The potential environmental impact of the decant of water from Witwatersrand

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ABSTRACT

With the cessation of dewatering from the Central and Western Witwatersrand Basins in recent years, the decanting of water into the environment has become a very real hazard. To date, two decant points have been identified, in the Western and Central Basins, with initial studies having been undertaken on the Western Basin decant.

In July 2002, water reported on surface from a borehole upstream of the Krugersdorp Game Reserve. Shortly after this, water began to flow from an abandoned shaft in the Black Reef Quartzite. This water is of extremely poor quality, with a pH of 3.4 and high concentrations of iron, sulphate. Around this time, the so-called "dry dam" in the neighbouring Krugersdorp Game Reserve began to fill with water. Before the first rains of the season, analysis of this water showed a pH of 4.7, and a sulphate concentration of more than 2000mg/l. Some distance downstream of the dam, a dolomitic spring also shows a degradation of water quality. This degradation of water quality is of particular concern, as the aquifer impacted will feed the Cradle of Humankind World Heritage Site.

Initial laboratory studies are not encouraging. Sulphur isotope studies of the water in the impacted areas show an identical isotope signature to the decant water. The ability of the environment to neutralize the pollution is questionable. Although the main aquifer is dolomitic, neutralization tests show that the precipitation of ferric hydroxide on the surface of the dolomite armours the surfaces where the neutralization reactions could take place.

While the mine owners are undertaking significant remediation measures, the long-term impact of this pollution, particularly what is expected after mine closure cannot be discounted.

INTRODUCTION

Since 1886, gold has been mined in the Witwatersrand basin of South Africa, with uranium having been produced as a by-product since the 1940s. It is estimated that 43 thousand tons of gold and 75 thousand tons of uranium have been produced to date from mines along a strike length of approximately 300km.

For safety and production reasons, numbers of adjacent mines are often interconnected, creating vast contiguous mine voids, which now act as single groundwater aquifers. In the Johannesburg area, three large basins have been identified, namely the Eastern, Central and Western Basins. Underground mining is now only practiced on a significant scale in the Eastern Basin, which is still actively dewatered at Grootvlei Mine. Water is pumped from the Central Basin at East Rand Proprietary Mines, also actively mining, while no water is pumped from the Western Basin. It is envisaged that all pumping will cease in the coming ten to twenty years, after which groundwater rebound and possible decant at surface is expected.

Groundwater rebound and decant from mine openings is a well known process in many of the world’s mining areas. Interconnected mine voids may provide preferential groundwater flow paths, and where surface openings are located in low-lying areas, water inflow may provide sufficient head to allow water to exit at the surface. Where sulphides are exposed in the underground workings, the first water to decant is often highly acidic and contaminated with a range of metals, extracted from the ore. This makes the decant of mine water a potentially significant environmental problem.

MINING IN THE WITWATERSRAND BASIN

In 1886, gold was discovered in what is now Johannesburg in an outcropping conglomerate of the Witwatersrand Supergroup. Within a few years, the mining of supergene enriched outcrop deposits was largely superceded by the underground mining of the conglomerates, often to great depths. The earliest underground mines generally used large numbers of incline shafts or shallow vertical shafts to access the gold bearing reefs, before these small operations were consolidated into larger mines. In the early days, record keeping was of lesser importance, and the locations of many of these shafts are now unknown.

In recent years, the gold mining industry in the Wiwatersrand has been in a decline, with the major mining houses withdrawing and almost all the mines in the Johannesburg area closing, or scaling back their operations significantly. As a result of this slowdown, pumping of underground operations has been significantly cut back or ceased completely. The combination of flooding mines and an incomplete knowledge of the positions of mine openings at surface means that it is difficult to predict the exact positions where decants could occur or to estimate the time when this will happen. The example presented on a decant from Harmony Gold’s operations in the Randfontein area is a good illustration of this problem.

DECANT OF WATER FROM WITWATERSRAND MINES

To date, two decant points have been identified in the Witwatersrand basin, one in the Central Basin and one in the Western basin. The decant in the Western Basin has sparked significant public interest, as highly acidic water is entering a stream which flows towards the Cradle of Humankind World Heritage Site. This area has been studied in some detail.

A decant point has been identified in the Germiston area of the Central Mining Basin. At present it is not clear what the origin of the water decanting is, and initial tests do not indicate that it is significantly acidified. At this point, water is decanting from openings at the surface into a wetland in the nearby Natalspruit.

DECANT IN THE WESTERN BASIN

Initial identification of the decant

In July 2002, an official of the Krugersdorp Municipality noticed water entering the Tweelopiesspruit from West Wits Mine and flowing towards the Krugersdorp Game Reserve. On the 28th of August, it was determined that the source of the water was a borehole immediately upstream of the Game Reserve. At this time, the water was disappearing into the dolomitic aquifer upstream of the "Dry Dam" approximately 400m into the Game Reserve. Around the 2nd or 3rd of September a large volume (estimated at 9Ml/d) of water began to discharge from an abandoned shaft, now named "Buks se Gat" (See Figure 2), in the Tweelopiesspruit valley immediately upstream of the Game Reserve boundary. A map of the area, together with the sampling points used for the second part of the study is shown on Figure 1.

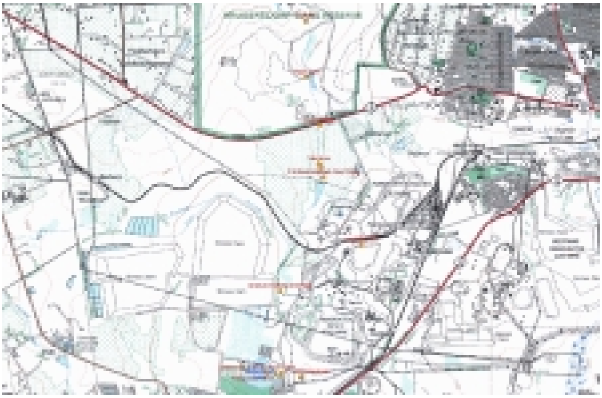

Figure 1. Locality of the area affected by discharge from West Wits Gold Mine. Sampling points are shown and annotated

Figure 2. Temporary dam constructed to store water at Buks se Gat.

The quality of the water decanting was poor, with a limited analysis of the initial decant from the borehole and from two springs in the Game Reserve presented in the following table.

Determinant	Acceptable Limit*	Borehole (Decant Point 1)	Spring 1	Spring 2
Conductivity (m S/m)	250	362	80	108
pH		3.4	6.1	6.2
Sulphate (mg/l)		2500	354	410
Zinc (mg/l)		10.8	<0.03	1.98
Nickel (mg/l)		22.5	<0.06	0.77
Manganese (mg/l)		218.5	<0.03	7.78
Iron (mg/l)		234.5	<0.05	0.66

** South African General Effluent Standard (DWAF)*

These results indicate that the quality of the water is unacceptable for discharge into a public watercourse and that mining is having a negative impact on the ground and surface water in the Game Reserve.

During this period, the Dry Dam began to fill with water, in response to a raised water table in the underlying dolomite. The water level in the dam is approximately the same as in an adjacent borehole.

It has been observed that water levels in mines are the same throughout the Western Basin mines (Pers. Comm. G Krige). During the pumping tests water levels in all accessible shafts in the basin rose and fell at the same rate supporting this idea. (Pers. Comm. K. Swartz). This suggests that the mines are hydraulically connected, and that the current decant point is the decant point for the entire basin.

When the water started to decant from the shaft, the mine operator built a sump and began introducing a flocculent into the water at the discharge point. The water was initially diverted to a nearby dam, where a significant amount of ferric hydroxide has been seen to contaminate the dam sediment, but was later pumped to Robinson lake with a limited holding capacity. Water has been observed seeping from the sump into the Tweelopiesspruit. Within the sump, the small dam where water was originally pumped and the seepage, ferric hydroxide precipitate was noted.

PRELIMINARY INTERPRETATION

The conditions observed and the analytical results reported are typical of the first flush of water when a mine floods. During mining sulphide minerals – in this case, mainly pyrite – are exposed to air and become oxidised, forming sulphates. On flooding, these oxidation products are dissolved, resulting in a metal-rich acidic solution which will decant on surface when the water level rises sufficiently. It can be expected that this first-flush will last for a period up to five times the time taken for the mine to flood (several years in this case) and that contamination levels will then decrease towards lower, but still elevated, levels. (Pers. Comm. P Younger). It can therefore be expected that the conditions currently being encountered will continue for several years, with lower, but still elevated, levels likely to continue for decades or longer.

The ubiquitous ferric hydroxide precipitate is also typical of the decant of post-flooding mine waters. In the anoxic conditions underground, iron is held in solution in the ferrous (Fe^{2+}) form. On decanting to the surface, this is oxidised to ferric iron (Fe^{3+}), which precipitates as insoluble ferric hydroxide or hydroxysulphate, consuming hydroxyl groups (OH^-) from the water, resulting in further reduction in pH. Observations in the Carletonville area as well as sequential extraction results suggest that these mineral species are a significant sink for uranium, although this has not been verified at the low pH values found on the West Wits site.

DISCUSSION OF THE INITIAL OBSERVATIONS AND DATA

The conditions observed in Krugersdorp are consistent with those recorded for first-flush events in other parts of the world. Based on observations in British coal mining areas, it can be expected that these conditions will continue for several years, with lower levels of contamination likely to continue for decades or more. These time frames are significantly longer than the projected lives of the mines in the Western Basin. Consequently, the responsibility for water treatment will at some point revert to the state and will be paid for by the taxpayer. It is therefore prudent to explore lower cost alternatives to pumping and treating the water.

The analyses of the water indicate several problems:

1. Low pH.
2. High acidity – This is not necessarily the same as low pH. pH refers only to the concentration of hydrogen ions, where acidity includes species such as Fe^{2+} and Fe^{3+}, which have the ability to consume hydroxyl ions.
3. High metal content. This is likely to include radionuclides.
4. High sulphate.

Research has been undertaken in the UK and elsewhere into passive treatment of these problems. Typical solutions include:

1. Precipitation of ferric hydroxide to remove iron. This is typically done by aerating the water and then allowing ferric hydroxide to settle out. This does create a significant volume of solid waste, but is necessary to prevent the creation of hydroxide and hydroxysulphate gels which cover the reactive surfaces within the rest of the passive treatment system.
2. Neutralisation of low pH by reaction with carbonates. Typically limestone is used, as this is more reactive than dolomite. The local availability of dolomite makes dolomite an attractive option.
3. Removal of sulphates by the action of sulphate reducing bacteria. These bacteria are found in the gut of most mammals. Cow or horse manure is often used as the undigested cellulose provides a carbon source for the bacteria. Locally available sources could be cattle feed-lots.
4. Addition of alkalinity by further reaction with carbonates. Again the possibility of using locally available dolomite is attractive.
5. Such a system provides an excellent habitat for wetland plants. These have the added benefit of baffling the water flow to allow longer residence times within the system, as well as providing a habitat for birds and other wildlife.

While there is little experience in the use of such engineered systems in the Witwatersrand, research in the Wonderfonteinspruit catchment (Coetzee *et al.*, 2002) has indicated the potential of such a system. The same research has also indicated that unless carefully monitored, these wetland systems may also operate as a source of further pollution. It should also be remembered that the passive treatment system is an engineered solution to a wastewater problem, which concentrates contaminants in a limited area, rather than allowing them to be discharged into the environment and spread over a large area.

FOLLOW-UP SAMPLING AND ANALYSIS

On 7 November 2002, a sampling trip was undertaken. The aim of this trip was to collect samples and to establish hydrogeochemical conditions in the field. The sample positions are shown on Figure 1 and the layout of the site is shown schematically on Figure 3. Also shown on this figure are the locations of sampling points, and seepages. At two sites, Harmony Gold have started water treatment activities. These are also indicated on the diagram.

SAMPLING AND FIELD MEASUREMENTS

At each sampling point, at least one water sample was collected. In some cases, a water sample was collected and acidified in the field, using HNO_3. This procedure preserves the sample, but strips adsorbed metals from the suspended load, giving an indication of the total metal content of the water. For some sites, a 25l sample was collected to allow for initial experimentation regarding the chemical behaviour of the water, as well as testing different passive treatment options. At all sites, the pH of the samples was measured in the field. The sample descriptions, positions and data recorded in the field are presented on Table 1.

Table 1. Sample descriptions, positions and field data

Sample No.	Description	Long.	Lat.	pH	EC (mS/cm)
HG17	Robinson Lake Pump Outlet	27.71592	-26.14761	4.19	
HG18	Robinson Lake Canal	27.71542	-26.14756	4.70	
HG19	Robinson Lake Mouth	27.71542	-26.14756	6.90	4.6
HG20	Buks se Gat stream	27.72242	-26.11397	3.12	3.8
HG21	Road Bridge	27.72256	-26.10753	3.14	3.6
HG22	Spring in Game Reserve	27.72019	-26.09086	5.50	0.8
HG23	Robinson Lake West	27.71000	-26.14678	3.06	5.1
HG24	Buks se Gat Borehole	27.72314	-26.11539	3.17	4.1
HG25	Buks se Gat Shaft	27.72314	-26.11539	3.41	4.5
HG26	Dry Dam	27.72008	-26.09994	4.71	2.4

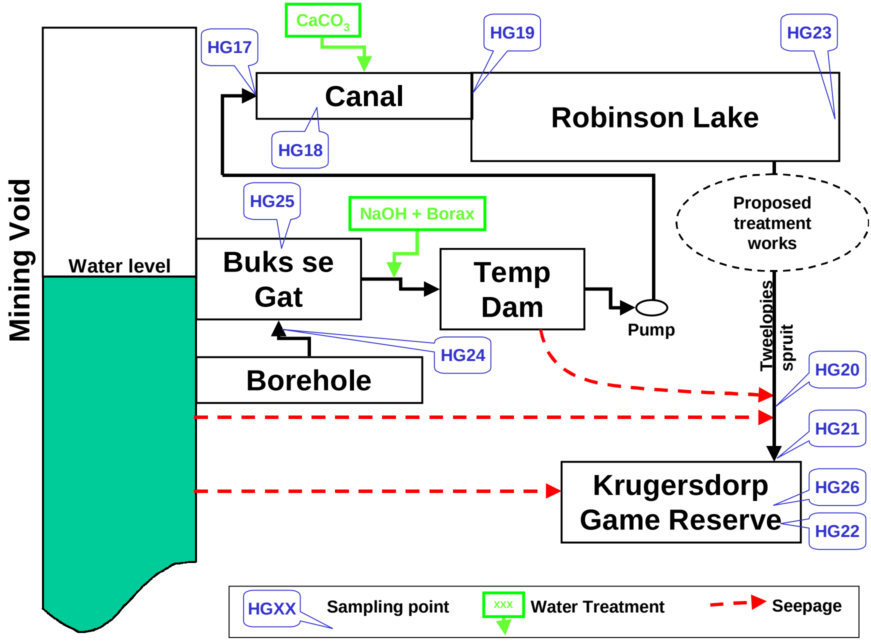

Figure 3. Schematic flow diagram of the West Wits area, showing water flows, seepages, water treatment methods and sampling

ANALYTICAL RESULTS

Water and sediment samples were submitted to the Council for Geoscience laboratory for analysis by ICP-MS. On all samples, semi-quantitative scans were performed for a large number of elements, while uranium was analysed quantitatively. The water samples were analysed for anions by ion chromatography. These results are shown on Table 2 and Table 3.

Sulphur isotope analyses of dissolved SO_4^{2-} were undertaken to trace possible provenances of the sampled waters and to establish eventual anthropogenic imprints.

Table 2. ICP-MS results for samples collected in the vicinity of the West Wits Mine. Underlined results exceed guideline levels for drinking water.

Element	Guideline (µg/l)[1]	HG 17 Robinson Lake Pump Outlet	HG 18 Robinson Lake Canal	HG 19 Robinson Lake Mouth	HG 20 Buks se Gat stream	HG 21 Road Bridge	HG 22 Spring in Game Reserve	HG 23 Robinson Lake West	HG 24 Buks se Gat Borehole	HG 25 Buks se Gat Shaft	HG 26 Dry Dam
B	300	1523	1713	1357	167	209	61	1753	153	151	210
Na	100000	67635	69914	71997	44555	42984	17902	92387	43923	48070	36220
Mg	30000	121964	129460	95094	110365	92228	31380	181925	117631	126110	79365
Al	150	52376	19475	69	38457	14395	98	70693	56291	55982	1118
K	50000	4610	4829	5625	6091	5753	1096	5929	4982	4684	5622
Ca	32000	444353	560428	838311	498044	522801	81777	469214	465566	451391	601772
V	100	0	10	10	0	0	0	0	0	19	0
Cr	50	123	86	71	63	35	33	43	42	68	0
Mn	50	189902	191854	90825	286124	192461	125	284704	330078	186906	59801
Fe	100	636000	613842	1284	41120	9387	631	122181	197335	692431	461
Ni	20	22929	21838	1434	17549	16063	74	71718	22886	22371	4159
Cu	1000	377	237	27	841	254	5	4071	1333	416	11
Zn	3000	13637	11808	238	11137	6855	116	57750	16437	12463	1932
As	10	97	123	7	10	5	0	43	13	473	2
Se	20	23	20	6	21	15	4	72	30	29	6
Ag	100	0	0	0	0	0	0	0	0	0	0
Cd	5	8	10	1	21	0	0	105	30	10	0
Sb	5	0	0	0	0	0	0	0	0	0	0
Ba	700	32	66	138	45	33	25	34	43	29	56
Hg	1	0	0	0	0	0	0	0	0	0	0
Pb	10	23	45	45	44	33	75	161	52	34	27
U	70	818	58	58	496	232	0	16155	747	862	10

[1]The guideline values used here are the Department of Water Affairs and Forestry's Target Water Quality Ranges for domestic use. Where no TWQR exists, the relevant guidelines from the European Union or US Environmental Protection Agency have been used.

Table 3. Anion concentrations of water samples

Constituent	Guideline	HG 17 Robinson Lake Pump Outlet	HG 18 Robinson Lake Canal	HG 19 Robinson Lake Mouth	HG 20 Buks se Gat stream	HG 21 Road Bridge	HG 22 Spring in Game Reserve	HG 23 Robinson Lake West	HG 24 Buks se Gat Borehole	HG 25 Buks se Gat Shaft	HG 26 Dry Dam
F	1.0	3	1	0	0	0	0	4	0	1	0
Cl	100.0	61	59	52	58	56	30	68	56	64	48
NO_2	20.0	0	0	0	0	0	0	0	0	0	0
Br		0	0	0	0	0	0	0	0	0	0
NO_3	22.0	0	0	0	8	0	18	0	0	0	0
PO_4		0	0	0	0	0	0	0	0	0	0
SO_4	200.0	4085	4078	2160	3084	2557	351	4454	3576	4254	2188

Table 4: Results of sulphur isotope analyses

Sample	Description	Mineral (Precipitate)	$\delta^{34}S$‰ CDT
HG17	Robinson Lake, pump outlet	$BaSO_4$	3.9
HG18	Robinson Lake, canal	$BaSO_4$	3.9
HG19	Robinson Lake, mouth	$BaSO_4$	3.3
HG20	Buk se Gat, stream	$BaSO_4$	4.2
HG21	Road Bridge	$BaSO_4$	3.7
HG22	Fontein (+HNO_3)	$BaSO_4$	3.3
HG23	Robinson Lake, West	$BaSO_4$	-1.3
HG24	Buk se Gat, borehole	$BaSO_4$	3.6
HG25	Buk se Gat, shaft	$BaSO_4$	3.8
HG26	Dry Dam	$BaSO_4$	2.6

INTERPRETATION OF ANALYTICAL RESULTS

COMPARISON TO GUIDELINES

From it can be clearly seen that water quality in the area is unacceptable. A particular concern are the high levels of macro-components such as iron, aluminium and zinc, which are all elevated to potentially toxic and eco-toxic levels. These metals, iron in particular will also contribute to the total acidity of the water. Furthermore, a number of trace constituents are elevated to alarming levels. Particular concerns are the high levels of uranium, which is both radioactive, creating a long-term cancer risk as well as being highly nephrotoxic, manganese and lead, both neurotoxins and other heavy metals such as nickel, cadmium and arsenic.

TRACING THROUGH PATHWAYS

From Figure 3 it can be seen that water flow can be broadly grouped into two pathways:

1. The treatment route, where water from Buks se Gat is treated with sodium hydroxide and borax, channeled into the temporary dam, after and from there pumped to Robinson Lake, where it is treated with lime in a small canal before discharge into the lake.
2. The environmental route, where seepage from the mine void and the temporary dam flow into the Tweelopiesspruit, enter the dolomitic aquifer reporting at surface in the Dry Dam (where the water level has been rising steadily for some months) and the spring in the Krugersdorp Game Reserve.

Graphs of the concentrations of selected elements are shown on Figure 6 The following trends are seen in the data:

WATER FLOW INTO THE KRUGERSDORP GAME RESERVE.

In the environmental pathway all parameters tend to improve with increasing distance from Buks se Gat, indicating the natural attenuation of pollution. It should however be noted that conditions inside the Krugersdorp Game Reserve are unacceptable, particularly in the Dry Dam, which is currently home to two hippos (See Figure 7). S du Toit of the Mogale Municipality reports that the water level in this dam has been steadily rising for several months. The current water quality is relatively poor.

A greater concern is that the wetland between Buks se gat and the Road separating the mine property from the Game Reserve is having only a minor influence on water quality. This could be due to the short residence time of the water in the wetland, as well as the coating of the reactive surfaces in the wetland with a ferric hydroxide precipitate (See Figure 8). A laboratory experiment conducted at the Council for Geoscience indicates that the same precipitate is likely to form when water reacts with dolomite surfaces, with the precipitate forming a gel that armours the dolomite preventing further neutralisation reactions. This precipitation of ferric hydroxide from the water as soon as it enters an oxidising environment will be a major constraint on any use of dolomite as a neutralising agent either in passive treatment plants or in any natural attenuation scenario. It is likely that the low pH value seen at the Spring in the Game Reserve illustrates the inability of the natural environment to fully attenuate the pollution from Buks se Gat. Nevertheless, the natural attenuation pathway is seen to outperform the limited treatment which has been undertaken.

SULPHUR ISOTOPIC AND RARE EARTH ELEMENNT (REE) COMPOSITIONS

The S isotopic composition of most of the samples covers a fairly narrow range between 2.6‰ and 4.2‰. These values are very similar to somewhat lower than most of those observed in a previous project on Witwatersrand water samples involving S isotopes (Horstmann, 2002). Only one sample (HG23, Robinson Lake, West) is notably different with –

1.3‰. This sample also differs from all others with a somewhat higher anion concentration (SO_4^{2-} and Cl^-) and significantly higher values of Pb, U, Si and Gd as well as the other REEs (Figure 4 and 5).

The $\delta^{34}SO_4^{2-}$ values of this study lie below those reported for fresh water systems world-wide, which are generally between +5‰ and +15‰ (e.g. Cortecci and Longinelli, 1970; Ivanov et al., 1983). The at present most plausible explanation for the S isotope values between 2.6‰ and 4.2‰ is interaction with Witwatersrand sediments (leaching). Hoefs et al. (1968) reported $\delta^{34}S$ values from 1‰ to 4‰ of pyrites from the Witwatersrand and Smit (2000) found such pyrites with S isotopic compositions between –5‰ and +5‰ in these sediments. Waters leaching these pyrites in the course of oxidative weathering can be expected to show $\delta^{34}SO_4^{2-}$ values as analysed in this study. The relatively high silica and REE contents of these samples (Table 4) would support this explanation, documenting that this water had enough time to exchange with the surrounding rock.

The negative $\delta^{34}SO_4^{2-}$ value of sample HG23, differing from all others found in and around the Robinson Lake area, may require another explanation. If leaching of sediment with a substantially different S isotopic composition can be excluded, another source of the sulphur in this sample is likely. A nearby power station firing coal is a possible origin for this sulphur, as S with such an isotopic composition can be found in South African coal. This assumption, however, would have to be substantiated by further investigations.

Anthropogenic pollution could be indicated by the concentrations of Gadolinium which is known to be a sensitive tracer in urban areas. HG23 has by far the highest Gd content of the sample suite, but Gd is not anomalous in either HG23 or the other samples. Although substantial REE concentrations are revealed by the patterns in Figure 5 (up to 11000 $\times$ chondrite), no rare earth element is genuinely anomalous.

The variation on the chlorine content of most samples (excluding HG22 and HG23, Figure 4) relative to the S isotopic composition could possibly point to some component mixing between mine effluent and surface water.

The positive S isotopic composition of SO_4^{2-} in water samples from this study points to leaching of Witwatersrand sediments by these waters. Only one sample, different from the others by a negative $\delta^{34}S$ value, may be explained by some kind of anthropogenic influence, possibly originating from a coal firing PowerStation. Further comparative studies are required to verify this assumption.

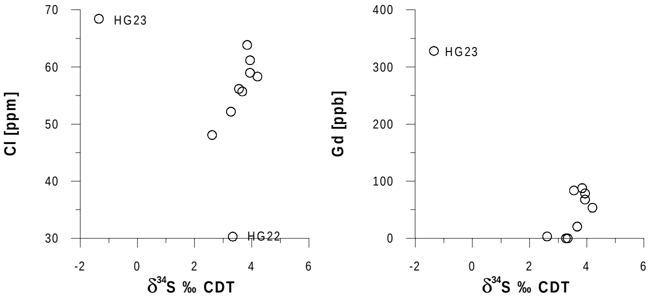

Figure 4: δ^{34}S values of dissolved sulphate vs. chlorine and gadolinium. Note negative δ-value of HG23 and its significantly higher cation concentration.

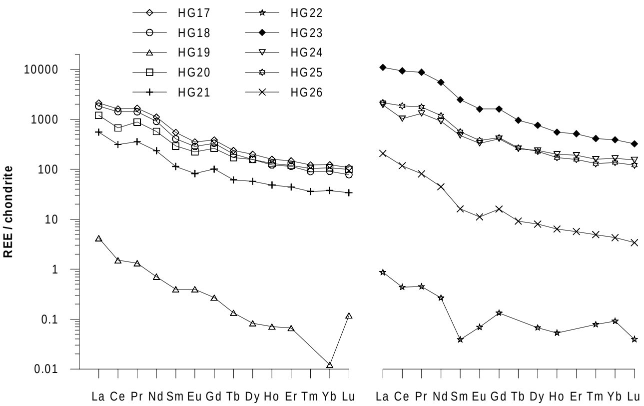

Figure 5: Chondrite normalised (after Evensen et al., 1978) REE profiles of the sample suite. Relatively high concentrations are observed, but no particular anomalies. The REE patterns of samples HG19 and HG22 show the lowest REE concentrations, but very unusual profiles. The "Yb anomaly" of HG19 and the "Sm anomaly" of HG22 are possibly artefacts.

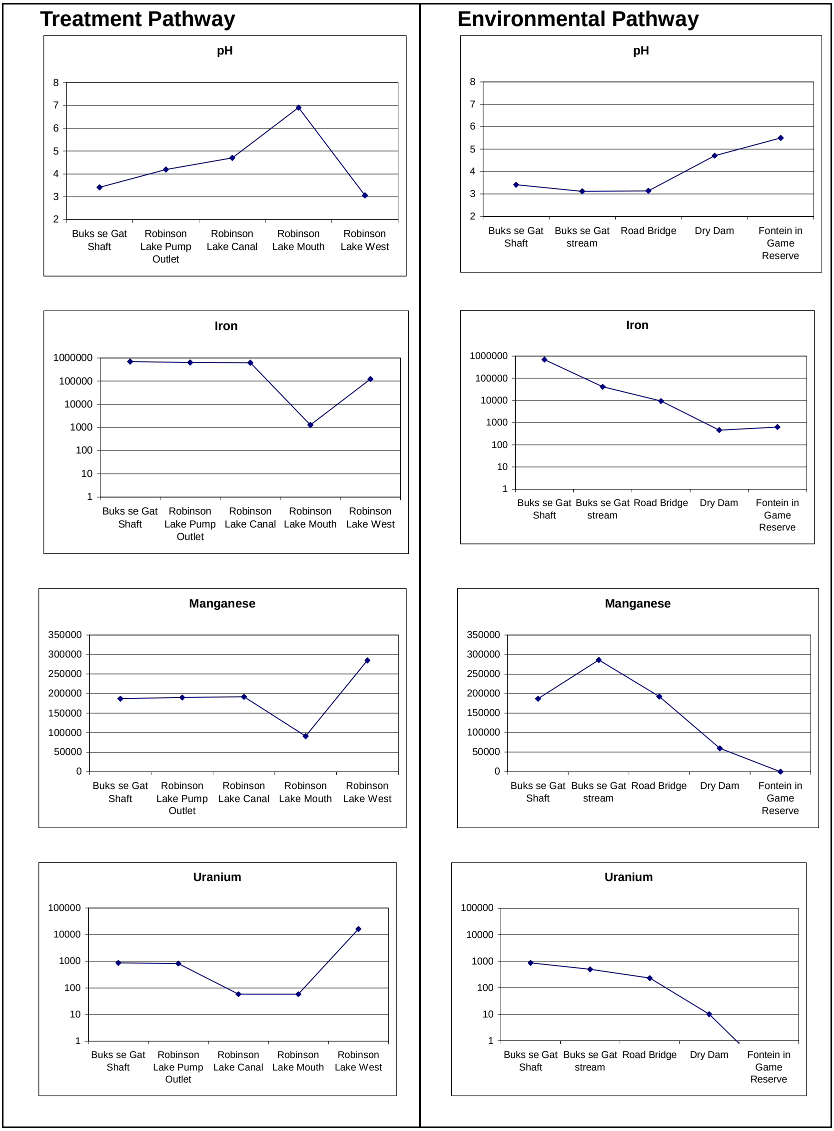

Figure 6. pH, iron manganese and uranium for the treatment and environmental pathways. (Note that iron and uranium have been plotted on a logarithmic scale.)

Figure 7. Hippos in the “Dry Dam” in Krugersdorp Game Reserve

Figure 8. Wetland downstream of Buks se Gat. Note the orange ferric hydroxide gel coating the vegetation and sediment.

INTRODUCTION OF NEW CONTAMINANTS IN THE TREATMENT PROCESS

The use of borax in the treatment process at Buks se Gat introduces boron at high levels in the treatment pathway. A small increase in boron concentration is also seen in the Tweelopiesspruit, possibly as a result of seepage from Buks se Gat and the storage dam.

ACIDIFICATION OF ROBINSON LAKE

The condition of Robinson lake is also most likely a result of the oxidation of Fe^{2+} to Fe^{3+} and the precipitation of ferric hydroxide. Water is pumped from Buks se Gat and discharged into Robinson Lake via a short canal, where lime is added in an attempt to control the low pH of the water (see Figure 9).

Figure 9. Worker adding lime to the water from Buks se Gat at the discharge into Robinson Lake.

This action has an immediate effect on the low pH of the water, raising it from 4.19 at the discharge to 6.9 at the end of the canal. Unfortunately, this does not adequately address the acidity of the water1. After entering the lake, the water mixes with the aerated water in the shallow lake (see Figure 10). The soluble $Fe2^{+}$ is oxidised to insoluble $Fe3^{+}$, which forms ferric hydroxide, removing hydroxyl ions from the water, leaving an excess of H^{+} and consequently a lower pH. This low pH will also increase the solubility of a number of metals in the water The increased concentrations of manganese and uranium in Robinson Lake seen on Figure 6 and Table 2 probably result from this decrease in pH and interactions with sediment in the lake, which was historically used to store cooling water for a now defunct coal-fired power station, and is likely to have been impacted on by local mining activities over the past century.

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[1] Acidity referring to the ability of the water to consume alkalinity, as opposed to pH, which is simply a dependent on the hydrogen ion concentration.

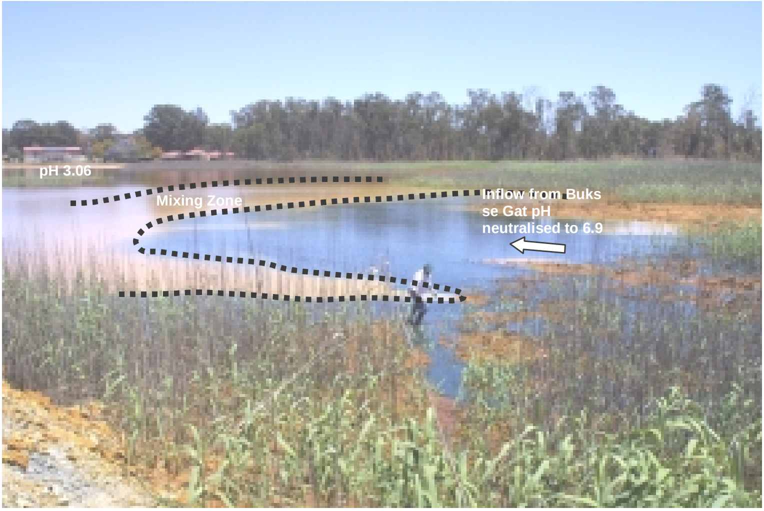

Figure 10. View across Robinson Lake from the discharge of water from Buks se Gat. Note the colour changes related to the mixing of the mine water and aerated dam water.

RECENT DEVELOPMENTS

Since the completion of the sampling and analysis described here, the mine operator has undertaken significant work towards remediation of the situation. The abandoned Millsite uranium plant has been converted into an active water treatment plant and there are plans to treat the water to a condition where it can be used in one of the surrounding mines' gold plants. This approach, namely utilising contaminated water in operations that do not necessarily require the high purity of water provided by local authorities is gaining popularity throughout the Witwatersrand and may provide part of the solution to the problems related to contaminated water decanting from mines.

CONCLUSIONS AND RECOMMENDATIONS

CONCLUSIONS

Water entering the environment from the overflow of the West Wits Gold Mine at Buks se Gat is highly acidic and contains a significant load of metals, many of them toxic to humans and the environment. While the major discharge points have been addressed, water of an unacceptable quality is entering the adjacent Krugersdorp Game Reserve via the Tweelopiesspruit and apparently via the local dolomitic aquifer.

Remediation actions to date have been limited to the diversion of the water to Robinson Lake, which is now highly acidic and carries an extremely high heavy metal load. That water which is not captured in the remediation actions is entering the Krugersdorp Game Reserve, where natural processes are attenuating the pollution. This natural attenuation is however inadequate for the volume of water. Furthermore, initial laboratory experiments suggest that the environment's assimilative capacity will be seriously limited by the armouring of reactive surfaces with ferric hydroxide gels. Already, conditions at a spring in the Game Reserve show the signs of contamination.

RECOMMENDATIONS

A significant amount of research is still required to answer all the questions raised by the egress of acid water from old Witwatersrand mining operations. Unfortunately the urgency of the problem does not allow for all the research to be undertaken before remedial action can be taken. It is therefore recommended research and remediation be undertaken incrementally, with the success or failure of remedial actions being used to inform the next phase of research.

Results so far show the natural attenuation is inadequate to address the problem at present. It is however encouraging that the natural attenuation processes outperformed the initial limited pH neutralisation efforts being undertaken by the mine operator, albeit with smaller volumes of water involved. Further research is required into natural attenuation processes to assess the potential of and assist in the design of passive remediation systems.

The mines in question currently are the responsibility of existing mining companies. While the State has a role to play in regulating and possibly assisting mining companies with rehabilitation, either through technical assistance and support for research, or in extreme cases via direct financial support, the mining companies should attempt to investigate sustainable solutions which will not place an unreasonable burden on future generations.

Unacceptably high levels of uranium have been detected in the water. It is also likely that other radionuclides will be soluble at the low pH values recorded. It is therefore a legal requirement that the National Nuclear Regulator be informed about these conditions.

ACKNOWLEDGEMENTS

Prof. B. Verhagen is thanked for permission to use facilities of the IAEA Environmental Isotope Laboratory at the Schonland Institute of the University of the Witwatersrand, Johannesburg. Mr. O. Malinga’s asssistance with the S isotope determinations is gratefully acknowledged. Ms. H. Maritz and Mr. L.J. Jordaan performed the chemical analyses, which is highly appreciated.

REFERENCES

- **Coetzee, H, Wade, P.W and Winde, F**, 2002. Reliance on existing wetlands for pollution control around the Witwatersrand gold/uranium mines of South Africa. Are they sufficient? In **Merkel, B.J, Planer-Friedrich, B and Wolkersdorfer, C,** *Uranium in the aquatic environment, proceedings of Uranium mining and hydrogeology III*, Freiberg, 15-21 Sept., 2002.
- **Cortecci, G. and Longinelli, A.** (1970). Isotopic composition of sulphate in rain water, Pisa, Italy. *Earth and Planet. Sci. Lett.*, **8**, 36–40.
- **Evensen, N. M., Hamilton, P. J., and O'Nions, R. K.** (1978). Rare earth abundances in chondritic meteorites. *Geochimica et Cosmochimica Acta*, **42**, 1199-1212.
- **Hoefs, J., Nielsen, H., and Schidlowski, M.** (1968). Sulphur isotope abundances in pyrite from the Witwatersrand conglomerates. *Economic Geology*, **63,** 975-977.
- **Horstmann, U.E.** (2002). Sulphur and strontium isotope analysis on 7 Witwatersrand water samples *Stable Isotope Laboratory, Council for Geoscience Report,* **2002–02**, unpubl. 8 pp..
- **Ivanov, M. V., Grinenko, V. A., and Rabinovich, A. P.** (1983). The sulphur cycle in continental reservoirs – Part II. Sulphur flux from continents to oceans. In: Ivanov, M. V. and Freney, J. R. (Editors), *The global biogeochemical sulphur cycle.* SCOPE, **19,** John Wiley & Sons, Chichester, 331-356.
- **Smit, C.M.** (2000). Sulfur isotope composition of pyrite from Witwatersrand gold reefs. *Department of Geology, University of Stellenbosch*, unpubl. report, 16 pp.