CHAPTER 7 - TAILINGS DAMS

7.1 Introduction

There are five tailings dams (refer to Figure 7.1). All, except North Mine Dam 3 are divided into two compartments. The springs associated with these tailings dams show poor water quality and are sometimes subjected to AMD (Anglo American Corporation of S.A, 1995). Sediment samples were collected at three different depths – at 150mm, 500mm and at 1000mm. Each sample was analysed for pH, sulphur concentration and pyrite as FeS_2.

The quality of water in the tailing dams is dependent on the mineral and chemical composition of the reefs being mined. The composition of a reef varies from mine to mine. There are three main types of reefs: Carbon Leader, Vendersdorp Contact Reef (VCR) and the Ventersdorp Lavas (Kenyon, pers comm., 1999). The capacity for acid generation increases with increasing sulphur content (Miller *et al*, 1990).

The risk of acid production is reduced by the fact that with increasing depth there is less oxygen available for oxidation and so the chances of oxidising pyrite are limited, unless there is another oxidising agent (Boer, pers comm, 1999).

The sampling was a once-off activity, and therefore it is not possible to determine whether seasonal weather changes played a role in the changes in pyrite, sulphur and pH.

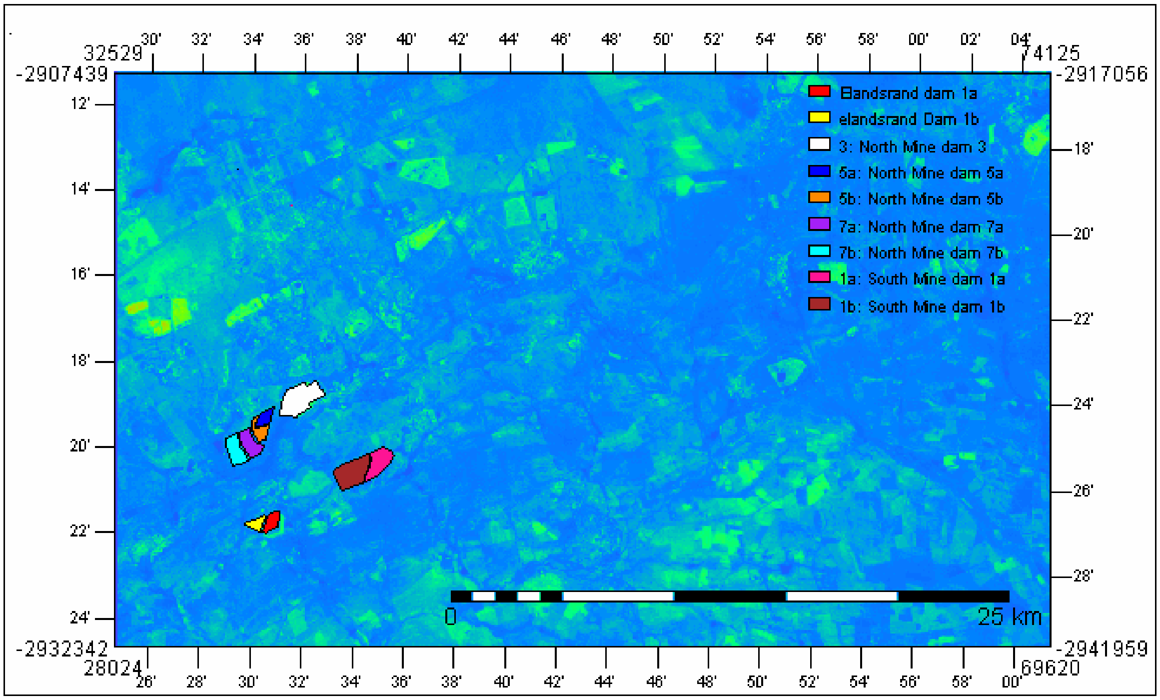

Figure 7.1 Tailings Dams Overlaid on a Short Wave Infrared Image

7.2 Historical Background

7.2.1 Elandsrand Dam Complex

The dam was commissioned in 1978. It is divided into upper and lower (1a & 1b respectively) compartments with a return water dam facility. Near the base of the slope in the dam basin the quartzite contacts shale, which is evident by the shale and slate quarrying to the southeast. There is minimal topsoil on the quartzite ridge. Overlying the residual shale is a thin layer of 200 mm topsoil of generally poor fertility. The site is not on dolomite and therefore there is no risk of sinkhole formation. The drainage and permeability characteristics in areas of quartzite and shale are poor (West Wits Operations, 1999).

7.2.2 North Mine dam 3

This dam has been in existence since 1961. Naturally transported soils originating from shale bedrock and localised zones of quartzite underlie the dam. The topsoil is 400 mm thick on average. The dam is not on dolomite and therefore there is no risk of sinkhole formation below the tailings dam. The site has relatively poor drainage characteristics due to the low permeability of the fine-grained alluvium. There is a major seepage along the southern toe.

7.2.3 North Mine Dams Complex - dams no. 5 & 7

The no. 5 dam complex was constructed in 1971. The no. 7 complex was constructed in 1979/80. Both dams (no. 5 & 7) have been founded on a thin layer of topsoil overlying shale. The topsoil is on average 200 mm thick where it overlies decomposed shale and 400 mm thick on average in low-lying areas over residual diabase. There is a dolomite outcrop half a kilometre from the northwest corner, which dips in the southeasterly direction and therefore there is a low risk of sinkhole formation beneath North Mine dam 7 and a very low risk under North Mine dam 5. The drainage characteristics are poor due to a thin layer of topsoil overlying a relatively impermeable shale layer. There is minor seepage south east of no. 7a dam.

7.2.4 South Slimes Dam Complex

The dam was commissioned in 1986. It is divided into an upper and a lower compartment (a & b respectively) with a return water facility. Both compartments are underlain by shale, which is covered by a thin layer of topsoil. The topsoil is generally poor and restricted to a maximum of 200 mm over most of the site. The complex does not overlay dolomite therefore there is no risk of sinkhole formation. The shallow ground has relatively good drainage characteristics. The underlying shale is relatively impermeable at depth. There is seepage in the catchment paddocks situated below the lowest point south of the lower compartment. This seepage is attributed to the original drainage path for natural stormwater runoff (West Wits Operations, 1999).

7.3 Chemical Analysis of the Tailings

Table 7.1 summarises the pH, sulphur and pyrite concentrations at three different depths – 150, 500 and 1000 mm – for all the tailings dams.

7.3.1 North Mine Dam 3

pH increases with depth and all samples are within the pH 6-9 range. Both sulphur and pyrite increase with depth. Oxidation of pyrite decreases with increasing depth. There is no decrease in pH that is normally associated with pyrite oxidation. There is therefore increasing pH and pyrite content with increasing depth. The high pH may suggest presence of neutralising agents. AMD potential is reduced by the high pH.

7.3.2 North Mine Dam 5a

pH decreases with depth. The 500 mm depth has the lowest concentration of both sulphur and pyrite; the highest concentration is experienced at 1000 mm depth.

7.3.3 North Mine Dam 5b

pH decreases with depth, with most samples having pH of less than 6. Both sulphur and pyrite increase with depth. The groundwater is likely to be adversely affected by the acidic water and the pyrite content that increase with depth. The potential for AMD is great due to the combination of decreasing pH and increasing pyrite with depth.

7.3.4 North Mine Dam 7a

pH increases with depth. Data for sulphur and pyrite are not available.

7.3.5 North Mines Dam 7b

There is a slight increase of pH with depth, with a few samples below pH 6. Both sulphur and pyrite increase with depth. The high levels of Fe in MBH 18 may have come from this dam as they are close to each other (refer to Figure 8.1 for location of tailings dams and boreholes). The elevation facilitates the flow (runoff and seepage) from North Mine dam 7b to areas overlying MBH 18.

Table 7.1: Chemical Analysis of the Tailings

Tailings Dam	Depth (mm)	pH	% Sulphur	Pyrite
Elandsrand Dam 1a	150	4.6	0.35	6520
	500	4.3	0.31	5740
	1000	4.9	0.49	9160
Elandsrand Dam 1b	150	6	0.7	13120
	500	6.4	0.63	11710
	1000	6.4	0.66	12320
N. Mine dam 3	150	7.8	0.2	3983
	500	7.5	0.19	3500
	1000	7.7	0.28	5200
N. Mine dam 5a	150	6.6	0.2	3740
	500	6.4	0.17	3220
	1000	6.2	0.25	4773
N. Mine dam 5b	150	5.5	0.2	2269
	500	5.6	0.13	2384
	1000	5.7	0.2	3762
N. Mine dam 7a	150	7.3		
	500	7.3		
	1000	6.7		
N. Mine dam 7b	150	7.8	0.6	3083
	500	7.7	0.19	3583
	1000	7.7	0.22	4050
S. Mine dam 1a	150	7.2	0.29	5515
	500	7.2	0.32	5908
	1000	7.5	0.39	7215
S. Mine dam 1b	150	6.7	0.28	5471
	500	6.5	0.43	8030
	1000	6.5	0.45	8207

7.3.6 Elandsrand Mine Dam 1a

Change of pH with depth is not significant. The pH is low, with most samples having pH of less than 6. Both sulphur and pyrite increase with depth in most samples. The potential for AMD production is great due to the combination of low pH and high sulphur and pyrite levels both (sulphur and pyrite) of which increase with depth.

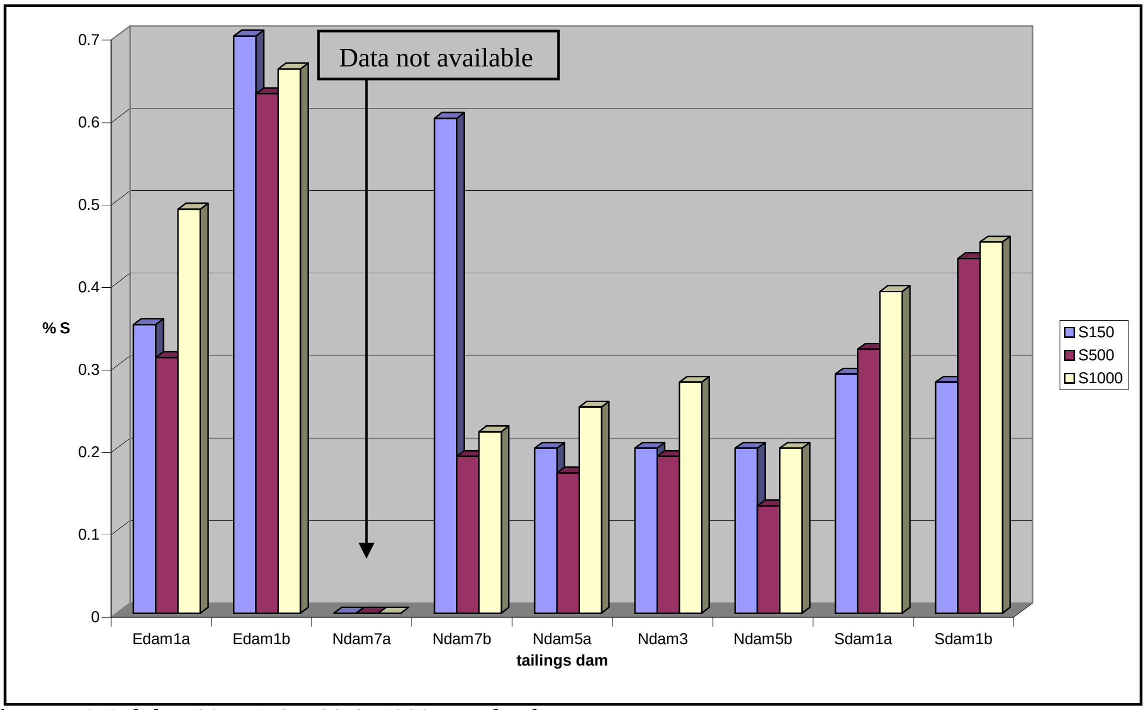

Figure 7.2 Sulphur % at 150, 500 & 1000 mm depth

7.3.7 Elandsrand Mine Dam 1b

pH increases with depth; most samples have pH below 6. Both sulphur and pyrite increase with depth. The increasing pH with depth may work against AMD production even though sulphur and pyrite increase with depth.

7.3.8 South Mines Dam 1a

pH increases with depth and the range of pH is 6-9. Both sulphur and pyrite increase with depth and therefore the risk of acid production increases with depth.

Analysis

All the dams, with the exception of South Mine dams, show lower concentrations at 500 mm depth compared to both 150 and 1000 mm depths. The lower sulphur concentration at 500 mm indicates more chemical reaction at this depth, that is, the sulphur has been converted to other forms. There is more reaction due to a combination of two factors- enough residence time for the sulphur to react and also the availability of oxygen. At 150 mm depth there is enough oxygen available but not enough time for the sulphur to react. At 1,000 mm depth the tailings have had enough time but there is lack of oxygen. The higher sulphur concentration at 150 mm poses a risk of acidic seepage to the areas that are at a lower elevation than the tailings dams. South Mine dams show an increase in sulphur concentration with increasing depth beyond 500mm depth. This means that the infiltration of wastewater into the groundwater will have high sulphur concentrations. The South Mines dams are different from the other damd due to their relatively good drainage characteristics and their shorter existence.

7.3.9 South Mines Dam 1b

The minimum pH measured was 2.78. A number of samples are below pH 6. The pH decreases with depth, while both sulphur and pyrite increase with depth. The low pH is conducive to acid production.

Figure 7.3 shows the amount of pyrite at three different depths, 150, 500 and 1000 mm. The graph is similar to the graph of sulphur concentration at the same depths, that is, the pattern of pyrite concentration in each dam is similar to the pattern of S concentration of the same dam. The exceptions are North Mine dam 7b and North Mine 5b where, unlike the sulphur pattern in which the lowest sulphur concentration is found at 500 mm, the pyrite concentration increases with depth as less pyrite is being oxidised at that depth. North Mine 7b, North Mine dam 5b and South Mine dams are likely to contaminate the groundwater with pyrite and its breakdown products (because of increasing pyrite with increasing depth). Oxidation of pyrite in these dams is slow. Most of the pyrite infiltrates the walls of the dams before it can be oxidised, hence the increase with depth. These dams are likely to be more porous than the other dams. In the other dams (Elandsrand dams, North Mine dam 3, North Mine dam 5a) oxidation of pyrite is faster, which explains why pyrite decreases with depth to a depth of 500-mm. Most oxidation takes place between 150-500 mm depth, which is why the amount of pyrite decreases at this depth. Beyond 500 mm, lack of oxygen inhibits oxidation of pyrite, hence the increase in the pyrite concentration. These dams will impact mainly on surface water as they have high concentrations of pyrite at 150 mm, the depth at which most oxidation (compared to the other two depths) takes place (Kenyon, pers comm). There is therefore the risk of generation of both acidity and iron hydroxide, a by-product of pyrite oxidation which covers and therefore suffocates any life forms in its path.

These results imply risk of contamination of the groundwater. The water is very acidic, and as it passes the rocks on its way to the groundwater it can dissolve the metals found in those rocks. The groundwater users are then faced with heavy metal toxicity. There is also the potential for groundwater pollution by pyrite.

Table 7.2 shows that the tailings of South Mine dams have the smallest specific gravity range (specific gravity is the density of a substance divided by the density of water). This means that the sediment is fine and almost homogenous, resulting in higher water retention capacity than the other dams. This reduces porosity, which in turn reduces seepage. The North Mine dams have a higher percentage of large particles (2.6 % of the slimes have the size particle of more than 150) compared to Elandsrand dams and South Mine dams with 1.43 and 1.5 respectively). This explains why North Boundary dam is more polluted than the other dams.

Table 7.2 Properties of tailings dams (West Wits Operations (1999)

Dam	Area (Ha)	Height (m)#[1]	Specific Gravity (no units)	Size particle (µm) & % of material of that size
No3	**66.1**	**56**	**1.35-1.55**	**+150 (2.6%)** +75 (24.6%) -75 (72.8%)
No. 5a	**52.16**	**25**	**1.35-155**	**+150 (2.6%)** +75 (24.6%) -75 (72.8%)
No. 5b	**45.86**	**23**	**1.35-1.55**	**+150 (2.6%)** +75 (24.6%) -75 (72.8%)
No. 7a	**96.23**	**34.7**	**1.35-1.55**	**+150 (2.6%)** +75 (24.6%) -75 (72.8%)
No. 7b	**101.48**	**31.3**	**1.35-1.55**	**+150 (2.6%)** +75 (24.6%) -75 (72.8%)
Elandsrand 1a	**48.63**	**37.7**	**1.42-1.64**	**+150 1.43%)** +75 (20.37%) -75 (78.18%)
Elandsrand 1b	**61.94**	**49.2**	**1.42-1.64**	**+150 1.43%)** +75 (20.37%) -75 (78.18%)
South 1a	**66.27**	**23.5**	**1.37-1.47**	**+150 (1.5%)** +75 (14.7%) -75 (83.8%)
South 1b	**88.5**	**27.2**	**1.37-1.47**	**+150 (1.5%)** +75 (14.7%) -75 (83.8%)

[1] # - determined from the lowest point to the highest above sea level

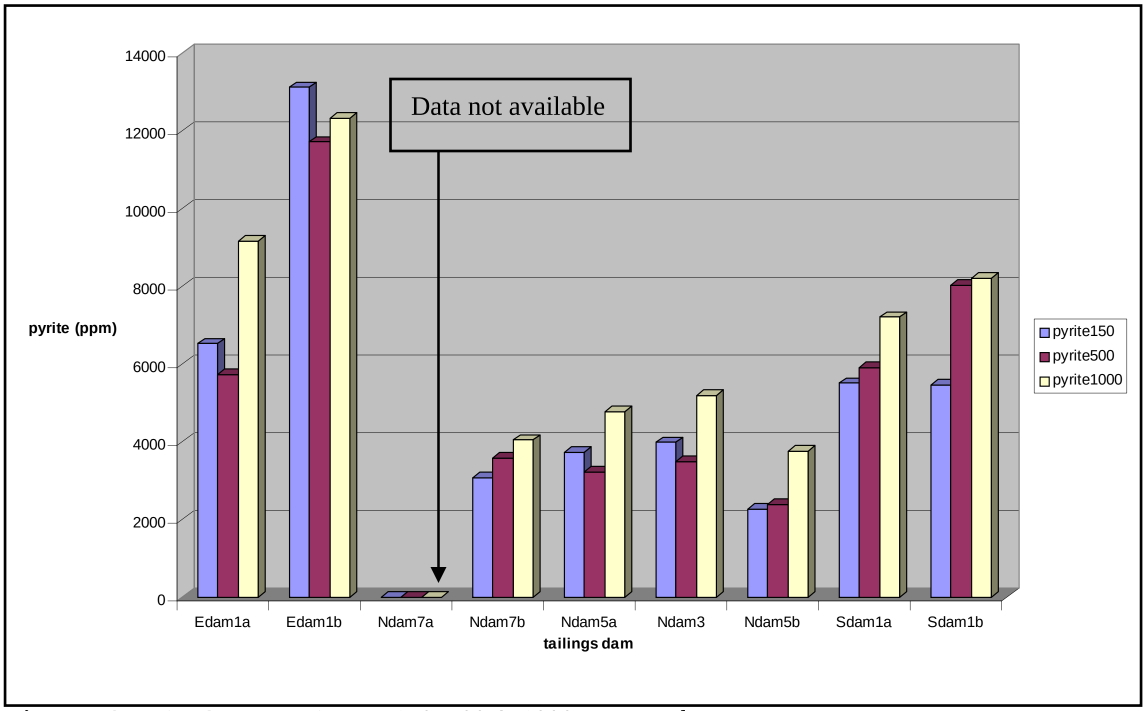

Figure 7.3 Pyrite Concentrations at 150, 500 & 1000 mm Depth

7.4 GIS Analysis

This group of operations combines several maps and thus gives new information that was not present in the individual maps. In this study the map showing the concentration of sulphur in the tailings dams have been overlaid on the false colour composite to show areas that are likely to be affected by AMD (see figure 7.3).

7.4.1 Sulphur at 150mm

The highest sulphur concentration is found in the Elandsrand slimes dams, especially Elandsrand dam 1b. The North Mine dams have the lowest sulphur; South Mine dam has intermediate sulphur concentrations.

7.4.2 Sulphur at 500mm

The distribution of sulphur at 500 mm is similar to that of sulphur at 150 mm, except for the S. mine dams and the surrounding areas where there is an increase in sulphur with increase in depth from 150 mm to 500 mm.

The size of the diamond is proportional to the concentration of sulphur. South Mine dams were only commissioned in 1986 and the satellite image was acquired in 1984 that is why the dams do not appear on the above figure. This was the only available image.

7.4.3 Sulphur at 1000 mm

The pattern is similar to the one at 150 mm.

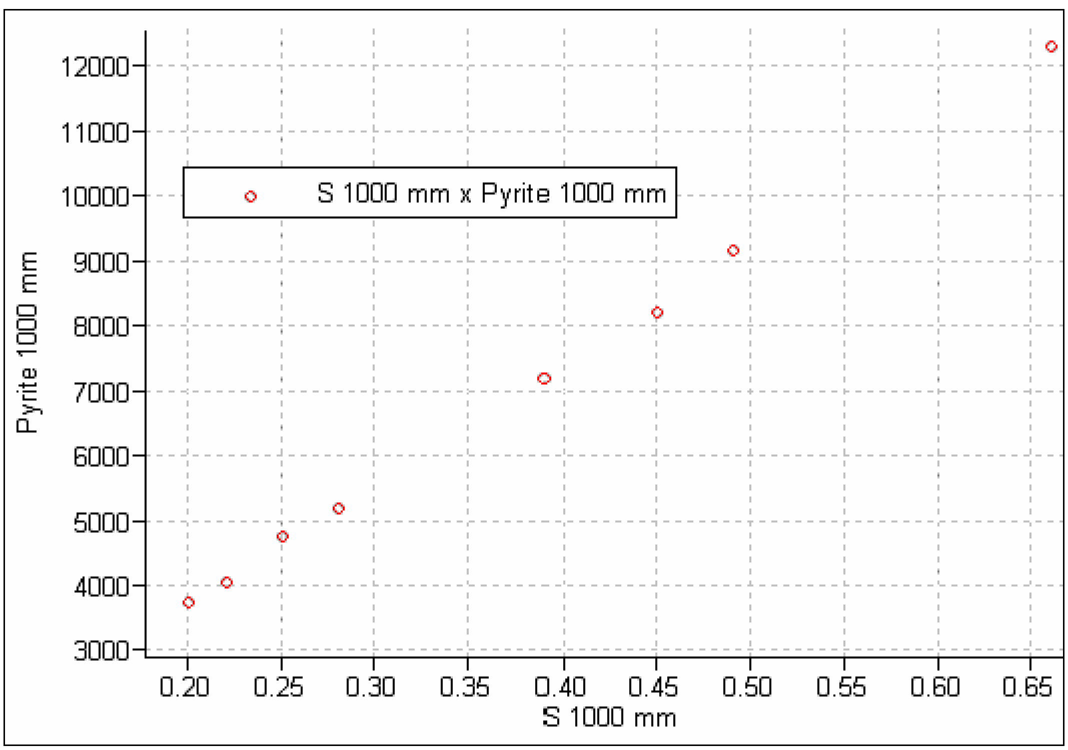

Figure 7.4 Relationship between Increases in S & FeS_2 at 1000 mm depth

The increase in S concentration with increasing depth is directly proportional to the increase in pyrite concentration with increasing depth.

7.4.5 Pyrite at 150 mm

The highest pyrite concentration is found at Elandsrand tailings dams. North Mine dams have the lowest pyrite concentration and South Mine dams have intermediate pyrite concentrations.

7.4.6 Pyrite at 500 mm

There has been a decrease in pyrite with depth in the following dams: Elandsrand dam 1a, North Mine dam 7b and North Mine dam 5a. Pyrite has increased in the remaining dams.

7.4.7 Pyrite at 1000 mm

The distribution of pyrite at this depth is similar to the distribution of pyrite at 500 mm.

The high pyrite content in Elandsrand tailings dams probably reflects the composition of the slurry being pumped into the tailings dams. The SO_4 in the boundary dam (Elandsrand DK dam) does not contribute to this, as the boundary dam is lower in elevation than the tailings dam.

The distribution of Fe around the boundary dam also shows elevated levels of Fe in the Elandsrand slimes dams. This Fe could explain the high pyrite content.

7.4.8 pH at 150 mm

The lowest pH is seen at Elandsrand slimes dams. The highest is found at N. mine dam 7, S. mine dam 1a, and the eastern parts of North Mine dam 3. North Mine dam 5 has intermediate pH values.

7.4.9 pH at 500 mm

There has been a slight increase in pH at North Mine dam 7a & 7b compared to at depth 150 mm.

7.4.11 pH at 1000 mm

There has been a slight increase of pH at South mine dam 1a compared to at depth 150 mm and a slight decrease of pH at North mine dam 5.

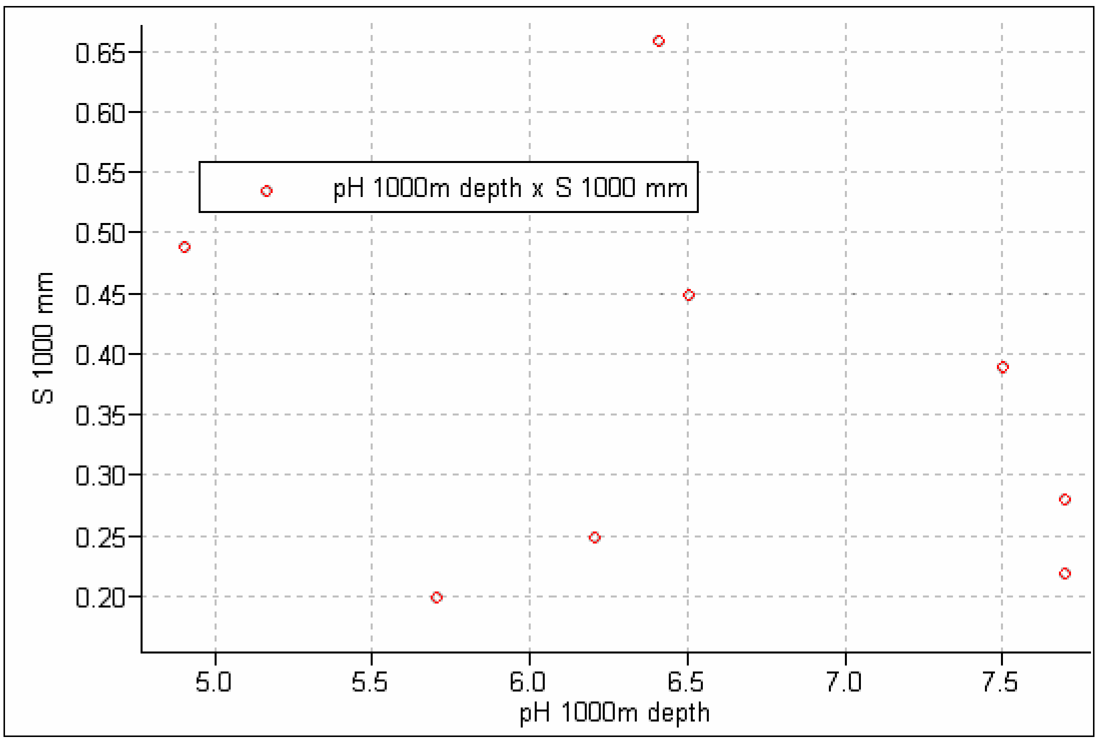

Figure 7.5 No Correlation Between pH & S at 1000 mm

There is no correlation between changes in pH and changes in S at 1000 mm depth. There is no correlation between pH and FeS2 at 1000 mm depth either. Except for S at 150 and at 500 mm depth, a linear relationship exists between the three parameters (pH, S and FeS2) at different depths, that is, the when pH increases at 150 mm there is a corresponding increase in pH at both 500 mm and 1000 mm depths.

7.4.12 Digital Elevation Model (DEM)

DEM is a digital representation of land surface elevation. DEMs have wide application. They are used as slope steepness maps, slope direction maps, slope convexity maps, hill-shading maps and three-dimensional views. A DEM can be used to determine the path followed by contaminated surface water flowing from both the mine dumps and the tailings dams and the area potentially affected by the pollution plume associated with this water. A DEM of the study area was generated by interpolation of 20 m contour lines on 1:50 000 government topographical maps of the area 2627AD Carltonville (see figure 7.4). In figure 7.4 the tailings dams (represented in cyan) and the mine dumps (represented in yellow) were overlaid on the DEM. Both the tailings dams and the mine dumps are located in the high-laying areas of the West Rand Region, none are found in the low-laying region to the south of the area. This suggests that the polluted runoff/seepage from these waste disposal structures can potentially impact on a large area downstream of these structures. The arrows show the possible pathway for runoff/seepage. The rivers surround the tailings dams and are therefore likely to receive any pollution seeping from the dams.

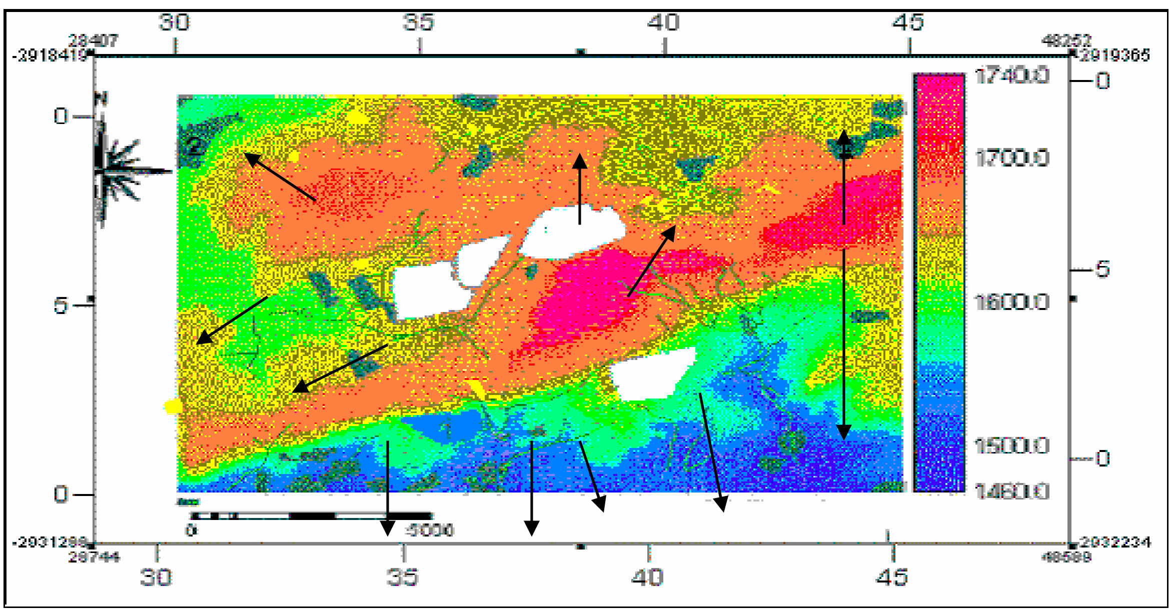

Figure 7.6 DEM (in metres) with arrows showing the flow of water in relation to the position of tailings dams and mine dumps (yellow). Rivers (green segments) have also been added to show their location in relation to the waste disposal structures.

AngloGold Ashanti, together with the University of the Witwatersrand, has initiated the Woodlands Project. The aim of this research project is to investigate ways of reducing environmental impact and liability. In 2004/5 season, 67, 000 trees were planted on polluted soils and seepage from tailings dams at the West Wits operations (AngloGold Ashanti, 2005). Some of the aims of this trial is to determine the most suitable tree species for that site and which species will best decontaminate and rehabilitate soils and groundwater. The trial, if successful, will reduce environmental degradation from seepage from the tailings dam.

7.5 Conclusion

Sulphur in the dams is likely to originate from pyrrhotite, the dominant sulphide mineral in the VCR. The high pyrite in the dams comes from both the Carbon Leader and the VCR. Oxidation of the pyrite is likely to release Ar, Ni and Pb as they reside in pyrite or occur in arseno-sulphides that are also likely to break down during pyrite oxidation.

The residue deposits contain high concentrations of sulphur, which, should it oxidise, would have significant environmental impact through acid generation. This is unlikely to happen because, in practice, the rate of oxidation and pollution from the old deposits is low owing to the inability of oxygen to penetrate more than 2 to 3 metres into a deposit.

Maximum oxidation of pyrite takes place in the dry upper zone of tailings dams. These oxidation reactions affect the primary sulphide minerals. Pyrite is oxidised into an array of secondary products, which include sulphate minerals. These sulphate minerals are more soluble than the primary sulphide minerals and are being leached to a horizon deeper in the tailings dams. Pyrite increases with depth because of lack of oxygen due to the abundance of moisture. The presence of water means that there is only a limited supply of oxygen due to the limited solubility of oxygen in water and this becomes more apparent in the saturated zone of the slimes dams. The increased sulphur at 500 mm is the result of pyrite oxidation in the upper oxidised zone. The positive correlation between changes in pyrite and sulphur indicates that the sulphur is a breakdown product of pyrite, therefore as pyrite concentration increases the sulphur concentration also increases.

Only very fine-grained pyrite is reactive, therefore the total sulphur content may be a poor predictor of potential acidity problems (Drever, 1982). But on the basis of increasing sulphur and pyrite concentrations and decreasing pH with depth, North Mine dam 5a and 5b, South Mine dam 1b and Elandsrand mine dam 1a are more likely to generate acid mine drainage.

Seepage from North Mine dams is significant due to the dams' high specific gravity range. This seepage is intercepted by the nearby North Boundary dam, resulting in a highly polluted dam.

The position of the tailings dams and the area of cultivation indicate that the cultivation can easily be polluted by the tailings dams through seepage and runoff during the rainy season, as the tailings dams are at a higher elevation than the cultivated areas. There are no sensitive sites in this area.