ferric iron is a denser, handle able product, which settles out rapidly and produces an effluent with a suspended solids content of less than 25 mg/L.

Methods

Monitoring of the HDS plant at the Grootvlei No 3 Shaft consisted of the collection of daily composite (15 min intervals) samples of the treated effluent from the HDS plant. Samples collected were sent to Waterlab (Pty) Ltd for analyses of pH, Electrical Conductivity and Suspended Solids by Standard Methods for water (APHA 1995), and metals by ICP-OES (Inductively Coupled Plasma – Optical Emission Spectrophotometer). In addition, two samples from each monthly batch (bi-weekly) were selected and analysed for additional parameters (table 1). Untreated underground water was also collected once a month and subjected to a number of analyses as listed (table 1). A number of additional tests were also conducted, which included toxicity testing and chemical monitoring on the Blesbokspruit wetland.

Monthly reports evaluating the daily, bi-weekly and underground water quality were submitted to Grootvlei Mine, indicating the compliance for each water quality parameter. These reports were submitted to the Department of Water Affairs and Forestry (DWAF). Compliance evaluation consisted of comparisons of water quality data with parameters set by DWAF (table 2), and calculations of monthly compliance figures for each. For the purpose of this paper, data from 1998 to 2009 were consolidated into one compliance sheet, and is reported in Tables 3–10.

Results

Water quality results obtained for monthly monitoring of the untreated underground water show the pH to vary between 5.6 and 6.9, while varying concentrations of Total Dissolved Solids (TDS) were measured, ranging between 1986 and 4090 mg/L, with an average of 2689 mg/L (table 3). Sulphate concentrations in the underground water ranged between 1003 and 3554 mg/L, while Sodium concentration showed a concentration range of 147 – 267 mg/L and and average of 217 mg/L. High Iron-Fe concentrations were measured during this monitoring period, ranging between 33 – 311 mg/L, with an average of 142 mg/L. Manganese concentrations also showed unacceptably high concentration levels (Range: 1.9 – 6.4 mg/L : Average: 3.6 mg/L) which was not permitted to be released into the environment (table 3).

Analysis Requirements	Monitoring Frequency	Parameters
Underground Water : Chemical	Monthly	Temperature, DO, pH, EC, TDS, Cl, SO_4, Na, Ca, Mg, Fe, Mn, Al
HDS Plant Treated Effluent : Chemical	Daily	pH, EC, Fe, SS
HDS Plant Treated Effluent : Chemical	Bi-Weekly	TDS, Cl, SO_4, Na, Ca, Mg, Mn, Al
HDS Plant Treated Effluent : Toxicity (US EPA 2002)	Monthly	*Daphnia* Definitive: 24 & 48 h
Blesbokspruit : Chemical	Bi-Weekly	Temperature, DO, pH, EC, TDS, Cl, SO_4, Na, Ca, Mg, Fe, Mn, Al
Bio-Monitoring (Dallas 2005)	Bi-Weekly	Macro-Invertebrates, Fish

Table 1 *Monitoring requirements of Treated ARD at the Grootvlei HDS Plant.*

Water Quality Variable	Monitoring Frequency	DWAF Licence Objective
Electrical Conductivity (mS/m)	Daily	**400**
pH	Daily	**6.5 – 8.5**
Suspended Solids (mg/L)	Daily	**25**
Sodium-Na (mg/L)	Bi-Weekly	**290**
Sulphate-SO_4 (mg/L)	Bi-Weekly	**2200**
Chloride-Cl (mg/L)	Bi-Weekly	**210**
Iron-Fe (mg/L)	Daily	**1.0**
Manganese-Mn (mg/L)	Bi-Weekly	**1.0**
Aluminium-Al (mg/L)	Bi-Weekly	**0.5**

Table 2 *DWAF water quality objectives for the Grootvlei Mine HDS plant.*

Water Quality Parameter	Range (mg/L)	Average (mg/L)
pH	5.6 – 6.9	6.4 (Median)
Electrical Conductivity (mS/m)	240 - 377	293
Total Dissolved Solids	1986 - 4090	2689
Chloride as Cl	124 - 243	160
Sulphate as SO_4	1003 - 3554	1585
Sodium as Na	147 - 267	217
Iron as Fe	33 - 311	142
Manganese as Mn	1.9 – 6.4	3.6

Table 3 *Summarised water quality of underground water from Grootvlei Mine.*

Summarised water quantity and quality monitoring data from the HDS plant, over a period of nearly ten years, is presented in (table 4). The HDS plant produced an average of 92 ML of treated water per day (ML/d), but producing as low as 31 ML/d during the dry seasons, and up to 133 ML/d during the wet season, depending on the amount of surface recharge. When compared with the quality of the untreated undergroundwater (table 3), the treated effluent showed a significant increase in the range and median pH (6.4 to 7.6), due to neutralising agents being added during the HDS process. Although the EC of HDS effluent (289 mS/m) showed a slight decrease when compared to the undergroundwater (293 mS/m), the effect of the HDS plant in reducing salt concentrations was more pronounced when the TDS concentrations are compared. While TDS concentrations in the undergroundwater ranged between 1986 – 4090 mg/L, the TDS concentrations in the HDS plant effluent ranged between 445 – 3406 mg/L, with a decrease in the average concentrations from 2689 mg/L underground to 1860 mg/L in the HDS plant effluent (table 4).

Similar to TDS concentrations, a significant decrease in the average sulphate concentration in the HDS plant was encountered. While the undergroundwater showed a range of 1003 – 3554 mg/L (average: 1585 mg/L), the HDS plant treated effluent showed a slightly lower range (814 – 1951 mg/L) and average (1261 mg/L). In contrast to the above however, Chloride-Cl and Sodium-Na showed a somewhat opposite pattern, when the ranges and averages are compared. Chloride showed a slight increase in range for the undergroundwater (124 – 243 mg/L; average: 160 mg/L) to the treated HDS effluent (105 – 208 mg/L; average: 162 mg/L), while Sodium increased from a 217 mg/L average (147 – 267 mg/L) underground to a 219 mg/L average (114 – 289 mg/L; table 4). For all purposes, the concentrations of both these parameters remained relatively constant.

Removal of Iron-Fe from the undergroundwater showed the best results. Concentrations in the treated effluent ranged between 0.010 – 39 mg/L, with an average of 0.753 mg/L, as compared to the average of the undergroundwater of 142 mg/L (table 4). This represents a removal of Iron of 99.5 % from the undergroundwater over this period. Although high concentrations of Iron were periodically measured in the HDS plant effluent, it was of short duration, as it was mainly caused by either mechanical or electrical failures of minor magnitude. However, if a composite daily sample contained a sub-sample of for example 30 minutes of non-compliant water, the average of that particular sample would not comply with the 1 mg/L standard for Iron set by DWAF. Subsequently, numerous days were encountered where, due to a small failure on the plant, non-compliance for that particular day was encountered.

Similar to Iron, significant, but less successful removal of Manganese was obtained during the total monitoring period. Manganese, showing a concentration range of 0.200 – 1.20 mg/L and an average of 0.667 mg/L (table 4) in the HDS plant effluent, was less successful, representing a removal of

Water Quality Parameter	Range (mg/L)	Average (mg/L)
Volume Treated (ML/d)	31 – 133	92
pH	6.1 – 11.6	7.6 (Median)
Electrical Conductivity (mS/m)	54 – 524	289
Total Dissolved Solids	445 – 3406	1860
Chloride as Cl	105 – 208	162
Sulphate as SO_4	814 – 1951	1261
Sodium as Na	114 – 289	219
Iron as Fe	0.010 – 39	0.753
Manganese as Mn	0.200 – 1.20	0.667

Table 4 *Summarised volumes and water quality of treated water from the Grootvlei Mine HDS Plant.*

85.1 % from the undergroundwater. However, due to the difference in the chemical properties of Manganese, remaining for a longer period in solution, and the HDS process not designed particularly for the removal of Manganese, it was expected that the removal of that metal would be less successful.

Compliance analyses of the daily and bi-weekly samples obtained from the HDS plant for pH, Electrical Conductivity (EC), Fe, Mn and Suspended Solids (SS) yielded results of varing compliances and success rates. A compliance analysis for pH showed that for 3528 days, the pH of the treated effluent remained within the set range of 6.5 – 8.5 (97.6 %). For 1 day (<0.1 %), the pH was less than 6.5, while for 85 days, the pH of the treated effluent was higher than 8.5, representing a non-compliance of 2.4 % (table 5).

Electrical conductivity of the treated effluent, which showed relatively little variation, showed the best compliance, with concentrations being less than 400 mS/m for 3553 days, or 99.9 % of the time. Only on 4 days of the monitoring period, did the EC exceed the limit of 400 mS/m, representing a non-compliance of 0.1 % (table 6).

Compliance analyses for Iron consisted of more concentration categories, ranging between 0 and >10 mg/L for comparative purposes. In the 0 – 1 mg/L compliance range, which was the standard required by DWAF, 3009 of the samples analysed showed an Iron concentration of less than 1 mg/L, representing a compliance of 83.4 %. In the 1 -2 mg/L category, 474 samples were classified, representing a non-compliance of 13.1 %. The 2 – 5 mg/L category showed 104 samples (2.9 %) to be non-compliant, while the 5 – 10 mg/L (17 samples) and >10 mg/L resulted in non-compliance figures of 0.5 % and 0.1 % respectively (table 7).

Manganese removal from the undergroundwater, as mentioned, was less successful than Iron. Subsequently, in comparison with a discharge limit of 1 mg/L set by DWAF, only 220 of the 600 bi-weekly samples complied with that standard, representing a compliance success of only 36.7 %. Manganese concentrations exceeding the 1 mg/L were measured on 380 of the 600 days, representing a non-compliance of 63.3 % (table 8).

Nearly similar to Iron compliance, SS concentrations complied on 2917 days with the discharge limit of 25 mg/L, representing a success rate of 80.8 %. For 531 days, or 14.7 % of the

pH Compliance Ranges	Number of Days	Percentage Compliance
Within Range: 6.5 – 8.5	3528	97.6
Below Range: <6.5	1	<0.1
Above Range: >8.5	85	2.4

__Table 5__ Compliance analysis of the pH of HDS plant effluents.

EC Compliance Ranges (mS/m)	Number of Days	Percentage Compliance
<400	3553	99.9
>400	4	0.1

__Table 6__ Compliance analysis of the EC of HDS plant effluents.

Iron-Fe Compliance Ranges (mg/L)	Number of Days	Percentage Compliance
0 – 1	3009	83.4
1 – 2	474	13.1
2 – 5	104	2.9
5 – 10	17	0.5
>10	4	0.1

__Table 7__ Compliance analysis of Iron concentrations in HDS plant effluents.

Mn Compliance Ranges (mg/L)	Number of Days	Percentage Compliance
<1	220	36.7
>1	380	63.3

__Table 8__ Compliance analysis of Mn concentrations in HDS plant effluents.

time, SS concentrations ranged between 25 – 50 mg/L, while for 112 days (3.1 %), concentrations were non-compliant between 50 – 100 mg/L. Extremely high SS concentrations of higher than 100 mg/L were encountered during 52 days (1.4 %) of the monitoring period (table 9).

Based on the flow discharges from the HDS plant (table 4), which ranged between 31 – 133 ML/d with an average of 92 ML/d, load discharge figures show TDS loads to range between 39 – 300 t/d, with an average of 177 t/d, or 5302 t/month being released from the HDS plant, into the Blesbokspruit. Suspended Solids loads ranged between 0.03 – 70 t/d, with an average of 2.3 t/d, or an average of 70 t/month. Due to the efficient operation of the HDS plant, the Iron loads being released were limited to a range of 0.01 – 4.5 t/d, or an average of 0.09 t/d. This represented and average release of Iron of 2.70 t/month (table 10). The calculated annual release for each of the listed parameters are 64 508 t/a (TDS), 848 t/a (SS) and 33 t/a (Fe) respectively.

Discussion

Although attempts were made with the Grootvlei Mine HDS plant to remove as much as possible Iron, Suspended Solids and salts form the underground water, before being released into the Blesbokspruit wetland, significantly large amounts were discharged over the 10 year period of operation. Results show thousands of tonnes of salts discharged annually, while, even though a compliance of 83.4 % for Iron was achieved, an estimated amount of 33 t/a of Iron was still discharged into the Blesbokspruit wetland. Under these circumstances, and with the technology and funds available, the Grootvlei Mine still managed to achieve a reasonable performance, and avoid any repetition of the environmental disaster which occurred in 1996. Regular toxicity testing of water from the Blesbokspruit during discharge, and well as bio-monitoring of the system, focusing on the avian, fish and invertebrate fauna of the wetland has shown that even though these high loads of salts and metals were being discharged, the most significant impact was limited to a relatively small section of the wetland downstream of the discharge point. The wetland in fact sustains a large number of fish and bird species during this period, and even now, after purification and pumping operations have ceased.

Due to the closure of the Grootvlei Mine and the No 3 shaft HDS plant in 2009, purification of underground water has ceased. It is expected that due to surface recharge, the water in the East Rand Basin may rise at a rate of 1 m per day from a depth of approximately 800 m below surface. Once the contaminated underground water approaches the surface, or decants at sites not known yet, a variety of potentially devastating environmental impacts may manifest.

Should contaminated underground water decant on the surface and reach the Blesbokspruit again, the environmental impacts could be equally devastating as it was in 1996. The Marievale Bird Sanctuary, a RAMSAR site of approximately 1000 ha, which sustains approximately 280 bird species, and mammals such as the Cape Clawless Otter, Reedbuck, Blesbok,

SS Compliance Ranges (mg/L)	Number of Days	Percentage Compliance
0 – 25	2917	80.8
25 – 50	531	14.7
50 – 100	112	3.1
>100	52	1.4

Table 9 *Compliance analysis of SS concentrations in HDS plant effluents.*

Water Quality Parameter	Range : Average (t/d)	Average (t/30 day month)
Total Dissolved Solids	39 – 300 : 177	5302
Suspended Solids	0.03 – 70 : 2.3	70
Iron as Fe	0.01 – 4.5 : 0.09	2.70

Table 10 *Summarised loads released from the Grootvlei Mine HDS Plant.*

Cape Hare and three species of Mongoose, could be severely affected should untreated decant water reach it. Equally, the quality of underground water previously being utilized for potable water and agricultural purposes by numerous farmers in this area may be so severely affected that it is not suitable for any of that uses any more.

A report to the Inter-Ministerial Committee on Acid Mine Drainage (2012) compiled by various experts in the field of Acid Mine Drainage recognize the potential impacts of AMD on the Western-, Central- and Eastern Basins of the Witwatersrand Gold Field. Various options are discussed and anticipated in order to treat AMD, which include pH adjustment by lime, aeration, precipitation, clarification and finally thickening and disposal of sludge. Other treatment options include sulphate and salt reduction by biological passive treatment, High Pressure Reverse Osmosis and precipitation processes using barium and calcium. Depending on Private and Government funding, the Department of Water Affairs (DWA) anticipate selecting appropriate treatment technologies for each of the Basins, and implementing these measures in order to curb any more potential AMD contamination and environmental damage which has already been experienced.

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