## **CHAPTER 8 - GROUNDWATER ANALYSIS**

## **8.1 Introduction**

There are 18 monitoring boreholes, MBH 1 to MBH 18; MBH 1 was dry throughout the sampling period. The boreholes were monitored in 1997/98 and then quarterly since December 1999 to July 2003. The groundwater was analysed for cations (Ca, Mg, Na, Fe and K), and anions (HCO<sub>3</sub>/CO<sub>3</sub>, SO<sub>4</sub>, Cl, NH<sub>4</sub>, PO<sub>4</sub> and NO<sub>3</sub>), heavy metals (Pb, Mn, Cu, Zn and Cd) as well as pH, EC, TDS, SS, and Au. Figure 8.1 below shows the location of the boreholes in relation to the location of the tailings dams.



Figure 8.1 Boreholes (and tailings dams) imposed on a Short Wave Infrared 1

Contaminants from the surface can percolate through the unsaturated zone to the saturated zone. Once contaminants reach the ground water table, lateral migration along the groundwater gradients occurs and groundwater contaminant plumes may result in

primary aquifer contamination. Secondary contamination of surface resources may result where the contaminant plumes establish hydraulic continuity with surface water resources - streams, rivers, pans and dams (Oryx Environmental, 2003).

The potential impact related to the enhanced infiltration, is in direct relation to the extent and magnitude of the groundwater moulds around infiltration sources, as well as the quality of the infiltrated water (Oryx Environmental, 2003). The sediments of the Pretoria Group, which cover the West Rand Region lease area, are considerably less permeable and transmissive than the underlying dolomites (Anglo American Corporation, 1995). Water-bearing zones in these quartzites and shales are likely to correspond to structural features, intrusions and zones of preferential weathering and thus the transportation of any contaminants which might emanate from the West Rand Region is likely to be restricted to these discrete zones.

Elevated sulphate concentrations are considered to be particularly diagnostic of contamination from gold mining source since it results from the oxidation of sulphidebearing pyrite in tailings dams (Anglo American Corporation, 1995). Of the many solutes found in groundwater relatively few are present at concentrations greater than 1 mg/l under typical natural conditions. These are generally called the major ions and they comprise the cations Ca, Mg, Na, and K and anions HCO<sub>3</sub>/CO<sub>3</sub>, SO<sub>4</sub>, Cl, and NO<sub>3</sub> (Drever, 1982). High concentrations of SO<sub>4</sub> and Cl would not be expected to occur naturally in water sourced from either the dolomite or the Pretoria Group.

## 8.2 Ion Balance

The cation anion balance was analysed by comparing the sum of cation milliequivalents/million to the sum of anion milliequivalents per million as follows:

Cation	Concentration (mg/l)	Equivalent weight	meq/million
Ca	8.66	20	0.43
Mg	2.26	32	0.07
Na	2.21	23	0.10
Total cation			0.60

Table 8.1 Ionic Balance of Groundwater

Anion	meq/million		
SO4	15.1	20	0.76
Cl	15.4	35.5	0.43
F	0.31	19	0.02
Total anio	n		1.21

The ratio of total cation to total anion was found to be more than 5%; this might indicate the inaccuracy of the lab analysis, lack of ions or metals analysed (for example K and  $HCO_3$ ).

# **8.3 Statistical Analysis**

There is no correlation between Fe and other variables (NO<sub>3</sub>, EC, SO<sub>4</sub>, Mn, TDS, TH, Na, Ca, Mg, and Cl); there is a weak correlation between Fe and NO<sub>3</sub>. There is no correlation between pH and other variables. This means that pH is buffered by some variable and these variables have no major impact on pH. There is no correlation between NO<sub>3</sub> and other variables for the same reason as that for boundary dams.

There is a very strong correlation between Cl and TDS and TH. The correlation between Cl and TDS is strong because Cl is one of the constituents of TDS. Permanent hardness is due to the presence of Ca and Mg sulphates and chlorides. There is a strong correlation between Cl and both Ca and Mg because they may come from the dissociation of CaCl<sub>2</sub> and MgCl<sub>2</sub>. The correlation between Cl and Mn is very weak.

There is a strong correlation between TDS and Mn and Na, and a very strong correlation between TDS and EC, TH, SO<sub>4</sub>, Cl, Ca, and Mg. Mn and Na make up TDS (with other

ions). Ions that cause hardness also contribute to TDS. SO<sub>4</sub>, Cl, Ca, and Mg are part of TDS.

There is a weak correlation between TH and Mn. Mn also contributes to hardness. There is a strong correlation between TH and SO<sub>4</sub>, Na, Ca, Mg as well as between TH and Cl, and TH and TDS. Both Ca and Mg contribute to hardness. The hardness may arise from the chlorides and sulphates, hence the increase in hardness with increasing chlorides and sulphates.

NO<sub>3</sub> Na CI Fe EC TDS TΗ  $SO_4$ Mn Ca Mg pН Na CI Fe NO<sub>3</sub> EC TDS TΗ Са Mg SO<sub>4</sub> 

Table 8.2 Correlation between groundwater variables (0= no correlation, 1= correlation).



Figure 8.3 Correlation between groundwater Ca and SO<sub>4</sub>





Figure 8.4 Correlation between groundwater Ca and Cl

There is no correlation between Fe and EC despite the fact that Fe is a good conductor of electricity. There is some correlation between Mn and EC, even though Mn is also a poor conductor of electricity. Ca is a very good conductor of electricity, which is why there is such a strong correlation between Ca and EC. Mg is also a good conductor of electricity (Liptrot, 1983). There is a very strong correlation between EC and TH because of the effect of Ca and, to a lesser extent Mg, on both EC and TH. TDS is strongly correlated to EC because the electrical current is transported by the ions in solution; the conductivity increases as the concentration of ions increases (Schroeder & Tchobanoglous, 1985). There is strong correlation between Na and EC because Na is an extremely good conductor of electricity (Liptrot, 1983).

Groundwater SO<sub>4</sub> exhibits a bimodal lognormal distribution. The first distribution accounts for 20 % of the data. It has a low average (37mg/l). This may be the background concentration of SO<sub>4</sub>. The second distribution accounts for 80 % and has a high average of 372 mg/l. This is indicative of pollution, which can be attributed to mining activities. Ca also shows two lognormal distributions: 36 % of the samples have an average of 12.5 mg/l, 64 % show an average of 120 mg/l. This distribution shows mining-related pollution. Cl also has a two bimodal lognormal distribution; the first distribution has an average of 135 mg/l accounts for approximately 49 % of the data. This is likely to be a result of mining-related pollution. The second distribution, the background Cl, has an average of only 19.8 mg/l.



Figure 8.5 bimodal lognormal distribution of groundwater SO<sub>4</sub>

# **8.4 Water Quality Analysis**

## MBH2

Most of the analysed parameters were below their respective limits for both domestic and irrigation purposes. The Fe, Pb and ammonia concentrations marginally exceeded their respective limits for domestic consumption. Mn concentration exceeded the limits for both the domestic and irrigation use. The water quality is good. The pH has been decreasing since January 2002 with fluctuating concentrations of Ca, Fe, Zn, Mn, Cu, Ni, Pb, and F. TDS, EC, Na and Cl show an increase while SS, alkalinity, Cd, ammonia, Mg, NO<sub>3</sub> and SO<sub>4</sub> show a decrease for the period January 2002 to July 2003.

The pH of water found in MBH 3 was within the permissible range for both domestic and irrigation purposes. Other parameters that were within their targets for domestic and irrigation uses were F, Cd, Cu and Zn. Conductivity exceeded both the domestic and irrigation guidelines. TDS exceeded the domestic use limit of 450 mg/l. SS exceeded the irrigation guideline of 50 mg/l. The Ca and CaCO3 concentrations (CaCO3 as a measure of total hardness), were exceeded approximately tenfold. Mg was also significantly higher than the domestic use limit. The domestic and irrigation guideline of 100 mg/l for Cl was exceeded. The high Cl concentration is likely to have resulted from ion exchange mechanisms operating during the transit of groundwater through underlying shale horizons of the Pretoria Group (Anglo American Corporation, 1995). NO<sub>3</sub> marginally exceeded the domestic use limit of 6 mg/l. The SO<sub>4</sub> concentration of 772 mg/l did not meet the domestic use target of 200 mg/l. The Fe concentration was four times the allowed concentration for domestic use of 0.1 mg/l. It however met the irrigation use target. This Fe does not come from North boundary dam as the dam has comparatively lower Fe concentration. The Mn concentration did not meet both the domestic and irrigation targets. The domestic use limits for Pb and ammonia were exceeded.

The EC has bee increasing since July 2000. The latest analysis (July 2003) shows a decrease in the EC concentration. MBH 3 experienced the poorest water quality (for the sampling period) between December 1999 and June 2000. TDS,  $CaCO_3$ , Ca, Mg, SO<sub>4</sub>, Fe, Ni and PO<sub>4</sub> reached their maximum concentrations during that six month period.

The borehole overlies ferruginous shale. Shale is most likely to react with water as it is extremely fine-grained and is most likely to contain reactive water-soluble minerals or salts. It, however, has a high retention capacity which minimises the regional extent of the impact on the groundwater (Water Research Commission, 1995). This could explain why the geology does not seem to affect the concentration of ions. The impact of pollution is likely to be seen years later when the water retained in the shale is slowly released.

The water was hard with CaCO<sub>3</sub> concentration of 217 mg/l. The Zn concentration reached a maximum concentration of 49 mg/l during two months over the sampling period (July 2002 and July 2003). Mn concentration reached a maximum of 40 mg/l in January 2003. The rest of the parameters (pH, EC, TDS, SS, Na, NO<sub>3</sub>, SO<sub>4</sub>, Fe, Cu and Ni) were within the targets. Mg concentration doubled the Mg limit for water used for domestic purposes. Ammonia concentration is slightly higher than the domestic limit. TDS, hardness, Na and Cl shows increasing trend while SS, alkalinity, Ca, Mg, SO<sub>4</sub>, Fe, Pb, ammonia and F have been decreasing. Flactuating concentrations have been observed for NO<sub>3</sub>, Zn, Mn, Cu, Ni, Cd and CN.

## MBH 5

The concentrations of Cu, Ni, Cd, F, Na and Zn were below their respective limits for domestic and irrigation uses. TDS, hardness, Ca, Mg, SO4, Fe, Pb, and ammonia exceeded their respective limits for domestic use. EC, Cl and Mn exceeded their limits for both domestic and irrigation purposes.

The water was hard (in excess of 600 mg/l) with a maximum concentration of 785.2 mg/l measured in 1997/8. The Ca concentration was high; it exceeded 130 mg/l with a maximum concentration of 537 mg/l. It decreased during the period January 2002 to July 2003. The SO<sub>4</sub> concentration was 539.9 mg/l in 1997/8, it has decreased sharply to 3.7 mg/l in July 2003. The quality of the water has been improving since January 2002. Except for Zn (which has been increasing) and pH (which has decreased slightly) there has been a decrease in the concentration of the parameters. The borehole is underlain by diabase. Diabase is highly impermeable and is likely to impede the downward movement from surface into the deeper aquifer system below.

Except for some heavy metals and ammonia, all the parameters' concentrations were within their respective limits for both domestic and irrigation guidelines. Fe, Zn, Ni and Pb exceeded their domestic use guidelines. Ammonia concentration was higher than the domestic limit of 1 mg/l. Cd exceeded its irrigation guideline.  $SO_4$  concentration has been decreasing since June 2000.

## **MBH 7**

The water is neutral with low salinity. The concentrations of Na, Cl and SO4 were low and as a result the concentration of TDS was also low. Ca, Mg, CaCO<sub>3</sub>, NO<sub>3</sub>, Fe, Pb and ammonia exceeded their guidelines for domestic use. Mn, EC and SS were the only parameters which exceeded their respective guidelines for irrigation use.

## MBH 8

MBH 8 was characterized by high Fe concentrations during the sampling period. The Fe concentration reached a maximum of 5.35 mg/l in January 2002 and a minimum concentration of 0.002 mg/l in January 2001. The Fe concentration has been increasing and decreasing sharply during the period 1998-2003. The pH increased from 8.1 in 1997/8 to 9.36 in Jan 2001. Since then the pH has stabilized to a range of 6.6 to 6.9. The EC was at its highest (for the period 1998-2003) at 248.9 mS/m in 1997/8. The lowest EC was measured in January 2001 at 128 mS/m; it then increased to 194 in January 2002. In June 2003 the EC was 163 mS/m. The changes in TDS have been inversely proportional to the changes in pH. The highest TDS concentration during the 1998-2003 period was 1415 mg/l (July 2001) and the lowest was measured in January 2001 (679 mg/l). With the exception of January 2002 when the SO<sub>4</sub> concentration reached the highest concentration of 715 mg/l for the period 1997-2003, SO<sub>4</sub> concentration changed

proportionally to the changes in pH.  $SO_4$  concentration shows a decreasing trend with the last sample (July 2003) having the lowest concentration of 376 mg/l.

The NO<sub>3</sub> concentration was below 1 mg/l for the whole period except in January 2001 when it reached a concentration of 46.4 mg/l. The Mg concentrations were high with the highest concentration at 527 mg/l (December 1999) and the lowest concentration of 70 mg/l measured in January 2001. The Mg concentration has been stable within a range of 110-126 mg/l since January 2002. The Ca concentration was also high at a maximum concentration of 190 mg/l (January 2002) and a minimum concentration of 37 mg/l in January 2001. The high concentration of Mg and Ca in MBH 8 originates from North boundary dam which overlays MBH 8 and its water also exceeds Ca and Mg concentration limits. The Ca concentration changes are inversely proportional to the changes in pH. The Mn concentration exceeded 0.05 mg/l, the limit for domestic purposes. A maximum concentration of 0.71 mg/l was reached in July 2001 and the minimum concentration of 0.01 mg/l was measured in January 2001. The Mn concentration decreased between 1998 and 2001, and then increased between January and July 2001. The trend has been downward since then. The total hardness is in excess of 300 mg/l with the highest concentration of 999 mg/l (January 2002).



Figure 8.5 MBH 8 pH & TDS Concentration

A 30m thick sill was intersected in this borehole. The sill is highly impermeable and is likely to impede the downward movement of water from surface into deeper aquifer system below (Sutton, unpublished). The borehole is underlain by ferruginous quartzite, which is not likely to be reactive.

## MBH 9

The water quality is good with the pH being within acceptable limit for domestic use; it ranges between 6.4 and 7.5. The Fe concentrations were high between 1997/8 and 1999 (range of 1.5 to 2.4mg/l). The Fe concentration has been decreasing since 2000 to a minimum of 0.05 mg/l in July 2003.

## **MBH 10**

The MBH 10 water quality was fairly good with slightly acidic to neutral pH, negligible salinity, low sulphate, sodium and heavy metals concentrations. The pH of water found in MBH 10 has decreased since 1997/8 from 7.4 to 5.4 in Jul 2003. The pH increased to 7.4 again in July 2001 but has been decreasing since then. The EC has decreased considerably since 1997/8 from 34.5 to 5.4 in July 2003. The EC has been below 10 during the period July 2000 to July 2003 with negligible changes ranging between 4 and 9 mS/m. The sulphate concentration also shows a decreasing trend; it was 15.1 in 1997/8, it has ranged between 0 and 1 during the Jan 2001-Jul 2003 period. Ca and Mg concentrations have also been decreasing since 1997/8.

#### **MBH 11**

The water quality is fairly good with most parameters meeting their respective targets for both domestic and irrigation purposes. The hardness, Ca, Mg and Fe's respective limits for domestic use were exceeded. The irrigation targets for Mn and EC were not met.

The quality of the water is good with the concentration of all the parameters except Ca and Mn being below their respective limits for both domestic and irrigation purposes. Ca marginally exceeded its limit for domestic use while Mn marginally exceeded its limit for irrigation purposes.

### **MBH 18**

The MBH 18 water is poor; it is slightly acidic to neutral, has high EC and TDS concentrations, a result of high Ca, Mg and Na concentrations. The water was very hard (above 1300 mg/l of CaCO<sub>3</sub>). Sulphate concentration exceeded 1100 mg/l. The heavy metals concentrations exceed the permissible levels for domestic use (except in January 2003, Fe limit of 0.1 mg/l for domestic use was exceeded throughout the 1999-2003 period). The maximum Fe concentration was 1.39 mg/l in December 1999. The minimum Mn concentration of 7.04 mg/l measured in 1997/8 exceeded the Mn limit of 0.05 for domestic use by more than 100 fold. Even the Mn limit for irrigation purposes (5 mg/l) was exceeded consistently throughout the sampling period. The Pb concentration was below the limit for domestic use of 0.01 mg/l between July 2001 and July 2003. During 1998-July 2001 the Pb concentration exceeded the domestic limit with the maximum concentration of 0.1 mg/l measured in January 2001.

The pH has been decreasing since 1997/8 – from 7.3 to 5.5 in July 2003. The pH has remained constant (between 5.5 and 5.6) since January 2002. EC has also been decreasing. In 1997/8 the EC was very high at 409.5 mS/m; it has since decreased to 298 mS/m in July 2003. The EC has remained stable between 284 and 315 mS/m in the June 2000 and July 2003 period. Except for a decrease in January 2002 to 1963 mg/l, the TDS was high during the 1998-2003 period. The TDS concentration was 2420.4 mg/l in 1997/8 and the latest (July 2003) concentration was 2736 mg/l.

MBH 18 is underlain by ferruginous quartzite. The quartzite, if pure, is likely to be unreactive. Although the sediments of the Pretoria Group are less permeable and transmissive, this borehole is found in a region where there are geotechnical faults and fractures, which could be passageways for contaminants.

## **8.5 GIS Analysis**

Overlay operations were used to combine a number of maps so as to derive new information. They were used to determine the relationship between groundwater and surface conditions.

Point interpolation, a geostatistical tool used to create raster maps in each pixel has a value calculated from the input point values was used. It performs an interpolation on randomly distributed point values and returns a regularly distributed point values. There are various point interpolation methods – Voronoi Tesselation, Moving Averages, Trend Surface and Moving Surface. In this study the Moving Average method was used. This method performs a weighted average on point values of a point map with domain type Value or Identifier (if its attribute table columns have domain type Value). The output value for each pixel is calculated as the sum of the products of weights and point values divided by the sum of the weights. Weights values are calculated in such a way that point close to an output pixel obtain large weights and points further away obtain small weights (ILWIS, 1997). This means that points close to an output pixel are of greater importance to the output pixel value than values of points further away.

A point map has to be created first (refer to Appendix 3 for the procedure) before point interpolation can be performed.

An attribute table is the descriptive link to the spatial data. An attribute table can either be imported into the GIS or manually created. In this study attribute tables were created (refer to Appendix 3 for the procedure).

To display the information contained in an attribute table on a point map, double click the map and in the Display Options dialogue that appears select Attribute and choose the

attribute table containing the data to be displayed. Select the column of interest from the columns in that table. A point map showing the information in that column is displayed.

To create the Moving Averages of the data see Appendix 3.

## 8.5.1 EC Moving Average

The EC is highest in boreholes overlain by North Mine (tailings) dams while the lowest EC concentrations were measured in boreholes overlain by South Mine dams. The intermediate EC concentrations were recorded in MBH 8 that is roughly overlain by the North boundary dam and the borehole overlain by North mine dam 3. The high EC in MBH 8 has probably been passed on from the North boundary dam which has a high EC value (265 mS/m). The high EC in MBH 5 could have arisen from percolation from North Mine tailings dam 3, while the EC in MBH 18 may be a result of percolation of wastewater from North Mine tailings dam 7a, which is situated close to the high EC concentration area. Increases in groundwater salinity could have an effect on vegetation and agriculture. The ion exchange mechanisms of plant root cells are disrupted at high concentration of salts such as Cl, Na and Mg (Water Research Commission, 1995).



Figure 8.6 Groundwater EC Moving Averages & Tailings Dams

## **8.5.2 Fe Moving Average**

The high Fe concentrations are seen in boreholes MBH 3, 8, 16 and 18. Intermediate Fe concentrations were found in MBH 5 and 7. The high Fe concentration in MBH 8 is likely to come from North boundary dam as the dam has high Fe content compared to other dams. Excess accumulation of Fe is likely to cause bronzing or tiny spots on leaf surfaces (Fertilizer Interpretation, downloaded 30/08/2000).



Figure 8.7 Groundwater Fe Moving Averages & location of tailings dams

## 8.5.3 Mn Moving Average

The Mn concentration is low in all boreholes except MBH 5 and 18. The high Mn concentration in MBH 18 came from North Mine dam 7 and North Mine dam 3 was the source of Mn in MBH 5. The low Mn concentration in MBH 8 reflects the low Mn concentration of 0.44 mg/l in North boundary dam.

Mn toxicity causes chlorosis or blotchy leaf tissue due to insufficient chlorophyll synthesis. Growth rate slows down and vigor declines (Fertilizer Interpretation, downloaded 30/08/2000).



Figure 8.8 Groundwater Mn Moving Averages & the location of tailings dams

The mine dumps were not the sources of Mn in boreholes as the dumps are distributed randomly in areas overlying the boreholes with low and intermediate Mn concentrations. There were no mine dumps in areas overlying boreholes with high Mn concentrations.



Figure 8.9 Groundwater Mn Moving Average & Location of Mine Dumps (represented by white dots)

## 8.5.4 SO<sub>4</sub> Moving Average

The high SO<sub>4</sub> concentrations were found in MBH 3 and 18 that are overlain by North Mine dam 7 and North mine 5 respectively. These tailings dams were sources of SO<sub>4</sub> in those two boreholes. MBH 5 and MBH 8 have intermediate SO<sub>4</sub> which originated from North Mine dam 3 and North boundary dam respectively. The boreholes overlain by South mine dams had low SO<sub>4</sub> concentrations. Mine dumps were found in areas of low and intermediate SO<sub>4</sub> concentrations.



Figure 8.12 Groundwater SO<sub>4</sub> Moving Averages & the location of tailings dams

## 8.5.5 Ca Moving Average

The Ca in MBH 18 may have come from both the North West boundary that had high Ca concentration. North Boundary dam was the source of Ca in MBH 8. The boundary dam had Ca concentration that exceeds the Ca limit. The North Mine tailings dams were also likely to have contributed to the high Ca concentrations in MBH 3, 5 and 18. Elandsrand tailings dam 1a may have contributed to the intermediate Ca concentration in the underlying MBH 15. Waste rock dump were found in intermediate Ca concentration areas and are therefore unlikely to be sources of Ca.

# 8.5.6 Mg Moving Average

The Mg in MBH 8 originated from North boundary dam, and Mg in MBH 18 came from North Mine dam 7a and 7b. North Mine dam 5b and North Mine dam 3 contributed to

the high Mg concentrations in MBH 3 and MBH 5 respectively. Waste rock dump were found in intermediate Mg concentration; they are unlikely to be sources of Mg. The high Mg concentrations can disrupt ion-exchange mechanisms of plant root cells (Water Research Commission, 1995).

## 8.6 Water Quality Modelling - Wateval

Wateval is a water quality evaluation program developed by A.W. Hounslow (Hounslow, 1995). In this study Wateval was used to determine the relative composition of water samples. This was achieved through the use of Piper diagrams. The Piper diagram plots the major ions as percentages of milliequivalents in two base triangles. The total cations and the total anions are set equal to 100% and the data points in the two triangles are projected onto an adjacent grid.

The water found in MBH 8 is permanently hard; this is shown by a plot towards the top of the diamond in Figure 8.13, lacks alkali carbonates and is not saline. The main causes of hardness are Ca and MgSO<sub>4</sub>. TDS is on average 1000 ppm. The hardness in MBH 8 is due to the presence of Mg, Ca, SO<sub>4</sub> and Cl to a lesser extent (it is present in smaller concentration). The other boreholes plotted similarly on Piper diagrams. They exhibit lower HCO<sub>3</sub> and CO<sub>3</sub> than MBH 8.



Figure 8.13 Piper diagram showing the composition of water found in MBH 8

## 8.7 Water Quality Modelling - Stasoft

Water from underground sources in dolomitic areas may become oversaturated with respect to  $CaCO_3$  when exposed to air at the surface (Friend & Loewenthal, 1992). The oversaturation results in excessive precipitation in storage dams and pipes. The water may have high concentrations of Ca and Mg which gives rise to high soap demand during washing and negative impacts to industrial processes. To attain the desired quality requires addition of chemicals but before the chemicals can be added the chemical state of the water has to be determined. Determining the chemical state of the water is based on equilibrium chemistry of the Ca-Mg-CO<sub>3</sub> system. The Stasoft software package was used to determine the equilibrium water chemistry of the selected boreholes.

There is an increase in pH at equilibrium for all the boreholes of concern- MBH 3, 5, 8, 16 and 18 due to the release of  $CO_{2.}$  The water becomes more alkaline. This prevents any mobilisation of heavy metals, but is, however, not ideal for plants, as they desire 6-7 pH range. The pH would be higher than 7 and this affects the soil and therefore the

plants onto which the water drains. The pH is too high for the optimum growth of plants. TDS decreases by almost 50% for all the above mentioned boreholes. EC decreases for all the boreholes. The water will not generate acidity.

MBH	pH increase	TDS	EC	ionic	Precipitation	$CO_2$
		decrease	decrease	strength	potential	
3	0.6	450.1	86.42	0.0145	0.92	-3.11
5	0.53	600.18	111.12	0.0182	10.4	4.02
8	0.91	775.72	156.9	0.0147	129.3	49.52
16	0.98	98.27	90.59	0.0113	-1.51	5.94
18	0.75	805.26	157.13	0.0404	-0.91	3.51

Table 8.3 showing the composition of groundwater at equilibrium

### **8.8** Conclusion

The quality of the water found in boreholes MBH2, 6, 9, 10, 11 and 12 was good. Borehole MBH7 had fairly good water quality. MBH 18 had poor water quality. The potential groundwater contamination in the areas surrounding MBH 18 is enhanced by the presence of faults which act as passageways for contaminants from the overlying North Mine dam 7. The water quality in MBH 8 is poor as a result of contamination from the overlying North boundary dam (especially with regards to Fe, Ca and Mg). The sill which intercepts this borehole is likely to prevent movement of contaminated water into the aquifers. The water quality in MBH 5 showed an improvement during the sampling period. Potential impact on the deeper aquifers is prohibited by the impermeable diabase. MBH 3 contained water of poor quality. The water was hard and had high concentration of cations. The potential pollution arising from this borehole is likely to be delayed due to high water retention capacity of the underlying shale.

The GIS analysis shows that most pollution found in the boreholes comes from North mine dams (North mine dam 7, North mine dam 5 and to a lesser extent North mine dam 3) and North boundary dam. The South mine dams are the least polluting. Mine dumps do not contribute to the pollution in the boreholes as they are found in areas of

intermediate to low concentration of potential pollutants. This was also verified by the water quality of the sampled water both upstream and downstream of Savuka dump (discussed in Chapter 6). Although the water was poor in some boreholes it appears that the quality had improved compared to a previous study. The water quality also improves at equilibrium although the pH may become too high for optimum plant growth.

Research conducted in 1990 (Funke, 1990) showed that the West Rand Mines intercepted the overlying dolomite aquifer and effects of mining and ore processing on the deterioration of the quality of underground and surface water were evident at many locations in the dolomite area. Uncontaminated dolomitic aquifer water comprised a bicarbonate solution with Ca and Mg as major cations, and was characteristically devoid of sulphates. Boreholes in the area, however, were severely contaminated by sulphates (up to 1400 mg/l), Mn (up to 300 mg/l). Compared to the 1990 study, the water quality of the West Rand Region has improved significantly.