

https://dspace.org/

Establishing effective, appropriate and applicable technologies in treating contaminated surface water as part of a rehabilitation strategy for the Princess Dump in Roodepoort, west of Johannesburg

Ngigi, Samuel M.

2009-09-02T11:35:00Z
http://hdl.handle.net/10539/7172

Downloaded from a DSpace repository. https://dspace.org/

ESTABLISHING EFFECTIVE, APPROPRIATE AND APPLICABLE TECHNOLOGIES IN TREATING CONTAMINATED SURFACE WATER AS PART OF A REHABILITATION STRATEGY FOR THE PRINCESS DUMP IN ROODEPORT, WEST OF JOHANNESBURG.

Ngigi Samuel M.

A Research Project submitted to the Faculty of Science, at the University of the Witwatersrand in partial fulfilment of the requirements for the degree of

Master of Science

in

Environmental Science.

University of the Witwatersrand, Johannesburg, South Africa

Supervisors:

Catherine Reichardt – Senior Lecturer, School of Mining Engineering.

Johannesburg, 2009

DECLARATION

I declare that this report is my own, unaided work except where acknowledged. It is being submitted for the degree of Master of Science in the University of the Witwatersrand, Johannesburg. It has not been submitted before for any degree or examination in any other university.



(Candidate's signature)

February 2009

ABSTRACT

This study aimed to identify an effective, appropriate and applicable technology for the treatment of contaminated surface water from the Princess Dump. Princess Dump is an old abandoned and unrehabilitated gold tailings storage facility situated in Roodepoort, west of Johannesburg. It falls within the Upper Klip River subcatchment, which forms part of the Klip River catchment.

Undoubtedly, abandoned gold tailings storage facilities have caused varying degrees of environmental damage especially those that have been abandoned and left unrehabilitated. Water pollution that results from these facilities does not only influence the local environment but also other receptors downstream of the source. In order to assess the extent of water pollution attributed to the abandoned Princess Dump, sampling was done on specific points around the study site. Other physical and chemical water quality sampling data was obtained from the Department of Water Affairs and Forestry (DWAF). The chemical analysis was performed on the data to determine whether the water quality parameter concentration was within the Target Water Quality Range (TWQR) as stipulated by DWAF for various uses, while correlation analysis determined the relationship between the various water quality parameters at the time of sampling. These analyses gave an indication of the potential liability of the abandoned Princess Dump as far as the degradation of the local surface water quality.

The study identified that pollution resulting from the Princess Dump is seriously impacting on the water quality environment around the site. Different surface water treatment systems, active and passive, were reviewed and analysed on the basis of their efficiency and applicability to the site and their ability to remediate the contaminated surface water around the site. This was done in comparison between the various identified systems and their ability to treat the contaminated water that is being released from the abandoned site.

A preferred water treatment system was identified based on its projected efficiency in treating the water quality from the site while considering the worst case scenario of the pollution. Other potential point and non point sources of pollution around the study site were also identified and elaborated on and recommendations made to improve the water quality around the site. It was concluded that the local surface water quality has been degraded and that a passive surface water treatment technology can adequately improve the water quality before it is released into the environment.

ACKNOWLEDGEMENTS

It is with great appreciation and recognition that I wish to thank the following persons for their tremendous efforts and contribution that they have made to the completion of this study:

- Cathy Reichardt, my supervisor for her time and effort in training and guidance provided on environmental science issues in general and in particular the impacts of the mining industry on the environment and the motivation and review of the study.
- Prof. Mary Scholes, School of Animal, Plant and Environmental Science for her understanding and humbling support during my study.
- Carla Hudson, formerly the Regional Manager, WESSA-Northern Region for the valuable information with regards to the study site.
- Mr Fayazi Morteza, Department of Water Affairs and Forestry (DWAF) for the water quality data provided as sampled by DWAF.
- My family and friends for their love and support through my studies.

TABLE OF CONTENTS

DECLARATION		**II**
ABSTRACT		**III**
ACKNOWLEDGEMENT		**IV**
1	**INTRODUCTION**	**1**
2	**RESEARCH PROBLEM**	**4**
3	**MOTIVATION AND OBJECTIVES OF STUDY**	**6**
4	**DESCRIPTION OF THE STUDY SITE**	**7**
4.1	Location	7
4.2	Climate	12
4.3	Temperature	12
4.4	Rainfall and Evaporation	13
4.5	Geology and Soils	13
4.6	Surface Water Hydrology	14
5	**LITERATURE REVIEW**	**16**
5.1	Introduction	16
5.2	Water Quality	18
5.3	Regulatory Guidelines	22
5.4	Surface Water Treatment Technologies	24
6	**DATA COLLECTION AND ANALYSIS**	**34**
6.1	Introduction	34
6.2	Data collection	35
6.3	Sampling	38
6.4	Shortcomings of the data	39
6.5	Water Quality Analytical Results	40
6.6	Summary and Data Interpretation	42
7	**APPLICATION OF SURFACE WATER TREATMENT OPTIONS**	**43**
7.1	Introduction	43
7.2	Assessment	44
7.3	Conclusion and recommendation	48

List of Figures

Figure 1: Location of the Study Site and the surrounding land use (SA1:50000 topographical map). 7
Figure 2: An aerial photo of the TSF and positions from where the pictures below were taken from. 8
Figure 3: Site Photographs 9
Figure 4: The sedimentation of eroded tailings into nearby water bodies. 10
Figure 5: The “yellow boy” colouration of the water in the wetland. 10
Figure 6: Contaminated seepage from the TSF near the wetland. 11
Figure 7: A tailings heap in the manmade wetland area. 11
Figure 8: Average temperatures for the period January 1960 to December 1990 (Source: South Africa weather service). 12
Figure 9: Average monthly rainfall for the period January 1960 to December 1990 (Source: South Africa Weather Service). 13
Figure 10: Area surface geology. 14
Figure 11: The surface hydrology around the study site. 15
Figure 12: Princess Dump monitoring points sampled by DWAF. 36
Figure 13:Piper Diagram 41
Figure 14: Showing the wetland during the summer (January 2007) (left), and autumn (April 2007) months (right). 46

List of Tables

Table 1: Water Quality Parameters utilised for biological, physical and chemical analysis (DWAF 1998) 22
Table 2: The Target Water Quality Range (TWQR) for the parameters used in the study as per use. 23
Table 3: DWAF Water Sampling Results 37
Table 4: Water Quality Results 39

1 INTRODUCTION

> ‘South Africa has been and is at present the world’s largest gold producer. The country has enormous gold ore reserves, estimated at 40 000 tons, representing 40% of global reserves. The main gold producing area is concentrated on the Archaean Witwatersrand Basin. The Witwatersrand basin, which has been mined for more than 100 years and has produced more than 41 000 tons of gold, remains the greatest un-mined source of gold in the world’. (Morrisson, 2004).

The impacts of this expansive gold mining industry have been huge and positive to the South Africa economy. While acknowledging the economic and social benefits of the mining industry, on the contrary, the industry has also lead to depletion of the natural resources and environmental degradation around the country. Gold extraction and processing activities have been a source of many contaminants entering our water, soil, and air environments. The environmental impacts of gold mining industry range from soil, water, human health and the built-up environment, to air, plants and animal life. Gold mining is responsible for many vast lands of infertile and unproductive landscapes that have been left behind after decommissioning of the mining activities (Martin *et al.,* 2002). Tailings Storage Facilities (TSF’s) are examples of these unproductive structures that exist in the Johannesburg area as a result of a history of gold mining activities in the Witwatersrand basin.

TSF’s are structures designed to store and contain mining waste that result from ore extraction and processing to obtain gold. TSF’s can be classified into the following categories:

- Active (deposition taking place);
- Fully rehabilitated;
- Un-rehabilitated;
- Partly rehabilitated;
- Partly reprocessed; and
- Currently being reprocessed.

Because of their composition (physical and chemical) and their changing status, TSF’s require proper designing, continuous management and maintenance during the operational period of the mine as well as after mine closure. This is to ensure that they do not impact negatively on the surrounding environment or contribute to environmental degradation.

Princess Dump is an old and abandoned TSF located in Roodepoort, west of Johannesburg on the farm Roodepoort 237 IQ, approximately 3 km north west of Durban Roodepoort Deep Gold Mine (DRD) in Gauteng Province. Currently there is no tailings deposition taking place at the site and the Department of Minerals and Energy (DME) classified the TSF as ownerless, with no record of previous mining licenses (SRK, 2006). Due to its abandoned state, the TSF and the surrounding site is heavily degraded. The Princess Dump is surrounded by residential settlements of Davidsonville to the north and north-west, small scale brick and scrap metal industries to the east and south, other mine dumps to the south, a road infrastructure around the site and a manmade wetland in close proximity to the west.

The abandoned TSF has not been rehabilitated and is currently impacting on the surrounding environment. The most prominent adversely affected environmental components that are identified at the site include:

- Dust pollution - High winds which blow in the region, especially before the onset of spring rains, result in wind blown tailings dust being generated from the TSF. In the past, complaints from the nearby community of Davidsonville have been received with regards to dust pollution adversely affecting the nearby air and water environment.

- Water pollution - Poor quality water with low pH values, high electrical conductivity, high sulphate and total dissolved solids values has been recorded at the site in the past (SRK, 2006). The pollution is attributed largely to the presence of the Princess Dump as well as disposal of household waste from the urbanised areas and industries located in the area. Sedimentation of eroded tailings is also occurring in the nearby waterways and wetlands.

- Topography - Decline in aesthetic appeal of the area owing to the unsightly visual intrusion of the TSF which is located in close proximity to residential and industrial areas. The presence of the unrehabilitated TSF has changed the original form of homogeneous landscape causing a negative visual impact on the landscape.

- Land capability and land use – Erosion from the unrehabilitated TSF into the nearby environments results in land degradation around the site including the riparian zones, wetlands and waterways close to the site.

SRK (2006) highlighted that Princess Dump is a major source of pollution into the surface water environment in the region. This study aimed to establish the level of degradation of the surface water and in turn propose an appropriate, applicable and cost effective remediation technology that may be applied specifically to the site to remediate the impacted surface water. It therefore included an analysis of the physical and chemical water quality parameters at various sampling points in order to determine their concentrations and compare these values to the specified Target Water Quality Range

(hereinafter referred to as TWQR) as set in the Water Quality Guidelines controlled by the Department of Water Affairs and Forestry (hereinafter referred to as DWAF). After establishing the surface water quality at the site, various treatment technologies were reviewed and assessed on their efficiency to treat the contaminated water and their applicability at the site. The study therefore identifies a treatment technology that can be applied to the site to treat the contaminated surface water and ensure that the water discharged meets the TWQR.

This research is important because there are numerous abandoned mining sites that are impacting on the water environment. The impacts is not only felt in the local environment, but the effects of the degraded water quality are often felt downstream of the mine site which may impact on aquatic life as well as the beneficial use of the water. Prudent management of the water resource is required which includes preventing pollution, clean up and rehabilitation of contaminated sites. The study ensures that the polluted water is restored to an acceptable state before being released into the environment.

2 RESEARCH PROBLEM

Gold mining impacts on the water quality as it causes moderate to severe changes in the physical and chemical characteristics of the water. Though there is enough proof about the levels of surface water pollution as a result of mining activities, little effort is going into the remediation of polluted sites and the minimisation of pollution. This research aims to identify sustainable ways to ensure that polluted surface water is remediated before it is released into the environment especially at abandoned mine sites where mining activities have ceased. The objective of the study was, after analyses of the surface water quality characteristics of the study site, and a review of past and current surface water treatment techniques, identify an appropriate, applicable and cost effective treatment system to treat the contaminated surface water.

To achieve the goal of this study, the following was undertaken:

- A preliminary literature review of the impact of the gold tailing dams on the environment.
- Information with regards to the study site was collected. A site specific investigation of the Princess Dump was done to identify the environmental impacts of the abandoned TSF and the potential to pollute the surface water in the area. The investigation aimed to identify failures of the TSF and how these failures have affected the surrounding environment.
- Surface water samples were collected at the site and analysed in order to determine the chemical and physical water quality parameters concentrations. In this study, analysis of the water quality parameters was restricted to the inorganic constituents (physical and chemical constituents) of the water.
- Surface water monitoring data was also obtained from DWAF.
- The data was scientifically analysed and the results interpreted with the aim of identifying the possible point and non-point sources of pollution. This included an analysis of the water quality physical and chemical parameters and an evaluation of the impacts of the mine impoundment on the surface water systems around the study site.
- Different surface water treatment systems, active and passive, were analysed and a comparison made between the technologies to identify their merits and demerits.
- After considering the water quality and the site specific opportunities and constrains, appropriate surface water treatment systems were identified to treat the contaminated surface water emanating from the study site.

The author focused on the worst case scenario of the contaminated surface water based on the analysed water quality data. That is, the data showing the poorest water quality characteristics identified was used to assess and identify the treatment systems that would effectively treat such contamination.

Other aspects that impact negatively on the environment, such as organic pollution, dust pollution and radiation risks were not included in the study due to time and budget constraints.

3 MOTIVATION AND OBJECTIVES OF STUDY

The motivation for the study was based on the fact that:

- Water is a scarce resource in South Africa and the available water resources are being polluted by industrial and domestic effluents, mine drainage, agricultural runoff and litter. Therefore sustainable remediation techniques need to be identified and applied on contaminated sites to ensure that pollution is reduced and or mitigated.
- The impacts associated with polluted water are far reaching in terms of affecting the use of the water in the vicinity of the site and downstream. As the run-off water from the site goes down stream, it was necessary to ensure that pollutants are not carried down stream at the same time.
- The presence of contaminated water creates a health hazard both to human life and aquatic health. The study aimed to contribute to the improvement of the ecosystem around the site.

This research is important because the outcomes of the study can be applied not only to the study site but also to other sites which have similar pollution problems within the country and elsewhere.

4 DESCRIPTION OF THE STUDY SITE

4.1 LOCATION

The Princess Dump study site is an old and abandoned gold tailings dam located in Davidsonville, Roodepoort, West of Johannesburg at Longitude 27º55'00"E and Latitude 26º09'30"S, approximately 3 km North-West of Durban Roodepoort Deep Gold Mine (DRD). The TSF area falls within the Upper Klip River sub-catchments, which falls within the Klip River catchments, a tributary to the Vaal River. The exact date of deposition of the tailings is unknown but records indicate that the gold tailings dam predates 1933 (SRK, 2006). Much of the property on the site falls under City of Johannesburg, with a smaller portion owned by Grifo Property Investments (SRK, 2006).

The site has not been closed or rehabilitated as required in terms of South African legislation which is intended to protect the environment and human health from pollution risks that source from the TSF.

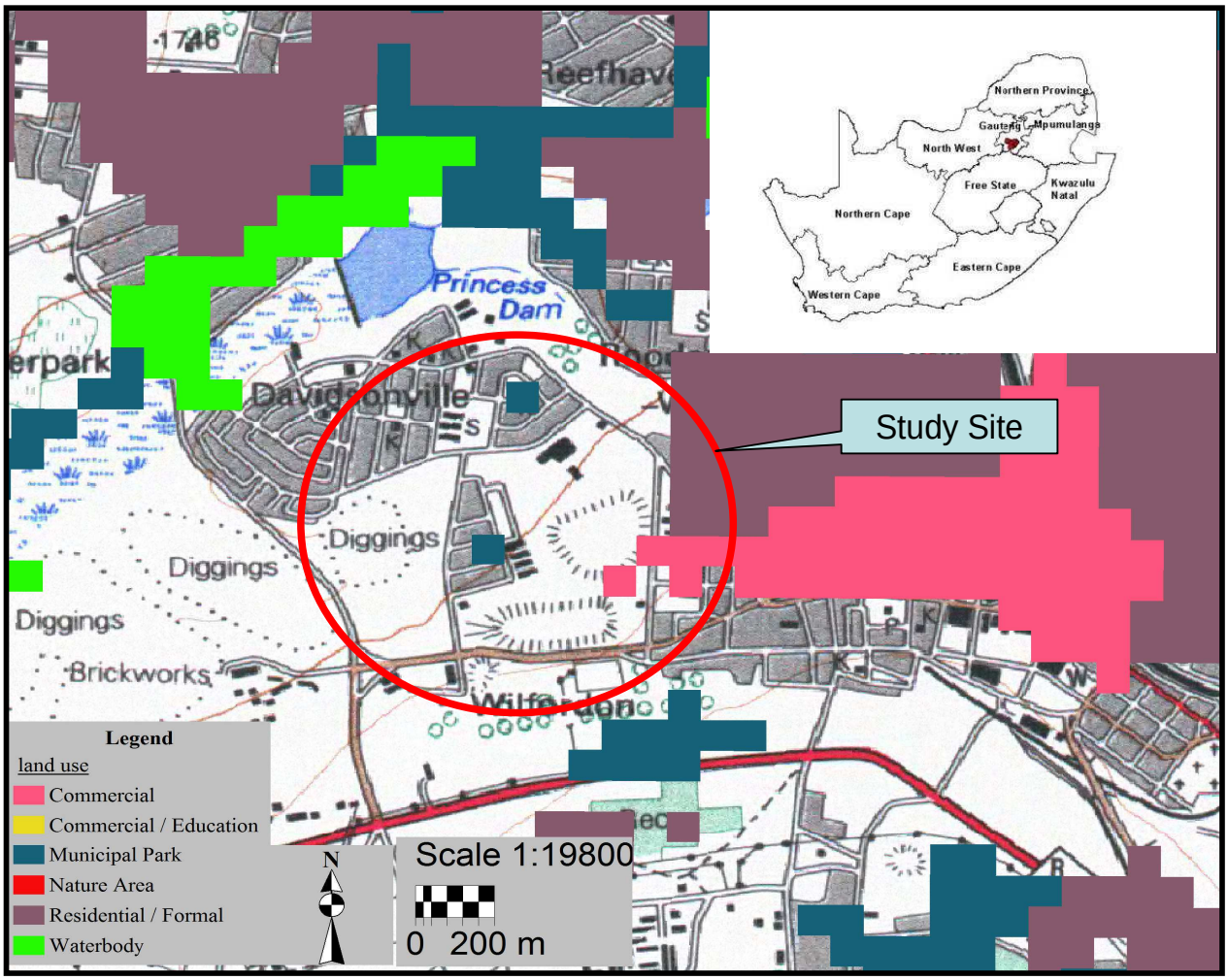


Figure 1: Location of the Study Site and the surrounding land use (SA1:50000 topographical map).

The Davidsonville area, where the TSF is located and its environs are characterised by a wide spectrum of land uses which include residential and commercial developments as shown in the Figure 1 above.

Princess Dump provides an example of the environmental and health risks caused by failure to rehabilitate a gold tailings dam. The TSF characteristics include the unprotected slopes, which are susceptible to wind and water erosion and the uncontrolled surface drainage which is continuously eroding the tailings into nearby waterway and wetland. The surfaces are exposed since there is little or no vegetation on the surface, there are disturbances occurring on the site due to various activities such as driving over the TSF and the small industries (the brick making industry) located at site. There is easy access to the site from existing roads since there is no fencing. Due to the disturbances occurring on the TSF, there is increased erosion of tailings which are chocking the water system in the vicinity.



Figure 2: An aerial photo of the TSF and positions from where the pictures below were taken from.



Position A facing south – Showing the impact of erosion on the unprotected slopes.



Position B facing west – shows metal waste disposed on the TSF



Position C facing east – shows eroded tailings leaving the TSF.



Position D facing west – shows eroded tailings leaving the TSF.

Figure 3: Site Photographs

There is a manmade wetland that has developed to the west of the TSF as a result of the previous mining activities, seepage and municipal discharge. Tailings sediments that leave the TSF have contaminated the artificial streams, manmade wetland and other riparian zones around the site as shown in the Figure 4 below.



Position E - facing West



Position E – facing South West

Figure 4: The sedimentation of eroded tailings into nearby water bodies.

The water in the vicinity of the TSF is visually observed to have a “yellow boy” colouration which is an indication that the water has come into contact with pyrite.



Figure 5: The “yellow boy” colouration of the water in the wetland.

NB: Notice the closeness to the houses in the background (Davidsonville) at approximately 150 meters from the polluted man-made wetland.



Figure 6: Contaminated seepage from the TSF near the wetland.

The ecological integrity of the watercourse and manmade wetland adjacent to the TSF has been severely compromised by the polluted runoff, seepage and deposition of eroded tailings. Also there are small tailings heaps deposited around the manmade wetland that are an additional source of pollution.



Figure 7: A tailings heap in the manmade wetland area.

There is evidence of serious environmental degradation that has, and is, continuously occurring on the site and surrounding areas as a result of the abandoned TSF presence. The quality of surface run-off has become increasingly compromised, rendering it a threat to the receiving surface water environment and a potential human health risk. Visually, the impact of the contaminated water on the surface water system is striking. The colour of the water in the wetland and the waterway has reddish brown ochre which is evidence of the ‘yellow boy’.

The TSF is located close to the densely populated settlement of Davidsonville. Some of the houses within this settlement have been erected at the foot of the TSF. This creates the potential risk to human

life. Also there is the potential risk of people in the settlements utilising the water for domestic or recreational activities.

4.2 CLIMATE

The study site has a typical Highveld climate with warm to hot summers (October – March) and cool but generally cloudless winter days with cold nights. Light frost is common and snow is an exceptional occurrence. The site is located in a relatively high altitude ground with elevation of 1758 meters above sea level. Prevailing wind direction is North-Westerly with an average speed of about 4m/s. Winds in the region are light except for short periods, particularly in the spring months of September and October just before the rains when strong winds are experienced.

4.3 TEMPERATURE

The temperature in the region is sub-tropic with the warmest month being January, with an average daily maximum temperature of 26^0C and 17^0C in July. Average minimum daily temperature ranges from about 15^0C in January to 4^0C in July.

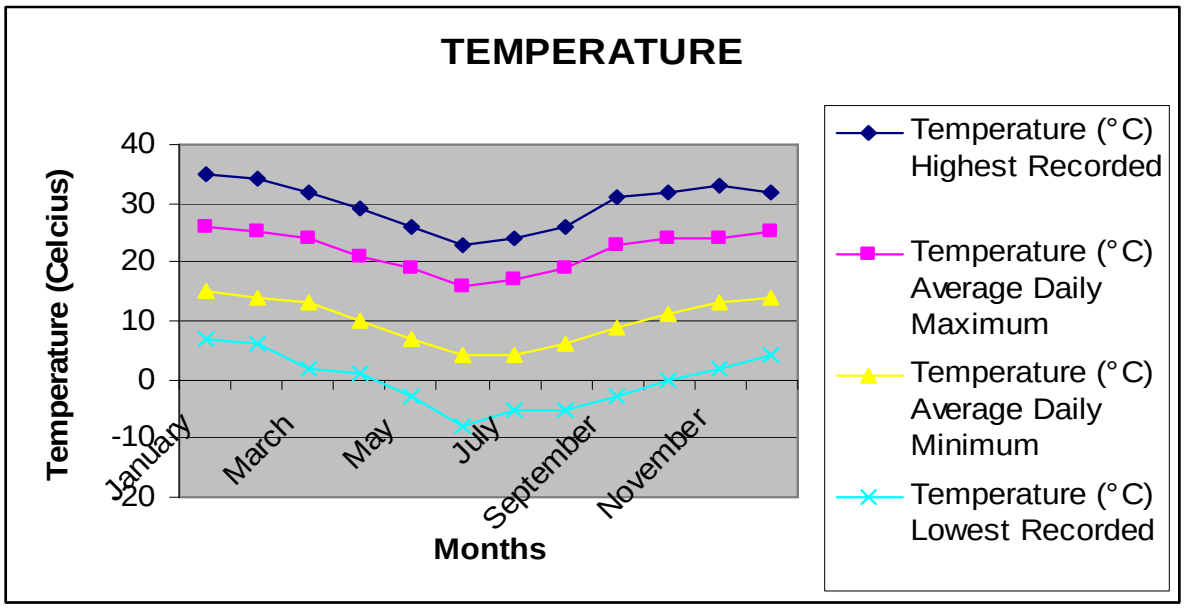


Figure 8: Average temperatures for the period January 1960 to December 1990 (Source: South Africa weather service).

4.4 RAINFALL AND EVAPORATION

Rainfall is almost exclusively due to showers and thunderstorms and falls mainly in summer. The highest rainfall occurs in January and the lowest in July. The average rainfall is between 600-750mm per annum.

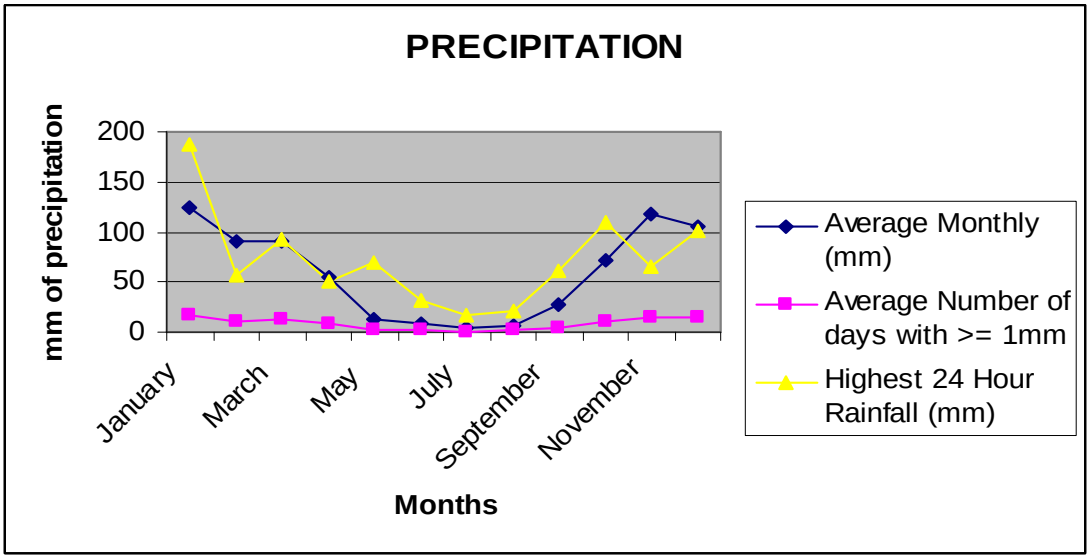


Figure 9: Average monthly rainfall for the period January 1960 to December 1990 (Source: South Africa Weather Service).

Average evaporation in the area amounts to 1600-1700mm per year. Evaporation is highest during the summer month of December (176mm) and lowest during the winter month of June (70mm). The amount of evapotranspiration affects the amount of surface runoff as it exceeds the precipitation every month of the year.

4.5 GEOLOGY AND SOILS

The geology of the study area comprises of a thick sequence of sediments overlain by Achaean sedimentary rocks. The surface geology of the site is dominated by quartzite and conglomerates of the Central Rand Group, a sub division of the Witwatersrand Super group (Figure 10). Fresh, hard rock dolomite is encountered at depths ranging from 0 – 50m below ground (DWAF, 1999).

Soils in the study area are predominantly sandy loams, red, yellowish soils with low to medium base status (SRK 2006). The soils are derived from the weathering of the underlying dolomite and quartzite. The site is highly susceptible to erosion which in turn results in a high sediment load that end up in water streams increasing the water course siltation, water turbidity and decreasing the water quality around the site (Kruger, 2004).

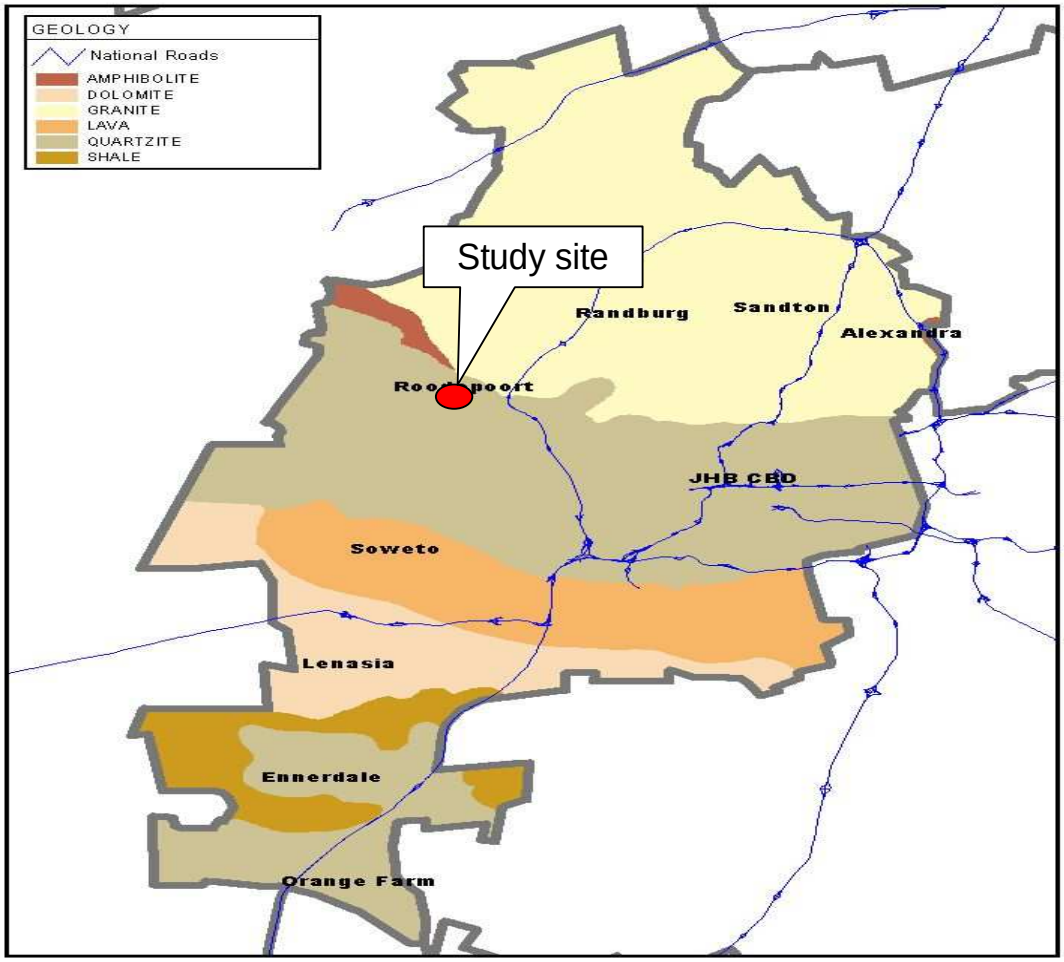


Figure 10: Area surface geology.

4.6 SURFACE WATER HYDROLOGY

The surface water flow patterns shows that the streams drain reef outcrop areas and from the TSF's that have been established on them. The area has undergone change to the extent that it hydrological system can no longer be regarded as a natural system but rather as a man-made system. This is because the natural features such as streams and wetlands have been impacted upon by human activities such as mining, creation of retention dams, roads and bridges.

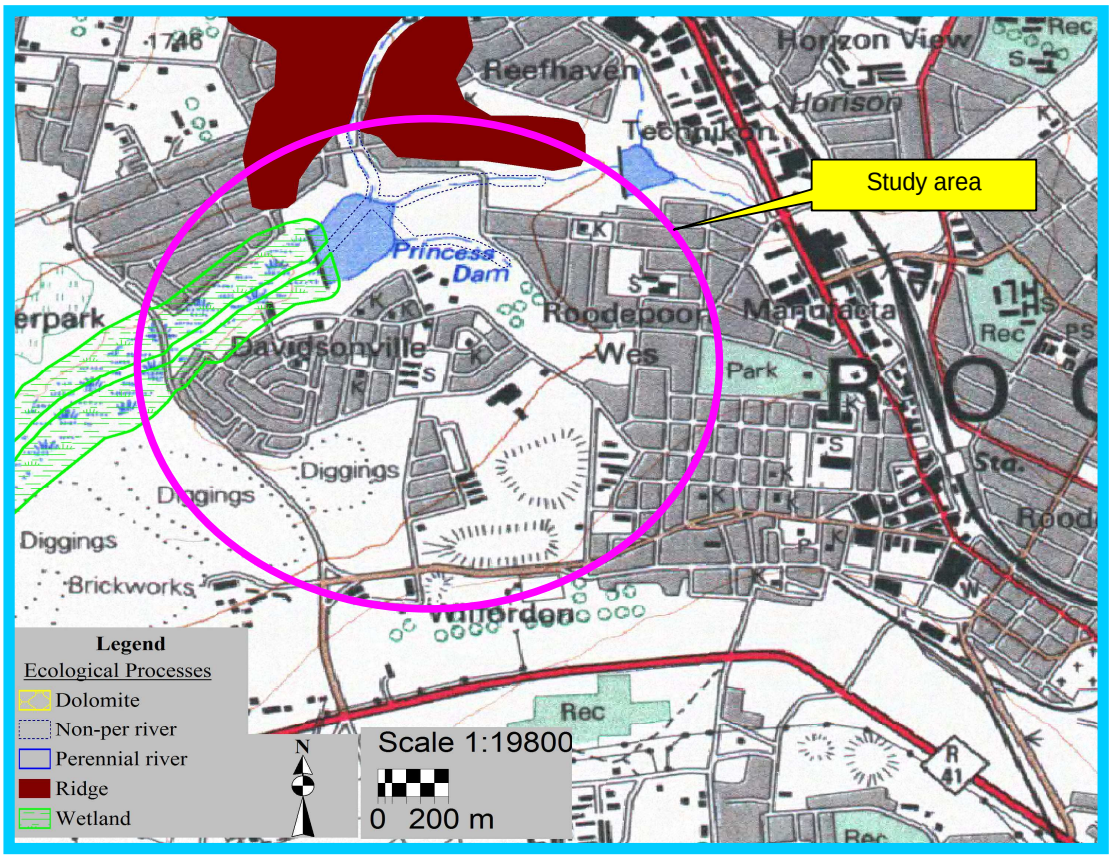


Figure 11: The surface hydrology around the study site.

5 LITERATURE REVIEW

5.1 INTRODUCTION

Mining is the second only to agriculture as the world's oldest and most important industry. Gold mining has long been an important part of the South African economy. In many cases, however, past mining activities have left a legacy of environmental degradation, and nearby communities struggle to cope with the environmental burdens associated with abandoned mining structures left behind (Robins, 2004). Gold TSF's are mine structures that have a long term impact on the environment.

Much of the skyline in the gold rich Witwatersrand basin is dotted with the conspicuous TSF's that serve as evidence of the history and the extent of the gold mining that has and is taking place within the basin. With the evolution of the mining industry and the different mines changing ownership, some of the TSF's in the region have been left uncared for and therefore in a position to cause environmental problems.

TSF's typically represents the most significant environmental liability associated with gold mining operations (Martin *et al.*, 2002). They contain numerous metal and non-metal residues from the minerals worked, along with concentrations of the process chemicals. Bell & Donnelly (2006) noted that the presence of potential environmentally harmful substances on these facilities may not necessarily require remedial action, that is if it can be demonstrated that they are inaccessible to living things or material that may be detrimentally affected. Consideration however must be given to the migration of substances especially by water or wind.

In the past, mine residues were deposited indiscriminately without regard to the environment, often adjacent to streams or on steep slopes (Steffen *et al.*, 1988). Poor design, construction, and management, in particular, of some of the older TSF's resulted in erosion and contaminated seepage that adversely affected both surface water and ground water. Currently all TSF's in South Africa release leachate to some degree since there are no lined TSF"s that have been constructed in the country (Reichardt, 2007).

The impact of gold mining on the water resource may range from minimal to severe. The effects depend on the location of the mine, the hydrology and the climate of an area, and the physical and chemical properties of the ore body and the associated geological strata. (Bridgett, 2001). Water from these gold mine residue structures is characterised mainly by acidic conditions (low pH) and high concentrations of dissolved metals caused by pyrite oxidation and blasting residue. Cyanide and radionuclide contamination may also occur as water seeps from the facility.

TSF's present two significant types of long-term environmental risks (i.e. the potential to cause environmental damage):

- The risk of the tailings dam structure failing;
- The risk of pollution. (McCauley *et al.*,2006)

In the absence of effective environmental management, TSF's on-site may also cause further impacts off-site, resulting from the water and wind erosion of unstabilised tailings. Eroded tailings and seepage of polluted water from the TSF's adversely affects the water system in the surrounding areas in a number of ways. These effects may include sedimentation of surrounding streams, and an additional decrease in water quality through the increase in salinity, acidity, and toxic element load in these streams (Wong *et al.*, 1999).

In the past, impacted surface water systems were considered unrecoverable and an unavoidable consequence of mining development (Geller *et al.*, 1998). According to Pullies, *et al.*, (1996), South Africa mining industry has not been able to cost-effectively eliminate acid saline conditions with mobilised dissolved metals and nutrient enrichment caused by pyrite oxidation of mine structures. Prior to the introduction of the Water Act in 1956 (Act No. 54 of 1956), very little was known in South Africa about the detrimental environmental impacts of polluted mine drainage. At closure of operations, mine residues were abandoned without the implementation of adequate pollution control measures. As a result, many of South Africa's water resources have become contaminated by various polluting constituents, which seep into water environments from mining sites thereby degrading water quality and limiting its usefulness (Jeanne, 1997).

This pollution impacts decreases the standards of the water quality making it unfit for original uses such as agriculture, recreation, human consumption, aquatic life and habitat as well as commercial and industrial use. Maintaining good quality of water is an important factor in determining the quantity of water that is potentially available for productive use.

The cumulative degradation of surface water due to pollution results in water with poor characteristics such as pH fluctuations and decrease in oxygen content caused by sewerage discharges. This poor quality water can have far-reaching economic impacts, including the erosion of property values, impact on the water supply for informal settlements, loss of aquatic wildlife, and the impairment of other recreational activities.

The long-lasting ability of TSF's to pollute were often not fully appreciated in the past, and consequently not properly considered when waste was disposed of. However, new closure drivers,

including ecological integrity, social equity and economic viability of mines, have reinforced the need to rehabilitate these facilities (Robins, 2004).

5.2 WATER QUALITY

Water quality is a term used to describe the chemical, physical and biological characteristics of water, usually in respect to its suitability for an intended purpose. South Africa is a semi-arid country and freshwater is limited natural resource. Water availability in the country now and in the future is heavily dependent on climate, water use and management and land-use practices (Pullies *et al.*, 1996).

The scarcity of water in South Africa is compounded by pollution of the surface and ground-water resources mainly by anthropogenic activities. The typical pollutants of South Africa's freshwater environment include industrial effluents, domestic and commercial sewage, acid mine drainage (AMD), agricultural runoff, and litter (Davies *et al.*, 1993). Population growth, increased economic and intensification of land use practices all lead to increased water demand and increasing degradation of the resource (Davies *et al.*, 1993). The primary results of the water pollution include extensive habitat loss, a decrease in biodiversity and an increase in invasive and alien species (MMSD, 2001). In extreme cases, these can result in ecological collapse of the functioning of the natural ecosystems (Wildman *et al.*, 1999).

Impacts on water quality are considered to be the most significant consequence of gold mining activities. This is partly because of the wide variety of undesirable contaminants that are derived from the mining operations and partially due to the frequency and persistence of the pollution problems. That is, the source remains there in perpetuity and is subject to potential leaching and seepage over the long term and often the present chemical contaminants have synergistic effects on a variety of different environmental components, increasing the levels of contamination and these can seldom be reduced or ameliorated.

According to MMSD, 2001, the five key areas of impact that gold mining may have on water systems are:

- Acid mine drainage (AMD);
- Release of metals;
- Cyanide;
- Erosion and Sedimentation; and
- Water use.

- These are discussed below.

5.2.1 Acid Mine Drainage

Acid Mine Drainage (AMD) is the mining industry's greatest environmental problem and its greatest liability, especially to the water bodies (Kyeyune, 2000). AMD forms from the natural oxidation of sulphide minerals, notably pyrite (FeS_2), that occur in mine rock or waste that are exposed to air and water. This is a consequence of the oxidation of sulphur in the material to a higher state of oxidation and, if aqueous iron is present and unstable, the precipitation of ferric iron with hydroxide (Bell & Donnelly, 2006). AMD does not occur if the sulphide minerals are non-reactive or if the rock contains sufficient alkaline material to neutralise the acidity (Bell & Donnelly, 2006).

In addition, the biotic micro-organism, *Thiobacillus ferrooxidans* may accelerate (catalyse) the acid generation reaction by enhancing the rate of ferrous iron oxidation, and reduced sulphur oxidation (Bell & Donnelly, 2006). The breakdown of pyrite and other sulphides by water or air releases acid, sulphates and metals into the environment. The main reactions involved are:

$$2FeS_2 + 2H_2O + 7O_2 \rightarrow 2FeSO_4 + 2H_2SO_4 \quad (1)$$

$$4FeSO_4 + O_2 + 2H_2SO_4 \rightarrow 2Fe_2(SO_4)_3 + 2H_2O \quad (2)$$

$$Fe_2(SO_4)_3 + 6H_2O \rightarrow 2Fe(OH)_3 + 3H_2SO_4 \quad (3)$$

$$4Fe^{2+} + O_2 + 4H^+ \rightarrow 4Fe^{3+} + 2H_2O \text{ (bacterial catalysis)} \quad (4)$$

$$FeS_2 + 14Fe^{3+} + 8H_2O \rightarrow 15Fe^{2+} + 2SO_4^{2-} + 16H^+ \quad (5)$$

The system is autocatalytic: the earlier reactions catalyse the later ones. This makes it difficult to stop their action series once it has started (MMSD, 2001).

The bacterium catalysis (Equation 4) is most active in waters with low pH value around 3.2 (Bell & Donnelly, 2006). The formation of sulphuric acid in the initial oxidation reaction (Equation 1) and concomitant decrease in the pH makes the conditions more favourable for the biotic oxidation of the pyrite. The biotic oxidation of pyrite is four times faster than the abiotic reaction at pH 3.0 (Bell & Donnelly, 2006).The character and rate of release of the AMD is influenced by various chemical and biological reactions that occur at the source of acid generation..

Acid generation gives rise to elevated levels of heavy metals and sulphates in the water, which pollutes natural waters and can be precipitated on or in sediments (Bell & Donnelly, 2006). Environmental consequences of AMD polluted waters include:

- Decrease in water quality. This is as a result of low pH due to increased acidity, which results in among others death of aquatic life, loss of biodiversity, salination of the water resource, and contamination of ground water (Kyeyune, 2000).

- Accelerated breakdown of gangue minerals that release lithophile elements, such as aluminium, manganese, iron, barium, as contaminants into the environment (Kyeyune, 2000). These processes also result in the formation of new secondary minerals which may have different geotechnical properties and therefore compound the pollution in the water (Kyeyune, 2000).

- Attacks buildings, culverts and bridge structures, resulting in shorter than normal life span for those types of structures (Kyeyune, 2000).

AMD, once started, can last for a long period, and its impacts can migrate many kilometres downstream. There are three key strategies in AMD management, namely, control of acid generation process, control of acid migration and collection and treatment of AMD (Bell & Donnelly, 2006).

5.2.2 Release of metals

Acidic conditions due to AMD can lead to elevated concentrations in water of trace metals, such as aluminium, iron, manganese, lead, copper, cadmium as well as radionuclides. Bridgett (2001) states that metal salts becomes soluble and add toxic pollutants to the water resource which have the potential to accumulate in the liver and the gills thereby interfering with the oxygen exchange in the aquatic environment.

In addition to these inorganic pollutants, there are also a large number of synthetic and persistent organic pollutants resulting from anthropogenic activities that can impact negatively on the water quality. These compounds when they exist in levels above the acceptable limits are harmful to living organisms.

5.2.3 Cyanide

Cyanide, a highly toxic substance, is used to oxidise gold and stabilise it in solution (“pregnant solution”) as a gold-cyanide complex (MMSD, 2001).Gold is later recovered, but cyanide remains in the waste slurry which ends up on the TSF’s. (MMSD, 2001). This cyanide can be released into the water environment through runoff and or seepage causing further pollution.

5.2.4 Erosion and Sedimentation

When erosion susceptible material is not well protected from disturbance and erosion forces like water runoff, large quantities of sediment are eroded and transported downstream. The sediment eventually drops out of the water and sedimentation occurs downstream from the erosive source. The degree of

erosion and subsequent sedimentation depends on the degree to which the surface has been disturbed, the prevalence of vegetative cover, the slope length, and the degree of the slope (Bell & Donnelly, 2006). TSF's normally possess chemical and physical characteristics that prevent the re-establishment of plants without some form of prior remedial treatment thereby making them more prone to erosion due to the lack of a cover layer.

Erosion and sedimentation adversely affects water ways and water bodies resulting in the loss or alteration of habitats for aquatic organisms and changes in water quality. This also promotes terrestrial ecological changes associated with disturbed areas, including the establishment of alien invasive plant species, altered plant community species composition and loss of habitat for indigenous fauna and flora (MMSD, 2001).

5.2.5 Water Use

Water use is dependent on the water quality. The salinity (the salt in the water) of the fresh waters of South Africa varies substantially depending on geology and atmospheric deposition (DWAF, 1998). Man-made salinity impacts include:

- Discharge of municipal and industrial effluents;
- Urban storm water runoff;
- Surface mobilisation of pollutants from mining and industrial operations;
- Seepage from waste disposal sites; and
- Irrigation water (DWAF 1998).

The water quality variables of most concern with regards to salinity include Total Dissolved Solids (TDS) and sulphates (DEAT/DWAF, 1998).

The impacts of salinisation include reduction in crop yields where water is used for agricultural purposes, increased scale formation and corrosion in domestic and industrial water conveyance systems, and increased requirement for pre-treatment of selected industrial water uses (such as boiler feed water) (Bell & Donnelly, 2006).

Water quality management involves efforts to control the physical, chemical and biological characteristics of water (Bridgett, 2001). Water quality monitoring aims to obtain quantitative information to determine the trends in the quality and establish whether the observed water quality is suitable for the intended uses.

In designing a water remediation strategy for a contaminated site, knowledge of the physical and chemical composition of water is required prior to identification of any remediation technology (Geller *et al.*, 1998).

5.3 REGULATORY GUIDELINES

The South African Water Quality Guidelines serve as the primary source of information for determining the water quality requirements of different water uses and for the protection and maintenance of the health of aquatic ecosystems. Table 1 below indicates the water quality parameters utilised for biological, physical and chemical water quality analysis.

Table 1: Water Quality Parameters utilised for biological, physical and chemical analysis (DWAF 1998)

Biological	Faecal coliforms
	Total coliforms
	Free available chlorine
Physical	pH*
	Conductivity*
	Turbidity
	Temperature*
Chemical	Arsenic
	Cadmium
	Calcium
	Sodium
	Chlorine
	Copper
	Fluoride
	Dissolved iron*
	Dissolved manganese*
	Total hardness
	Total alkalinity
	Magnesium
	Nitrate and nitrite
	Potassium
	Sulphate*
	Zinc
	Dissolved aluminium
*** denotes parameters used in the study.**	

For the purpose of this study, only the inorganic (chemical and physical) parameters were included, as these were considered the most pertinent to the evaluation of the water quality with respect to gold TSF. The inclusion of other parameters is feasible but beyond the scope of this study. The parameters that were utilized in the analysis are the following; pH, Conductivity, Temperature, Iron, Manganese and Sulphates. These parameters were evaluated in terms of the TWQR as stipulated in the Water Quality Guidelines according to a determined use (Table 2). The South African Water Quality Guidelines serve as the primary source of information for determining the water quality requirements for different water uses and for the protection and maintenance of the health of aquatic ecosystems.

Table 2: The Target Water Quality Range (TWQR) for the parameters used in the study as per use.

Water quality parameter	Unit	SANS 241 Class 1	Industry (Cat1)	Irrigation	Aquatic system	Domestic use
Aluminium	mg/l	N/A	NA	0-5	0-0.005	0-0.15
Calcium	mg/l	<150	NA	0-200	-	0-32
Chloride	mg/l	<200	0-20	0-150	-	0-100
Conductivity*	mS/m	<150	NA	0-19	-	0-40
Iron*	mg/l	<0.2	0-0.1	0-5	0-1	0-0.1
Magnesium	mg/l	<70	NA	0-200	-	0-30
Manganese	mg/l	<0.1	0-0.05	0-1	0-0.05	0-0.05
pH*	-	5.0-9.5	7-8	6.5-8.5	6.5-9	6-9
Sodium	mg/l	<200		<10	-	0-100
Sulphate*	mg/l	<400	0-30	0-600	0-400	0-200
Total alkalinity	Mg $CaCO_3$/l	Unspecified	0-50	<0.2	NA	NA

* Denotes parameter used in the study.

NA – not available/Not established in DWAF Water Quality Guidelines

5.4 SURFACE WATER TREATMENT TECHNOLOGIES

5.4.1 Introduction

The generation of Acid Mine Drainage (AMD) is a natural process that becomes accelerated and intensified by mining (Metesh *et al.*, 1998). AMD events are more persistent in the environment since the metal pollutants remain in the environment in one form or another (Evangelou, 1995). Under certain conditions like winter, metals maybe concentrated in the environment and others they may be dispersed (Foster, 1998). Without appropriate treatment, there are no controls as to where these metals are concentrated or dispersed and they therefore continue polluting the local environment for extended periods of time (Foster, 1998).

A wide range of technologies are available for the remediation of AMD contaminated sites. The applicability of a particular method depends on the site conditions, the nature and extent of contamination, and the extent of remediation required (Bell & Donnelly, 2006). In some cases the remedial operation requires the employment of more than one method. It is necessary that the remedial work does not raise the pollution on site or in the immediate surroundings to unacceptable levels.

The types and amounts of pollutants especially metals in the water heavily influence the selection of an AMD treatment system (Skousen, 1998). Keeping a water treatment system at the optimal pH and redox potential for precipitation of target metals ensure successful water treatment (ecosystem restoration, 2007). The pH required to precipitate most metals from water ranges from pH 6 to 9 (except ferric iron which precipitates at about pH 3.5). Soluble manganese changes to insoluble manganese hydroxide at a pH of 9.5 or greater (ecosystem restoration, 2007). It is therefore necessary to ensure that the optimum pH is maintained for the precipitation of target metals.

Surface water treatment option can be grouped into:

- Active treatment systems; and
- Passive treatment systems.

5.4.2 Active Treatment Technologies

Active treatment is the improvement of water quality by methods which require ongoing input of energy and/or (bio) chemical reagents. It involves chemical neutralisation of the acidity followed by precipitation of metals and other suspended solids. According to Bell & Donnelly (2006), the classic approach to active treatment of AMD involves three steps:

- First, oxidation , that helps convert soluble ferrous iron to the less soluble ferric state, as well as permitting the pH value to raise by venting carbon dioxide, where present, until equilibration with the atmosphere has been achieved.
- Second, dosing with alkalis, generally hydrated lime [$Ca(OH)_2$] or caustic soda [NaOH], which raises the pH value, thereby lowering the solubility of most problematic metals and providing hydroxyl ions for rapid precipitation of metal hydroxides; and
- Third, accelerated sedimentation normally brought about by using a clarifier or lamellar plate thickener, frequently aided by addition of flocculants and/or coagulants.

According to DWAF (2007), active treatment technologies of contaminated mine water include chemical or biological processes and can be broadly subdivided into:

- pH modification;
- Metal precipitation;
- Ion exchange;
- Biology-based technology (sulphate reduction/removal);
- Adsorption technology;
- Electrochemical technology; and
- Physical process technology (gravity settling, filtration, evaporation).

These processes are discussed below.

a) pH Modification

The basis of such treatment is to raise the pH of the AMD causing first the iron, and then other metals, to precipitate out of solution. Lime treatment is used for this chemical process (Foster, 1999).

b) Metal Precipitation

Metals found in AMD water occurs because they are present in the ore body which was mined similar to pyrite. The metals naturally dissolve from the slow weathering over time. The dissolution process is sped up when the pH of the water is outside of the neutral range. The treatment systems aim to form insoluble and stable hydroxides of the metals. This is achieved by adjusting the pH to within the neutral range of 6 - 9.

c) Ion Exchange

Ion exchange technology is utilised as an active treatment technology to strip valuable metals from the mine water before it is limed and subsequently extracting the metal from the ion-exchange material in a far more concentrated form. It is often a very expensive process (Foster, 1999).

d) Biology-Based Technology

This involves the use of the sulphate reducing bacteria to produce a biologically-based active treatment system (Foster, 1999). The bacteria require a good carbon-based substrate for metabolism but use sulphate instead of oxygen (Foster, 1999). Another example of biologically-based treatments is the use of biologically-produced adsorbents for the concentration of metals from the waste stream (Foster, 1999).

e) Adsorption Technology

The aim of this process is to utilise particles of known size and density (non-biological adsorbents) to adsorb the metals from solution and to exploit knowledge of physical processes in the separation of the solids later in the treatment (Foster 1999).

f) Electrochemical Technologies

This involves the use of electrical technologies in the treatment of AMD. The problems that may be associated with the use of such technology include the requirement for nearby technical support and a constant electrical supply (Foster 1999).

g) Physical Process Technology

This involves utilising physical process technology such as gravity, filtration and evaporation to remove the metals from AMD as salt crystals rather than as sludges or precipitates (Foster, 1999).

- Neutralising chemicals

There are different chemicals used as neutralising agents for the treatment of acidic water and each chemical has characteristics that make it more or less appropriate for a specific condition (Skousens *et al.,* 1998). The best choice among alternatives depends on both technical and economic factors. The technical factors include acidity levels, flow, the types and concentrations of metals in the water, the rate and degree of chemical treatment needed, and the desired final water quality (Skousens *et al.,* 1998). The economic factors include prices of reagents, labour, machinery and equipment, the number of years that treatment will be needed and risk factors (Skousens *et al.,* 1998). The following discussion highlights some of the characteristics of each of these neutralising agents.

a) Limestone (calcium carbonate)

Calcium forms calcium carbonate which is alkaline thereby neutralising the acidity of the water. Advantages of using limestone include low cost, ease of use, and formation of a dense, easily handled, sludge. Disadvantages include slow reaction time, low solubility, loss in efficiency of the system because of coating of the limestone particles with iron precipitates, difficulty in treating AMD with a high ferrous-ferric ratio, and ineffectiveness in removing manganese (Acid mine treatments and costs, 2006).

b) Hydrated Lime (calcium hydroxide)

Hydrated lime is an easy, safe to use, effective, and relatively inexpensive neutralising agent. The major disadvantages are the voluminous sludge that is produced (when compared to limestone) and high initial costs that are incurred because of the size of the treatment plant (Acid mine treatments and costs, 2006).

c) Soda Ash (sodium carbonate)

Soda ash briquettes are especially effective for treating small AMD flows in remote areas (Skousen *et al.,* 1998). Major disadvantages are higher reagent cost (relative to limestone) and poor settling properties of the sludge (Acid mine treatments and costs, 2006).

d) Caustic Soda (sodium hydroxide)

Caustic soda is especially effective for treating low flows in remote locations and for treating AMD having high manganese content (Acid mine treatments and costs, 2006). Caustic is very soluble in water, disperses rapidly, and raises the pH of the water quickly (Skousen *et al.,*1998). Major disadvantages are its high cost, the dangers involved with handling the chemical, poor sludge properties and freezing problems in cold weather (Acid mine treatments and costs, 2006).

e) Ammonia

Anhydrous ammonia is effective in treating AMD having a high ferrous iron and/or manganese content. It is highly soluble and reacts rapidly to raise the pH and precipitate metals. Ammonia costs less than caustic soda and has many of the same advantages (Acid mine treatments and costs, 2006). However, ammonia is difficult and dangerous to use and can affect biological conditions downstream from the mining operation. The possible off-site impacts are toxicity to fish and other aquatic life forms, eutrophication and nitrification (Acid mine treatments and costs, 2006).

Each of the above mentioned chemicals has advantages and disadvantages for certain water conditions, site conditions and the treatment required. Under low flow situations, pebble quicklime and ammonia

are the most cost effective (Skousen *et al.,* 1998). Under high flow situations, hydrated lime and pebble quicklime are the most cost effective due to their low reagent cost compared to the other chemicals (Skousen *et al.,* 1998).

- Analysis of Active Treatment Systems;

According to the US Office of Surface Mining Reclamation and Enforcement, active treatment involves chemical neutralisation of the acidity followed by precipitation of metals and other suspended solids. These treatment systems require:

- Equipment for feeding the neutralising agent to the AMD;
- Means for mixing the two streams (AMD and neutralising agent);
- Procedures for ensuring metal oxidation;
- Settling ponds for removing iron, manganese, and other co-precipitates; and
- Constant maintenance of the system such as supply of lime and transportation of the waste generated from the site.

The major advantages identified for the active treatment systems are:

- Effective removal of acid and metals;
- Frequent process monitoring;
- Precise process control;
- Can be accommodated at small sites; and
- Design is similar to conventional waste water plants.

The major disadvantages identified for the active treatment systems are:

- Initial capital costs are high;
- Disposal of sludge;
- Ongoing labour costs are high; and
- Ongoing operational costs are high.

5.4.3 Passive Treatment Systems

'Passive in-situ remediation' signifies an engineering intervention which prevents, diminishes and/or treats polluted waters at source, using only naturally-available energy sources (such as topographical gradient, microbial metabolic energy, photosynthesis and chemical energy), and which requires only infrequent maintenance to operate successfully over its design life (Younger, 2001). Passive systems try to minimise input of energy, materials and manpower, and so reduce operational costs (Bell & Donnelly, 2006).

According to MEND (1996), passive treatment systems for AMD use the chemical, biological and physical removal processes that occur naturally in the environment to modify the influent water characteristics and ameliorate and associated environmental impacts. Passive treatment systems involve the use of sulphate reducing bacteria or limestone or both to neutralise acidity and precipitate metals. They are sometimes called “wetlands or “bioreactors”. They involve engineering a combination of low maintenance biochemical systems such as anoxic limestone drains, aerobic reed beds and anaerobic wetlands and rock filters for aerobic treatment of ferruginous waters (Bell & Donnelly, 2006). They are designed to funnel the AMD through limestone drains and artificial wetlands of various designs, thereby removing the acidity and metals.

Passive treatment systems are proven treatment technologies if designed and implemented properly (Skousen *et al.,* 1998). The selection and design of an appropriate passive system is based on water chemistry, flow rate and local topography and site characteristics (Wildman *et al,* 1989).

Passive treatment systems include:

a) Constructed Wetlands

Constructed wetlands are man-made ecosystems that mimic their natural counterparts. They utilise soil and water-borne microbes associated with wetland plants to remove dissolved metals from mine drainage (Skousen *et al.,* 1998). Often they consist of shallow excavations filled with a flooded gravel, soil, and organic matter to support wetland plants (Skousen *et al.,* 1998).

Treatment depends on dynamic biogeochemical interactions as contaminated water travels through the constructed wetland (Wildman *et al,* 1989). Wetlands are generally effective in removing iron and they are best utilised in the treatment of small flows of a few gallons per minute (Acid mine treatments and costs, 2006).

According to Wildman *et al*., (1989), low cost immobilisation of pollutants for long time periods is the goal of using wetlands for AMD treatment and the removal mechanisms include:

- Filtering suspended and colloidal material from water;
- Uptake of contaminants into roots and leaves of live plants;
- Adsorption or exchange of contaminants onto soil materials, live plant material, dead plant material, or algal materials; and
- Precipitation of metals in the oxidising and reducing zones catalysed by bacterial activity.

AMD contaminated water should not be routed to natural wetland for treatment because they may not have the capacity to treat the water. Instead, a wetland should be constructed to meet the needs of AMD treatment. The way in which a wetland is constructed ultimately affects how water treatment occurs. Two construction styles currently predominate:

a) Aerobic wetlands:

Aerobic wetlands consisting of wetland vegetation planted in shallow (<30 cm), relatively impermeable sediments comprised of soil, clay or mine spoil (Skousen *et al.,* 1998). They are generally used to collect water and provide residence time and aeration so metals in the water can precipitate. Because of their extensive water surface and slow flow, aerobic wetlands promote metal oxidation and hydrolysis, thereby causing precipitation and physical retention of iron, aluminium and manganese hydroxides. (Skousen *et al.,* 1998).

The extent of metal removal depends on dissolved metal concentrations, dissolved oxygen content, pH, the presence of active microbial biomass and detention time of the water in the wetland (Skousen *et al.*, 1998). The pH is particularly important because it influences both the solubility of metal hydroxide precipitates and the kinetics of metal oxidation and hydrolysis (Skousen, 1998).

Aerobic wetlands are used to treat water which has a net alkalinity (Wildman *et al*, 1989). Wetland plant species are planted in these systems for aesthetics and to add some organic matter. Wetland plants encourage more uniform flow and thus more effective wetland area (Skousen *et al*., 1998).

b) Compost/Anaerobic wetlands

Anaerobic wetlands consisting of wetland vegetation planted into deep (>30 cm), permeable sediments comprised of soil, peat moss, spent mushroom compost, sawdust, straw/manure, hay bales, or a variety of other organic mixtures, which are often underlain or mixed with limestone (Skousen, 1998). In anaerobic wetlands, treatment involves major interactions within the substrate. (Skousen, 1998).

Contaminated water passes through organic rich substrates, which contribute significantly to treatment (Skousen, 1998). Wetland plants are transplanted into the organic substrate. These systems are used

when the water has net acidity, so alkalinity must be generated in the wetland and introduced to the net acid water before dissolved metals will precipitate (Skousen, 1998).

Several treatment mechanisms are enhanced in anaerobic wetlands compared to aerobic wetlands, including formation and precipitation of metal sulphides, metal exchange and complexation reactions, microbially generated alkalinity due to reduction reactions, and continuous formation of carbonate alkalinity due to limestone dissolution under anoxic conditions (Skousen *et al*, 1998).

Since anaerobic wetlands produce alkalinity, their use can be extended to poor quality, net acidic, low pH, high Fe, and high dissolved oxygen (>2 mg/L) AMD (Skousen, 1998).

Wetland systems have naturally occurring bacteria in the sediments that is capable of reducing the sulphate in the acid to hydrogen sulphide which can react with the metals to form the metal sulphide minerals which originally caused the AMD (Skousen, 1998). More so, wetlands are engineered to enhance the efficiency of natural systems and if the metals contained within the wetland are left undisturbed, they would be unavailable and non-polluting to the environment (Skousen, 1998).

The main problems with the wetlands solution are the time it may take for a natural system to react to the, sometimes extreme, changes in water flow and the fact that whilst the water flows all year round the bacteria are most active when the weather is warm (Skousen, 1998).There is also an engineering problem where the water is required to contact the anaerobic (oxygen-free) parts of the wetland where the remedial process is most efficient (Skousen, 1998).

c) Anoxic Limestone Drains

Anoxic Limestone Drains (ALD) are buried cells or trenches of limestone into which anoxic water (water with insufficient or low oxygen) is introduced (Skousen, 1998). The limestone dissolves in the acid water, raises pH, and adds alkalinity. Under anoxic (anaerobic) conditions, the limestone does not coat with iron hydroxides because ferrous ions (Fe^{+2}) does not precipitate as $Fe(OH)_2$ at pH <6.0 (Skousen, 1998).

Allowing flow through an ALD before entrance into a wetland can improve metals removal since the additional alkalinity added to the AMD from the ALD is favourable for the chemical and biological processes that precipitate metals in wetlands (Skousen, 1998). Longevity of treatment is a concern for ALDs, especially in terms of water flow through the limestone. If appreciable dissolved ferric ions (Fe^{3+}) and aluminium ions (Al^{3+}) are present, clogging of limestone pores with precipitated Al and Fe hydroxides can occur (Skousen, 1998). For an accepted design, no Fe^{3+}, dissolved oxygen (DO), or Al^{3+} should be present in the AMD (Skousen, 1998). Selection of the appropriate water and environmental conditions is critical for long term alkalinity generation in an ALD (Skousen, 1998).

ALDs simply raise the pH and add alkalinity to acid water (Skousen, 1998). Once the water exits the drain, sufficient area must be provided for metal oxidation, hydrolysis and precipitation to occur (Skousen, 1998).

d) Successive Alkalinity Producing Systems (SAPS)

Successive Alkalinity Producing Systems (SAPS) combine the use of an ALD and an organic substrate into one system (Wildman *et al*, 1989). In SAPS, acid water is ponded from 1m to 3m over 0.2m to 0.3 m of organic compost, which is underlain by 0.5 to 1 m of limestone (Skousen, 1998). Below the limestone is a series of drainage pipes that convey the water into an aerobic pond where metals are precipitated. Water with high metal loads can be passed through additional SAPS to reduce high acidity (Wildman *et al*, 1998).

e) Bioremediation

Bioremediation of water involves the use of micro-organisms to convert contaminants to less harmful species in order to remediate contaminated sites. Micro-organisms can aid or accelerate metal oxidation reactions and cause metal hydroxide precipitation (Skousen, 1998). Other organisms can promote metal reduction and aid in the formation and precipitation of metal sulphides. Reduction processes can raise pH, generate alkalinity, and remove metals from AMD solutions (Skousen, 1998).

Passive systems use natural processes in the removal of acidity, sulphates and metals from contaminated water. These systems can treat AMD to varying degrees at lower capital and operating costs than conventional active treatment plants and they can be installed at abandoned mines and in remote locations. Because they take advantage of natural processes to improve contaminated water conditions, they do not require significant operation and maintenance. (Menesh *et al*.**,** 1998).

The nature of AMD is that it persists for long periods of time, often requiring constant low level treatment. Passive treatment systems are designed to allow little or no maintenance and should be self contained with regards to treatment and waste.

Selection of an appropriate passive system is based on water chemistry, flow rate, local topography and site characteristics. In general, aerobic wetlands can treat net alkaline water; ALDs can treat water of low Al, Fe^{3+}, and DO; and SAPS and anaerobic wetlands can treat net acidic water with higher Al, Fe^{3+}, and DO.

The major advantages of the passive treatment systems are that they:

- Do not require electrical power;
- Do not require any mechanical equipment, hazardous chemicals , or buildings;

- Do not require daily operation and maintenance;
- Are more natural and aesthetic in their appearance and may support plants and wildlife; and
- Are less expensive.

The major disadvantages associated with the passive treatment systems include:

- May not meet stringent water quality based effluent discharge; and
- May fail because of poor design or severe weather conditions such as flooding and winter (no water).

While there are potential drawbacks to these systems, passive treatment potentially offers several advantages over active treatment methods. For example, while passive treatment systems usually require larger areas for construction and do not always meet effluent standards, they may cost less than alternative methods and they offer long-term treatment. Also passive systems do not produce large volumes of sludge, the metals being precipitated as oxides or sulphides in the substrate materials.

The choice between active and passive water treatment technologies depends very much on the period in the mines life cycle since both active and passive water treatment technologies are capable of addressing primary constituent of concern typically associated with mine waters. (DWAF 2007)

6 DATA COLLECTION AND ANALYSIS

6.1 INTRODUCTION

According to Bridgett (2001), prior to sampling the study site, data collection needs to be divided into the following components:

- Selection of water quality parameters
- Locating sampling stations
- Sampling frequency
- Data collection methods.

Specific water quality parameters were chosen to describe the water quality of the local surface water. They were chosen as they represent parameters that might be influenced by gold TSF's and their subsequent increase or decrease may be impact on the quality of the water. Water quality parameters used in this study included:

- Dissolved Oxygen

Dissolved oxygen (DO) measures the amount of gaseous oxygen (O_2) dissolved in an aqueous solution (Hounslow, 1995). DO in water depend on the physical, chemical, and biochemical activities in the water body. Low DO concentrations can have harmful effects on aquatic life that require oxygen for survival. AMD leads to low DO levels in water as much of the oxygen is used up in the microbiological reactions that catalyse AMD.

- Electrical Conductance

The Electrical Conductance (EC) of a solution is a measure of the ability of a solution to conduct a current. It is a property attributable to the ions in solution. It is also an indirect measure of the Total Dissolved Solids (TDS) concentration in the water (Hounslow, 1995). The higher the conductivity, the higher the number of ions present implying more dissolved solids.

- pH

pH is a measure of acidity or basicity of the water. pH varies between 0 and 14 where lower numbers indicate more acidity and higher numbers more alkalinity. pH of most raw water usually falls within the range (6.5-8.5) (Hounslow, 1995).

Low pH is an indication of the development of the AMD. The acidic conditions cause mobilisation of trace metals into the surface water environment. Most kinds of life are adapted to live in environments that are neutral or slightly acidic in nature (pH range between 5.5 - 7.5). When environments become severely acidic (less that 5), the result is usually a drastic decline in biodiversity (Hounslow, 1995).

- Temperature

Site conditions and temperature impact the rate of chemical reactions High temperatures have the potential of enhancing chemical processes that lead to AMD generation.

- Total Suspended Solids

Total Suspended Solids (TSS) is a measure of all suspended (not dissolved) particles in a solution that do not pass a given filter size. Water high in suspended solids may be aesthetically unsatisfactory for purposes such as bathing or drinking. TSS can also block gills of aquatic organisms and settle out under low energy conditions to clog wetlands and alter the natural flow characteristics of the water course.

- Metals

The low pH value (acidic conditions) usually causes an increase in dissolved metals which are carried into the surface water and ground water environments (Hounslow, 1995). Common metal ions include sodium, iron, potassium, aluminium, calcium and magnesium.

- Sulphate

The sulphate ion (SO_4^{2-}) is a naturally occurring ion and it results from the dissolution of mineral sulphates in soil and rock, particularly gypsum (calcium sulphate). Most sulphates are highly soluble in water and therefore they tend to accumulate and progressively increase in concentration (Kruger, 2004). Increased levels of sulphate are usually the first indication of acid generation from sulphidic materials such as mine wastes (Kruger, 2004).

6.2 DATA COLLECTION

The objective of the study was to identify a remediation system while considering the worst case scenario of the polluted water. DWAF had sampled and analysed the water quality from different sampling points around the study site in the past. Some of the sampling sites relevant to this study are shown in the Figure 12 below. The sampling was done between the months of September and December 2003. This was during the rainy season. The data was used for the preliminary assessment of the water quality at the study site.

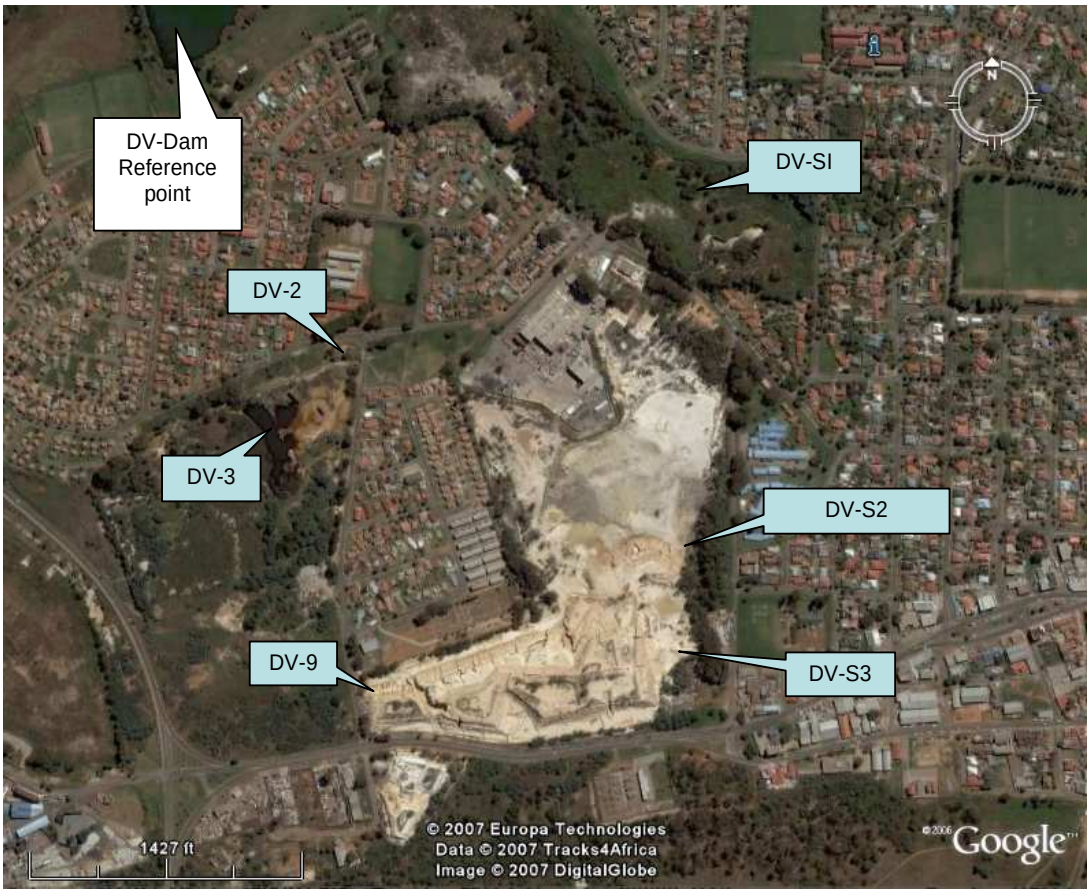


Figure 12: Princess Dump monitoring points sampled by DWAF.

Monitoring point	**Location**
DV-2	Stormwater discharge point, below park (Klip River tributary).
DV-3	Wetland area
DV-9	Stormwater runoff from TSF before entering stormwater drain
DV-S1	Water pool on Princess Dump near Hebel Street
DV-S2	Water pool on Princess Dump near Ethel street
DV-S3	Water pool on Princess Dump above seepage sump
DV-Dam	Dam adjacent to slimes, north of Hebel Street (reference point)

A summary of results of chemical analyses obtained for the selected sampling points are shown in Table 3 below. Complete DWAF laboratory results are attached in Appendix A.

Table 3: DWAF Water Sampling Results

Constituents(mg/l)	DV-2		DV-3	DV-S1	DV-S2	DV-S3	DV-9.	DV-DAM (Reference point)	TARGET WATER QUALITY RANGE (DWAF)
Date	Sept 30 2003	Dec 11 2003	Sept 30 2003	Nov 25 2003	Nov 25 2003	Nov 25 2003	Nov 18 2003	Dec 11 2003	
EC(mS/m)	625	803	1384	8	127	334	737	18	70
TDS	10388	13590	33520	64	1034	4548	20378	116	40
Total Alkalinity (As $CaCO_3$)	<10	<10	<10	<10	<10	<10	<10	42	>65
Cl	26	16	99	10	<3	<3	700	8	100
F	0.1	0.2	<0.1	0.2	0.2	0.1	<0.1	0.3	1.0
SO_4	5000	7425	17600	25	400	2240	9600	24	200
Ca	46	72	54	3.6	6.4	12	15	15	32
Mg	169	165	798	0.4	12	35	220	3.4	30
K	7	6	2	2	0.2	0.5	0.5	3.4	20
Na	49	48	208	3	3	3	5	14	100
pH(units)	2.9	3.1	2.2	5.3	2.7	2.4	2.2	7.1	>6 - <9
Cd	<0.04	0.07	<0.04	<0.04	<0.04	<0.04	0.26	<0.04	5
Cr	0.75	1.54	1.8	<0.03	0.32	1.95	8.6	<0.03	50
Co	7.9	14.6	29	<0.04	0.65	3.02	15.7	<0.04	250
Cu	4	6.1	2.5	<0.03	1.05	3.66	17.03	<0.03	1.0
Fe	1480	1516	3078	0.53	40.74	421.9	3053	1.12	0.1
Pb	0.42	0.76	0.99	0.29	0.35	0.49	0.6	0.2	80
Mn	15	****	77.7	0.13	0.32	3.28	****	<0.06	0.05
Ni	13	18.04	44	<0.06	1.23	5.17	26.1	0.05	100
Zn	12	19.3	39.5	0.03	1.16	6.25	22.3	0.3	5.0

Al	368	442	1148	0.4	59.4	149	730	***	1.5

All units in mg/l apart from EC.

The preliminary reliability of the DWAF data above was done as follows:

1. If carbonate is absent (it is less than 10 for the sites apart from the reference point), the pH should be less than 8. The pH is found to be less than 8 implying acidic conditions (Hounslow, 1995).

2. In acidic waters, sulphate (SO_4^{2-}) concentration is usually greater than calcium (Ca) concentration. The primary assumption is that SO_4^{2-} is generally the result of direct dissolution of gypsum or the neutralisation of acid waters by limestone or dolomite. (Hounslow, 1995). Preliminary observations show that there is a correlation between SO_4^{2-} and pH.

3. Conductivity (EC) is a good estimator of TDS.

   TDS (mg/l) = A* EC (µS/cm), where A=0.54 – 0.96 (approx 0.66)

   1mS/m = 0.01mS/cm = 10µS/cm

   From the above data, the values between TDS and EC do not agree according to the above equation. Therefore, the value of EC and TDS had to be investigated further.

4. An Anion-Cation balance was performed.

   Balance = $(\sum C - \sum A)/(\sum C + \sum A) *100$, where $\sum C$ is the sum of cations and $\sum A$ is the sum of anions.

   = (187.662 – 369.217)/ (187.662 + 369.217)*100 = 32.6%

A deduction which can be drawn from the balance (it is greater that 5%) is that the water may be very acidic and the H^+ ions were not included (Hounslow, 1995).

6.3 SAMPLING

During the study, the author did water sampling and measurement to establish whether there have been any significant changes in the water quality since the sampling done by DWAF and to establish the accurate electrical conductance and TDS. The sampling was done in the month of April 2007 (autumn). Samples were collected from the wetland area (DV-3) and the water course (DV-2). The sampling sites were selected after review of the previously monitored data which showed the two sampling points as having the highest levels of contamination. Also since it was after the rainy season, the other sampling points could not be sampled as they did not contain water.

Surface water samples were taken on site and analysed for pH, electrical conductivity (EC) and temperature using a portable pH/conductivity meter.

Table 4 below lists the physical water parameter results obtained from analysis carried out on the surface water at the sampled points.

Table 4: Water Quality Results

Water quality variable	**units**	**Sampled data (14 April 2007)**	
		DV-2	DV – 3(wetland)
Temperature	^{0}C	25^{0}C	25^{0}C
pH	Units	2.68	1.88
EC	mSm^{-1}	941	1413

TDS calculations:

- TDS (mg/l) = 0.66* conductivity (micromhos);
- TDS (DV-2) = 0.66* (941*10) = 6210.6mg/l (ppm);
- TDS (DV-3) = 0.66*(1413*10) = 9325.8mg/l (ppm);

From the sampled data, the values of the EC were found to agree within a good range to the data from the DWAF. Therefore, the EC values were taken to be representative of the water sample and the TDS value in the data from DWAF was discarded.

6.4 SHORTCOMINGS OF THE DATA

1. It was identified that DWAF did a once of sampling of the study site to establish the level of contamination (between the month of September and December 2003). The duration in which sampling was done by DWAF is considered a limitation, as changes that have occurred in the water quality over time could not be established and are therefore not included in the study. Data for DV - 3 for example was only available for September and not for December. However, the data was confirmed to be representative of the site conditions after the confirmation sampling carried out during the study.
2. Flow measurements of the water at the site could not be established due to the lack of engineering structures such as weirs. However, heavy surface runoff is expected at the site during the rainy season especially from the built up areas around the site. Due to the fact that there is no upstream

water flowing above the dam, the TSF was taken to be the main contributor of the surface water pollutants.

3. DWAF did its sampling during the rainy season. The author did his sampling during autumn. It is expected that during the rainy season, there was some dilution effect on the quality of the surface water by runoff from the built up areas. In autumn, this dilution is not expected and only the base flow quality was measured.

6.5 WATER QUALITY ANALYTICAL RESULTS

The study focussed on the major variables that are identified to be critical in assisting to identify the appropriate treatment option. When analysing water quality from the study site, physical and chemical parameters were used as indicators of the quality of the water. These include pH, EC (electrical conductivity), sulphates, and iron.

pH and electrical conductivity(EC): There exists a relationship between the variables EC and pH. Water with low pH usually has high EC values due to the increase in dissolved metal ions in the solution (Ji-Eun & Yeongkyoo, 2007). From the data, the low pH values obtained indicates that the water at the study site is acidic (<3.5). This was also verified during sampling where the lowest pH recorded was at the wetland area with pH value of 1.88. This pH will be used in the analysis to determine the most appropriate treatment system using the surface water polluted in the worst case scenario

Elevated sulphate concentrations above the TWQR value of 200mg/l were observed in the data. The wetland area (DV – 3) has the highest concentration of sulphates (17600mg/l).

The site data was plotted on a Piper Diagram for the various ions present. The position of the analysis data as plotted on a piper diagram assist in making a tentative conclusion as to the origin of the water represented by the analysis. Piper diagrams are a combination of anion and cation triangles that lie on a common baseline.

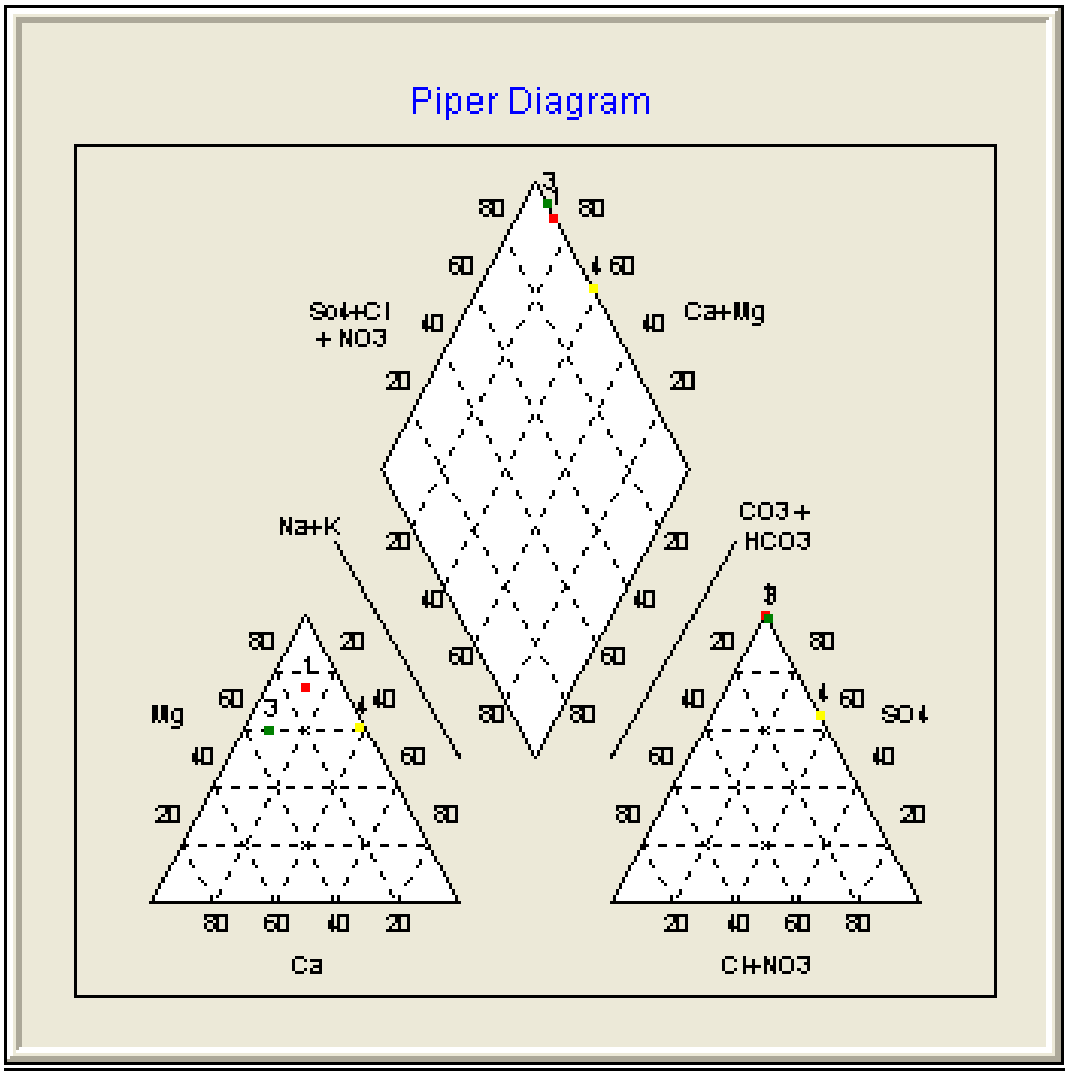


Figure 13:Piper Diagram

- Red = Artificial Wetland
- Green = Water way
- Yellow = DV - 9

The result showed that the water is high in both Ca^{2+} + Mg^{2+} and Cl + SO_4^{2-} ions, which results in permanent hardness. Permanent hardness (noncarbonated) is the calcium and magnesium that exists as sulphates or chlorides and cannot be removed by boiling. (Hounslow, 1995). The data plots at the top of the diamond indicating that the water originates from a rock high in gypsum (CaSO4.2H2O) which is usually found in sedimentary geological environments.

Since the SO_4^{2-} ions are as a result of pyrite oxidation, it was considered to be a good indicator of the influence of the mine deposits on the surface water.

6.6 SUMMARY AND DATA INTERPRETATION

It is noted that from an investigation on the site and the sampling data available, AMD is active in the area. The surface water at the study site show AMD characteristics such as:

- Low pH;
- Presence of high concentrations of dissolved metals; and
- Presence of high concentrations of SO_4^{2-} ions.

This can be attributed to the presence of the TSF as well as the erosion taking place. From the data above, high concentrations of pollutants are observed which are above the TWQR as stipulated by DWAF.

7 APPLICATION OF SURFACE WATER TREATMENT OPTIONS

7.1 INTRODUCTION

This section identifies and describes the treatment technology (ies) that when applied at the study site will enable the effective treatment of the AMD impacted water in the long term. The identified technology (ies) should be appropriate to the environmental, cultural and economic situation of the site by requiring fewer resources for its implementation. That is, the technology should not impact negatively on the environmental or cultural aspects of the site and at the same time it should be economically viable.

Evangelou (1995) notes that the development of a long term strategy for the treatment of mine water requires:

- The determination of appropriate water quality objectives for which the treatment options will be evaluated;
- An assessment of potential economic benefits which might be achieved from progressive improvement in surface water quality; and
- Technical and financial reviews of a range of potential treatment options.

From the literature review, active as well as passive treatment technologies were described. Remediation of AMD using active treatment technologies is effective in removing contamination but can be expensive and require time, manpower and constant maintenance to keep the system operative. It was identified that active systems would not suit favorably with the study site conditions due to:

- Electricity/power requirements;
- Generation of sludge which need to be efficiently disposed;
- Establishment and maintenance costs;
- There is not sufficient water flow to allow for active treatment options; and
- Active systems can be subject to vandalism and theft.

Passive treatment systems on the other hand offer a low-cost, low-maintenance solution to AMD problems. While they do not always provide effluent that meets water quality regulations, they improve the water quality, and with proper design they can effectively treat AMD from the abandoned mine site (Skousen, 1998). Passive systems can be reliably implemented as a single permanent solution for many types of AMD and at a much lower cost than active treatment (Skousen, 1998). Passive treatment systems are therefore more appropriate for this abandoned site because they require:

- Little or no maintenance therefore the major costs are the capital costs;
- They can efficiently treat small flows of water;
- The systems can be incorporated into the natural landscape and provide aesthetic appeal;
- The construction of the passive systems will have a positive impact on the local community by creating of temporary employment since much of the work can be done using local labour as opposed to active systems which largely use chemicals purchased and/or treatment plants assembled elsewhere;
- By implementing a passive treatment system at the site, the improved water quality and biodiversity can have a positive impact on the recreational activity of the nearby manmade wetland; and
- Passive systems are not exposed to vandalism and theft.

Identification of the appropriate technology for the treatment of the contaminated surface water on the study site is based on analysing the site specific opportunities and constraints and ensuring that the overall goal of ecological restoration is achieved. It is paramount that the selected technology will provide restoration levels consistent with the project's objectives using the minimum intensity treatment required to attain the goals. To effectively analyse the passive systems the following issues were considered:

- Data on the water quality and the TWQR;
- Requirements of the different systems and their application at the study site;
- The treatment rate-limiting steps and causes of failure;
- Cost implications and material requirements; and
- An evaluation of the long-term suitability of the systems and the potential for metal precipitates to remobilise.

7.2 ASSESSMENT

The surface water at the Princess Dump site is characterised by high levels of sulphates, low pH, high levels of TDS/Conductivity, and high levels of dissolved metals such as iron, aluminium and calcium. The objective is to achieve near neutral pH of between 6 – 9, lower the total iron concentration in the water to less than 1mg/l, sulphate to less than 200mg/l and the total suspended solids to less than 50mg/l.

The following factors were considered during the selection of the appropriate passive treatment system:

- The chemistry and the flow of the AMD drainage discharge;
- Aerobic wetlands are best suited for net alkaline water;
- If the water is net acidic but has low dissolved oxygen, ferric iron, and aluminium, an anoxic limestone drain may be selected;
- Higher concentrations of dissolved oxygen, ferric iron, and aluminium are most suited for anaerobic wetlands, SAPS, or limestone channels.

Anaerobic systems or SAPS with limestone drains are therefore required to remove sulphates under the acidic conditions. When mine water flows through an anaerobic environment that contains an organic substrate, bacterial sulphate reduction occurs (Geller *et al.*, 1998). Bacterial sulphate reduction directly affects concentrations of dissolved metals by precipitating them as metal sulphides. Anaerobic systems can therefore simultaneously remove heavy metals and sulphates (DWAF, 2007). Since the water is net acidic, aerobic systems cannot be used as they require water to have net alkalinity. It was also identified that SAPS require under drain pipes which have the potential of clogging and also they may not have substantial adaptive capability during rainy seasons to cater for potential floods. Therefore anaerobic wetlands were identified to be appropriate for the treatment of the contaminated surface water at the study site.

- Applicability

Wetlands are engineered to enhance the efficiency of natural systems and if the metals contained within the wetland are left undisturbed, they would be unavailable and non-polluting to the environment (Wildman *et al*., 1989). The system is cheap to implement, relative to others, as it does not require huge capital investments and specialised skills. There is an existing manmade wetland on site which can be improved to become an anaerobic wetland. This will increase the aesthetic appeal of the wetland as well as provide a treatment option that is low cost and easy to maintain.



Figure 14: Showing the wetland during the summer (January 2007) (left), and autumn (April 2007) months (right).

During the designing of the treatment systems, the state of the site and its topography, manmade and natural drainage, site hazards and signs of contamination, presence or absence of vegetation, its type and condition, and site access and adjacent land uses need to be considered. Also the site hydrograph and seasonal variations need to be investigated further to ensure that the system is implemented successfully.

- Cost and benefits

When properly designed and constructed, a passive treatment system can be operated with a minimum amount of attention and money and can be able to meet the water quality objectives (Hedin *et al.*, 1994).The cost of a passive treatment system depends primarily on the amount of land needed for the system. Because passive systems rely on processes that are slower than conventional treatment, they require longer retention times and larger areas to achieve similar results (Hedin *et al.*, 1994). Cost factors associated with the anaerobic treatment system include but not limited to:

- Land cost
- Capital cost
- Operational costs and Maintenance costs
- Legal costs.

Much of the property at the study site is owned by the Johannesburg municipality. Therefore the land cost may not apply. The treatment facility may be developed as a recreational park for the residents in the area.

- Legal Requirements.

Since this site is an orphan site, the responsibility to rehabilitate the site lies with Department of Minerals and Energy (DME). The DME is the custodian of all primary pollution sources that result

from mining activities where the owners cannot be established. However, other interested and affected parties need to be consulted to create ownership and support for the project. The ability of passive treatment systems to consistently meet effluent standards is a function of the quality of the influent and the effectiveness of the system. By designing an efficient system, the Target Water Quality Range (TWQR) may be attained before the water is discharged into the environment.

- Efficiency:

The efficiency of a treatment process can be considered in terms of:

- The chemistry of the product water, whether it requires a further polishing stage or is suitable for reuse or discharge into the receiving water courses.
- The nature of the sludge, its toxicity/hazard potential, its volume, long term stability and disposal requirements. (DWAF 2007)

The main problems with the wetlands treatment systems relates to:

- The extended detention time required for the system to treat the water. Also increase in water flow during rainy seasons may interfere with the treatment systems. There is enough space within the man-made wetland to allow for extended retention time as may be required.
- Whilst the water flows all year round the bacteria are most active when the weather is warm (Skousen, 1998).
- There is also an engineering problem where the water is required to contact the anaerobic (oxygen-free) parts of the wetland where the remedial process is most efficient (Skousen *et al*., 1998).

Variation of the flow and quality of the inflow can cause the process performance efficiency to reduce or even fail if not managed properly. Appropriate management measures such as the separation of contaminated water from other surface runoff though diversion and trenches must be implemented. Also to regulate the flow entering the system, equalisation ponds can be established to accommodate varying flow while ensuring a near constant outflow from the ponds to the anaerobic wetland treatment plant.

Appropriate design of the passive water treatment systems can ensure that the risk is minimised and compliance of the order of 95% could reasonably safely be assured (DWAF 2007).

- Treatment plant sustainability

Long term successful treatment by a staged anaerobic wetland has been reported for net acidic water (Skousen, 1998). Passive systems attain optimum efficiency when the biological systems reach maturity, which may take several years (Geller *et al.*,1998) This implies that with proper design and efficient maintenance, anaerobic wetlands can sustainably treat the surface water at the site.

7.3 CONCLUSION AND RECOMMENDATION

In South Africa innovative response than those that have been applied in the past need to be developed to reduce the impacts of mining on water and the environment. Passive treatment can be considered proven technology for the removal of sulphates, acidity and most heavy metals and sufficient understanding and experience is available to confidently design appropriate treatment systems. Passive treatment is the most economical way to deal with AMD remediation in abandoned mine sites around the country. It will not guarantee complete removal of contaminants but can significantly improve the watersheds.

The objective of the study was to identify a surface water treatment option that is sustainable, efficient and cost effective while considering the site specific conditions of the Princess Dump. Conclusions reached from the foregoing literature research, field analysis and results are as follows:

Many factors influence the degree and rate of surface water pollution from the TSF. Results from previous studies undertaken on the site were reviewed and compared to the results obtained during the course of this study. Water quality monitoring results show agreement with previously monitored data sampled by DWAF (2003). Relatively high levels of AMD contamination were observed to occur at the site which has resulted in a steady decline in surface water quality.

Passive surface water treatment techniques afford a sustainable, relatively low maintenance means of treating contaminated water especially on abandoned sites. It was found that anaerobic wetland technology would be appropriate for the treatment of contaminated water on at the abandoned site. The treatment system provides useful opportunities of incorporating environmental remediation strategies with planning, recreation and landscaping in the area.

It was noted that for this particular site, the uncovered slopes provide a serious pollution threat from the eroded tailings that are constantly being transported to the water ways. Efforts need to be put in place to rehabilitate the TSF itself to control the source of the pollution.

Further studies recommended include:

The movement of water through and out of the TSF's. The dynamics need to be understood in the context of abandoned TSF's. Also the direction and rate of movement of ground water affected by seepage from the TSF. This will aid in establishing seepage flow and optimising seepage collection for treatment.

Water quality management and any environmental remediation needs to be considered, for both surface and ground water, within a local and regional context at the study site to ensure that the resource is remediated around the area as well as in the greater catchments' area.

Because every site is heterogeneous and offers unique challenges, system designs need to be modified based on site characteristics, constraints, flow and contaminant concentrations (McCauley *et al*). Even if AMD problem may not completely disappear, reducing it impacts will go a long way toward conserving the environment.

Appendix A Water Quality Survey Report – Department Of Water Affairs and Forestry

PRINCESS MINE DUMP

Report on the water quality survey around the Princess Mine Dump and its negative effects on the water resources (both surface water and ground water)

By

M Fayazi

February 2005

PRINCESS MINE DUMP

Report on the water quality survey around the Princess Mine Dump and its negative effects on the water resources (both surface water and ground water)

The abandoned Princess mine dump is one the few mine dumps of a previously active gold mine in the Witwatersrand Mining Basin at the Roodepoort area. The mine dump remains as a pollution source by producing Acid Mine Drainage (AMD) into the Klip River. It is therefore more economical if the pollution be controlled at its source which is the mine dump.

• Locality

The area is situated at the upper Klip River catchment area, at around the the Longitude 27 55 00 E and Latitude 26 09 30 S. It is located at the Roodepoort West area and about 10 kilometers south-east of town Krugersdorp. The Durban Roodepoort Deep Gold Mine is situated at approximately 3 kilometers south-east of the Princess mine dump.

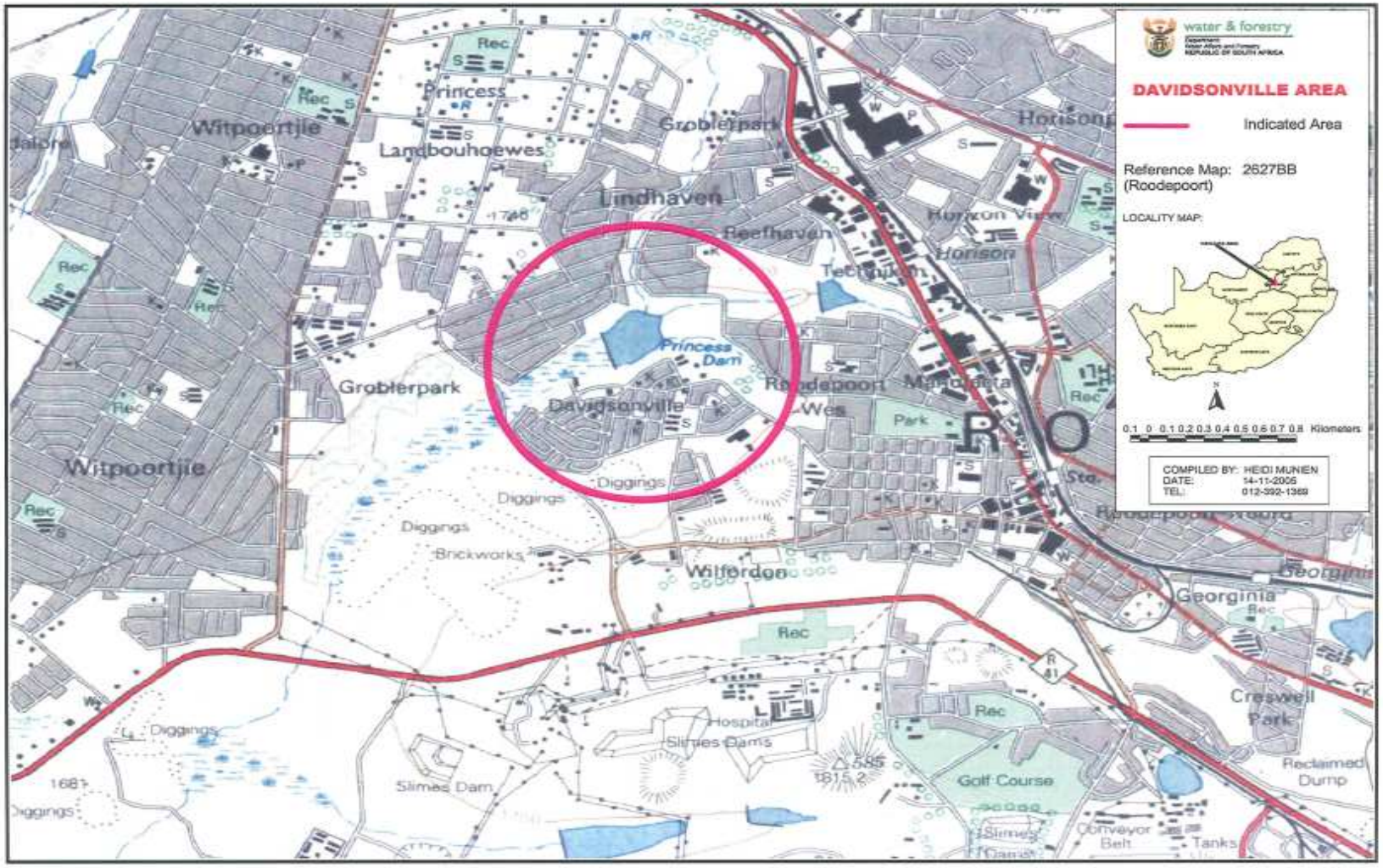
• Site inspection and water sampling

The above site was inspected during the September and December months of 2003 and a number of water samples were collected. The chemical results from various sampling points indicate that water quality varies from one point to another point. The changes in chemical constituents is controlled by the remaining residue of the mine dump of the past gold mining activity in the area.

• General Geology

The general surface geology is dominated by quartzite and conglomerates (Rjo, of the Central Rand Group, a subdivision of Witwatersrand Supergroup. The strata strikes east to west dipping between 30 and 45 degrees to the south (WES-RAND, Geological Series 1:250 000, 1986). The thickness of strata could reach up to 1500 m.

The mine dump residue covers the surface geology. It is expected that first few meters of the geological sequence (+/- 10m) are highly weathered. No information could be found in the DWAF's Archives regarding the old mining activity.


water & forestry
DAVIDSONVILLE AREA
Indicated Area
Reference Map: 2627BB
(Roodepoort)
LOCALITY MAP:
0.1 0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 Kilometers
COMPILED BY: HEIDI MUNIEN
DATE: 14-11-2005
TEL: 012-392-1369
Witpoortjie
Princess
Landbouhoewes
Groblerpark
Lindhaven
Beethaven
Princess Dam
Davidsonville
Roodepoort
Wes
Park
Diggings
Brickworks
Wilferdon
Georginia
Rec
Golf Course
Slimes Dam
Hospital
Creswell Park
Reclaimed Dump
Conveyor Belt
Tanks
R 41

• Result of water sampling

The water samples were analysed for major cations and anions and selected trace metals. The results of the chemical analyses are given in Table 1. The main important points of these analyses are as follows:

• Sulphate (SO4) concentartion

Elevated sulphate concentration (refer to sulphate Map) was observed at the following points:

DV-2 (7 425 mg/l) and DV-10 (6 650 mg/l) at discharge point, below the park, where.the water originates from storm whenever it rain.

DV-9 (9 600 mg/l) at a point when rain carrird mine dump particles.
DV-S4 (12 650 mg/l) at point where seepage water originates from mine dump.
DV-3 (17 600 mg/l) at the Wet Land Area which has a the highest concentration of sulphate in the area.

DV-1 (2 900 mg/l) at the underground point (about 2 meters below ground level) which indicates that groundwater (perched aquifer) below the industrial park is polluted.

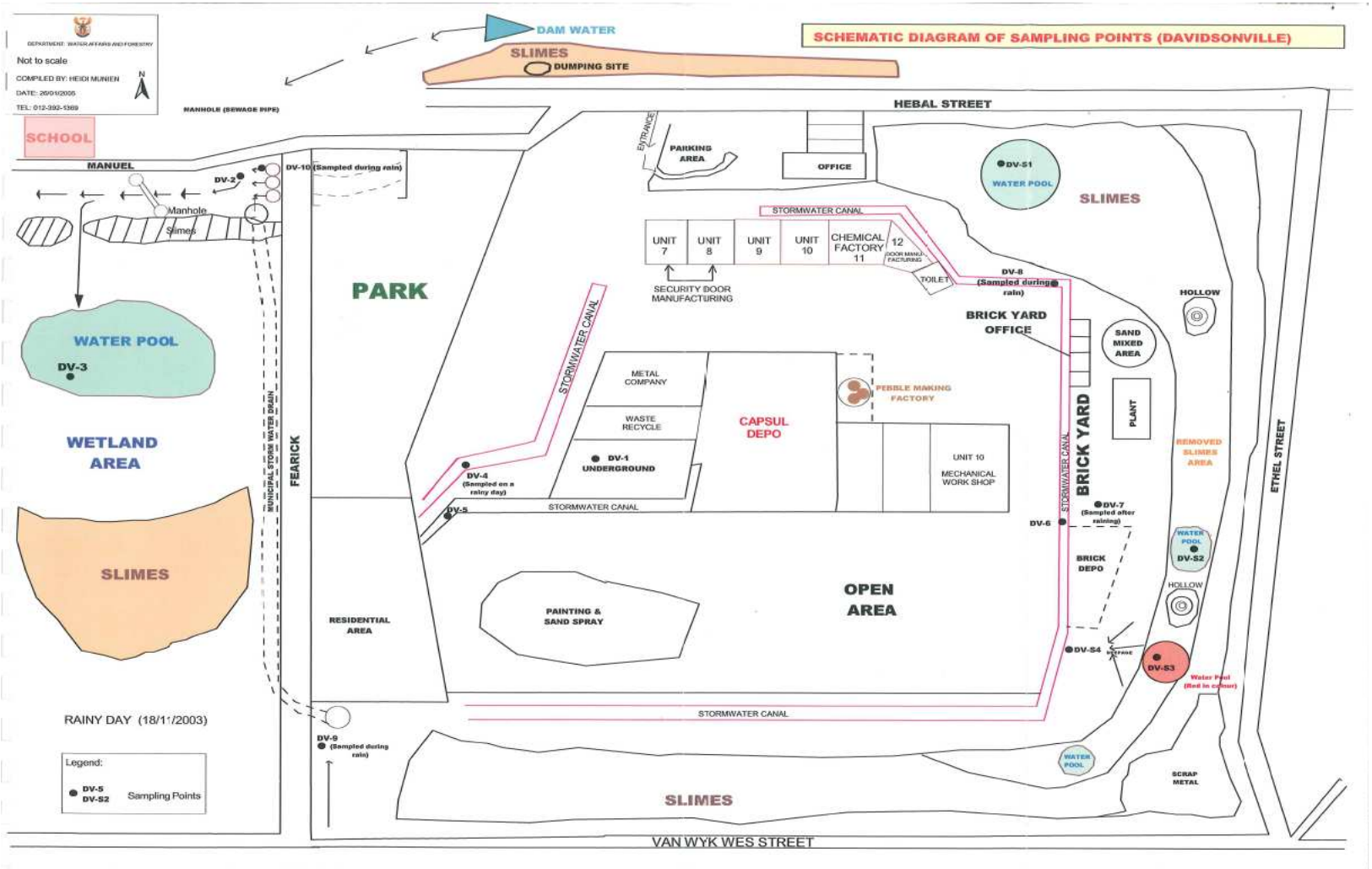
DV-S3 (2 240 mg/l) which is pool of water contains elevated sulphate.

DV-7 (249 mg/l) at the Brickyard shows elevated sulphate concentration after rain. This is due to the chemical constituent of the ash and cement used for manufacturing the bricks.

In general, surface water contains more sulphate than the shallow groundwater in the investigated area. The sulphate is controlled by oxidation process of pyrite and other sulfide minerals in the mine dump particles which is transported into the surface water environment during raining period. This was noticed from sampling at point DV-9. The oxidation process of pyrite plays a key role in acid mine drainage (AMD) and contributes to high sulphate and iron concentration in both surface and groundwater. In this case the effect is more on the surface water than the groundwater.

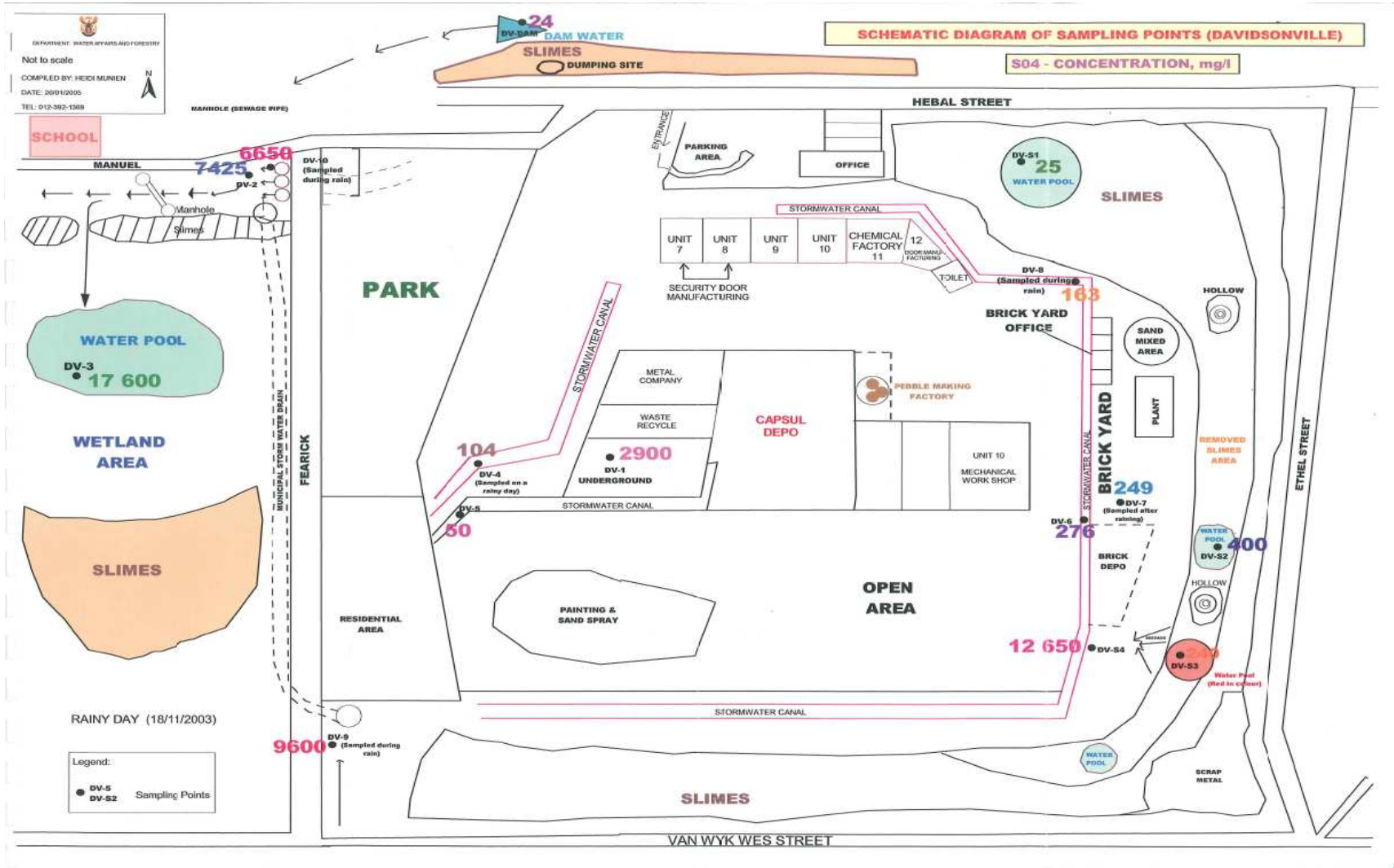
• Hydrogen Ion Concentration (pH)

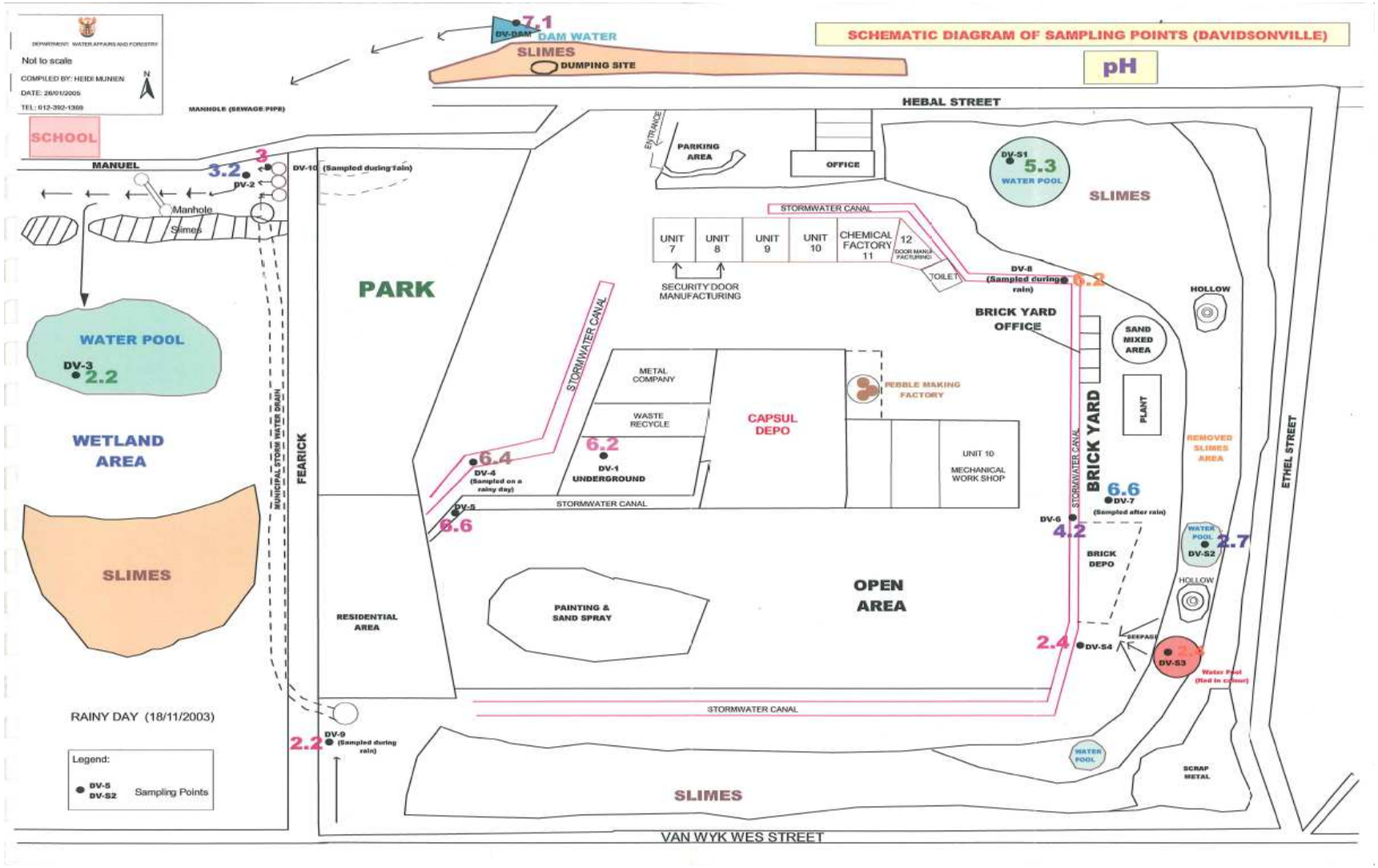
The pH map indicates a very acidic water (< 3.5) at points DV-2, DV-3, DV-9, DV-10, DV-S3 and DV-S4. The lowest pH value was recorded at the Wet Land Area


SCHEMATIC DIAGRAM OF SAMPLING POINTS (DAVIDSONVILLE)
DEPARTMENT: WATER AFFAIRS AND FORESTRY
Not to scale
COMPILED BY: HEIDI MUNIEN
DATE: 26/01/2005
TEL: 012-392-1369
N
DAM WATER
SLIMES
DUMPING SITE
MANHOLE (SEWAGE PIPE)
HEBAL STREET
SCHOOL
MANUEL
DV-2
DV-10 (Sampled during rain)
Manhole
Slimes
PARK
ENTRANCE
PARKING AREA
OFFICE
DV-S1
WATER POOL
SLIMES
STORMWATER CANAL
UNIT 7
UNIT 8
UNIT 9
UNIT 10
CHEMICAL FACTORY 11
12
DOOR MANUFACTURING
TOILET
SECURITY DOOR MANUFACTURING
DV-8 (Sampled during rain)
BRICK YARD OFFICE
HOLLOW
SAND MIXED AREA
PLANT
REMOVED SLIMES AREA
WATER POOL
DV-3
WETLAND AREA
METAL COMPANY
WASTE RECYCLE
DV-1 UNDERGROUND
CAPSUL DEPO
PEBBLE MAKING FACTORY
UNIT 10
MECHANICAL WORK SHOP
BRICK YARD
ETHEL STREET
DV-4 (Sampled on a rainy day)
DV-5
STORMWATER CANAL
DV-7 (Sampled after raining)
DV-6
BRICK DEPO
DV-S2
HOLLOW
MUNICIPAL STORM WATER DRAIN
FEARICK
SLIMES
RESIDENTIAL AREA
PAINTING & SAND SPRAY
OPEN AREA
DV-S4
DV-S3
Water Pool (Red in colour)
STORMWATER CANAL
DV-9 (Sampled during rain)
WATER POOL
SCRAP METAL
SLIMES
VAN WYK WES STREET
RAINY DAY (18/11/2003)
Legend:
DV-5
DV-S2
Sampling Points

Constituents (mg/l)	DV-I	DV-1	DV-2	DV-2	DV-3	DV-4	DV-5	DV-6	DV-7	DV-8	DV-9	DV-10	DV-S1	DV-S2	DV-S3	DV-S4	DV-Dam	Constituents (mg/l)
EC(mS/m)	411	391	625	803	1 384	24	20	61	256	27	737	659	8	127	334	1 121	18	EC (mS/m)
TDS	4 606	4 224	10 388	13 590	33 520	194	176	512	2 578	220	20 378	10 978	84	1 034	4 548	22 462	116	TDS
TAL (As CaCO	31	170	<10	<10	<10	41	36	<10	46	25	<10	<10	<10	<10	<10	<10	42	TAL (as CaCO3)
Cl	34	36	26	16	99	17	8	13	23	14	700	425	10	<3	<3	7	8	Cl
F	0.1	0.1	0.1	0.2	<0.1	0.2	0.4	0.3	0.4	0.2	<0.1	<0.1	0.2	0.2	0.1	0.1	0.3	F
SO4	2 900	2 600	5 000	7 425	17 600	104	50	276	249	163	9 600	6 650	25	400	2 240	12 650	24	SO4
Ca	422	376	46	72	54	23	20	42	531	22	15	63	3.6	6.4	12	61	15	Ca
Mg	470	349	169	165	798	3	2	19	88	4	220	153	0.4	12	35	161	3.4	Mg
K	14	16	7	6	2	6	6	8	25	5	0.5	6	2	0.2	0.5	0.2	3.4	K
Na	111	105	49	48	208	20	16	31	45	27	5	37	3	3	3	6	14	Na
NH4=N	14	14	1	0.2	21	0.6	0.8	1.3	3	0.5	4	2	<0.1	0.4	1	1.8	0.3	NH4=N
TKN	14	10	10	7.7	14	2.5	2.8	5	3	3	6	9	<1	<1	3.5	7.4	<1	TKN
NO3=N	<0.1	0.3	<0.1	<0.1	<0.1	1	2	3	3	3	1	1	<0.1	0.4	0.4	<0.1	0.4	NO3=N
NO2=N	<0.1	0.1	<0.1	<0.1	<0.1	<0.1	0.1	0.3	0.2	0.2	0.1	<0.1	<0.1	<0.1	<0.1	<0.1	0.1	NO2=N
Ortho P	<0.1	<0.1	0.1	1.5	4.4	0.2	4	<0.1	5	0.5	14	0.3	0.2	0.2	1.9	8.9	<0.1	Ortho P
Total P	<0.1	<1.0	2.2	3.7	1.5	<1	5	<1	<1	1	8	2	<1	<1	2.9	8.5	<1	Total P
pH (Units)	6.2	5.9	2.9	3.1	2.2	6.4	6.6	4.2	6.6	6.2	2.2	3	5.3	2.7	2.4	2.4	7.1	pH (Units)
Cd	<0.04	<0.04	<0.04	0.07	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	0.26	0.16	<0.04	<0.04	<0.04	0.16	<0.04	Cd
Cr	<0.03	<0.03	0.75	1.54	1.8	<0.03	0.05	0.03	0.03	<0.03	8.6	0.8	<0.03	0.32	1.95	4.64	<0.03	Cr
Co	0.23	3.14	7.9	14.6	29	0.08	0.06	1	0.12	0.26	15.7	7.7	<0.04	0.65	3.02	17.51	<0.04	Co
Cu	0.04	0.03	4	6.1	2.5	0.06	0.54	0.66	0.06	0.28	17.03	4.02	<0.03	1.05	3.66	12.47	<0.03	Cu
Fe	70	10.5	1 480	1 516	3 078	9.5	38	9.5	0.7	0.71	3 053	1 633	0.53	40.74	421.9	2 714	1.12	Fe
Pb		0.18	0.42	0.76	0.99	0.08	<0.06	<0.06	0.11	0.06	0.6	0.36	0.29	0.35	0.49	1.05	0.2	Pb
Mn	109	185	15	****	77.7	****	****	****	****	****	****	*****	0.13	0.32	3.28	9.27	<0.06	Mn
Ni	0.13	0.85	13	18.04	44	0.08	0.12	0.89	0.16	0.11	26.1	13.9	<0.06	1.23	5.17	31.83	0.05	Ni
Zn	1.01	0.52	12	19.3	39.5	1.8	1.03	2.2	0.1	1.21	22.3	11.3	0.03	1.16	6.25	39.6	0.3	Zn
Al	0.1	<0.1	368	442	1 148	0.4	0.7	6.4	2.1	0.9	730	352	0.4	59.4	149	1 099	****	Al
Si	5.4	*****	51	****	116	2.7	4.3	3.7	5.1	3.5	29	44	***	****	***	****	****	Si
V	<1	*****	<1	****	<1	****	****	****	****	****	****	****	<1	<1	<1	<1	****	V
Ba	0.1	*****	0.3	****	0.6	****	****	****	****	****	****	***	<0.1	<0.1	0.1	0.5	****	Ba
B	<1	*****	<1	****	<1	<1	<1	<1	1	<1	<1	<1	<1	<1	<1	<1	****	B
Mo	<0.3	*****	<0.3	****	<0.3	****	****	****	****	****	****	****	<0.3	<0.3	<0.3	<0.3	****	Mo
Sr	1.2	*****	0.6	****	<0.1	<0.1	<0.1	<0.1	1.6	<0.1	<0.1	0.5	<1	<1	<1	0.9	****	Sr
As		*****	*****	****	*****	<1	<1	<1	<1	<1	2.3	<1	<1	<1	<1	1.9	****	As
Oil&Grea.	85	<10	<10	<10	<10	<10	<10	<10	<10	14	<10	<10	****	****	****	****	<10	Oil&Grea.
Phenols	0.08	0.1	<0.05	<0.05	<0.05	0.05	<0.05	*****	*****	0.28	<0.05	<0.05	****	****	****	****	<0.05	Phenols
Surfactants	<10	*****	<10	****	<10	*****	*****	*****	*****	****	****	****	****	****	****	****	****	Surfactants
Samling ID	DV-1	DV-1	DV-2	DV-2	DV-3	DV-4	DV-5	DV-6	DV-7	DV-8	DV-9	DV-10	DV-S1	DV-S2	DV-S3	DV-S4	DV-Dam	Samling ID
Date	30 Sept.03	13 Nov.03	30 Sept.03	11 Dec.03	30 Sept.03	30 Sept.03	18 Nov. 03	18 Nov. 03	18 Nov. 03	18 Nov. 03	18 Nov. 03	19-Nov-03	25 Nov.03	25 Nov.03	25 Nov.03	25 Nov.03	11 Dec. 03	Date

Table 1: Results of chemical analyses for selected sampling points


DEPARTMENT: WATER AFFAIRS AND FORESTRY
Not to scale
COMPILED BY: HEIDI MUNIEN
DATE: 26/01/2005
TEL: 012-392-1369
SCHEMATIC DIAGRAM OF SAMPLING POINTS (DAVIDSONVILLE)
S04 - CONCENTRATION, mg/l
24
DV-DAM
DAM WATER
SLIMES
DUMPING SITE
MANHOLE (SEWAGE PIPE)
HEBAL STREET
SCHOOL
MANUEL
6650
7425
DV-2
DV-10 (Sampled during rain)
Manhole
Slimes
ENTRANCE
PARKING AREA
OFFICE
DV-S1
25
WATER POOL
SLIMES
STORMWATER CANAL
UNIT 7
UNIT 8
UNIT 9
UNIT 10
CHEMICAL FACTORY 11
12
DOOR MANUFACTURING
TOILET
SECURITY DOOR MANUFACTURING
PARK
DV-8 (Sampled during rain)
163
HOLLOW
BRICK YARD OFFICE
SAND MIXED AREA
WATER POOL
DV-3
17 600
METAL COMPANY
WASTE RECYCLE
CAPSUL DEPO
PEBBLE MAKING FACTORY
PLANT
REMOVED SLIMES AREA
STORMWATER CANAL
104
DV-4 (Sampled on a rainy day)
2900
DV-1 UNDERGROUND
UNIT 10
MECHANICAL WORK SHOP
BRICK YARD
249
DV-7 (Sampled after raining)
DV-5
50
STORMWATER CANAL
DV-6
276
WATER POOL
DV-S2
400
BRICK DEPO
HOLLOW
WETLAND AREA
MUNICIPAL STORM WATER DRAIN
FEARICK
SLIMES
RESIDENTIAL AREA
PAINTING & SAND SPRAY
OPEN AREA
12 650
DV-S4
DV-S3
Water Pool (Red in colour)
ETHEL STREET
RAINY DAY (18/11/2003)
9600
DV-9 (Sampled during rain)
STORMWATER CANAL
WATER POOL
SCRAP METAL
SLIMES
VAN WYK WES STREET
Legend:
DV-5
DV-S2
Sampling Points


SCHEMATIC DIAGRAM OF SAMPLING POINTS (DAVIDSONVILLE)
pH
DEPARTMENT: WATER AFFAIRS AND FORESTRY
Not to scale
COMPILED BY: HEIDI MUNIEN
DATE: 26/01/2005
TEL: 012-392-1369
N
MANHOLE (SEWAGE PIPE)
SCHOOL
MANUEL
DV-DAM
7.1
DAM WATER
SLIMES
DUMPING SITE
HEBAL STREET
ENTRANCE
PARKING AREA
OFFICE
DV-S1
5.3
WATER POOL
SLIMES
STORMWATER CANAL
UNIT 7
UNIT 8
UNIT 9
UNIT 10
CHEMICAL FACTORY 11
12
DOOR MANUFACTURING
TOILET
SECURITY DOOR MANUFACTURING
DV-8
(Sampled during rain)
6.3
HOLLOW
BRICK YARD OFFICE
SAND MIXED AREA
PARK
3
3.2
DV-2
DV-10 (Sampled during rain)
Manhole
Slimes
WATER POOL
DV-3
2.2
WETLAND AREA
SLIMES
MUNICIPAL STORM WATER DRAIN
FEARICK
STORMWATER CANAL
METAL COMPANY
WASTE RECYCLE
6.2
DV-1
UNDERGROUND
CAPSUL DEPO
PEBBLE MAKING FACTORY
UNIT 10
MECHANICAL WORK SHOP
PLANT
BRICK YARD
REMOVED SLIMES AREA
ETHEL STREET
6.4
DV-4
(Sampled on a rainy day)
STORMWATER CANAL
DV-5
6.6
6.6
DV-7
(Sampled after rain)
DV-6
4.2
WATER POOL
DV-S2
2.7
BRICK DEPO
HOLLOW
RESIDENTIAL AREA
PAINTING & SAND SPRAY
OPEN AREA
2.4
DV-S4
SEEPAGE
DV-S3
Water Pool (Red in colour)
STORMWATER CANAL
2.2
DV-9
(Sampled during rain)
WATER POOL
SCRAP METAL
SLIMES
VAN WYK WES STREET
RAINY DAY (18/11/2003)
Legend:
DV-5
DV-S2
Sampling Points

(DV-3) and DV-9 with pH value of 2.2. Sampling point DV-1 (shallow groundwater), does not show acidic condition as surface water. Generation of acidic condition at the mine dump area had caused mobilization of trace metals into surface water environment and some of these trace metals were recorded at some sampling points indicated in Table 1.

• Iron (Fe) concentration

The Iron concentration Map corresponds with Sulphate concentration Map. A number of red water pools were noticed in the area, such as Wet Land Area (DV-3) and DV-S3. The coloring of the water in the pools was related to elevated iron concentration. The highest iron concentration was recorded at the.Wet Land Area, DV-3 (3 078 mg/l) and DV-9 (3 053 mg/l). At DV-1 (70 mg/l) which is a shallow groundwater, an elevated iron concentration was also observed.

In general, the iron concentration in surface water is more dominant than groundwater and this is an indication of the oxidation of pyrite.

• Trace Metals

Some selected trace metals were analysed at selected sampling points and the results are indicated at Table 1. The low pH values (acidic condition) had caused an increase in dissolved Al and other trace metals which are carried into the surface water and groundwater environments.

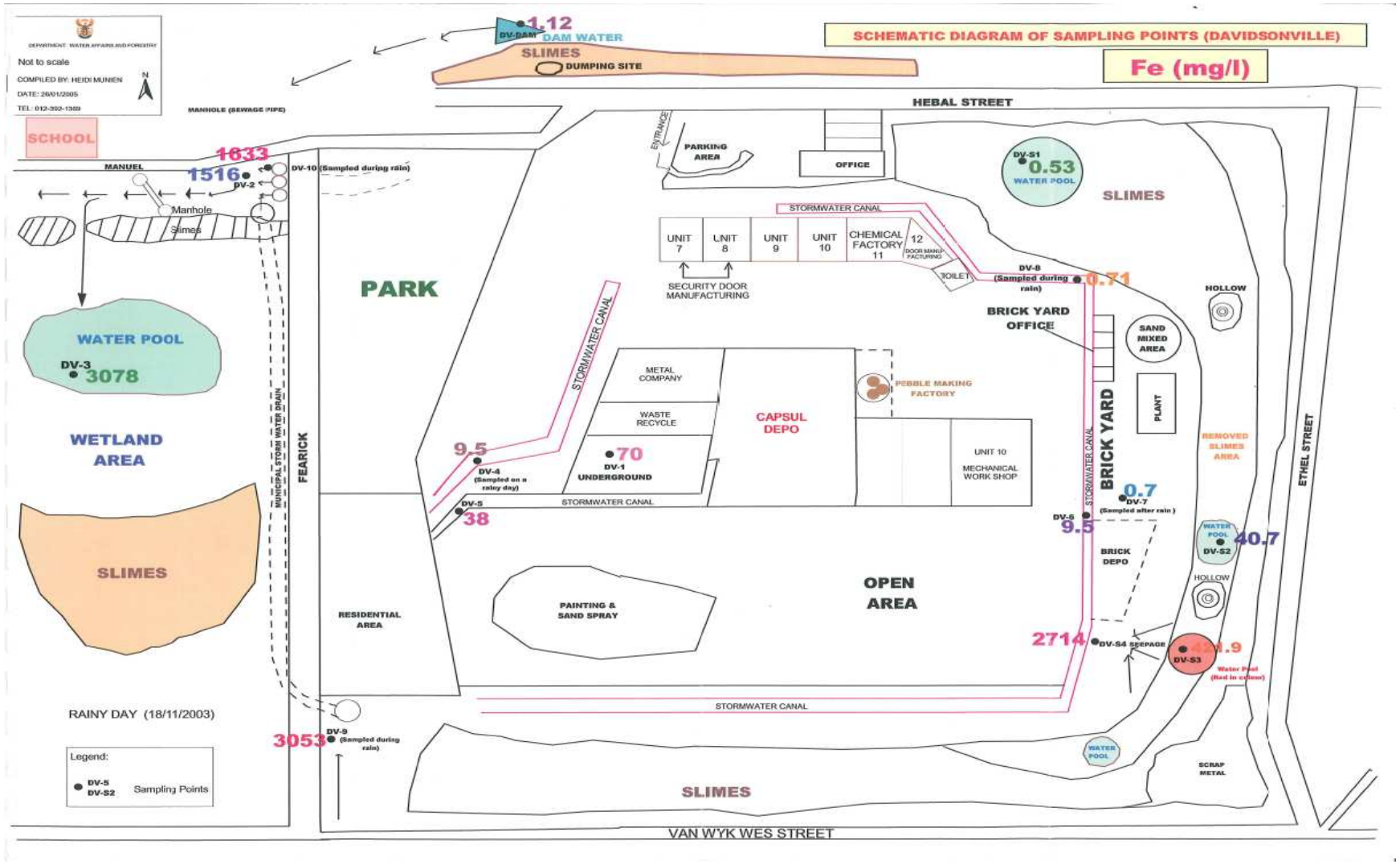
The elevated trace metals were recorded at the following sampling points:

Cd **DV-9** (0.29 mg/l), DV-10 (0.16 mg/l) and **DV-S4** (0.16 mg/l)
Cr **DV-9** (8.6 mg/l) and **DV-S4** (4.64 mg/l)
Co DV-3 (29 mg/l), **DV-S4** (17.51 mg/l), **DV-9** (15.7 mg/l) and DV-2 (14.6 mg/l)
Cu **DV-9** (17.03 mg/l) and **DV-S4** (12.47 mg/l)
Pb **DV-S4** (1.05 mg/l), DV-3 (0.99 mg/l) and **DV-9** (0.6 mg/l)
Mn DV-1 (185.6 mg/l), DV-3 (77.7 mg/l) and **DV-S** (4 9 9.27) mg/l)
Ni DV-3 (44 mg/l), **DV-9** (26.1 mg/l), **DV-S4** (31.83 mg/l), DV-2 (18.04 mg/l), DV-10 (13.9 mg/l) and DV-2 (13 mg/l)

Zn **DV-S4** (39.6 mg/l), DV-3 (39.5 mg/l), **DV-9** (22.3 mg/l) and DV-10 (11.3 mg/l)
Al DV-3 (1 148 mg/l), **DV-S4** (1 099 mg/l), **DV-9** (730 mg/l), DV-10 (352 mg/l), DV-S3 (149 mg/l) and DV-S2 (59.4 mg/l)

The other trace metals such as **V, Ba, Mo, Sr and As** were found in a lower concentration as compared with the above trace metals.

It can be noticed that major elevated trace metals were found at sampling points which are related to surface water, such as seepage water due to rain over the mine dump and rain itself which carries the mine dump particles.


SCHEMATIC DIAGRAM OF SAMPLING POINTS (DAVIDSONVILLE)
Fe (mg/l)
DEPARTMENT: WATER AFFAIRS AND FORESTRY
Not to scale
COMPILED BY: HEIDI MUNIEN
DATE: 26/01/2005
TEL: 012-392-1303
N
1.12
DV-DAM
DAM WATER
SLIMES
DUMPING SITE
MANHOLE (SEWAGE PIPE)
HEBAL STREET
SCHOOL
1633
1516
MANUEL
DV-2
DV-10 (Sampled during rain)
Manhole
Slimes
ENTRANCE
PARKING AREA
OFFICE
DV-S1
0.53
WATER POOL
SLIMES
STORMWATER CANAL
UNIT 7
UNIT 8
UNIT 9
UNIT 10
CHEMICAL FACTORY 11
12
DOOR MANUFACTURING
TOILET
SECURITY DOOR MANUFACTURING
DV-8
(Sampled during rain)
0.71
HOLLOW
PARK
BRICK YARD OFFICE
SAND MIXED AREA
WATER POOL
DV-3
3078
STORMWATER CANAL
METAL COMPANY
WASTE RECYCLE
CAPSUL DEPO
PEBBLE MAKING FACTORY
PLANT
BRICK YARD
REMOVED SLIMES AREA
WETLAND AREA
9.5
DV-4
(Sampled on a rainy day)
70
DV-1
UNDERGROUND
UNIT 10
MECHANICAL WORK SHOP
ETHEL STREET
MUNICIPAL STORM WATER DRAIN
FEARICK
DV-5
38
STORMWATER CANAL
STORMWATER CANAL
0.7
DV-7
(Sampled after rain)
DV-6
9.5
BRICK DEPO
WATER POOL
DV-S2
40.7
HOLLOW
SLIMES
RESIDENTIAL AREA
PAINTING & SAND SPRAY
OPEN AREA
2714
DV-S4 SEEPAGE
DV-S3
Water Pool (Red in colour)
STORMWATER CANAL
RAINY DAY (18/11/2003)
3053
DV-9
(Sampled during rain)
WATER POOL
SCRAP METAL
SLIMES
VAN WYK WES STREET
Legend:
DV-5
DV-S2
Sampling Points

The elevated trace metal such as Cr (1.54 mg/l), Co (14.6 mg/l), Cu (6.1 mg/l), Ni (44 mg/l), Zn (39.3 mg/l) and Al (442 mg/l) were observed at sampling point DV-2, which represents the shallow groundwater.

The highest concentration of Al (1 148 mg/l) and Ni (44 mg/l) were recorded at the Wet Land Area (DV-3). The Wet Land Area is surrounded by the mine dump and it receives seepage flow as well as storm water containing the trace metals.

• Remediation options and further field investigation

From the hydrochemical sampling it is clear the AMD is active in the area and it is more related to surface water, specially during the rainy period when rainwater/storm water carry the mine dump particles (containing pyrite and other minerals) into surface water environment.

• Groundwater

Not much data is available on the depth of weathering and contamination of saturated and unsaturated zones underlying the mine dump and Davidsonville area. It is expected that some degree of pollution at the shallow aquifer (perched water table aquifer) below the park, mine dump, industrial park and residential areas due to underground seepage flow (Data of DV-1). This seepage will most probably enter the Wet Land Area (lower area).

It is essential to drill a few shallow holes to identify the depth of pollution (perched aquifer). It can be within the industrial area, in the park and at the edge of the Wet Land Area. The underground polluted seepage flow can be captured by drilling by one or two shallow holes (not more than 10 meters in depth, depending on the depth of pollution) at the lower hydraulic head (Northwest of the park).

• Surface water

The source of surface water pollution is the mine dump located around the industrial and residential areas. The mobilization of mine dump particles into surface water by rain/ storm water needs to be controlled. This required re-shaping of the mine dump, re-designing the storm water canal around the mine dump (separation of fresh and polluted water as a result of rainfall over the area). The polluted water should be diverted into the temporary storage pond or tank for purification process. Vegetation cover of the mine dump will also prevent movement of the mine dump particles.

• Wet Land Area

The Wet Land Area (WLA) is a pollution source for the surface water as well as ground water environments. The origin of the pollution at the WLA is the mine dump which is located around the WLA. The AMD process resulted in highest sulphate (17 600 mg/l), and iron (3 078 mg/l) concentration with lowest pH 2.2 at this point.

The mine dump around the WLA which is the source of pollution should be removed (low volume) and existing water in the Wet Land Area and any lateral seepage flow into the WLA should be captured and purified. The Wet Land Area may change to a storm water collection dam and be used as a re-creation facility.

• Control the industrial activities

Pollution from the small industry in the industrial park (Sand blasting dust, brick manufacturing and chemical factory) can be contrclled if authorities apply the applicable regulatory measures.

• Domestic Waste

Disposal of domestic waste was observed around the mine dump by the local residents, which contributes to the surface water pollution.

The local municipality, providing better services, public awareness among the residents of Davidsonville could control the disposal of domestic waste.

END

M Fayazi
DWAF
February 2005

Reference to sampling points at Davidsonville

Sampling Point	Latitude Deg; Min; Sec. (S)	Longitude Deg; Min; Sec. (E)	Remarks
DV-1	26 09 23	27 50 18	Groundwater seepage, at the basement of painting factory.
DV-2	26 09 26	27 51 08	Seepage flow at the outlet of municipal concrete pipe, at the corner of Manuel and Fearick streets.
DV-3	26 09 29	27 51 04	Western water pool in the wetland area, at the southern point.
DV-4	26 09 23	27 51 16	At the end of storm water canal, opposite the re-cycling unit.
DV-5	26 09 24	27 51 17	At the end of storm water concrete canal, water entering the municipal drain system.
DV-6	26 09 29	27 51 19	Opposite the entrance to the brickyard, inside the canal, behind the control flow gate.
DV-7	26 09 27	27 51 20	Inside the brickyard, from pool water formed after rain, 3 meters inside the yard from the entrance.
DV-8	26 09 27	27 51 20	Inside the storm water concrete canal, close to the corner, sample collected after rain.
DV-9	26 09 42'	27 51 06	+/- 20 meters upstream of the municipal storm water concrete pipe, opposite of the first house from the south in the Fearick street, sample taken while it was raining.
DV-10	26 09 26	27 51 09	Close to DV-2 (upstream of DV-2), at the corner of Manuel and Fearick Streets, at the outlet of concrete pipe, just after rain.
DV-S1	26 09 25	27 51 22	Water pool on the slime, north of the brickyard.
DV-S2	26 09 29	27 51 22	Water pool on the slime, east of the brickyard.
DV-S3	26 09 32	27 51 19	Red water pool on the slime, southeast corner of the brickyard.
DV-S4	26 09 30	27 51 13	Seepage water entering the storm water canal, just southeast corner of brickyard depo, seepage water originated from surrounding slime dumps.
DV-Dam	26 09 05	27 50 55	Northeast of the surface water dam.

ERWAT

Laboratory Services
P.O.Box 13106
NORKEM PARK
1631

SANAS
T0062
Accredited Testing Laboratory

Tel: (011) 929-7014
(011) 929-7000
Fax: (011) 929-7065
(011) 929-7031

Certificate of analysis

Client:	Department of Water Affairs, M. Fayazi	**No:**	2003/11/133
Address:	Private Bag X995, PRETORIA, 0001	**Tel No:**	012-392-1382
Date Sampled:	13/11/2003	**Date certificate completed:**	20/11/2003
Date Sample received:	14/11/2003	**Date Analysed:**	14-19/11/2003

Sample description: Water

Analysis results

Sample no.	ERWAT no.	Container description
[1] DV-1 (Davidsville)	03EX11/14/072	2L Plastic Bottle
[2] QC		

CHEMICAL ANALYSIS

DETERMINAND	Sample No.1	Sample No.2
Conductivity (mS/m)	391	17
Total Dissolved Solids (mg/L)	4224	304
Total Alkalinity (mg/L $CaCO_3$)	170	150
Chloride (mg/L Cl)	36	99
Fluoride (mg/L F)	0.1	0.4
Calcium (mg/L Ca)	376.0	29.7
Magnesium (mg/L Mg)	349.1	20.3
Potassium (mg/L K)	15.6	9.7
Sodium (mg/L Na)	104.7	39.2
Cadmium (mg/L Cd)	<0.04	1.02
Chromium (mg/L Cr)	<0.03	0.93
Cobalt (mg/L Co)	3.14	0.98
Copper (mg/L Cu)	0.03	1.00
Iron (mg/L Fe)	10.49	0.96
Lead (mg/L Pb)	0.18	1.02
Manganese (mg/L Mn)	184.60	1.00
Nickel (mg/L Ni)	0.85	0.99
Zinc (mg/L Zn)	0.52	1.02
Aluminium (mg/L Al)	<0.1	1.0
Ammonia Nitrogen (mg/L N)	14.1	4.8
*Total Kjeldahl Nitrogen (mg/L N)	10.4	5.0
Nitrate Nitrogen (mg/L N)	0.3	-
Nitrite Nitrogen (mg/L N)	0.1	0.42
Orthophosphate (mg/L P)	<0.1	5.0
*Total Phosphorus (mg/L P)	<1.0	4.6
pH	5.9	4.0
Sulphate (mg/L SO_4)	2600	98
Oil and Grease (mg/L)	<10	99
Phenols (mg/L)	0.10	0.95

*Not "SANAS" Accredited
All quality control results were within the acceptable control limits.

Signed : .....
Alison Chapman, Laboratory Manager

Date : 24/11/2003

*Tests marked "Not SANAS Accredited" in this report are not included in the SANAS Accreditation Schedule for our laboratory.
All results and information relating will be treated in a confidential manner. The results relate only to samples tested according to the client request and are subject to an estimated uncertainly of measurement of ±3 standard deviation. This certificate shall not be reproduced except in full without the written approval of the Executive Manager, Erwat Laboratory Services.

ERWAT

SANAS

T0082
Accredited Testing Laboratory

Laboratory Services
P.O.Box 13106
NORKEM PARK
1631

Tel: (011) 929-7014
(011) 929-7000

Fax: (011) 929-7065
(011) 929-7031

Certificate of analysis

Client:	Department of Water Affairs, M. Fayazi	**No:**	2003/10/047
Address:	Private Bag X995, PRETORIA, 0001	**Tel No:**	012-392-1382
Date Sampled:	30/09/2003	**Date certificate completed:**	16/10/2003
Date Sample received:	01/10/2003	**Date Analysed:**	02-13/10/2003
Sample description:	Ad Hoc Surface Water		

Analysis results

Sample no.	ERWAT no.	Container description
[1] DV-1 10:20	03EX10/02/088	2L Plastic Bottle
[2] DV-2 10:50	03EX10/02/089	2L Plastic Bottle
[3] DV-3 12:50 Wetland	03EX10/02/090	2L Plastic Bottle
[4] QC		

CHEMICAL ANALYSIS

DETERMINAND	Sample No.1	Sample No.2	Sample No.3	Sample No.4
Conductivity (mS/m)	411	625	1384	94
Total Dissolved Solids (mg/L)	4606	10388	33520	300
Total Alkalinity (mg/L $CaCO_3$)	31	<10	<10	152
Chloride (mg/L Cl^-)	34	26	99	97
Fluoride (mg/L F^-)	0.1	0.1	<0.1	0.4
Calcium (mg/L Ca)	422.0	45.5	54.3	29.5
Magnesium (mg/L Mg)	469.9	168.8	798.0	19.8
Potassium (mg/L K)	13.7	7.2	1.5	9.8
Sodium (mg/L Na)	110.5	49.4	208.3	39.5
Cadmium (mg/L Cd)	<0.04	<0.04	<0.04	1.02
Chromium (mg/L Cr)	<0.03	0.75	1.83	0.98
Cobalt (mg/L Co)	0.23	7.86	28.80	0.99
Copper (mg/L Cu)	0.04	3.98	2.45	1.00
Iron (mg/L Fe)	69.94	1479.50	3078.00	1.01
Lead (mg/L Pb)	0.22	0.42	0.99	0.96
Manganese (mg/L Mn)	108.56	14.78	77.73	1.01
Nickel (mg/L Ni)	0.13	13.43	43.98	0.99
Zinc (mg/L Zn)	1.01	11.60	39.50	1.00
Aluminium (mg/L Al)	0.1	367.9	1148.0	1.1
Ammonia Nitrogen (mg/L N)	13.9	1.1	20.6	5.0
Total Kjeldahl Nitrogen (mg/L N)	13.5	9.9	13.7	5.3
Nitrate Nitrogen (mg/L N)	<0.1	<0.1	<0.1	4.5
Nitrite Nitrogen (mg/L N)	<0.1	<0.1	<0.1	0.4
Orthophosphate (mg/L P)	<0.1	0.1	4.4	4.9
Total Phosphorus (mg/L P)	<1.0	2.2	1.5	5.2
pH	6.2	2.9	2.2	9.0
Sulphate (mg/L SO_4)	2900	5000	17600	99
Oil and Grease (mg/L)	85	<10	<10	100
Phenols (mg/L)	0.08	<0.05	<0.05	0.95
Surfactants (mg/L)	<10	<10	<10	297

***Not "SANAS" Accredited**

All quality control results were within the acceptable control limits.

Signed : .....

Alison Chapman, Laboratory Manager

Date : 16/10/2003

*Tests marked "Not SANAS Accredited" in this report are not included in the SANAS Accreditation Schedule for our laboratory.
All results and information relating will be treated in a confidential manner. The results relate only to samples tested according to the client request and are subject to an estimated uncertainty of measurement of ±3 standard deviation. This certificate shall not be reproduced except in full without the written approval of the Executive Manager, Erwat Laboratory Services.

ERWAT
EAST RAND WATER CARE COMPANY

East Rand Water Care Company (Association incorporated in terms of Section 21) Reg. No. 1998/005753/08
Bapsfontein Road, Kempton Park, ✉ 13106, Norkem Park 1631, Republic of South Africa
☎ +27 11 929-7000 ☎ +27 11 929-7031 e-mail: mail@erwat.co.za www.erwat.co.za

Department of Water Affairs
Private Bag X995
PRETORIA
0001

Attention : M Fayazi

12 November 2003

Dear Sir

CERTIFICATE OF ANALYSIS

We enclose our certificate of analysis No. 2003/10/047 for the analysis of sample/s submitted to our laboratories on 01 October 2003.

Sub-contracted / referral results:

Sample name	ERWAT no.	ppm Si	ppm V	ppm Ba	ppm B	ppm Mo	ppm Sr
DV-1 10:20	03EX10/02/088	5.4	<1	0.1	<1	<0.3	1.2
DV-2 10:50	03EX10/02/089	51	<1	0.3	<1	<0.3	0.6
DV-3 12:50 Wetland	03EX10/02/090	116	<1	0.6	<1	<0.3	<0.1

Should you have any queries regarding the above please do not hesitate to contact the undersigned.

Yours faithfully

Alison Chapman
Laboratory Manager

DEPARTEMENT VAN WATERWESE
HOOF REGISTRASIE
MAIN REGISTRY
2003 -11- 20
PRIVAATSAK / PRIVATE BAG X995
PRETORIA, 0001
DEPARTMENT OF WATER AFFAIRS

Directors : Ms.M.M. Twala (Chairman); N.P. Twala (Managing Director); M.G.H. Aloen; E.V. Magerman; Ms. N. Dube; T.J. Motla; Ms. S.C. Mani

Member of:
International Water Association (IWA)
Water Environment Federation (WEF)
Water Institute of Southern Africa (WISA) - Fellow

ERWAT

Laboratory Services
P.O.Box 13106
NORKEM PARK
1631

SANAS
T0082
Accredited Testing Laboratory

Tel: (011) 929-7014
(011) 929-7000
Fax: (011) 929-7065
(011) 929-7031

Certificate of analysis

Client:	Department of Water Affairs, M. Fayazi	**No:**	2003/11/183
Address:	Private Bag X995, PRETORIA, 0001	**Tel No:**	012-392-1382
Date Sampled:	18/11; 19/11/2003	**Date certificate completed:**	28/11/2003
Date Sample received:	19/11/2003	**Date Analysed:**	20-27/11/2003
Sample description:	Water		

Analysis results

Sample no.	ERWAT no.	Container description
[1] DV-4 18/11 13:35	03EX11/20/116	2L Plastic Bottle
[2] DV-5 18/11 13:45	03EX11/20/117	2L Plastic Bottle
[3] DV-6 18/11 14:25	03EX11/20/118	2L Plastic Bottle
[4] DV-7 18/11 14:30	03EX11/20/119	2L Plastic Bottle

CHEMICAL ANALYSIS

DETERMINAND	Sample No.1	Sample No.2	Sample No.3	Sample No.4
Conductivity (mS/m)	24	20	61	256
Total Dissolved Solids (mg/L)	194	176	512	2578
Total Alkalinity (mg/L $CaCO_3$)	41	36	<10	46
Chloride (mg/L Cl)	17	8	13	23
Fluoride (mg/L F)	0.2	0.4	0.3	0.4
Calcium (mg/L Ca)	23.0	20.3	41.6	530.5
Magnesium (mg/L Mg)	3.4	2.3	19.2	88.3
Potassium (mg/L K)	5.7	6.0	8.2	25.3
Sodium (mg/L Na)	20.1	15.6	31.4	45.0
Cadmium (mg/L Cd)	<0.04	<0.04	<0.04	<0.04
Chromium (mg/L Cr)	<0.03	0.05	0.03	0.03
Cobalt (mg/L Co)	0.08	0.06	1.00	0.12
Copper (mg/L Cu)	0.06	0.54	0.66	0.06
Iron (mg/L Fe)	9.45	37.53	9.45	0.70
Lead (mg/L Pb)	0.08	<0.06	<0.06	0.11
Nickel (mg/L Ni)	0.08	0.12	0.89	0.18
Zinc (mg/L Zn)	1.76	1.03	2.16	0.10
Aluminium (mg/L Al)	0.4	0.7	6.4	2.1
Ammonia Nitrogen (mg/L N)	0.6	0.8	1.3	3.0
*Total Kjeldahl Nitrogen (mg/L N)	2.5	2.8	5.0	3.0
Nitrate Nitrogen (mg/L N)	1.1	1.6	2.7	3.1
Nitrite Nitrogen (mg/L N)	<0.1	0.1	0.3	0.2
Orthophosphate (mg/L P)	0.2	4.3	<0.1	5.0
*Total Phosphorus (mg/L P)	<1.0	4.9	<1.0	<1.0
pH	6.4	6.6	4.2	6.6
Sulphate (mg/L SO_4)	104	50	276	249
Oil and Grease (mg/L)	<10	<10	<10	<10
Phenols (mg/L)	0.05	<0.05	<0.05	<0.05

*Not "SANAS" Accredited

Signed : .....
Alison Chapman/Laboratory Manager

Date : 1/12/2003

*Tests marked "Not SANAS Accredited" in this report are not included in the SANAS Accreditation Schedule for our laboratory.
All results and information relating will be treated in a confidential manner. The results relate only to samples tested according to the client request and are subject to an estimated uncertainty of measurement of ±3 standard deviation. This certificate shall not be reproduced except in full without the written approval of the Executive Manager, Erwat Laboratory Services.

ERWAT

Laboratory Services
P.O.Box 13106
NORKEM PARK
1631

SANAS
T0082
Accredited Testing Laboratory

Tel: (011) 929-7014
(011) 929-7000
Fax: (011) 929-7065
(011) 929-7031

Certificate of analysis

Client:	Department of Water Affairs, M. Fayazi	**No:**	2003/11/183
Address:	Private Bag X995, PRETORIA, 0001	**Tel No:**	012-392-1382
Date Sampled:	18/11; 19/11/2003	**Date certificate completed:**	28/11/2003
Date Sample received:	19/11/2003	**Date Analysed:**	20-27/11/2003
Sample description:	Water		

Analysis results

Sample no.	ERWAT no.	Container description
[5] DV-8 18/11 14:45	03EX11/20/120	2L Plastic Bottle
[6] DV-9 18/11 15:10	03EX11/20/121	2L Plastic Bottle
[7] DV-10 19/11 14:00	03EX11/20/122	2L Plastic Bottle
[8] QC		

CHEMICAL ANALYSIS

DETERMINAND	Sample No.5	Sample No.6	Sample No.7	Sample No.8
Conductivity (mS/m)	27	737	659	17
Total Dissolved Solids (mg/L)	220	20378	10978	300
Total Alkalinity (mg/L $CaCO_3$)	25	<10	<10	52
Chloride (mg/L Cl^-)	14	700	425	100
Fluoride (mg/L F^-)	0.2	<0.1	<0.1	0.4
Calcium (mg/L Ca)	22.5	14.7	62.8	29.9
Magnesium (mg/L Mg)	3.5	220.1	153.0	20.5
Potassium (mg/L K)	5.3	0.5	5.8	10.0
Sodium (mg/L Na)	26.8	5.3	37.2	39.9
Cadmium (mg/L Cd)	<0.04	0.26	0.16	1.01
Chromium (mg/L Cr)	<0.03	8.60	0.80	1.06
Cobalt (mg/L Co)	0.26	15.68	7.70	0.99
Copper (mg/L Cu)	0.28	17.03	4.02	0.99
Iron (mg/L Fe)	0.71	3053.00	1633.00	0.97
Lead (mg/L Pb)	0.06	0.60	0.36	0.96
Nickel (mg/L Ni)	0.11	26.08	13.90	1.00
Zinc (mg/L Zn)	1.21	22.30	11.30	1.01
Aluminium (mg/L Al)	0.9	730.0	352.0	0.9
Ammonia Nitrogen (mg/L N)	0.5	3.7	1.5	5.2
*Total Kjeldahl Nitrogen (mg/L N)	2.8	5.9	8.7	5.0
Nitrate Nitrogen (mg/L N)	2.8	1.1	0.9	-
Nitrite Nitrogen (mg/L N)	0.2	0.1	<0.1	0.4
Orthophosphate (mg/L P)	0.5	13.5	0.3	5.1
*Total Phosphorus (mg/L P)	1.1	8.2	1.8	5.6
pH	6.2	2.2	3.0	4.0
Sulphate (mg/L SO_4)	163	9600	6650	103
Oil and Grease (mg/L)	14	<10	<10	96
Phenols (mg/L)	0.28	<0.05	<0.05	1.00

*Not "SANAS" Accredited
All quality control results were within the acceptable control limits.

Signed : .....
Alison Chapman, Laboratory Manager

Date : 1/12/2003

*Tests marked "Not SANAS Accredited" in this report are not included in the SANAS Accreditation Schedule for our laboratory.
All results and information relating will be treated in a confidential manner. The results relate only to samples tested according to the client request and are subject to an estimated uncertainty of measurement of ±3 standard deviation. This certificate shall not be reproduced except in full without the written approval of the Executive Manager, Erwat Laboratory Services.

East Rand Water Care Company (Association incorporated in terms of Section 21) Reg. No. 1992/005753/08
Bapsfontein Road Kempton Park, ✉ 13106 Norkem Park 1631, Republic of South Africa
Tel: (27 11) 929-7000, Fax: (+27 11) 929-7031, e-mail: mail@erwat.co.za, www.erwat.co.za

Department of Water Affairs
Private Bag X995
PRETORIA
0001

Attention : M Fayazi

8 January 2004

Dear Sir

CERTIFICATE OF ANALYSIS

We enclose our certificate of analysis No. 2003/11/183 for the analysis of sample/s submitted to our laboratories on 19 November 2003.

Sub-contracted / referral results:

Sample name	ERWAT no.	ppm As	ppm B	ppm Sr	ppm Si
DV-4 18/11 13:35	03EX11/20/116	<1	<1	<0.1	2.7
DV-5 18/11 13:45	03EX11/20/117	<1	<1	<0.1	4.3
DV-6 18/11 14:25	03EX11/20/118	<1	<1	<0.1	3.7
DV-7 18/11 14:30	03EX11/20/119	<1	1	1.6	5.1
DV-8 18/11 14:45	03EX11/20/120	<1	<1	<0.1	3.5
DV-9 18/11 15:10	03EX11/20/121	2.3	<1	<0.1	29
DV-10 19/11 14:00	03EX11/20/122	<1	<1	0.5	44

Should you have any queries regarding the above please do not hesitate to contact the undersigned.

Yours faithfully

Alison Chapman
Laboratory Manager

DEPARTEMENT VAN WATERWESE
HOOF REGISTRASIE
MAIN REGISTRY
2004 -01- 13
PRIVAATSAK / PRIVATE BAG X995
PRETORIA, 0001
DEPARTMENT OF WATER AFFAIRS

Directors : Ms M.M. Twala (Chairman); N.P. Twala (Managing Director); M.G.H. Alcock; E.V. Magerman; Ms. N. Dube; T.J. Mothe; Ms. S.C. Marx

Member of
International Water Association (IWA)
Water Environment Federation (WEF)
Water Institute of Southern Africa (WISA) - Pretoria

ERWAT

Laboratory Services
P.O.Box 13106
NORKEM PARK
1631

SANAS
T0082
Accredited Testing Laboratory

Tel: (011) 929-7014
(011) 929-7000
Fax: (011) 929-7065
(011) 929-7031

Certificate of analysis

Client:	Department of Water Affairs, M. Fayazi	**No:**	2003/12/024
Address:	Private Bag X995, PRETORIA, 0001	**Tel No:**	012-392-1382
Date Sampled:	25/11/2003	**Date certificate completed:**	01/12/2003
Date Sample received:	25/11/2003	**Date Analysed:**	26-11-01-12/2003

Sample description: Water

Analysis results

Sample no.		ERWAT no.	Container description
[1]	DVS-1 11h40	03EX11/26/082	2L Plastic Bottle
[2]	DVS-2 12h00	03EX11/26/083	2L Plastic Bottle
[3]	DVS-3 12h20	03EX11/26/084	2L Plastic Bottle
[4]	Slimes Water entering outlet canal	03EX11/26/085	2L Plastic Bottle

CHEMICAL ANALYSIS

DETERMINAND	Sample No.1	Sample No.2	Sample No.3	Sample No.4
Conductivity (mS/m)	8	127	334	1121
Total Dissolved Solids (mg/L)	64	1034	4548	22462
Total Alkalinity (mg/L $CaCO_3$)	<10	<10	<10	<10
Chloride (mg/L Cl)	10	<3	<3	7
Fluoride (mg/L F)	0.2	0.2	0.1	0.1
Calcium (mg/L Ca)	3.6	6.4	11.7	61.3
Magnesium (mg/L Mg)	0.4	12.0	34.6	161.0
Potassium (mg/L K)	2.0	0.2	0.5	0.2
Sodium (mg/L Na)	2.9	2.7	2.6	6.4
Cadmium (mg/L Cd)	<0.04	<0.04	<0.04	0.16
Chromium (mg/L Cr)	<0.03	0.32	1.95	4.64
Cobalt (mg/L Co)	<0.04	0.65	3.02	17.51
Copper (mg/L Cu)	<0.03	1.05	3.66	12.47
Iron (mg/L Fe)	0.53	40.74	421.90	2714.00
Lead (mg/L Pb)	0.29	0.35	0.49	1.05
Manganese (mg/L Mn)	0.13	0.32	3.28	9.27
Nickel (mg/L Ni)	<0.06	1.23	5.17	31.83
Zinc (mg/L Zn)	0.03	1.16	6.25	39.60
Aluminium (mg/L Al)	0.4	59.4	149.0	1099.0
Ammonia Nitrogen (mg/L N)	<0.1	0.4	1.0	1.8
*Total Kjeldahl Nitrogen (mg/L N)	<1.0	<1.0	3.5	7.4
Nitrate Nitrogen (mg/L N)	<0.1	0.4	0.4	<0.1
Nitrite Nitrogen (mg/L N)	<0.1	<0.1	<0.1	<0.1
Orthophosphate (mg/L P)	0.2	0.2	1.9	8.9
*Total Phosphorus (mg/L P)	<1.0	<1.0	2.9	8.5
pH	5.3	2.7	2.4	2.4
Sulphate (mg/L SO_4)	25	400	2240	12650

*Not "SANAS" Accredited

Signed : .....
Alison Chapman, Laboratory Manager

Date : 2/12/2003

*Tests marked "Not SANAS Accredited" in this report are not included in the SANAS Accreditation Schedule for our laboratory.
All results and information relating will be treated in a confidential manner. The result relate only to samples tested according to the client request and are subject to an estimated uncertainty of measurement of ±3 standard deviation. This certificate shall not be reproduced except in full without the written approval of the Executive Manager, Erwat Laboratory Services.

East Rand Water Care Company (Association incorporated in terms of Section 21) Reg. No. 1992/005753/08
Bapsfontein Road Kempton Park, PO 13106 Norkem Park 1631, Republic of South Africa
Tel: (27 11) 929-7000, Fax: (+27 11) 929-7031, e-mail: mail@erwat.co.za, www.erwat.co.za

Department of Water Affairs
Private Bag X995
PRETORIA
0001

Attention : M Fayazi

8 January 2004

Dear Sir

CERTIFICATE OF ANALYSIS

We enclose our certificate of analysis No. 2003/12/024 for the analysis of sample/s submitted to our laboratories on 25 November 2003.

Sub-contracted / referral results:

Sample name	ERWAT no.	ppm As	ppm B	ppm Sr	ppm Mo	ppm V	ppm Ba
DVS-1 11h40	03EX11/26/082	<1	<1	<0.1	<0.3	<1	<0.1
DVS-2 12h00	03EX11/26/083	<1	<1	<0.1	<0.3	<1	<0.1
DVS-3 12h20	03EX11/26/084	<1	<1	<0.1	<0.3	<1	0.1
Slimes Water entering outlet canal	03EX11/26/085	1.9	<1	0.9	<0.3	<1	0.5

Should you have any queries regarding the above please do not hesitate to contact the undersigned.

Yours faithfully

Alison Chapman
Laboratory Manager

DEPARTEMENT VAN WATERWESE
HOOF REGISTRASIE
MAIN REGISTRY
2004 -01- 13
PRIVAATSAK / PRIVATE BAG X995
PRETORIA, 0001
DEPARTMENT OF WATER AFFAIRS

Directors : Ms.M.M. Twala (Chairman); N.P. Twala (Managing Director); M.G.H. Akoon; E.V. Magerman; Ms. N. Dube; T.J. Motla; Ms. S.C. Marx

Member of:
International Water Association (IWA)
Water Environment Federation (WEF)
Water Institute of Southern Africa (WISA) - Patron

ERWAT

Laboratory Services
P.O.Box 13106
NORKEM PARK
1631

SANAS
T0082
Accredited Testing Laboratory

Tel: (011) 929-7014
(011) 929-7000
Fax: (011) 929-7065
(011) 929-7031

Certificate of analysis

Client:	Department of Water Affairs, M. Fayazi	**No:**	2003/12/159
Address:	Private Bag X995, PRETORIA, 0001	**Tel No:**	012-392-1382
Date Sampled:	11/12/2003	**Date certificate completed:**	18/12/2003
Date Sample received:	11/12/2003	**Date Analysed:**	12-18/12/2003

Sample description: Water

Analysis results

Sample no.	ERWAT no.	Container description
[1] DV-Dam Water 11h45	03EX12/12/080	2L Plastic Bottle
[2] DV-2 10h15	03EX12/12/081	2L Plastic Bottle
[3] QC		

CHEMICAL ANALYSIS

DETERMINAND	Sample No.1	Sample No.2	Sample No.3
Conductivity (mS/m)	18	803	100
Total Dissolved Solids (mg/L)	116	13590	296
Chloride (mg/L Cl)	8	16	105
Fluoride (mg/L F)	0.3	0.2	0.4
Calcium (mg/L Ca)	15.3	72.2	30.1
Magnesium (mg/L Mg)	3.4	164.9	20.4
Potassium (mg/L K)	3.4	5.7	9.7
Sodium (mg/L Na)	13.9	48.3	46.7
Cadmium (mg/L Cd)	<0.04	0.07	0.99
Chromium (mg/L Cr)	<0.03	1.54	0.94
Cobalt (mg/L Co)	<0.04	14.56	0.99
Copper (mg/L Cu)	<0.03	6.09	1.01
Iron (mg/L Fe)	1.12	1516.00	1.01
Lead (mg/L Pb)	0.20	0.76	1.01
Nickel (mg/L Ni)	<0.06	18.04	0.99
Zinc (mg/L Zn)	0.05	19.30	0.99
Aluminium (mg/L Al)	0.3	442.1	1.0
Ammonia Nitrogen (mg/L N)	0.3	0.2	4.9
*Total Kjeldahl Nitrogen (mg/L N)	<1.0	7.7	4.9
Nitrate Nitrogen (mg/L N)	0.4	<0.1	-
Nitrite Nitrogen (mg/L N)	0.1	<0.1	0.4
Orthophosphate (mg/L P)	<0.1	1.5	5.0
*Total Phosphorus (mg/L P)	<1.0	3.7	4.9
pH	7.1	3.1	9.0
Sulphate (mg/L SO_4)	24	7425	97
Oil and Grease (mg/L)	<10	<10	98
Phenols (mg/L)	<0.05	<0.05	1.04
Total Alkalinity (mg/L $CaCO_3$)	42	<10	50

*Not "SANAS" Accredited
All quality control results were within the acceptable control limits.

Signed : .....
Alison Chapman, Laboratory Manager

Date : 19/12/2003

*Tests marked "Not SANAS Accredited" in this report are not included in the SANAS Accreditation Schedule for our laboratory.

All results and information relating will be treated in a confidential manner. The results relate only to samples tested according to the client request and are subject to an estimated uncertainty of measurement of +3 standard deviation. This certificate shall not be reproduced except in full without the written approval of the Executive Manager, Erwat Laboratory Services.

Reference

Audouin, J.C., 1997: Geophysical study of Acid Rock Drainage in the City Deep Area, Johannesburg, Gauteng. Msc. Thesis Engineering Faculty, University of the Witwatersrand (Civil Engineering).

Bell, F.G and Donnelly, L.J. 2006: *Mining and its Impacts on the Environment*. London. New York: Taylor & Francis.

Bridgett, J. 2001: Determination of the ground and surface water quality in the vicinity of the Ballengeich coal mine in Newcastle: Kwa Zulu Natal. (Mini Dissertation).

Davies, B.R., O'Keeffe, J.H and Snaddon, C.D. (1993) A Synthesis of the Ecological Functioning, Conservation and Management of South African River Ecosystems. Water Research Commission Report No. TT 62/93, Pretoria. Water Research Commission.

Department of Environmental Affairs and Tourism, Department of Water Affairs and Forestry: (1998) Integrated White Paper on Integrated Pollution and Waste Management in South Africa. http://easd.org.za/sapol/polwp2&3.htm

Department of Water Affairs and Forestry (DWAF), March 1999: Development of a Water Quality Management Plan for the Klip River Catchments: Phase 1 – Situation Analysis. Draft Final Report. Pretoria: Government Printer.

Department of Water Affairs and Forestry, 2007: Water Treatment. Best practice guidelines for Water Resource Protection in the Southern African Mining Industry.

Ecosystem Restoration (n.d) – Technical guide: water treatment: surface water: active treatment systems. Retrieved June 2007 from http://ecorestoration.montana.edu/mineland/guide/construction/water/surface/active/default.htm

Evangelou V.P. (Bill), 1995: Pyrite Oxidation and its Control. CRC Press, Inc

Fayazi,M., 2005: Princess Mine Dump. Report on the water quality survey around the Princess Mine Dump and its negative effects on the water resources.

Foster , S.M.,1998: Mining and Environmental Management, Financial Times, Energy.

Geller,W., Klapper, H., Salomons,W., (Eds), 1998: Acidic Mining Lakes- acid mine drainage, limnology and reclamation.

Hounslow, A.W. (1995) *Water Quality Data. Analysis and Interpretation*. Lewis Publishers.

Kyeyune, S.K., 2000: Impacts of Acid Mine Drainage on the Kromdraaispruit system. Msc Research Report. Faculty of Science. University of the Witwatersrand.

Lee, JE and Yeongkyoo Kim,Y. 2007: A quantitative estimation of the factors affecting pH changes using simple geochemical data from acid mine drainage http://www.springerlink.com/content/00019r6164g650j0/fulltext.pdf

Martin T.E, M P Davies, S Rice, T Higgs, and P C Lighthall, 2002: Stewardship of Tailings Facilities - Mining, Minerals and Sustainable Development.

McCauley, C.A., O'Sullivan, A.D., Weber, P and Lindsay, P. (2006) Mitigating Acid Mine Drainage Impacts in New Zealand using Engineered Wetlands. http://ir.canterbury.ac.nz/bitstream/10092/405/1/12603871_Main.pdf

MEND, 1996: Review of Passive Systems For Treatment of Acid Mine Drainage. Report

Metesh, John J.; Jarrell, Terrie; Oravetz, Steve. 1998: Treating Acid Mine Drainage from abandoned mines in remote areas. Tech. Rep. 9871-2821-MTDC. Missoula, MT: United States Department of Agriculture, Forest Service, Missoula Technology and Development Center. 22p. http://www.fs.fed.us/eng/pubs/pdfpubs/pdf98712821/pdf98712821.pdf

MMSD 2001:. Impacts of Mining, Mineral Processing on the Biophysical Environment in Southern Africa. Final report. Southern Africa Research Topic 4. www.mining.wits.ac.za/Final/Report-section2.doc.

Morrison, R. 2004: Environmental Information Systems: A challenge to meet corporate environmental strategy in the South Africa mining industry. (mini dissertation).http://etd.rau.ac.za/theses/available/etd-11172004-104318/restricted/040730MSCProjectRoganMorrisonfinal.pdf

Pullies,W., Heath, R. and Howard, M.1996: A manual to assess and manage the impacts of gold mining operation on the surface water environment. Prepared for Chamber of Mines of South Africa and the Water Research Commission http://www.ceroi.net/reports/johannesburg/csoe/images/envissues/soil/geology.jpg

Robins, M., 2004: Closure of tailings facilities: Current practice review and guidelines for success. Msc. Thesis Engineering Faculty, University of the Witwatersrand (Civil Engineering).

Skousen,J., 1998: Overview of Passive Systems for Treating Acid Mine Drainage. West Virginia University. http://www.wvu.edu/~agexten/landrec/passtrt/passtrt.htm

Skousen,J., Rose,A., Geidel, G., Foreman,J., Evans, R., Heller, W. and Members of the Avoidance and Remediation Working Group of the Acid Drainage Technology Initiative (ADTI), 1998: A handbook of technologies for avoidance and remediation of Acid Mine Drainage. http://www.ott.wrcc.osmre.gov/library/hbmanual/hbtechavoid/front.pdf

Smith, K., 1997: Constructed Wetlands for Treating Acid Mine Drainage http://horticulture.coafes.umn.edu/vd/h5015/97papers/smith.html

South Africa Weather Service. http://www.weathersa.co.za/Climat/Climstats/JohannesburgStats.jsp

SRK Consultants. (2006) Princess Dump Pre-feasibility Study for Rehabilitation report. Unpublished).

Steffen, Robertson & Kirsten (Pretoria) Ing, 1988: Research on the contribution of mine dumps to the mineral pollution load in the Vaal Barrage. Water Research Commission

surface and ground water). (Unpublished/Attached)

US Office of Surface Mining Reclamation and Enforcement, 2006: Acid Mine Drainage treatment techniques and costs. http://www.osmre.gov/amdtcst.htm

Wildman, T. R.; and Laudon, L. S. 1989: Use of wetlands for treatment of environmental problems in mining non-coal-mining applications. Constructed wetlands for wastewater treatment, D. A. Hammer (ed.). 221-231 Chelsea, Michigan: Lewis

Younger,P.L. 2001: Passive treatment of European mine waters: the European commission's 'pyramid' project. http://www.ceg.ncl.ac.uk/research/pubdetailxml.aspx?id=38043