APPENDIX D2

Geohydrological Specialist Report

FINAL

GEOHYDROLOGICAL SPECIALIST REPORT FOR THE XSTRATA RHOVAN SITE

REF : 10305
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COMPILED FOR:

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Rhovan
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"at the edge of ground water innovation"

SUMMARY

The geohydrological specialist report forms part of the larger environmental study currently performed by Jasper Müller Associates (JMA) at Xstrata Alloys Rhovan.

JMA's primary approach for describing the ground water environment consists of the capturing, description and interpretation of *site specific data*. The methodology for the reporting on the geohydrology comprised of a thorough description of:

1) The ground water aquifer,
2) The impact on the ground water environment, and
3) The associated potential risk induced by the respective impacts.

The description of the current status of the aquifer is possible by the detailed description and interpretation of existing and newly collected field data. This includes the drilling and the collecting of geological, geohydrological and hydro-chemical information from old and newly drilled monitoring boreholes.

The data for Xstrata Alloys Rhovan was interpreted for each area based on the type of impact and regulatory requirements:

1) The Processing Plant Area (hereafter called the Plant Area),
2) The Calcine Tailings Dump and ancillary infrastructure (hereafter called the Calcine Dump),
3) The Slimes Dam and ancillary infrastructure (hereafter called the Slimes Dam),
4) The total Mining Area,
5) The rural settlements of Bethanie, Modikwe & Berseba.

A detailed impact assessment is performed based on baseline data collected and hydrological and geochemical modelling performed on waste sites and the underlying unsaturated zone.

Two types of activities exist at Xstrata Alloys Rhovan that may potentially impact on the ground water environment, namely mining activities and Waste Dumps/Lagoons and Water Dams.

The impacts on the groundwater are both quantity and quality related:

- The impact on the ground water quantity comprises of the influx of ground water into the mining pits (water lost from the aquifer) and the flux of contaminated/non-contaminated leachate from Waste Dumps/Lagoons and Water Dams, towards the underlying ground water environment (water added to the aquifer).

- The impact on the ground water quality comprises of the influx of contaminated leachate from waste dumps towards the underlying unsaturated and saturated aquifer, and the influx of ground water into mining pits and the resultant potential contamination thereof with mined material.

It was found that the impact relating to mining activities is small, insignificant and therefore acceptable. The impact of the Slimes Dam, Slimes Return Water Dam and Clean Storm Water Dams are also acceptable, since only leachate of acceptable quality is introduced into the underlying aquifer from these facilities. The impact of the FeV Slag Dump, the Purge Dams, Scrubber Ponds, Dirty Storm Water Dams, Calcine Dump and Calcine Return Water Dam on the ground water quality is, however, unacceptable and some of these features must be rehabilitated/reconstructed. All future developments of these sites must also be in full compliance with the Minimum Requirements for Hazardous Waste Sites and/or Section 21(g) Water Use License requirements of the Department of Water Affairs and Forestry.

As part of the baseline information gathered, a plume that extends from the Plant Area towards the Tshukutswe River was identified. No impact on the river was however identified. It is important to note that the contamination at Xstrata Alloys Rhovan is contained within the aquifer and that the only impact is towards the ground water environment and not to any external users or to the surface water environment. Remediation will only improve the current situation and all future impacts will become smaller.

The risk to both Human Health and to the Environment was identified based on baseline data and the impact assessments. The risks are currently limited to only the environment since no external user's of ground water are present within 1 km radius from the Xstrata Alloys Rhovan operations and no impact on surface features is currently present or foreseen. The only <u>direct</u> risk currently is towards the ground water environment.

An extensive pump-and-treat system is proposed for remediation of the ground water contamination plume at Xstrata Alloys Rhovan. Remediation of the plume in the aquifer at Xstrata Alloys Rhovan is seen as a priority and actions must be performed on detailed remediation planning and implementation.

It is important to note that remediation of the plume in the aquifer would be a useless and costly exercise if contaminated leachate from sources are not substantially minimized. The existing sources of impact were identified in the impact assessment and will be reconstructed or demolished and rehabilitated during the operational/expansion phase. All remediation measures in terms of the sources must be completed during the operational and decommissioning phase.

Since Xstrata Alloys Rhovan is committed to the remediation of impacts, the risk induced by the impacts will be addressed during the operational phase. In the light hereof it could be stated that no post-closure risk will exist on Human Health and the Environment.

Respectfully submitted,

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Jaco J van der Berg (Pr.Sci.Nat.)

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1 APPROACH AND METHODOLOGY

The geohydrological specialist report forms part of the larger environmental study currently performed by Jasper Müller Associates (JMA) at Xstrata Alloys Rhovan.

JMA's primary approach for describing the ground water environment consists of the capturing, description and interpretation of *site specific data*. The methodology for the reporting on the geohydrology comprised of a thorough description of

1) The ground water aquifer,
2) The impact on the ground water environment, and
3) The associated potential risk induced by the respective impacts.

The description of the current status of the aquifer is possible by the detailed description and interpretation of existing and newly collected field data. This includes the drilling and the collecting of geological, geohydrological and hydro-chemical information from old and newly drilled monitoring boreholes.

The impacts on the ground water environment are both in terms of *quantity* and *quality*. The risks induced by the impacts on the ground water environment were described both in terms of *Risk to Human Health* and *Risk to the Environment*.

The Impact and Risk Assessments are described for the current status, the ongoing operational phase and the post-closure phase. Data from the baseline study was used where possible to quantify the current impact or risk. Geochemical/hydrological modeling was used as a predictive tool in order to assess critical future impacts. In order to define the scale and significance of each impact and risk, the assessment was done on a full range of descriptive criteria.

After a thorough study of the physical and hydro-chemical aquifer properties, as well as the impact and risk to the ground water has been performed, constructive remediation goals and measures for the ground water environment could be proposed. Protection of the ground water environment is critical both with respect to its water resource capacity and its wider influence on the broader natural and cultural environment.

2 ACTIONS PERFORMED

The data for Xstrata Aloys Rhovan was interpreted for each area based on the type of impact and regulatory requirements:

1) The Processing Plant Area (hereafter called the Plant Area),
2) The Calcine Tailings Dump and ancillary infrastructure (hereafter called the Calcine Dump),
3) The Slimes Dam and ancillary infrastructure (hereafter called the Slimes Dam),
4) The total Mining Area,
5) The rural settlements of Bethanie, Modikwe & Berseba.

Jasper Müller Associates (JMA) has been involved in the siting as well as the drilling of 51 monitoring boreholes (GWW-1 to GWW-45; SGM-B1 to SGM-B6) at Rhovan from 1999 to 2005. All boreholes drilled by JMA were geologically logged, EC-profiled and slug tested. Geological, geohydrological and construction details were well documented. The discussion and interpretation of the geological profiles around the site, water level distribution, the results of slug tests and other information obtained from the geohydrological boreholes is done in **Part 3** of this document.

A total of 561 hydro-chemical samples have been taken from March 1999 to September 2005 from a total of 54 boreholes, spanning over some 23 sampling runs. The results of the last full geohydrological cycle (July 2005) have been used in all impact assessments. Another sampling run has been performed since then, but given the length of the overall monitoring dataset (1999-2005), no significant changes in pollution status or pollution trends have occurred in the last year. The full details of the samples taken, as well as the analyses of these samples are attached and thoroughly discussed and interpreted in **Part 3** of this document.

For the Impact Assessment on the *ground water quantity* the ground water influx into the mining pits was calculated, as well as the leachate quantity from the dams and waste dumps/lagoons towards the aquifer was modeled.

For the Impact Assessment on the *ground water quality* the latest hydro-chemical data was assessed in order to describe any current pollution, and geochemical modeling was performed in order to determine the contamination load towards the saturated zone from waste dumps, lagoons and dams.

The Risk Assessment was performed based on the comparison of Standards of Human Health and Environmental Fitness to the results of the Impact Assessment.

Site specific remediation goals and measures for the ground water environment are proposed. The importance of some remediation measures was outlined and some of these must take immediate effect at Xstrata Alloys Rhovan.

3 DESCRIPTION OF CURRENT SITUATION

The Xstrata Alloys Rhovan site is located in the North-West Province of South Africa, 25 km west of Brits and some 40 km north-east of Rustenburg. The Xstrata Alloys Rhovan current and proposed expanded site layout is depicted in **Figure 3(A)** below.

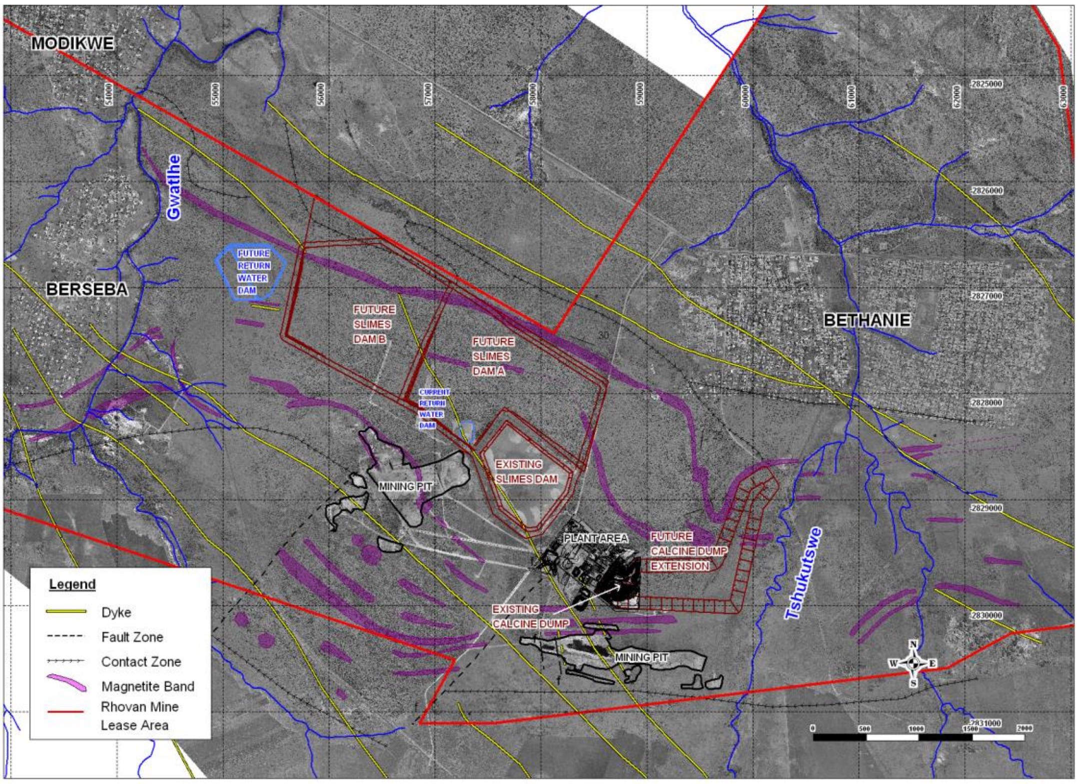


Figure 3(A): The Xstrata Alloys Rhovan site layout (current and proposed expansions).

In **Figure 3(A)** the position of the Mining Pits is shown south and west of the Processing Plant. The existing Calcine Dump is located to the east of the Plant Area and indicated with an arrow in **Figure 3(A).** Future extensions of the Calcine Dump will be towards the east of the existing facility.

The existing Slimes Dam is situated towards the north-west of the Plant Area and the future extensions thereof (Slimes Dam A & B) will be further to the north-west. The existing Slimes Return Water Dam is situated next to the north-western boundary of the existing Slimes Dam. Together with the future Slimes Dam Extensions, a larger Slimes Return Water Dam will be build to the west of the future extensions.

Percussion drilling of geohydrological boreholes was performed at Xstrata Alloys Rhovan since 1999 in order to collect baseline information on the aquifer beneath the site. The sequential drilling of the boreholes since 1999 was as follows:

GWS-1 to GWS-4	Rhovan Water Supply boreholes – Construction Date not known	
GWW-1 to GWW-14	January/February 1999	GWW-2 to GWW-4 destroyed
GWW-15 to GWW-23	August 2001	GWW-19 destroyed
GWW-24 to GWW-28	April 2002	
GWW-29 to GWW-35	July/August 2003	
GWW-36 to GWW-39	June 2004	
GWW-40 to GWW-42 SGM-B1 to SGM-B5	March 2005	
GWW-43 to GWW-45 and SGM-B6	June 2005	

The position of monitoring boreholes at the Calcine Dump, the Slimes Dam, the Plant Area and the Mining Area at Rhovan are given respectively in **Figures 3(B) to (E)** below. Bethanie, Berseba and Modikwe are respectively situated 1.6 km north-east, 4.6 km and 6 km north-west of the Rhovan Plant Area. The position of the boreholes at Bethanie is given in **Figure 3(E)** below and those at Modikwe and Berseba in **Figure 3(F)**. **Table 3(A)** attached in **APPENDIX 3.0** gives the basic information of these boreholes.

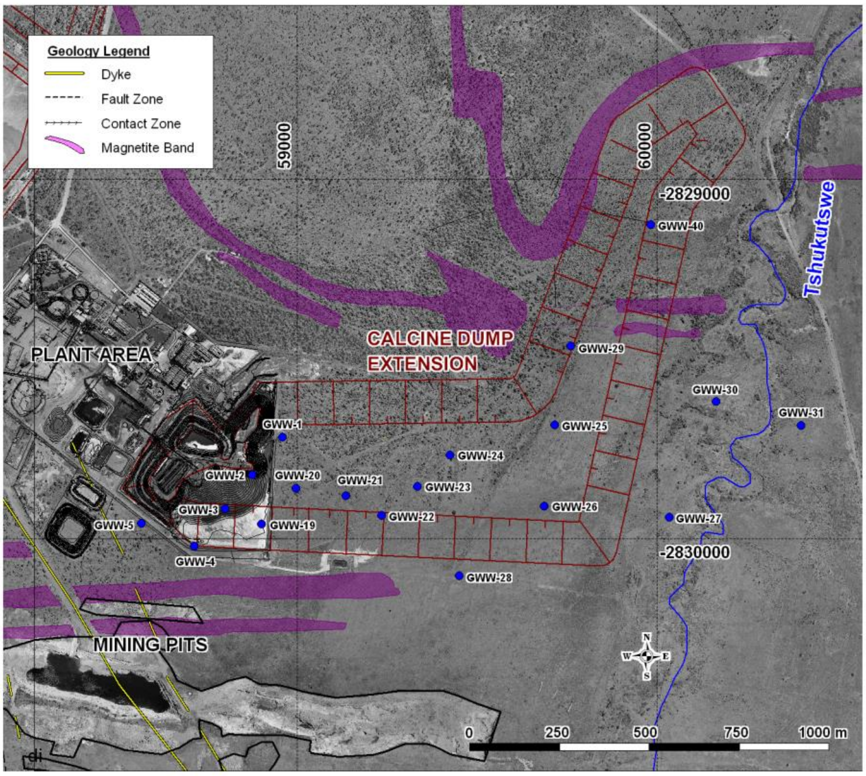


Figure 3(B): Location of boreholes at the Calcine Dump Area.

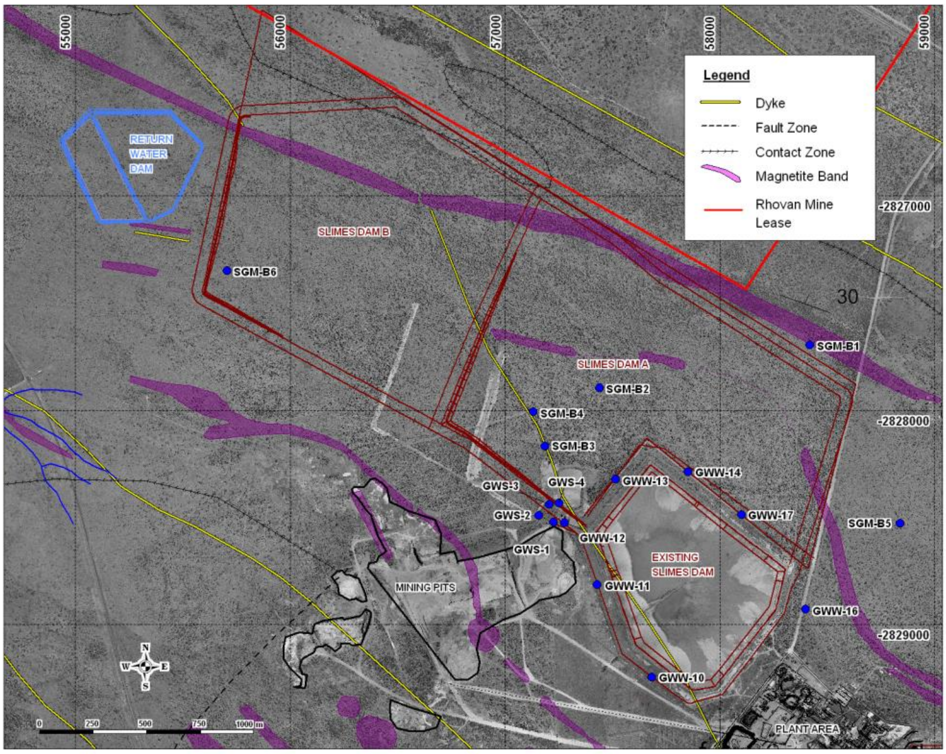


Figure 3(C): Location of boreholes at the Slimes Dam Area.

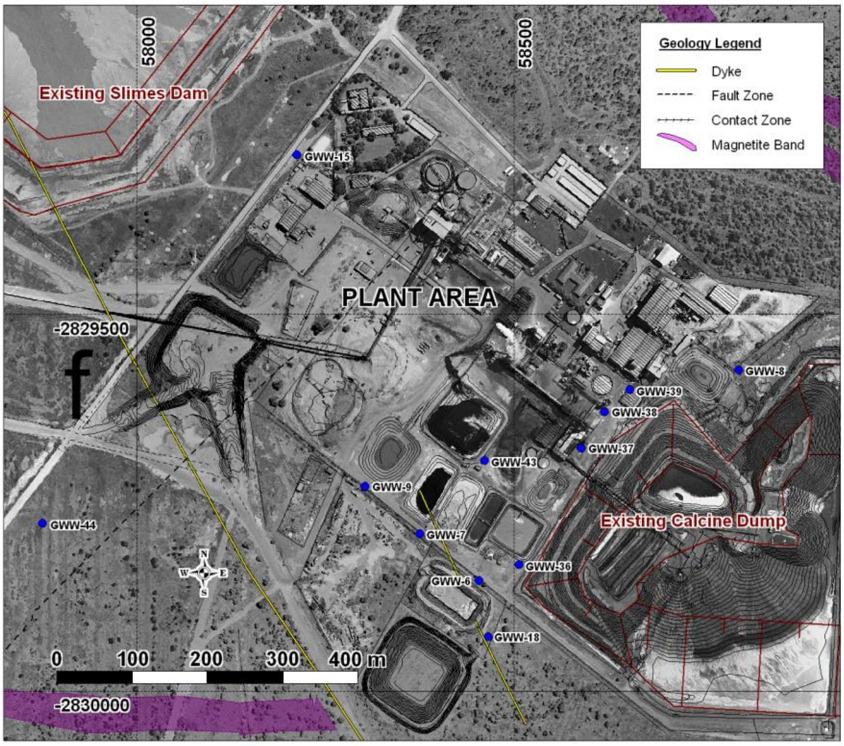


Figure 3(D): Location of boreholes at the Plant Area.

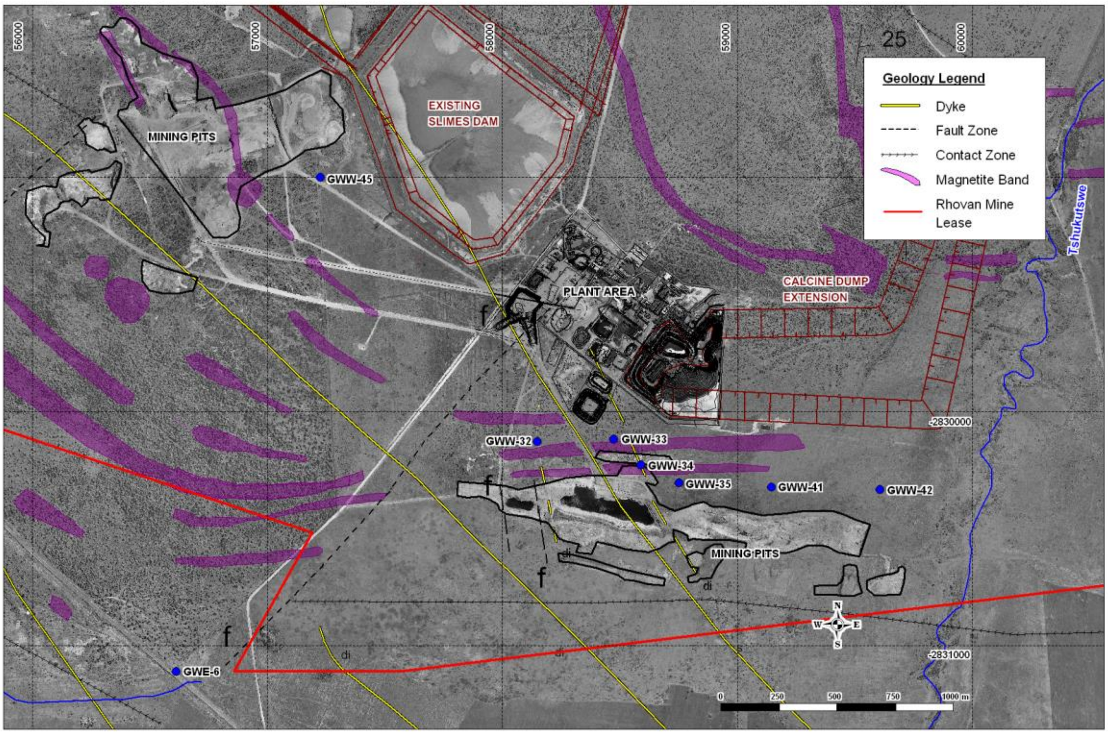


Figure 3(E): Location of boreholes at the Mining Area.

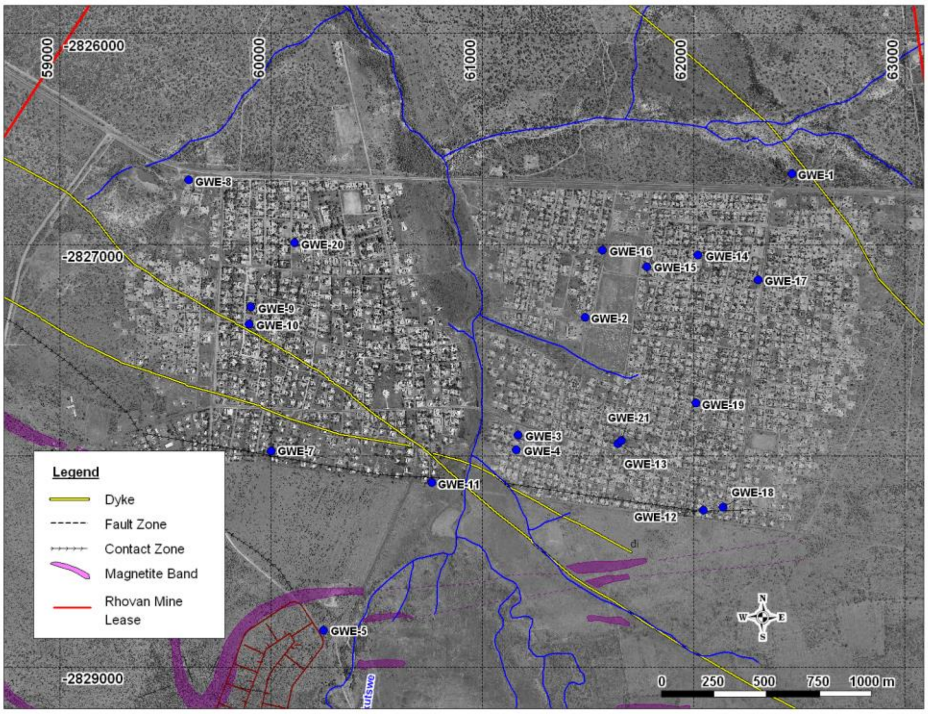


Figure 3(F): Location of boreholes at Bethanie.

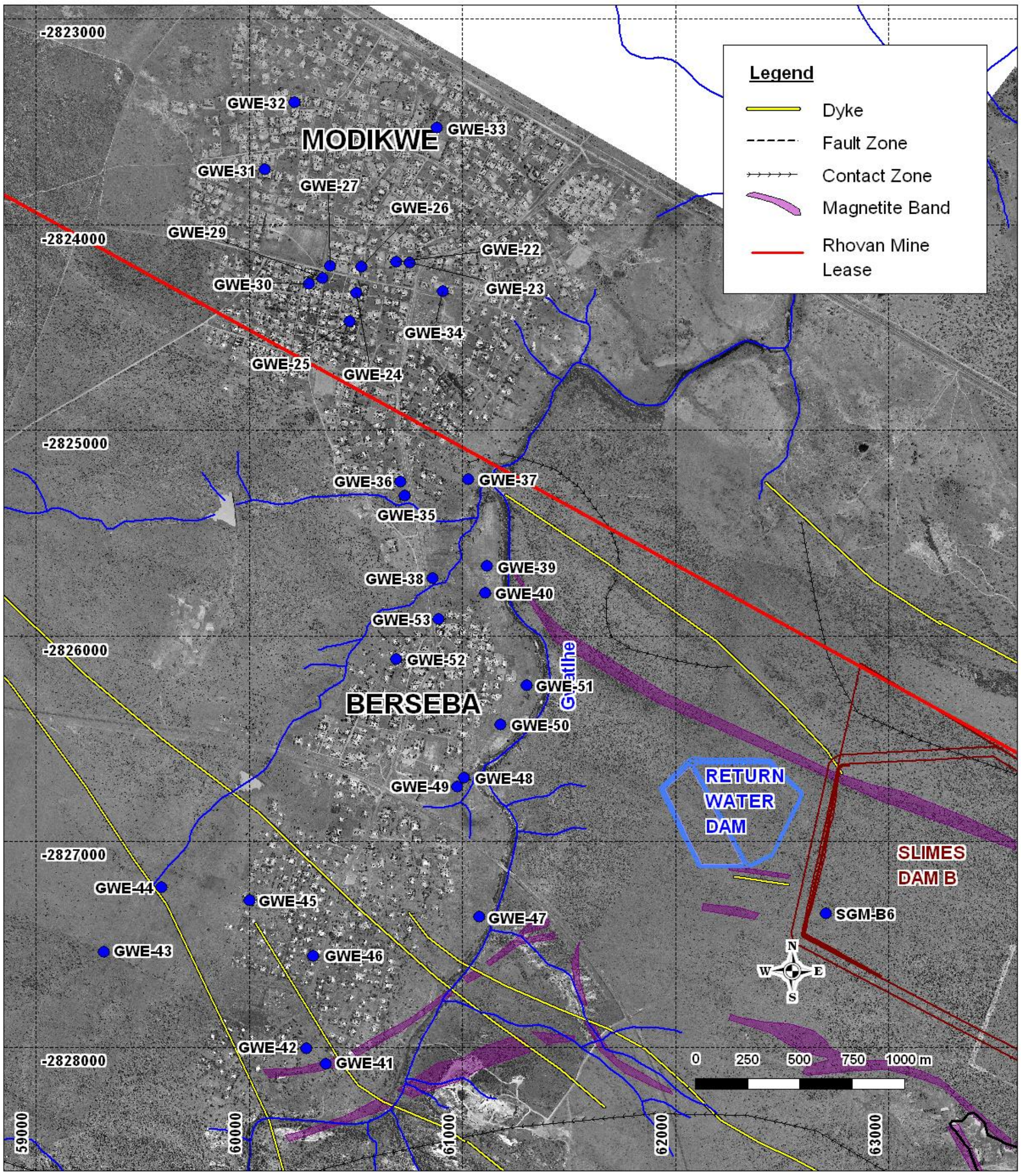


Figure 3(G): Location of boreholes at Modikwe and Berseba.

The first hydro-census at Bethanie was performed in November 1999 by JMA. Since then a total of 9 sampling runs were performed on accessible boreholes at Bethanie of which the most recent was in March 2005. A hydro-census was performed by JMA in May 2005 at Modikwe and Berseba.

The communities of Modikwe, Berseba and Bethanie mainly rely on bulk water supply from Magalies Water Board since 1997. Boreholes are now used as standby for periods of technical problems with the main water supply. However, private boreholes are still used for domestic purposes such as laundry, garden watering etc.

Except for the external user's boreholes at Bethanie, Berseba and Modikwe, one borehole (GWE-6), is situated 2 km south of the Xstrata Alloys Rhovan Plant Area. The position of this borehole is given in **Figure 3(E).**

Basic information on all external users' boreholes is given in **Table 3(B)** attached in **APPENDIX 3.0**

3.1 DEPTH TO WATER TABLE

All water level measurements over time are listed in **Dataset 3.1(A)** in **APPENDIX 3.0.** The most recent water level depth measurements of each individual borehole for the respective areas at Rhovan and Bethanie, Modikwe and Berseba are given in **Figures 3.1(A) to (F)** below:

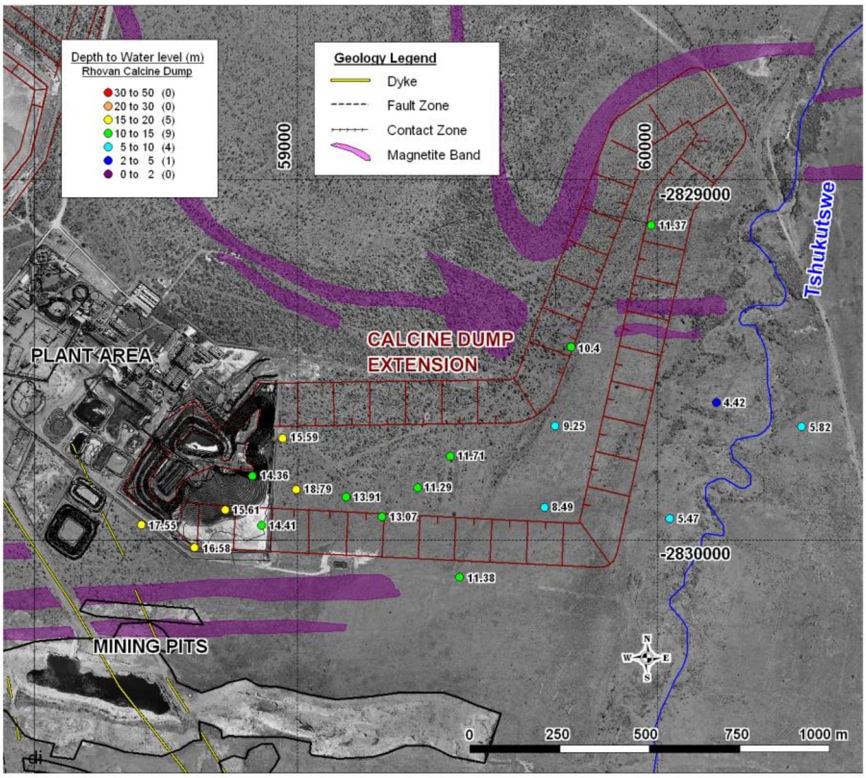


Figure 3.1(A): Most recent water level depth measured at the Calcine Dump Area.

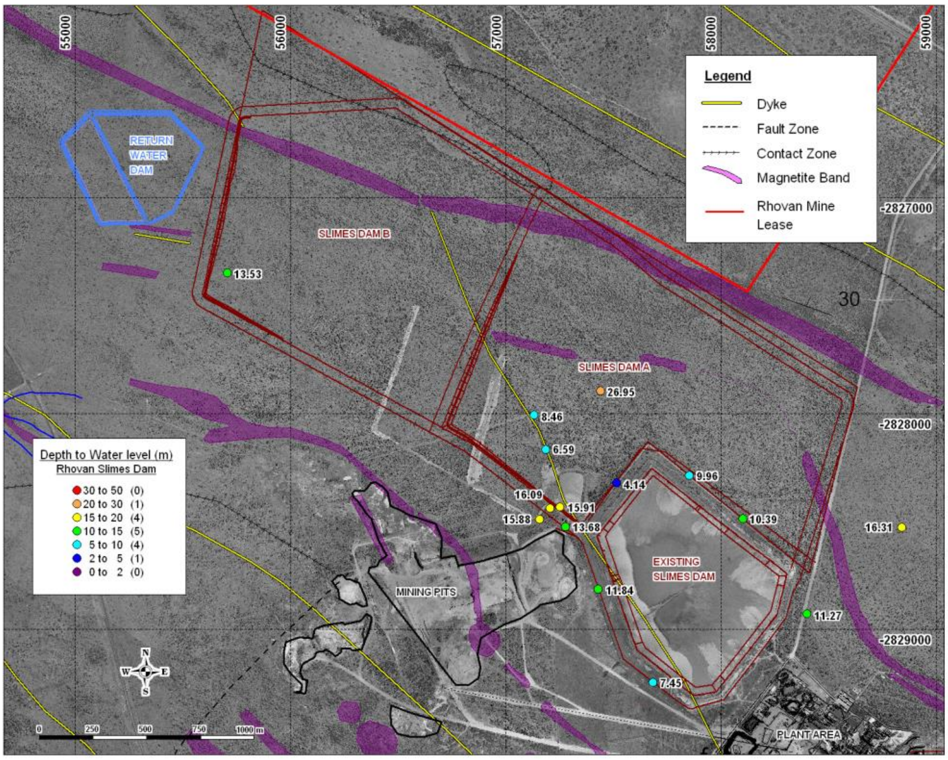


Figure 3.1(B): Most recent water level depth measured at the Slimes Dam Area.

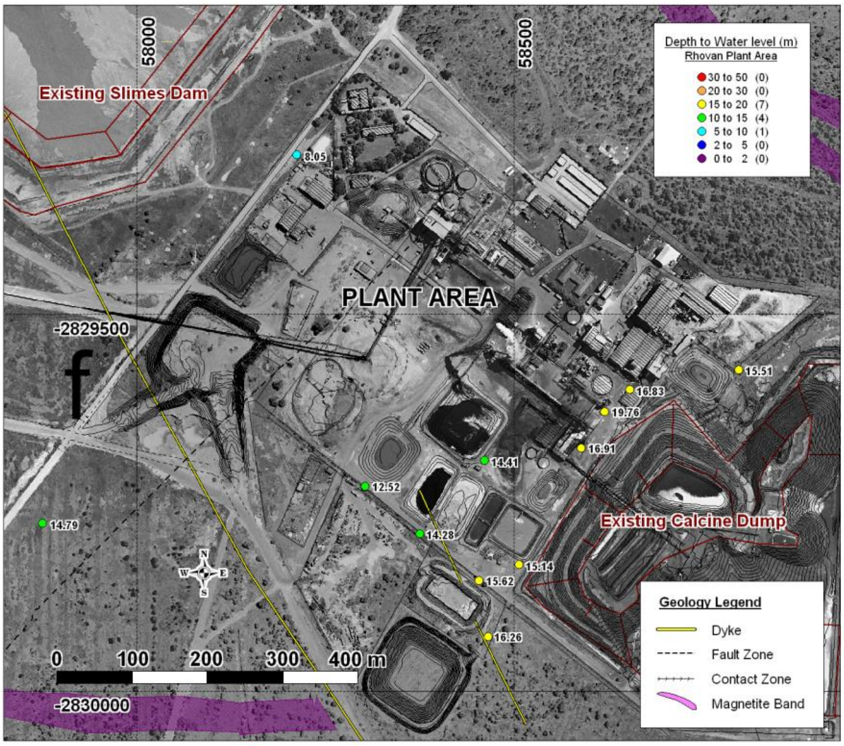


Figure 3.1(C): Most recent water level depth measured at the Plant Area.

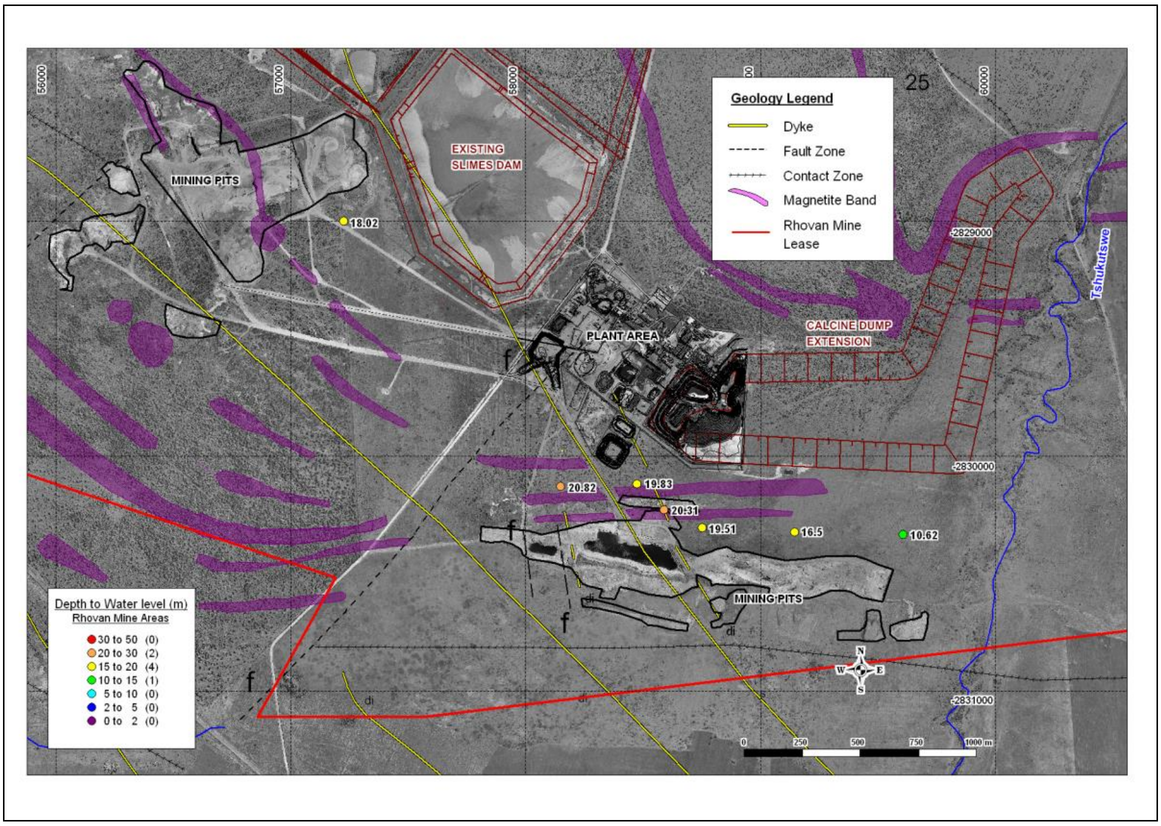


Figure 3.1(D): Most recent water level depth measured at the Mining Area.

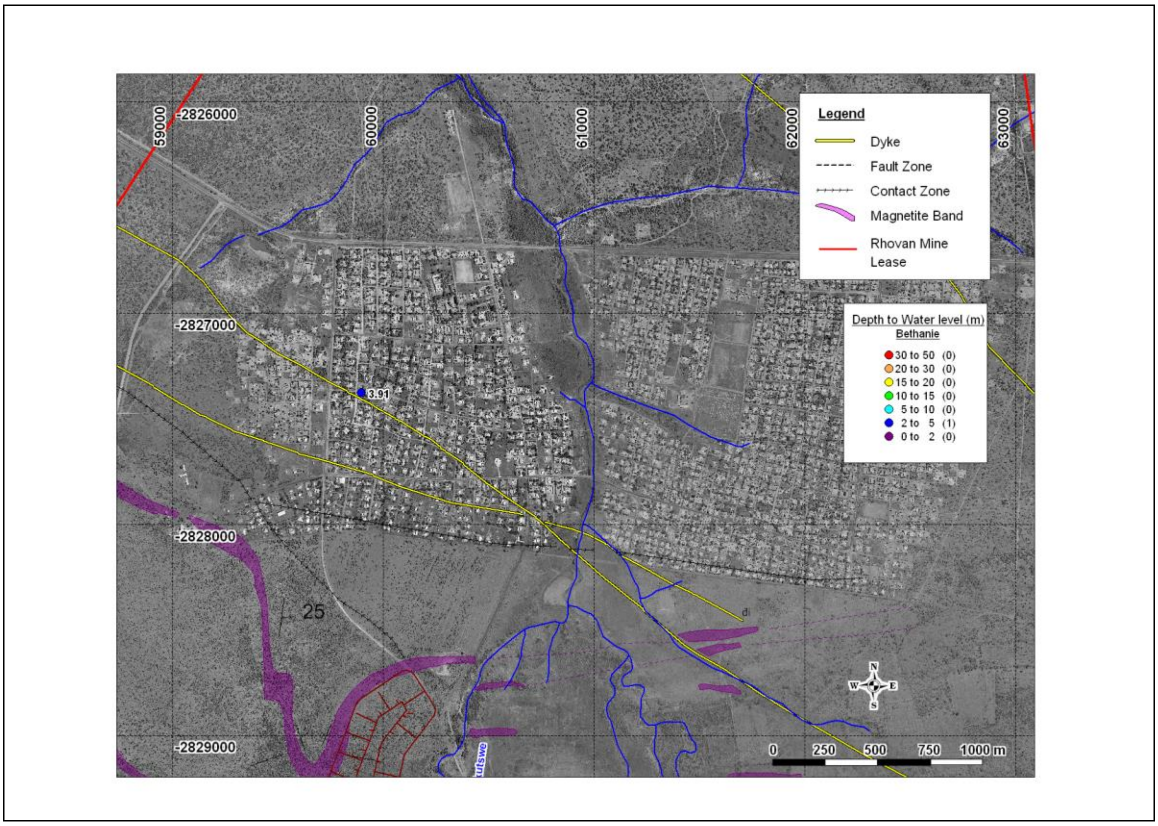


Figure 3.1(E): Most recent water level depth measured at Bethanie.

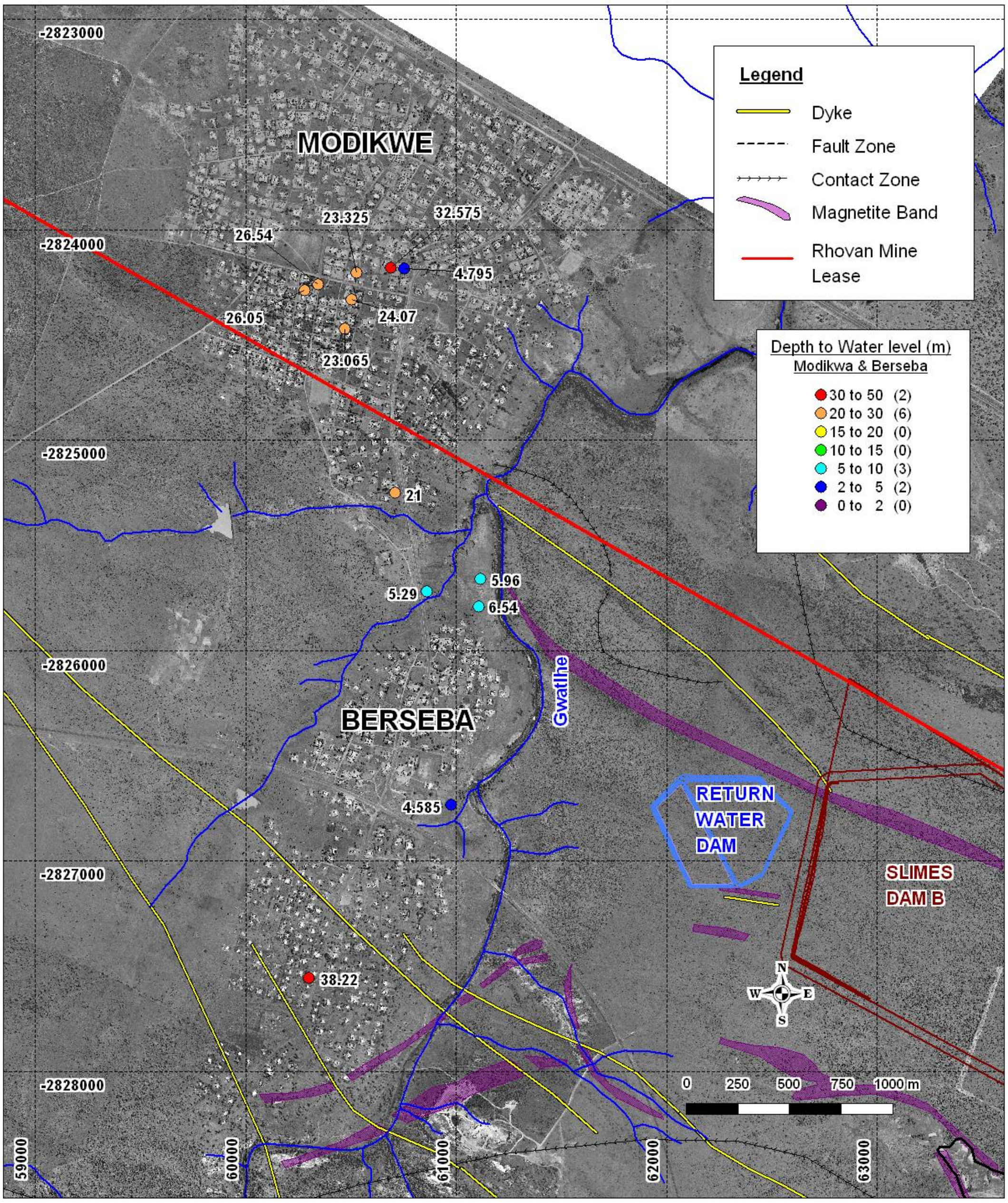


Figure 3.1(F): Most recent water level depth measured at Modikwe & Berseba.

Statistics of the latest water level measurements at each respective area (as depicted in **Figures 3.1(A)** to **(F)** above) are summarized in **Table 3.1(A)** below:

Table 3.1(A): Latest water level depth statistics for all boreholes.

Water level depth (m)	Min	Max	Arithmetic Mean	Harmonic Mean	Geometric Mean
Calcine Dump	4.42	18.79	12.08	10.33	11.28
Slimes Dam	4.14	26.95	12.56	10.35	11.47
Plant Area	8.05	19.76	15.01	14.35	14.71
Mining Areas	10.62	20.82	17.94	17.11	17.57
Bethanie	3.91	3.91	3.91	3.91	3.91
Modikwe and Berseba	4.59	38.22	18.62	10.44	14.32

The following conclusions could be made with respect to the depth of water level within the larger Xstrata Alloys Rhovan area:

- The depth of the water level at the Calcine Dump ranges from <5 m below surface near the Tshukutswe River in the east, to between 15 m and 19 m below surface next to the Plant Area. The change in water level is gradual and the colour-coded values in **Figure 3.1(A)** change gradually from the west towards the east. The average water level is at about 12 m.

- At the Slimes Dam area the water level depth ranges between 4.14 m and 26.95 m averaging at 12.56 m. It is observed that the depth to water level is shallower directly east of the syenite dyke in SGM-3 and SGM-4 than to the west of it. This shows that ground water might accumulate against the less permeable dyke.

- At the eastern part of the Plant Area the water level near the Calcine Dump ranges between 15 m and 20 m. Towards the west it is shallower (<15 m) and in the north-western side it is 8 m. The average water level depth over the Plant Area is at about 15 m.

- At the Mining Areas the depth to water level is deeper than at the Calcine Dump, Plant and Slimes Dam areas, and except for the borehole in the east that has a water level of 10.62 m, all boreholes have water levels of deeper than 15 m. The average water level depth of the boreholes at the Mining Area is at about 18 m. This is a general indication of partial aquifer dewatering due to mining activities.

- Only one borehole at Bethanie was accessible for water level measurements. The measured water level was at 3.91 m.

- At Berseba and Modikwe the water level depth is also deeper than at the Rhovan area, which can be attributed to water use. The water level depth range in this area at between 4.59 m and 38.22 m, averaging at 18.62 m.

Overall, almost no boreholes show a water level of less than 10 m. It seems that the natural water level depth at the Calcine Dump, Slimes Dam and Plant Area varies between 11 m and 15 m. Nearer to the Tshukutswe River in the east the water level is however shallower than 10 m. Boreholes that have a lowered water level (due to pumping or mining activities) is typically below ±17 m.

3.2 ESTIMATED BOREHOLE YIELD

All borehole yield information is listed in **Tables 3(A) and (B)** in **APPENDIX 3.0**. The estimated blow yields (l/s) of each individual borehole for the respective areas at Xstrata Alloys Rhovan are given in **Figures 3.2(A) to (D)** below:

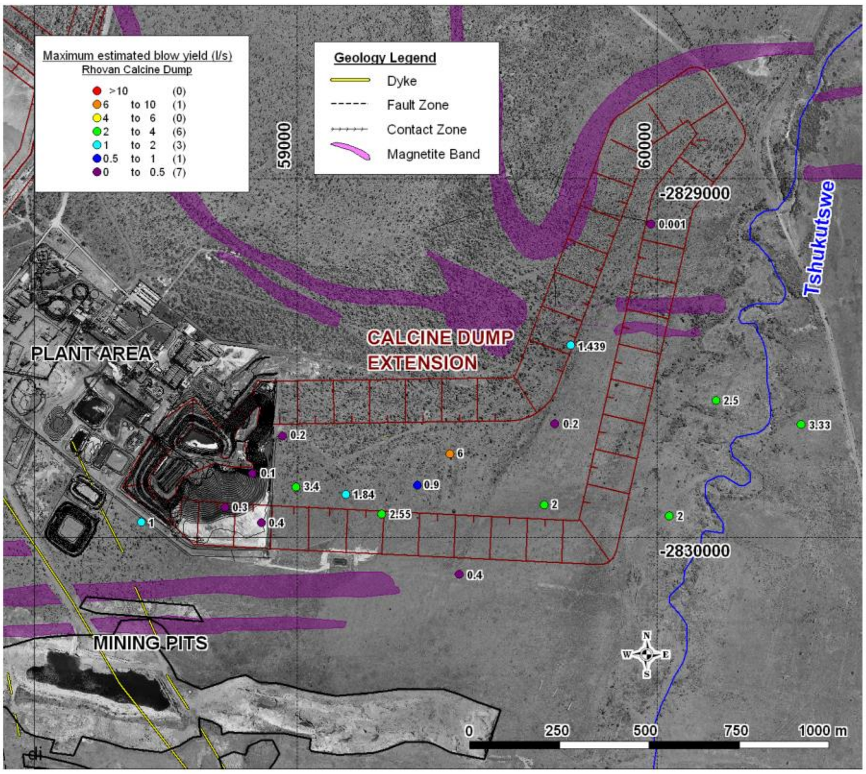


Figure 3.2(A): Borehole blow yields at the Calcine Dump.

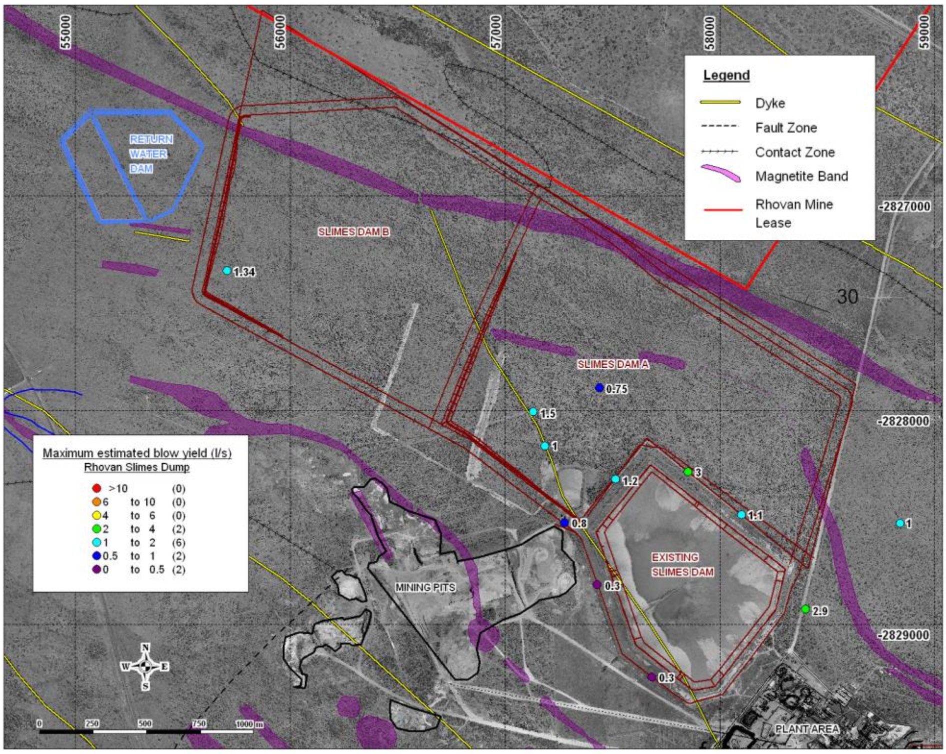


Figure 3.2(B): Borehole blow yields at the Slimes Dam.

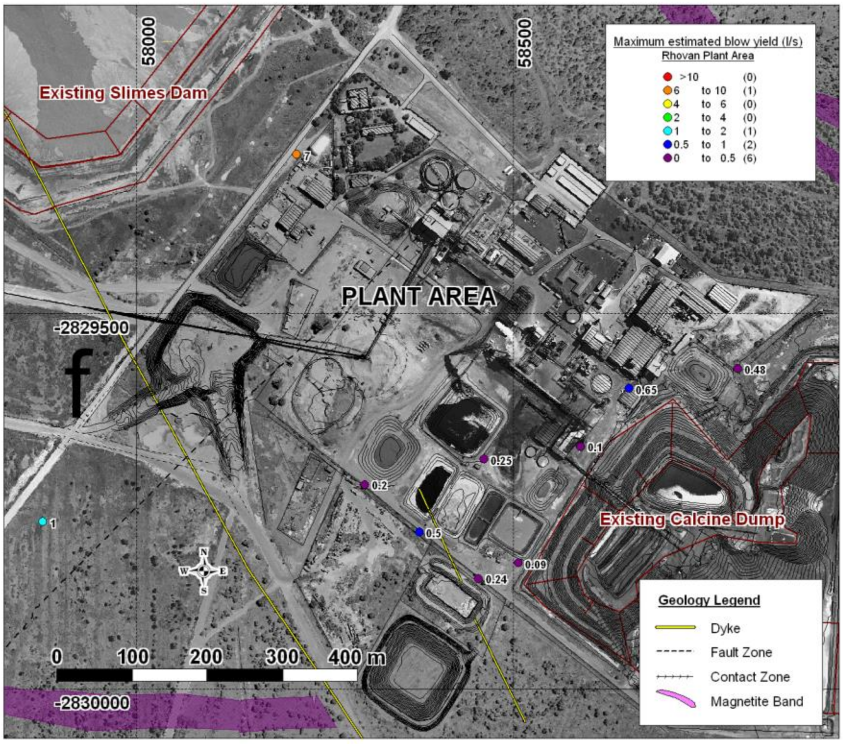


Figure 3.2(C): Borehole blow yields at the Plant Area.

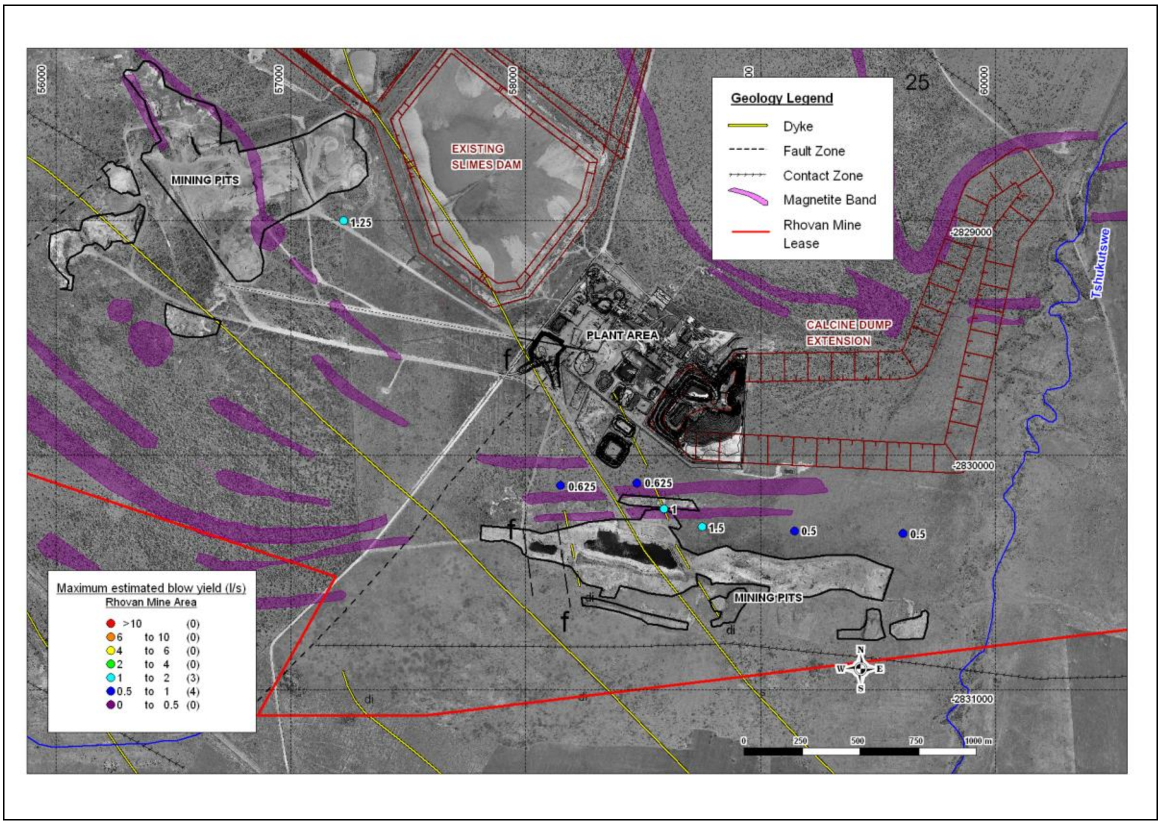


Figure 3.2(D): Borehole blow yields at the Mining Area.

Statistics of the estimated blow yields at each respective area (as depicted in **Figures 3.2(A) to (D)** above) are summarized in **Table 3.2(A)** below:

Table 3.2 (A): Yield (l/s) statistics for boreholes at Rhovan.

Yield (l/s)	**Min**	**Max**	**Arithmetic Mean**	**Harmonic Mean**	**Geometric Mean**
Calcine Dump	0.001	6.000	1.587	0.017	0.673
Slimes Dam	0.300	3.000	1.266	0.796	1.019
Plant Area	0.090	7.000	1.051	0.244	0.405
Mining Area	0.500	1.500	0.857	0.724	0.785

The following conclusions could be made with respect to the borehole yields within the larger Xstrata Alloys Rhovan area:

- The estimated borehole yields at the Calcine Dump range between 0.001 l/s and 6 l/s, averaging at 1.6 l/s. In the area that stretch from the current Calcine Dump eastwards towards the Tshukutswe River, all borehole yields are above at least 1 l/s. This indicates a possible zone of higher permeability in the aquifer. The average depth of the water strikes are between 17 m and 18 m.

- At the Slimes Dam area the estimated borehole yield range between 0.3 l/s and 6 l/s, averaging at 1.3 l/s. The average depth of the water strike in the area is between 21 m and 22 m.

- At the Plant Area all boreholes in the eastern part show yields of lower than 1 l/s. The borehole in the north-western corner of the Plant shows a yield of 7 l/s. The average depth of the water strike in the area is between 22 m and 24 m within the fractured gabbro.

- At the Mining Area the estimated borehole yield range between 0.5 l/s and 1.5 l/s, averaging at 0.9 l/s. The average depth of the water strike in the area is between 24 m and 26 m.

Except for boreholes SGM-B3, SGM–B5 and GWW-45, all water strikes recorded were within the fractured gabbro, and a few at the contact between the gabbro and the underlying magnetite gabbro. The main water strikes of SGM-B3 and SGM–B5 were recorded respectively in a syenite dyke and in granite – both 1 l/s. The water strike of GWW-45 was recorded in a thin anorthosite layer within the fractured gabbro.

It is important to note that water strikes were recorded in almost all boreholes drilled at Rhovan. For the detailed water strike information of each individual borehole, please refer to **Dataset 3(A)** attached in **APPENDIX 3.0**.

3.3 GROUNDWATER QUALITY

The ground water quality data is discussed for samples taken for the period from January 1999 to July 2005.

3.3.1 Background ground water quality

It is important to establish a background ground water quality for the Rhovan area in order to compare contaminated water with natural qualities. The background quality was determined by the following screening process:

- A total of 675 borehole water samples over time exist that could be used to establish the background ground water quality.

- Two of the primary parameters of contamination in ground water at Rhovan are SO_4 and V. A cut-off concentration value had to be established for the maximum SO_4 and V that may be present in the background ground water. A graph was drawn of the log concentration of SO_4 and V against the increasing SO_4 concentration and shown in **Figure 3.3.1(A)** below. From this figure it is evident that no cut-off concentration of V could be made lower than 0.5 mg/l. Therefore this must be accepted as the maximum background value. All samples with V above 0.5 mg/l were discarded from further screening. The chosen background ground water of 0.5 mg/l is also equal to the Maximum Allowable limit of the SABS 241 Drinking Water Standard.

The V value above corresponds to a maximum SO_4 value of about 200 mg/l as could be seen in **Figure 3.3.1(A)** below. If SO_4 increase above this value, V often also increases indicating a good chance of contamination. All borehole samples with SO_4 above 200 mg/l were also discarded from further screening.

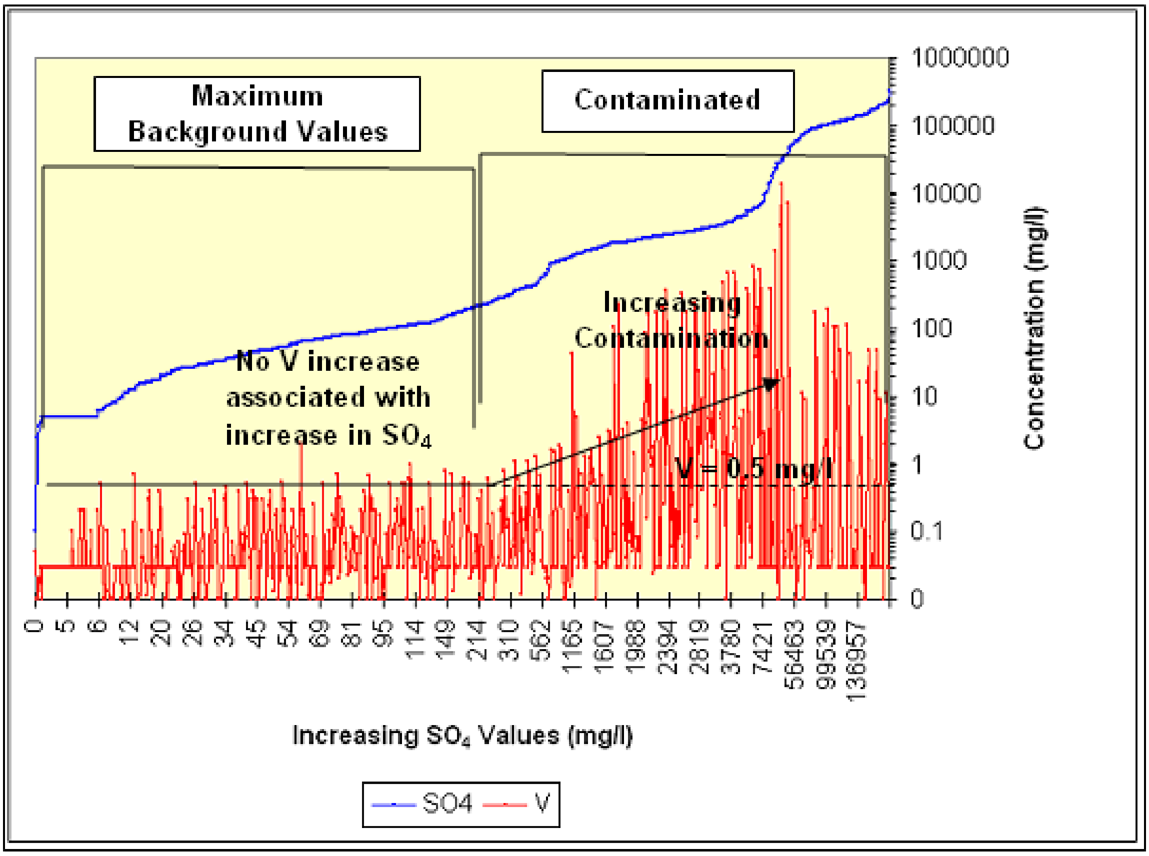


Figure 3.3.1(A): SO_4 and V measured in 675 borehole samples.

- Contamination of N and F exist in the ground water. Because no source of these parameters exist within the natural aquifer, all samples were discarded from further screening that have a NO_3 (as N) higher than 6 mg/l and a F higher than 1 mg/l. These values also correspond to the limits for respectively ideal and acceptable drinking water according to the SABS 241 Drinking Water Standard.

- Furthermore, all samples were discarded that are outliers in terms of other parameters. Finally, only 121 samples were left that were regarded to represent the background ground water quality at Rhovan. The statistical summary of the background water is given in **Table 3.3.1(B)** below. The 122 samples that were defined as background are listed in **Table 3.3.1(A)** in **APPENDIX 3.0(A).**

Table 3.3.1(B): Background ground water at Xstrata Alloys Rhovan.

Parameter	Minimum	Probable Maximum	Average	Harmonic mean	Geometric mean
pH	6.6	8.8	7.8	7.8	7.8
EC (mS/m)	18	124	75	68	72
TDS (mg/l)	108	868	490	446	468
Ca (mg/l)	12	160	65	55	60
Mg (mg/l)	5	90	33	27	30
Na (mg/l)	11	106	37	30	33
K (mg/l)	0.4	11.9	3.2	1.8	2.4
Si (mg/l)	2	37	20	12	16
T-Alk (mg/l)	35	478	212	163	188
Cl (mg/l)	10	149	71	54	64
SO_4 (mg/l)	5	197	71	39	55
N (mg/l)	0.010	6.000	2.635	0.127	1.239
F (mg/l)	0.010	1.000	0.286	0.147	0.227
Al (mg/l)	0.010	0.250	0.089	0.024	0.051
Fe (mg/l)	0.010	116.000	11.284	0.041	0.361
Mn (mg/l)	0.010	0.770	0.129	0.027	0.057
V (mg/l)	0.010	0.500	0.092	0.027	0.044

A Piper Image of the background ground water quality at Rhovan is shown below:

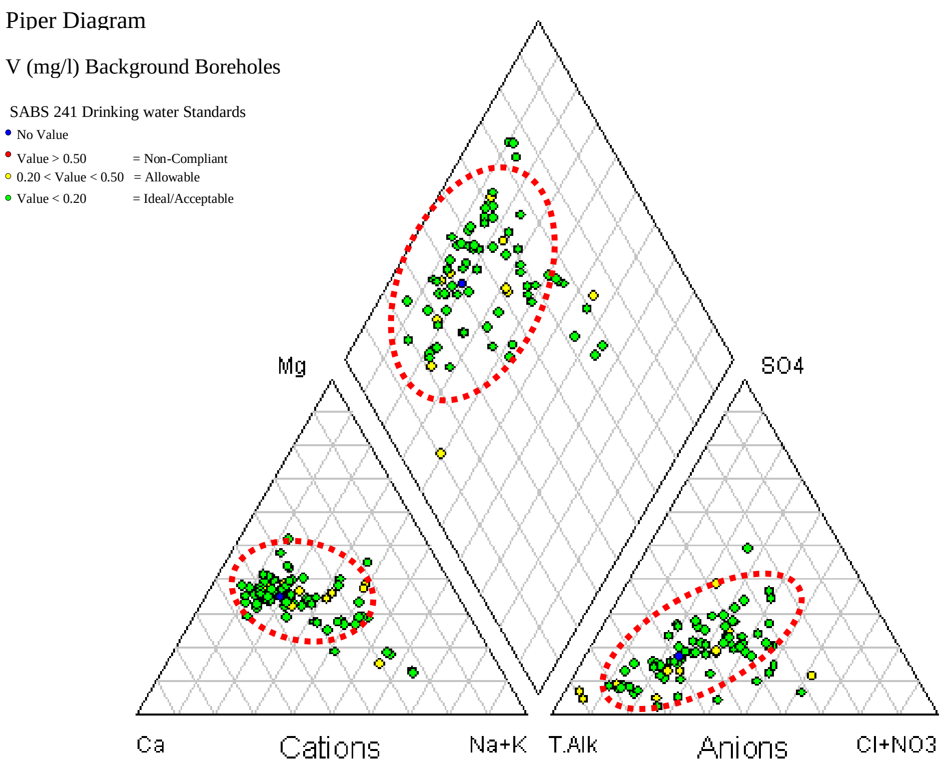


Figure 3.3.1(B): Piper Diagram (V) of background ground water at Rhovan.

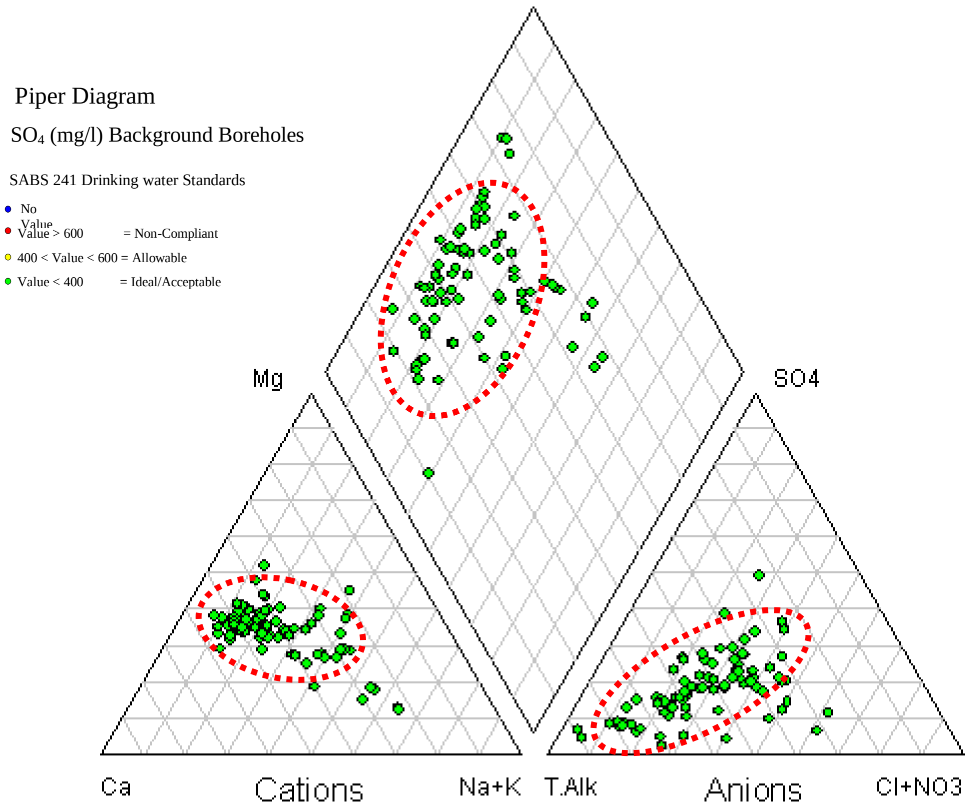


Figure 3.3.1(C) Piper diagram (SO_4) of background ground water at Rhovan

The following conclusions can be made from **Figures 3.3.1(B) and (C)**:

- It is evident that the background ground water is a Ca-Mg-HCO_3 dominated water.
- The background ground water is also compliant in terms of SO_4, NO_3 and V. These parameters have been identified as major parameters of contamination at Rhovan.
- Any impact on the ground water at Rhovan will show an elevation in either SO_4 and/or NO_3 and will clearly be identified.

3.3.2 <u>Ground water quality and distribution</u>

All chemistry data of each individual borehole is given in **Dataset 3.3** in **APPENDIX 3.0**. Due to the huge volume of data, only TDS and SO_4 distribution and compliance maps were created respectively for the Calcine Dump area, Slimes Dam, Plant Area, Mining Area, external user borehole GWE-6 and Bethanie.

These figures are given below as **Figure 3.3.2(A) to (L).**

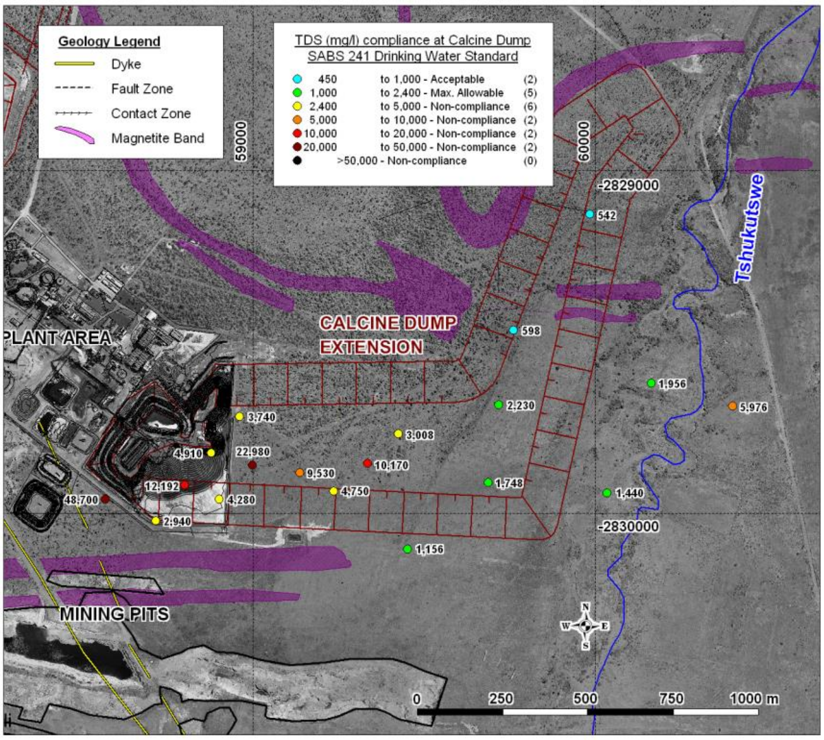


Figure 3.3.2(A): Compliance of TDS at the Calcine Dump.

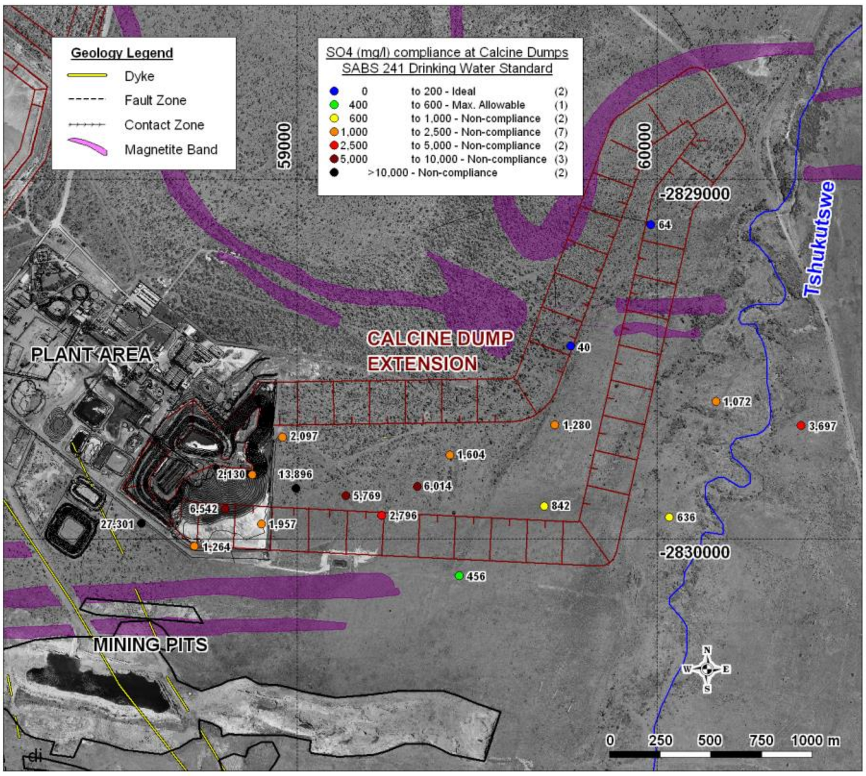


Figure 3.3.2(B): Compliance of SO_4 at the Calcine Dump.

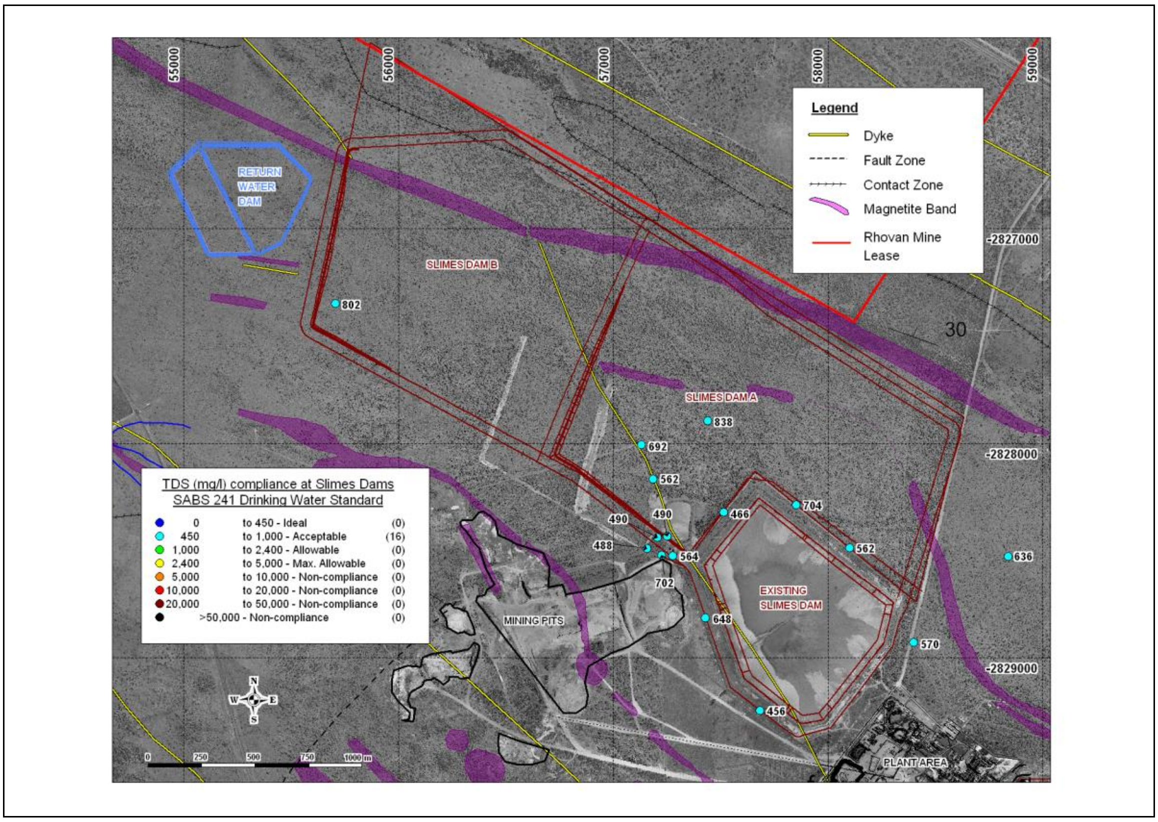


Figure 3.3.2(C): Compliance of TDS at the Slimes Dam.

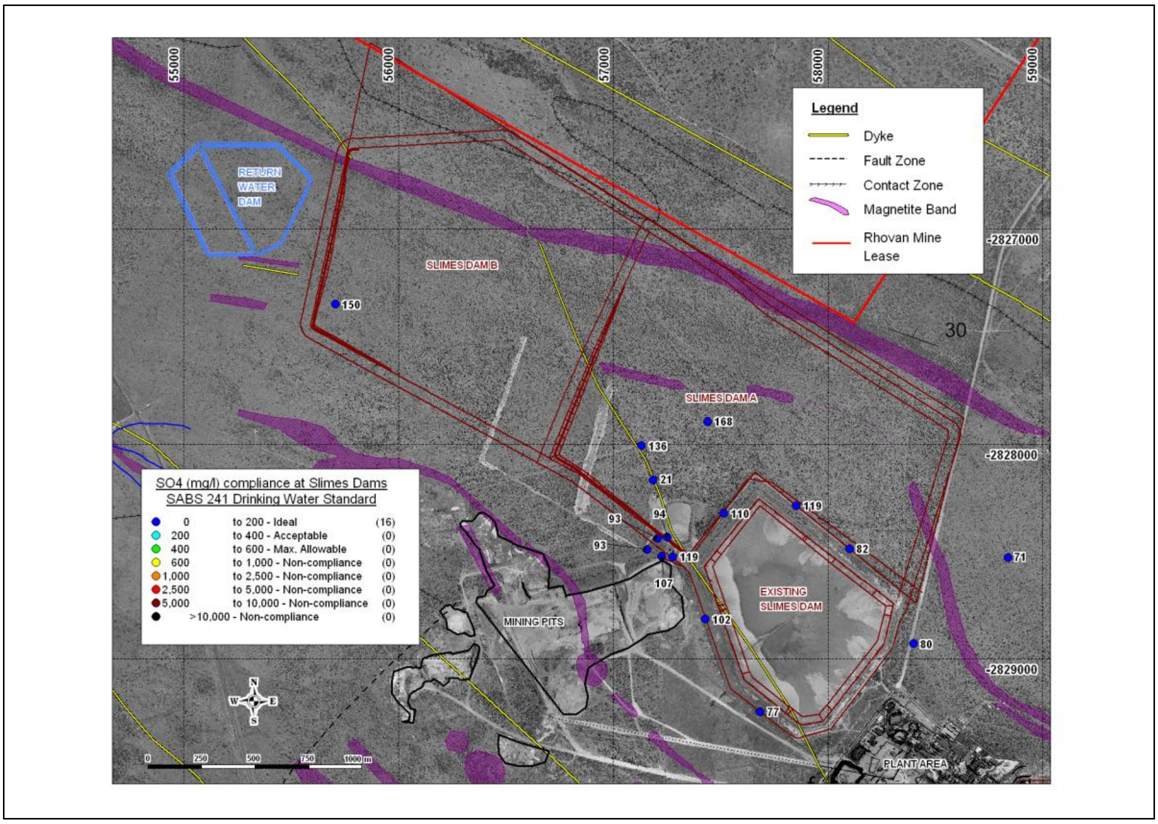


Figure 3.3.2(D): Compliance of SO_4 at the Slimes Dam.

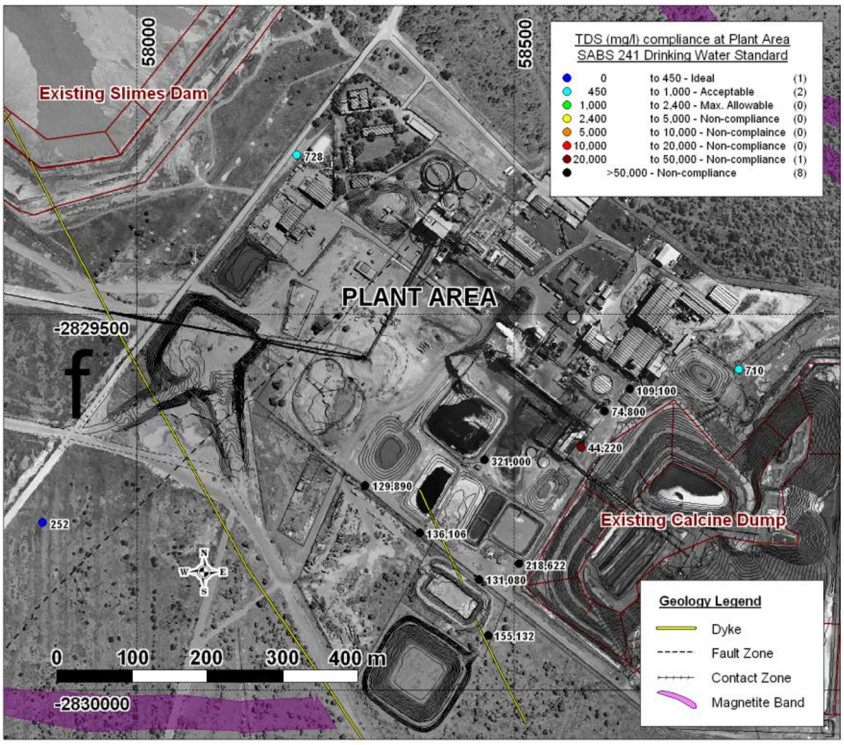


Figure 3.3.2(E): Compliance of TDS at the Plant Area.

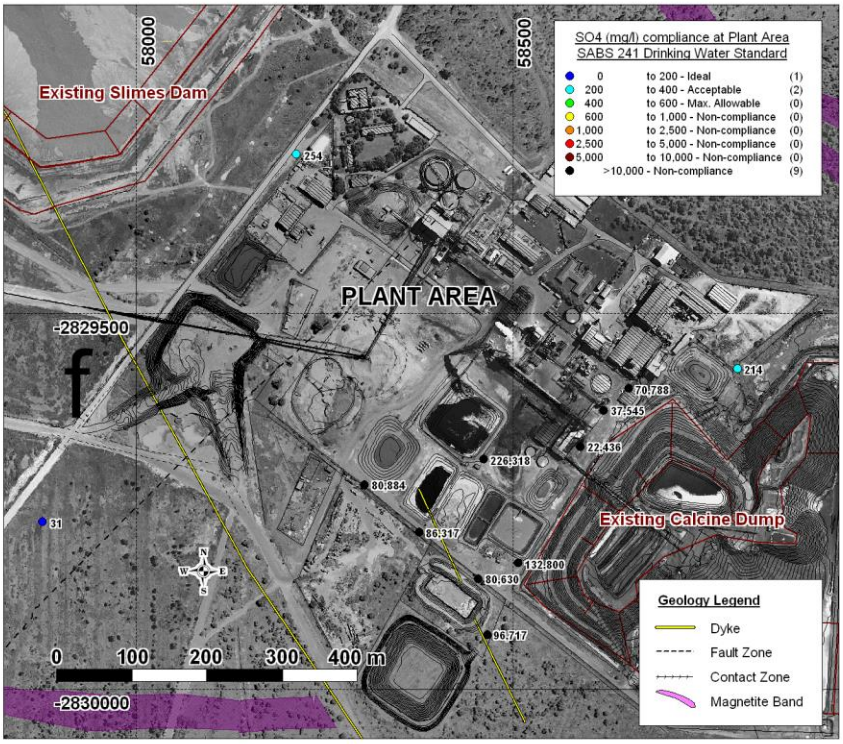


Figure 3.3.2(F): Compliance of SO_4 at the Plant Area.

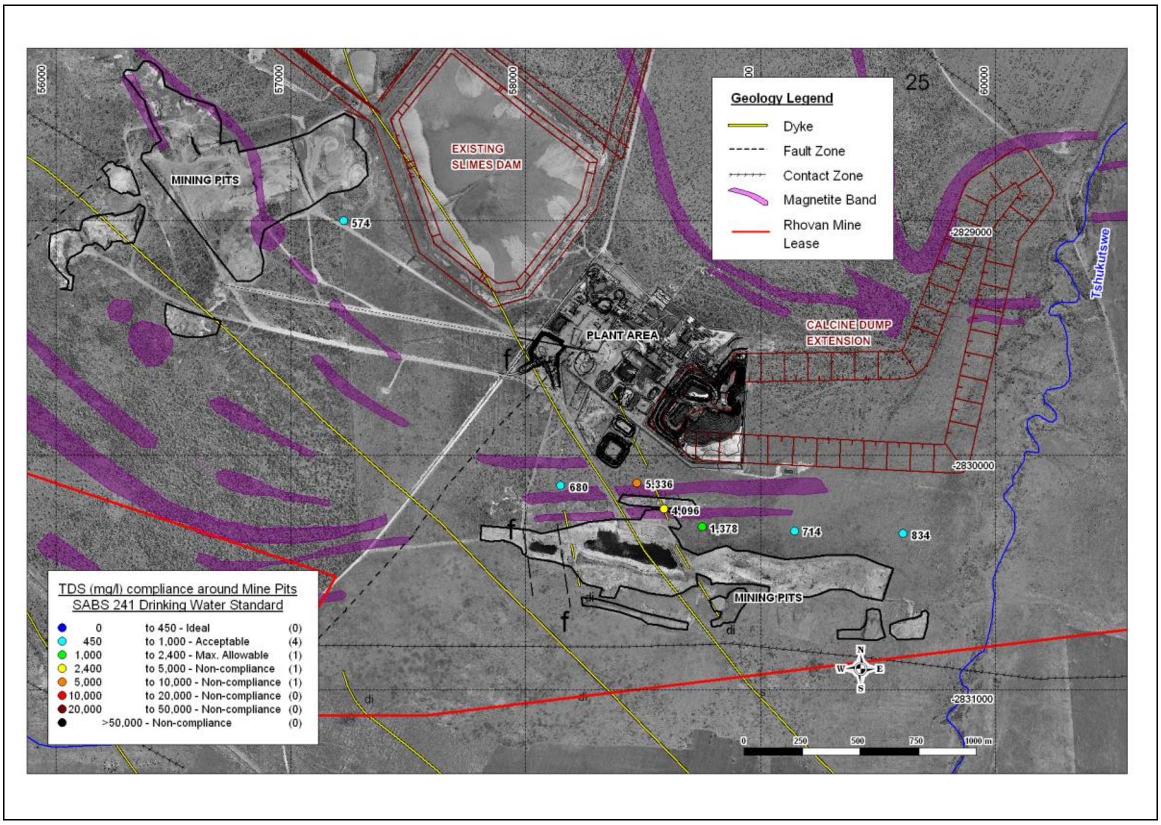


Figure 3.3.2(G): Compliance of TDS at the Mining Area.

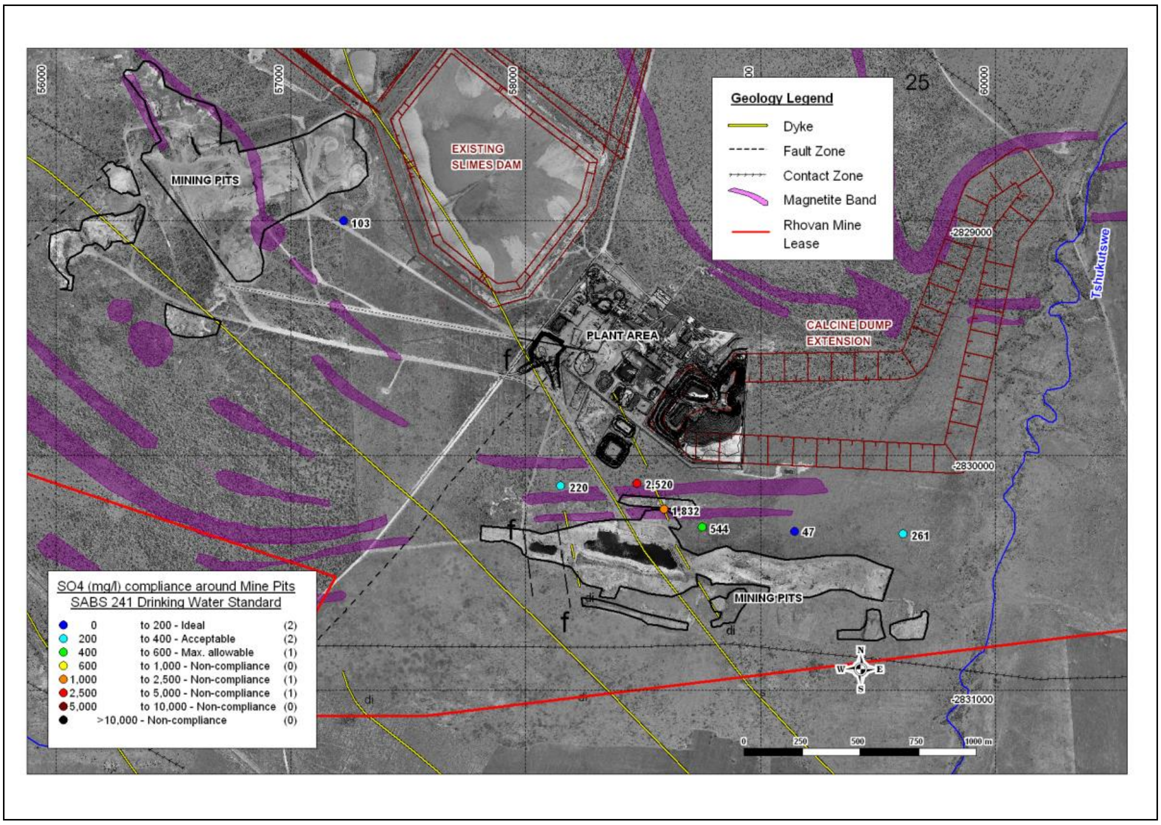


Figure 3.3.2(H): Compliance of SO_4 at the Mining Area.

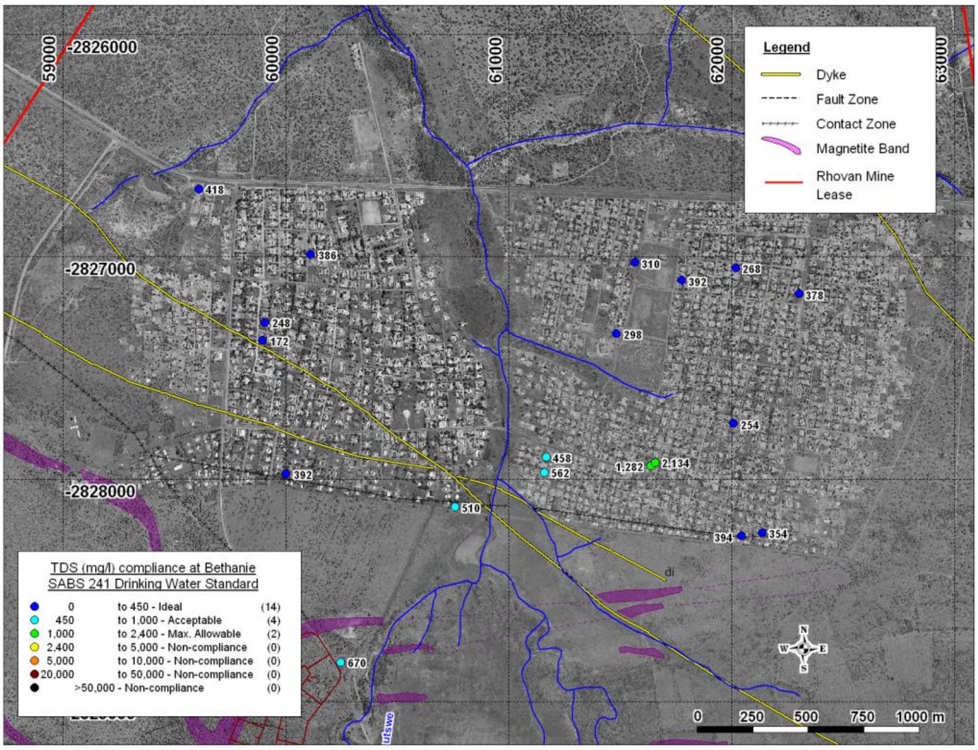


Figure 3.3.2(I): Compliance of TDS at Bethanie.

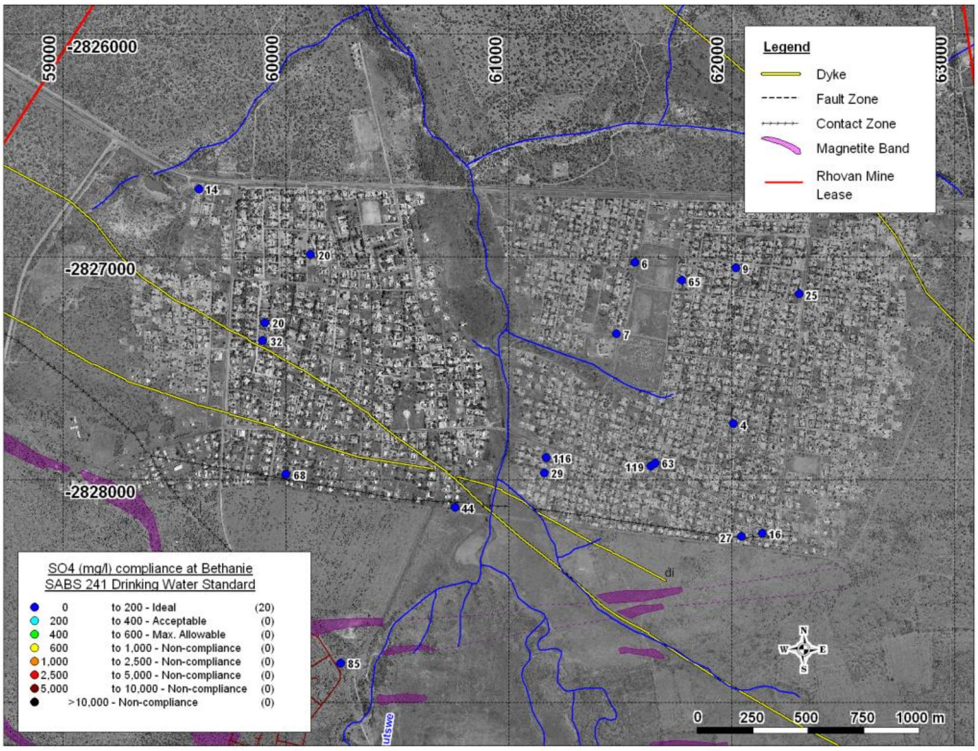


Figure 3.3.2(J): Compliance of SO_4 at Bethanie.

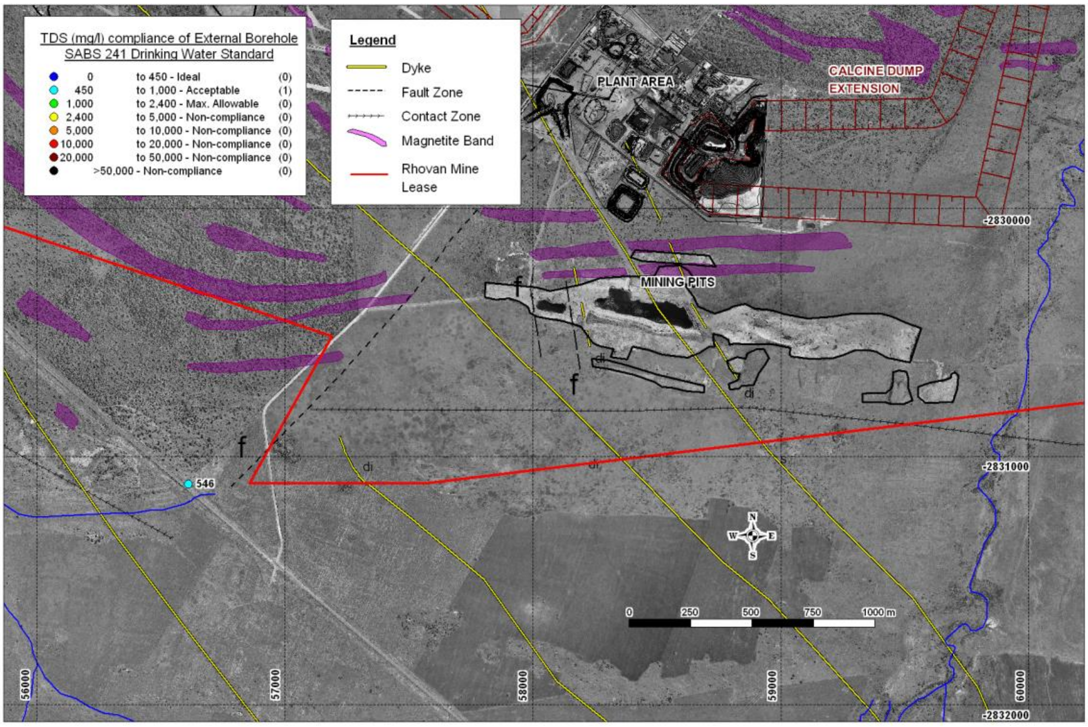


Figure 3.3.2(K): Compliance of TDS at GWE-6.

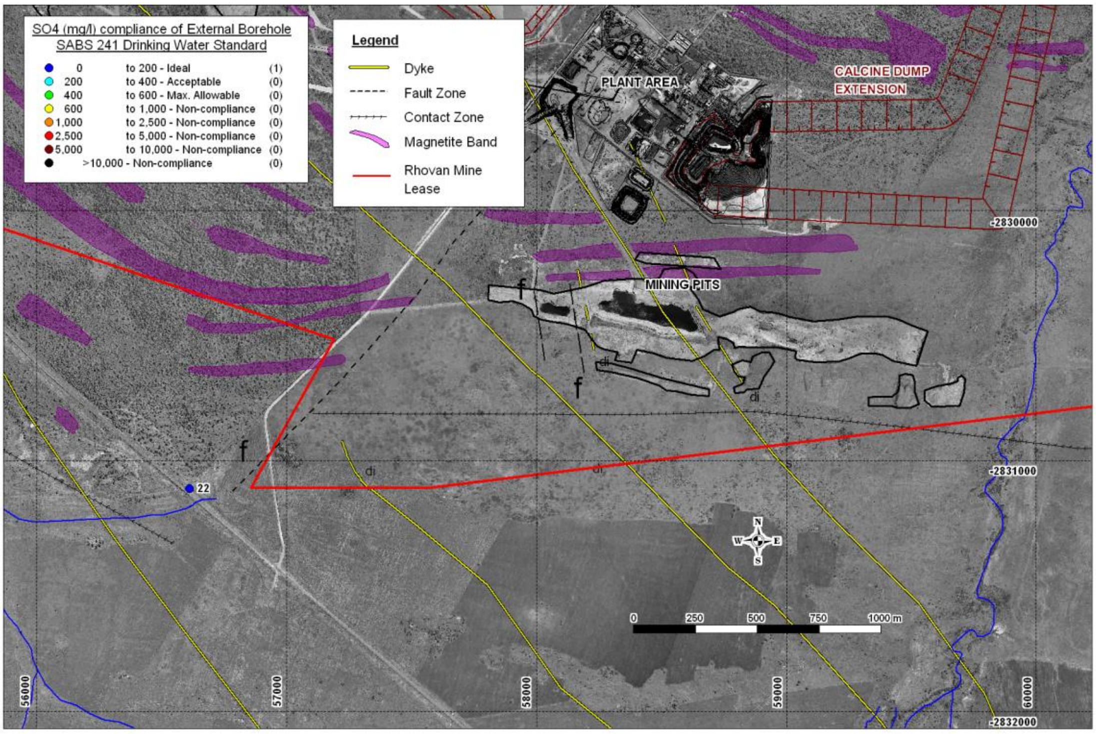


Figure 3.3.2(L): Compliance of SO_4 at GWE-6.

Table 3.3.2(A) below summarizes the latest TDS, SO_4, V and NO_3 distribution and compliance:

Table 3.3.2(A): Summary of most recent analysis of major contamination parameters at Xstrata Alloys Rhovan.

Area	Parameters	Minimum	Maximum	Arithmetic Mean	Borehole Samples assessed in terms of SABS 241 Drinking Water Standard*				
					Ideal	Acceptable	Allowable	Non-compliant	Total
Calcine Dump	TDS (mg/l)	542	48700	7518	0	2	5	12	19
	SO_4 (mg/l)	41	27301	4182	2	0	1	16	19
	V (mg/l)	0.010	839	103	9	1	1	8	19
	N (mg/l)	0.200	244	42.8	3	1	6	9	19
Slimes Dam	TDS (mg/l)	456	838	604	0	16	0	0	16
	SO_4 (mg/l)	21	168	102	16	0	0	0	16
	V (mg/l)	0.010	0.500	0.063	15	0	1	0	16
	N (mg/l)	0.010	8.000	4.221	11	5	0	0	16
Plant Area	TDS (mg/l)	252	321000	110137	1	2	0	9	12
	SO_4 (mg/l)	31	226318	69578	1	2	0	9	12
	V (mg/l)	0.010	7180	716	8	1	0	3	12
	N (mg/l)	0.900	1079	281	1	1	1	9	12
Mining Area	TDS (mg/l)	574	5336	1945	0	4	1	2	7
	SO_4 (mg/l)	47	2520	790	2	2	1	2	7
	V (mg/l)	0.010	1.150	0.240	4	1	1	1	7
	N (mg/l)	3.90	49.0	23.1	2	0	2	3	7
GWE-6	TDS (mg/l)	546	546	546	0	1	0	0	1
	SO_4 (mg/l)	23	23	23	1	0	0	0	1
	V (mg/l)	0.010	0.010	0.010	1	0	0	0	1
	N (mg/l)	7.88	7.88	7.88	0	1	0	0	1
Bethanie	TDS (mg/l)	172	2134	514	14	4	2	0	20
	SO_4 (mg/l)	4	120	42	20	0	0	0	20
	V (mg/l)	0.010	2.000	0.110	19	0	0	1	20
	N (mg/l)	0.010	190	23.9	8	4	3	5	20

*** Ideal: TDS <450 mg/l, SO_4 <200 mg/l, V < 0.1 mg/l, NO_3 as N < 6 mg/l**

Acceptable: TDS 450-1000 mg/l, SO_4 200-400 mg/l, V 0.1-0.2 mg/l, NO_3 as N 6-10 mg/l

Allowable: TDS 1000-2400 mg/l, SO_4 400-600 mg/l, V 0.1-0.5 mg/l, NO_3 as N 10-20 mg/l

Non-compliant: TDS >2400 mg/l, SO_4 >600 mg/l, V >0.5 mg/l, NO_3 as N >20 mg/l

The following observations in terms of compliance and the overall trend in ground water quality can be made with reference to **Dataset 3.3(A), Figure 3.3.2(A) to (L)** and **Table 3.3.2(A)**:

Calcine Dump Area

- From **Dataset 3.3(A)** the overall trend of pollution/contamination for the various boreholes at the Calcine Dump area could be established and are given below, along with the latest TDS and SO_4 compliance as depicted in **Figures 3.3.2(A)** and **(B):**

Borehole Nr.	Alternative Nr.	TDS Compliance	SO_4 Compliance	Overall Trend
GWW-1	RGM-B1	Non-compliant	Non-compliant	Sideways trend
GWW-2	RGM-B2	Non-compliant	Non-compliant	(Destroyed)
GWW-3	RGM-B3	Non-compliant	Non-compliant	(Destroyed)
GWW-4	RGM-B4	Non-compliant	Non-compliant	(Destroyed)
GWW-5	RGM-B5	Non-compliant	Non-compliant	Sideways trend
GWW-19	RGM-B19	Non-compliant	Non-compliant	(Destroyed)
GWW-20	RGM-B20	Non-compliant	Non-compliant	Deteriorating trend
GWW-21	RGM-B21	Non-compliant	Non-compliant	Sideways trend
GWW-22	RGM-B22	Non-compliant	Non-compliant	Sideways trend
GWW-23	RGM-B23	Non-compliant	Non-compliant	Sideways trend
GWW-24	RGM-B24	Non-compliant	Non-compliant	Sideways trend
GWW-25	RGM-B25	Max. Allowable	Non-compliant	Sideways trend
GWW-26	RGM-B26	Max. Allowable	Non-compliant	Sideways trend
GWW-27	RGM-B27	Max. Allowable	Non-compliant	Sideways trend
GWW-28	RGM-B28	Max. Allowable	Max. Allowable	Sideways trend
GWW-29	RGM-B29	Acceptable	Ideal	Sideways trend
GWW-30	RGM-B30	Max. Allowable	Non-compliant	Sideways trend
GWW-31	RGM-B31	Non-compliant	Non-compliant	Sideways trend
GWW-40	RGM-B40	Acceptable	Ideal	(Sampled once)

- From **Dataset 3.3(A)** it is observed that other chemical parameters that are often non-compliant are Ca, Mg, Na and Cl. The EC reflect the non-compliance as observed with TDS.

- Parameters that show overall ideal to marginal compliance most of the time are K, F, Fe, Al and Mn.

- pH show overall ideal compliance.

- Overall it could be concluded that the most significant contaminants at the Calcine Dump are therefore SO_4, V and NO_3. These parameters indicate influence from the current Calcine Dump and as indicated in **Table 3.3.2(A)**, show overall non-compliance in most ground water samples.

- Currently 11 boreholes show sideways trends in terms of their non-compliance and one borehole (GWW-20) show a deteriorating trend. GWW-20 is situated directly east of the existing Calcine Dump.

<u>Slimes Dam Area</u>

- From **Dataset 3.3(A)** the overall trend of pollution/contamination for the various boreholes at the Slimes Dam area could be established and are given below along with the latest TDS and SO_4 compliance as depicted in **Figures 3.3.2(C) and (D)**:

Borehole Nr.	Alternative Nr.	TDS Compliance	SO_4 Compliance	NO_3 Compliance	Overall Trend
GWW-10	RGM-B10	Acceptable	Ideal	Ideal	Deteriorating trend
GWW-11	RGM-B11	Acceptable	Ideal	Ideal	Deteriorating trend
GWW-12	RGM-B12	Acceptable	Ideal	Acceptable	Sideways trend
GWW-13	RGM-B13	Acceptable	Ideal	Ideal	Sideways trend
GWW-14	RGM-B14	Acceptable	Ideal	Ideal	Sideways trend
GWW-16	RGM-B16	Acceptable	Ideal	Ideal	Deteriorating trend
GWW-17	RGM-B17	Acceptable	Ideal	Ideal	Sideways trend
GWS-1	DWBH-01	Acceptable	Ideal	Acceptable	(Sampled once)
GWS-2	DWBH-02	Acceptable	Ideal	Acceptable	Improving trend
GWS-3	DWBH-03	Acceptable	Ideal	Acceptable	Improving trend
GWS-4	DWBH-04	Acceptable	Ideal	Acceptable	Improving trend
SGM-B1	-	Dry	Dry	Dry	Dry
SGM-B2	-	Acceptable	Ideal	Ideal	(Sampled once)

Borehole Nr.	Alternative Nr.	TDS Compliance	SO_4 Compliance	NO_3 Compliance	Overall Trend
SGM-B3	-	Acceptable	Ideal	Ideal	(Sampled once)
SGM-B4	-	Acceptable	Ideal	Ideal	(Sampled once)
SGM-B5	-	Acceptable	Ideal	Ideal	(Sampled once)
SGM-B6	-	Acceptable	Ideal	Ideal	(Sampled once)

- From **Dataset 3.3(A)** it is observed that parameters that show ideal to marginal compliance most of the time are Ca, Mg, Na, Cl, Al, Fe and Mn.

- Parameters that show overall ideal compliance are pH, K and F.

- Overall it could be concluded that no significant contaminants are identified currently at the Slimes Dam area. However, borehole GWW-10, -11 and -16 show a slight deteriorating trend although full compliance is still present at these boreholes.

Plant Area

- From **Dataset 3.3(A)** the overall trend of pollution/contamination for the various boreholes at the Plant Area could be established and are given below along with the latest TDS and SO_4 compliance as depicted in **Figures 3.3.2(E) and (F)**:

Borehole Nr.	Alternative Nr.	TDS Compliance	SO_4 Compliance	Overall Trend
GWW-6	RGM-B6	Non-compliant	Non-compliant	Deteriorating trend
GWW-7	RGM-B7	Non-compliant	Non-compliant	Deteriorating trend
GWW-8	RGM-B8	Acceptable	Acceptable	Sideways trend
GWW-9	RGM-B9	Non-compliant	Non-compliant	Sideways trend
GWW-15	RGM-B15	Acceptable	Acceptable	Sideways trend
GWW-18	RGM-B18	Non-compliant	Non-compliant	Deteriorating trend
GWW-36	RGM-B36	Non-compliant	Non-compliant	(Sampled once)
GWW-37	RGM-B37	Non-compliant	Non-compliant	Unsure
GWW-38	RGM-B38	Non-compliant	Non-compliant	Deteriorating trend
GWW-39	RGM-B39	Non-compliant	Non-compliant	Deteriorating trend
GWW-43	RGM-B43	Non-compliant	Non-compliant	(Sampled once)
GWW-44	RGM-B44	Ideal	Ideal	(Sampled once)

- From **Dataset 3.3(A)** it is observed that other chemical parameters that are often non-compliant are Ca, Mg, Na, K and Cl. The EC reflect the overall non-compliance as observed with TDS.

- Parameters that show overall marginal compliance most of the time are F, Fe, Al and Mn.

- pH show overall ideal compliance.

- Overall it could be concluded that the most significant contaminants at the Plant Area are therefore SO_4, V and NO_3. These parameters indicate influence from the surface features and as indicated in **Table 3.3.2(A),** show overall non-compliance in most ground waster samples.

- Currently 3 boreholes show sideways trends in terms of their non-compliance and 5 boreholes (GWW-6, -7, -18, -38, -39) show a deteriorating trend. These boreholes are situated near pollution dams and may also been influenced by the leachate from the existing Calcine Dump.

Mining Area

- From **Dataset 3.3(A)** the overall trend of pollution/contamination for the various boreholes at the Mining Area could be established and are given below along with the latest TDS and SO_4 compliance as depicted also in **Figures 3.3.2(G) and (H)**:

Borehole Nr.	Alternative Nr.	TDS Compliance*	SO_4 Compliance*	Overall Trend
GWW-32	RGM-B32	Acceptable	Acceptable	Sideways trend
GWW-33	RGM-B33	Non-compliant	Non-compliant	Sideways trend
GWW-34	RGM-B34	Non-compliant	Non-compliant	Sideways trend
GWW-35	RGM-B35	Max. Allowable	Max. Allowable	Sideways trend
GWW-41	RGM-B41	Acceptable	Ideal	(Sampled once)
GWW-42	RGM-B42	Acceptable	Acceptable	(Sampled once)
GWW-45	RGM-B45	Acceptable	Ideal	(Sampled once)

- In contaminated boreholes it is observed that other chemical parameters that are often non-compliant are Ca, Mg, Na and Cl. The EC reflect the non-compliance as observed with TDS.

- Values of Fe, Mn and Al vary from ideal to non-compliant over time and show no definite trend.

- F, K, pH show overall ideal compliance.

- Overall it could be concluded that the most significant contaminants at the Mining Area are therefore SO_4 and NO_3. V is sometimes also elevated.

- Currently 3 boreholes (GWW-33 to GWW-35) show sideways trends in terms of their marginal to non-compliance. These boreholes are probably influenced by the contamination from the existing Calcine Dump and Plant Area.

- Water samples taken from the open mining pits indicate non-compliance of SO_4 and NO_3. The SO_4 is below 1000 mg/l in the mine water but the NO_3 may be as high as 100 mg/l.

GWE-6

- From **Dataset 3.3(A)** the overall trend of pollution/contamination for external user borehole GWE-6 could be established and is given below along with the latest TDS, SO_4 and NO_3 compliance:

Borehole Nr.	Alternative Nr.	TDS Compliance	SO_4 Compliance	NO_3 Compliance	Overall Trend
GWE-6	EUB-6	Acceptable	Ideal	Acceptable	Sideways trend

- At GWE-6 all parameters show mostly ideal values except for NO_3 and TDS that are marginal and Fe and Mn that are sometimes marginal.

- GWE-6 shows a sideways trend in terms of its marginal compliance. It is therefore evident that the NO_3 contamination is persistent. The contamination could be most likely attributed to human/agricultural influences.

Bethanie

- From **Dataset 3.3(A)** the overall trend of pollution/contamination for the various boreholes at the Bethanie could be established and are given below along with the latest TDS, SO_4 and NO_3 compliance:

Borehole Nr.	Alternative Nr.	TDS Compliance	SO_4 Compliance	NO_3 Compliance	Overall Trend
GWE-1	EUB-1	Ideal	Ideal	Ideal	Sideways trend
GWE-2	EUB-2	Ideal	Ideal	Allowable	Sideways trend
GWE-3	EUB-3	Acceptable	Ideal	Ideal	Sideways trend
GWE-4	EUB-4	Acceptable	Ideal	Non-compliant	Sideways trend
GWE-5	EUB-5	Acceptable	Ideal	Ideal	Sideways trend
GWE-7	EUB-7	Ideal	Ideal	Ideal	Sideways trend

Borehole Nr.	Alternative Nr.	TDS Compliance	SO_4 Compliance	NO_3 Compliance	Overall Trend
GWE-8	EUB-8	Ideal	Ideal	Acceptable	Sideways trend
GWE-9	EUB-9	Ideal	Ideal	Acceptable	Sideways trend
GWE-10	EUB-10	Ideal	Ideal	Ideal	Sideways trend
GWE-11	EUB-11	Acceptable	Ideal	Acceptable	Sideways trend
GWE-12	EUB-12	Ideal	Ideal	Acceptable	Sideways trend
GWE-13	EUB-13	Max. Allowable	Ideal	Non-compliant	Sideways trend
GWE-14	EUB-14	Ideal	Ideal	Ideal	Sideways trend
GWE-15	EUB-15	Ideal	Ideal	Ideal	Sideways trend
GWE-16	EUB-16	Ideal	Ideal	Allowable	Sideways trend
GWE-17	EUB-17	Ideal	Ideal	Non-compliant	Sideways trend
GWE-18	EUB-18	Ideal	Ideal	Non-compliant	Sideways trend
GWE-19	EUB-19	Ideal	Ideal	Allowable	Sideways trend
GWE-20	EUB-20	Ideal	Ideal	Ideal	Sideways trend
GWE-21	EUB-21	Max. Allowable	Ideal	Non-compliant	(Sampled once)

- At Bethanie all parameters show mostly ideal to slightly marginal values except for NO_3. F is non-complaint in the latest sampling run of all boreholes only in GWE-B3. GWE-21 showed a NO_3 of 190 mg/l and a V of 2 mg/l. This borehole could unfortunately only been accessed once (in 2002/09/11) and it could not be established by a follow-up whether this analysis was accurate.

- Except for the outliers discussed above, the overall contamination at Bethanie is therefore only NO_3.

- Currently 5 and 7 boreholes show sideways trends in terms of their respective non- and marginal compliance. It is therefore evident that the NO_3 contamination is persistent. The contamination could be most likely attributed to human/agricultural influences.

3.3.3 Ground water image

A Piper diagram for background ground water was shown in **Figure 3.3.1(A)**. Piper diagrams of all monitoring and external user's boreholes are shown in **Figures 3.3.3(A) to (F)** below:

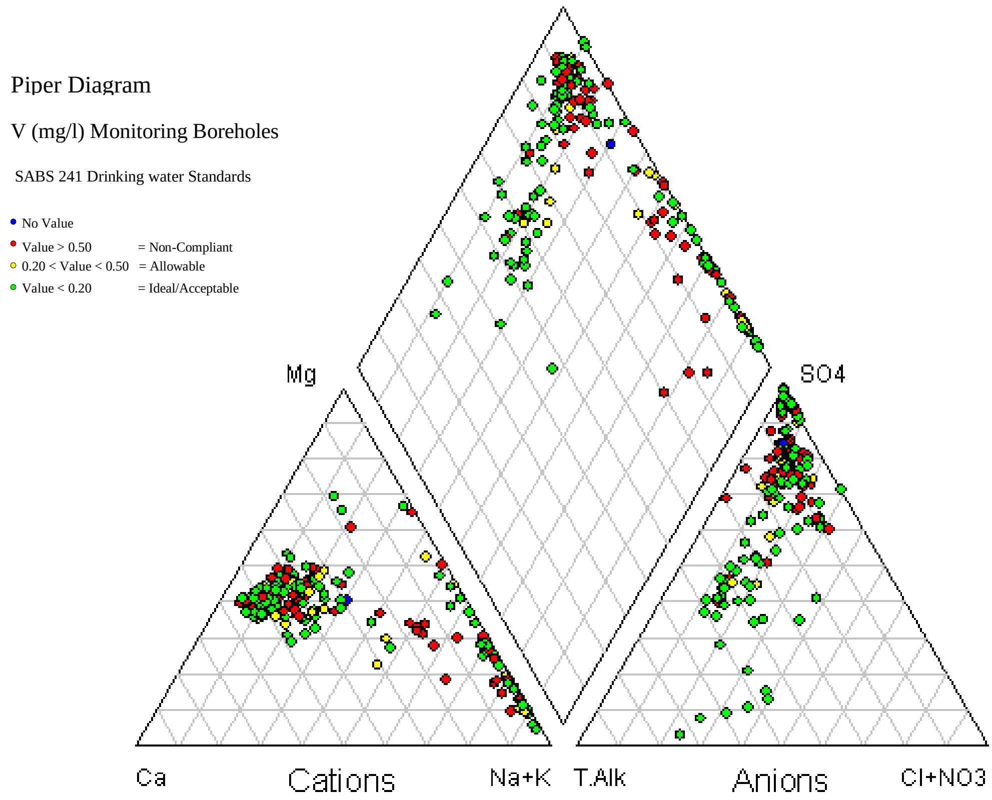


Figure 3.3.3(A): Piper diagram for all monitoring boreholes and V compliance.

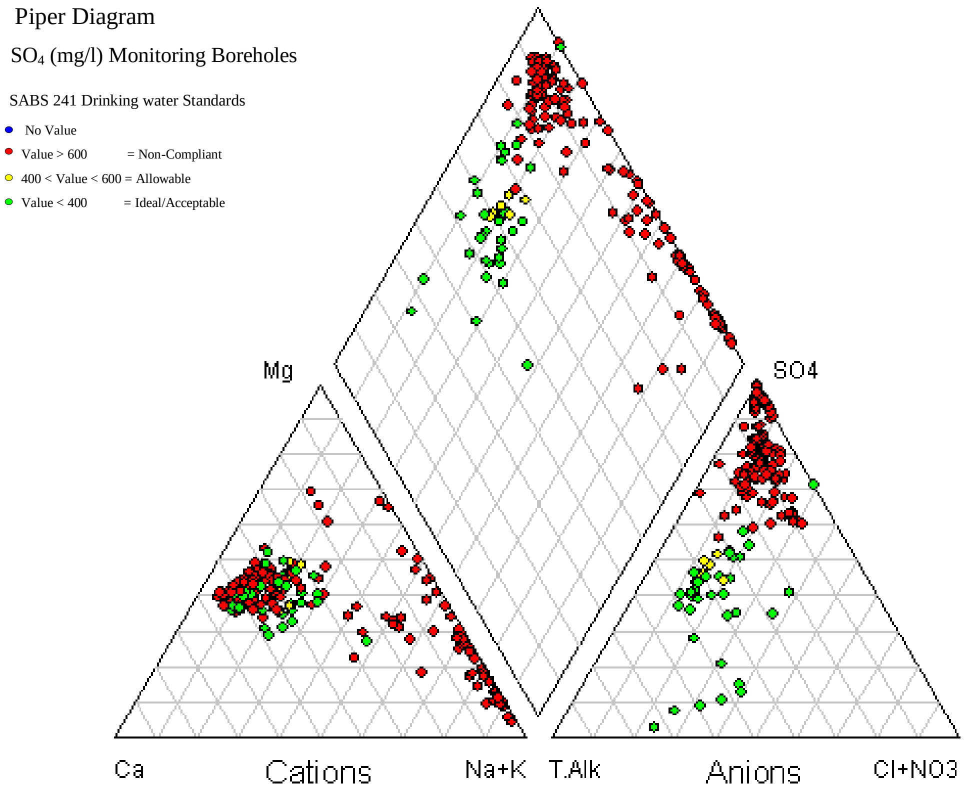


Figure 3.3.3(B): Piper diagram for all monitoring boreholes and SO_4 compliance.

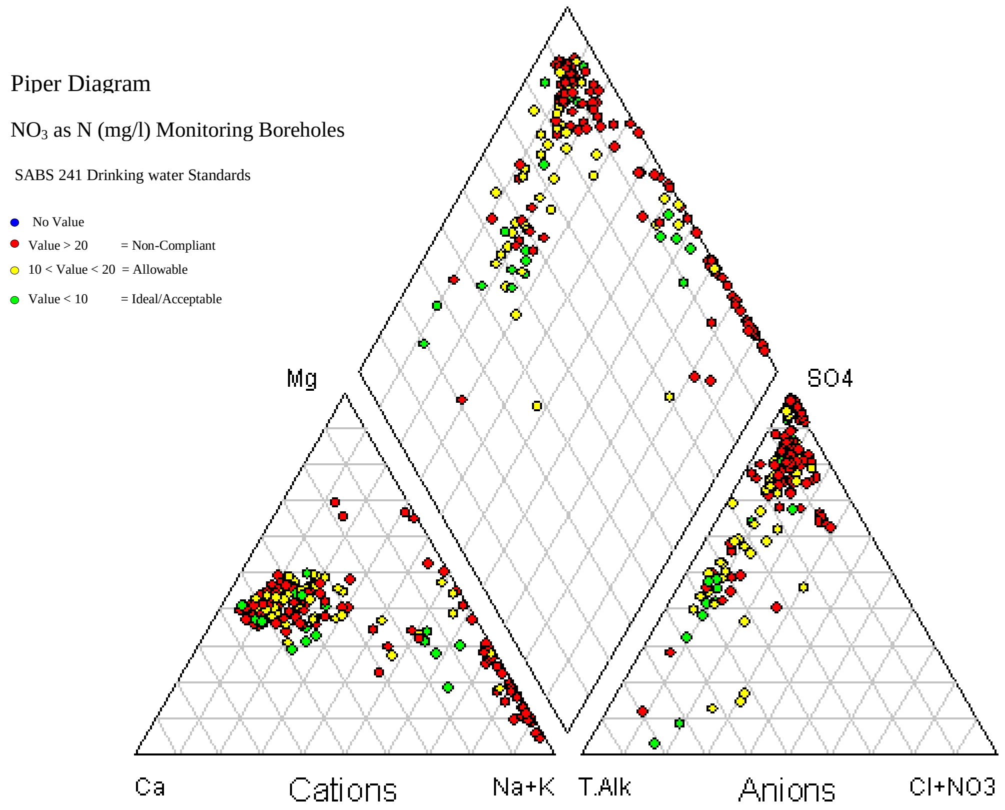


Figure 3.3.3(C): Piper diagram for all monitoring boreholes and NO_3 compliance.

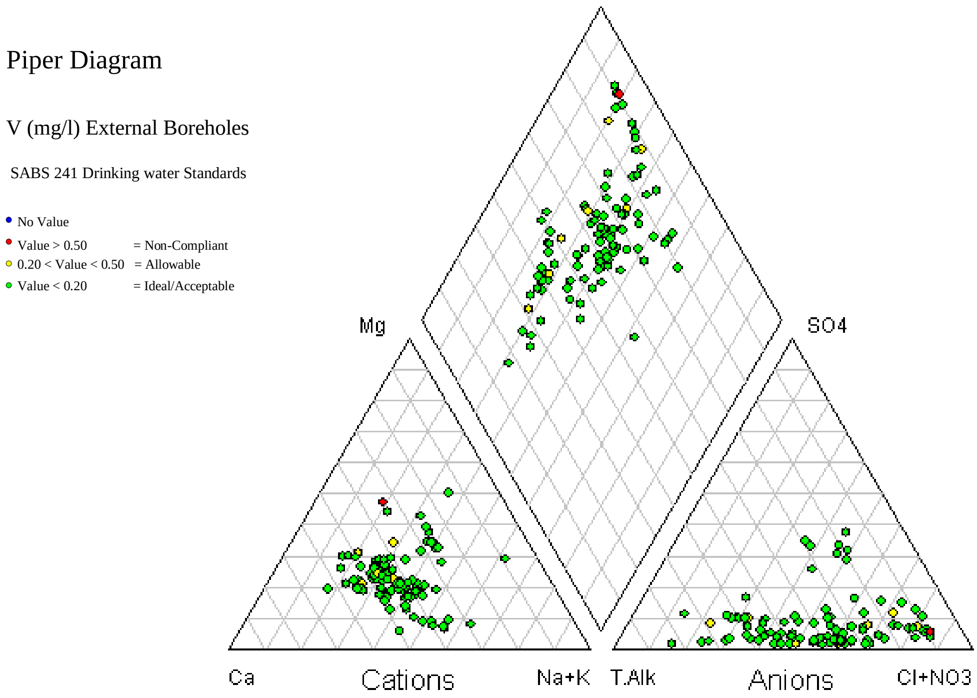


Figure 3.3.3(D): Piper diagram for all external user's boreholes and V compliance.

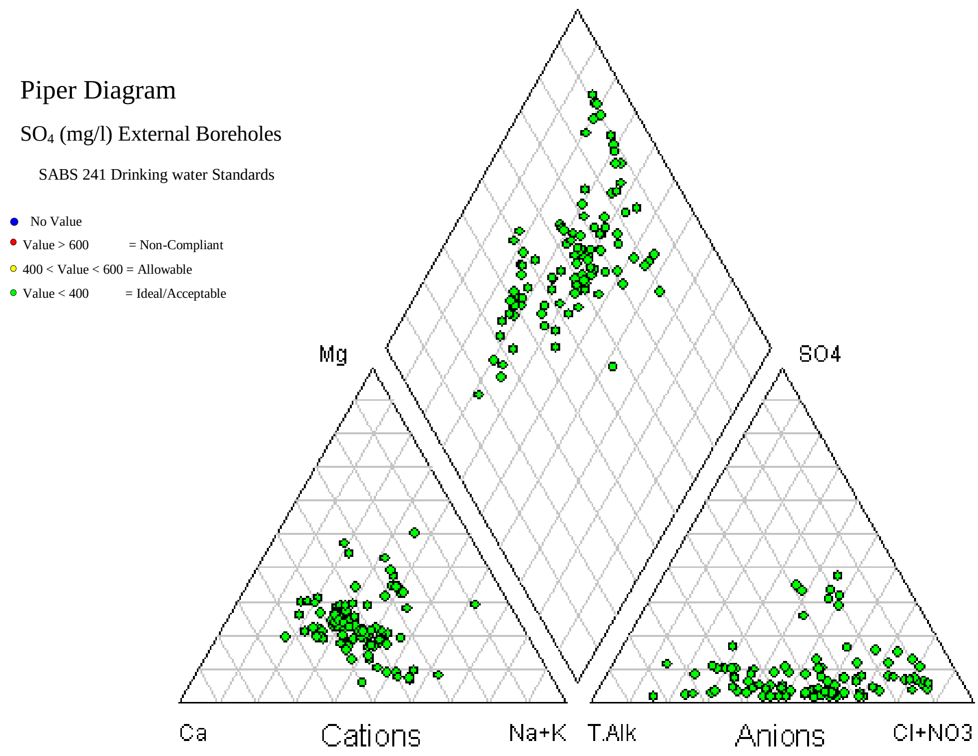


Figure 3.3.3(E): Piper diagram for all external user's boreholes and SO_4 compliance.

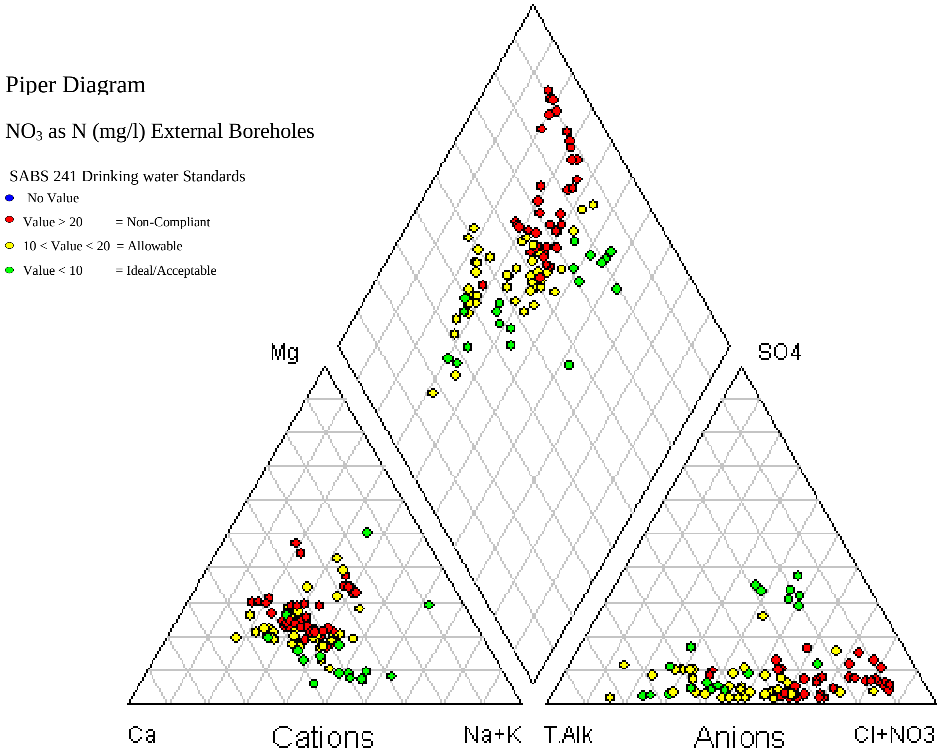


Figure 3.3.3(F): Piper diagram for all external user's boreholes and NO_3 compliance.

The following observations can be made from **Figures 3.3.3(A) to (F):**

- A major shift from the background as shown in **Figure 3.3.1(A)** towards SO_4 dominance can be seen in monitoring boreholes in **Figures 3.3.3(A) to (C).**

  Non-compliance for SO_4, NO_3 and V are also evident in monitoring boreholes.

- A major shift from the background as shown in **Figure 3.3.1(A)** towards NO_3 dominance can be seen in external user's boreholes in **Figures 3.3.1(D) to (F).** Non-compliance in NO_3 but compliance in SO_4 and V is evident in external user's boreholes.

3.3.4 <u>Multi-parameter profiles</u>

Multi-parameter profiling was performed after the drilling of boreholes GWW-15 to GWW-45 and SGM-B2 to SGM-B6. The resulting profiles are attached in **Dataset 3(A) – APPENDIX 3.0**. These profiles include:

- Temperature (ºC)
- Electrical Conductivity (mS/m)
- Dissolved Oxygen concentration (mg/l)
- pH (-log[H^+])
- Orp (Oxidation-reduction potential) (mV)

Interpretation of the profiles for the first few meters must take into account the presence of solid casing. The different parameters in each borehole compliment each other directly or indirectly and can be interpreted together.

- Generally the temperature of ground water in a geo-hydrological borehole is in the range of 16-24ºC. From the top of the water level to about 1 m - 5 m below it, most boreholes show generally a slight increase or decrease in temperature of 1ºC – 5ºC. Below this depth, the temperature nearly stays constant or may slightly decrease or increase down the borehole with a change of no more than 1ºC - 5°C.

- Generally a change below the solid casing is present with the EC lower or higher than in the casing. This change below the casing is due to the flow of ground water present in the underlying rocks which are of course absent in the solid casing. Further down the borehole dissolved solids is usually at a higher concentration especially in contaminated/polluted boreholes with a subsequent increase in EC.

- The dissolved oxygen is naturally higher at the top because of the contact with the atmosphere and depletes further down the borehole. Water in contact with the atmosphere will have a maximum oxygen concentration of about 8 mg/l.

- Overall the pH profiles do not vary much in depth in the different newly drilled boreholes and stay at near-neutral values in all boreholes. The biggest variation in pH is associated with the difference with pH conditions as the profile move below the solid casing. The pH stays neutral or near-neutral in all boreholes.

- It must be kept in mind that the determination of the oxidizing-reduction potential (Orp) cannot be measured very accurately by any field method and must be interpreted alike. All boreholes show mostly a very constant Orp-profile that stays often between narrow limits. Variations in the Orp-profile of boreholes should be interpreted as follows:

  - Profiles may show conditions deeper down the boreholes that are more reducing or becoming less oxidizing. The reason could be two-fold: 1) because of the contact with the atmosphere at the top of the borehole the oxygen content will be higher, which will result in more oxidizing conditions at the top and less oxidizing conditions deeper down where less oxygen occur and/or, 2) reduced flow through the deeper parts of the aquifer or through very impermeable layers may result in older, stagnant water.

  - Profiles may also show conditions deeper down the boreholes that are less reducing or more oxidizing. The reason is because of flow through the deeper parts of the aquifer that is higher than in the shallower parts of the aquifer. This could be the result of more permeable layers deeper down the aquifer and also the presence of water strikes or fracturing in deeper parts.

3.4 GROUND WATER USE

Bethanie, Berseba and Modikwe are respectively situated 1.6 km north-east, 4.6 km and 6 km north-west of the Xstrata Alloys Rhovan Mine and Plant Area. The position of the boreholes at Bethanie is given in **Figure 3(F)** and those at Modikwe and Berseba in **Figure 3(G).** Basic information of all external users' boreholes is given in **Table 3(B)** attached in **APPENDIX 3.0.**

The first hydro-census at Bethanie was performed in November 1999 by JMA. Since then a total of 9 sampling runs were performed on accessible boreholes at Bethanie of which the latest were in March 2005. From **Table 3(A)** it could be observed that a total of 21 boreholes exist at Bethanie of which 18 are in use, 2 are not in use and 1 borehole's status could not be established.

A hydro-census was performed by JMA in May 2005 at Modikwe and Berseba. Interviews have been conducted with tribal authorities (Mr. Solly Bele (Counselor) and Mr. More (Head of Modikwe)) of Modikwe village. The following information pertaining to demographic data of Modikwe, Berseba and Bethanie has been revealed:

- There are about 3000 houses in the three villages.
- It has been found that there are 400 houses in Berseba and 850 houses in Modikwe.
- All three villages collectively have approximately 18000 dwellers (based on Year 2001 census).
- Each house is estimated to have 4 to 6 occupants.

Number of boreholes found in the area is given below.

Village	**Private boreholes**	**Project boreholes (Agric. Irrigation schemes)**	**Community boreholes (Water supply)**	**Total boreholes**
Modikwe	12	3	4	19
Berseba	3	3	7	13
Total	**15**	**6**	**11**	**32**

From these boreholes 18 are in use, 12 are not in use and 2 boreholes are destroyed.

The community of Modikwe, Berseba and Bethanie mainly rely on bulk water supply from Magalies Water Board since 1997. Boreholes are now used as standby for periods of technical problems with the main water supply. However, private boreholes are still used for domestic purposes such as laundry, garden watering, etc.

Berseba and Modikwe share one reservoir located in Modikwe village whilst Bethanie has its own reservoir. Bulk water supply exists in the aforementioned villages. Water abstraction is from the Vaalkop Dam (see **Figure 3.4(A)** below), which is 30 to 40 km away from Modikwe.

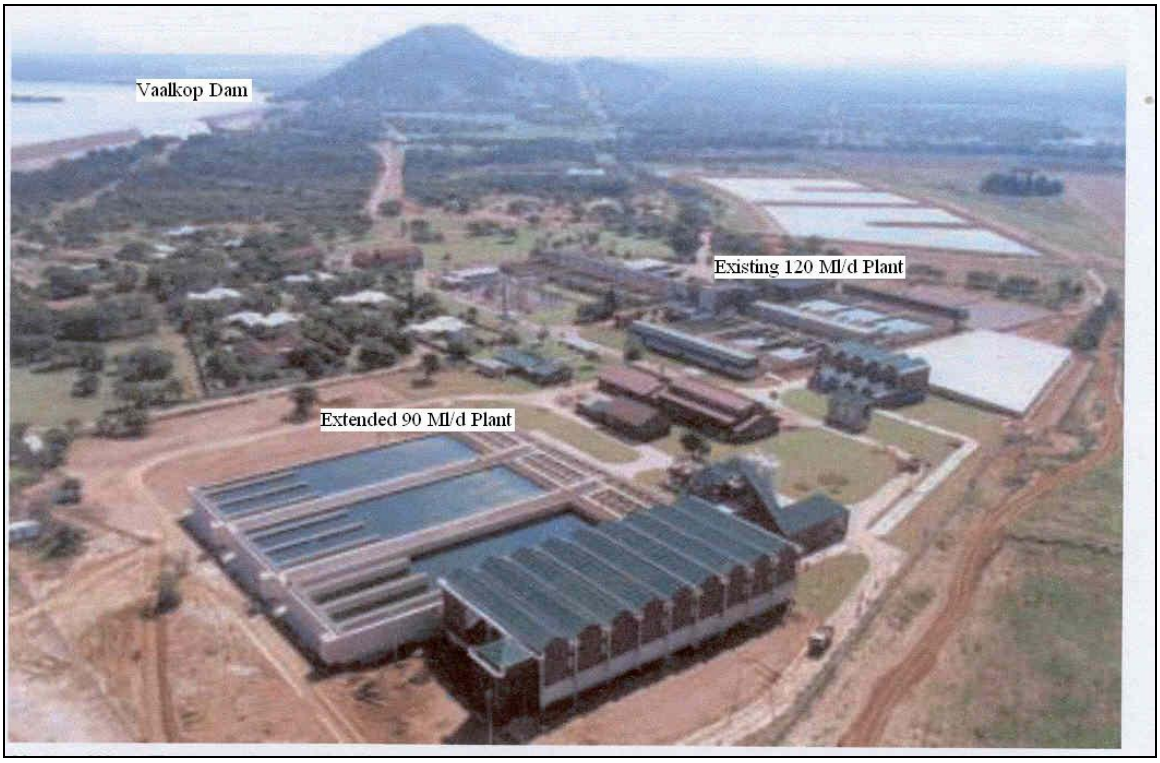


Figure 3.4(A): Vaalkop water treatment Plant: 90 Ml/d extension in the foreground with the existing 120 Ml/d Plant in the centre of the photograph.

Magalies Water offices are located at Mogwase location (near Rustenburg) some 10 km from Sun City. The Head Office of Magalies Water is situated in Rustenburg

3.5 AQUIFER DESCRIPTION

3.5.1 <u>Type of Aquifers</u>

The aquifer underlying the larger Xstrata Alloys Rhovan area exists of three different zones that are classified as aquifers in their own respect:

- Perched conditions in the soil horizon

  The top of the Rhovan aquifer consists of in-situ formed soils – alluvium is absent from the area. The shallow perched conditions are essentially restricted to clay lenses where present in the soil (soft overburden) horizon. The perched aquifer has unconfined conditions.

- The weathered zone aquifer and the deep fractured aquifer

  The host rock for these two aquifer types is mostly gabbro. The gabbro has a deep weathering profile that ranges from highly weathered below the soil horizons to slightly weathered. The fractured part of the gabbro coincides with the lower part of the slightly weathered profile and extents only for a few metres deeper. A few granite outcrops are present within the gabbro and granite is also present in the north. No boreholes are drilled within the granite but the granite will be less weathered than the gabbro and will mostly represent a fractured aquifer.

The weathered zone aquifer displays unconfined to semi-unconfined conditions, while the fractured aquifers (granite and deep fractured gabbro) predominantly display confined conditions.

Within the gabbro, several geological structures are present that will also influence ground water flow:

- Several post-Waterberg linear intrusives in the form of syenite and diabase dykes are present in the Mining Area. Pilanesberg ring dykes (syenite) and Karoo dolerite dykes also occur. The general strike direction is northwest-southeast as could be seen in **Figure 3.1.1(A)**. Widths range between 1.5 m and 30 m. The dykes are believed to be vertical or sub-vertical.

- The area is also faulted as indicated in **Figure 3.1.1(A)** and the layers are occasionally disrupted. The folding combined with the shallow dip of the sequence has caused significant changes in the orientation of the layers.

- Faulting, after emplacement of the complex, is indicated by faults which intersect it. One prominent southwest-northeast striking fault and two lesser, almost north-south striking faults, are present within the study area.

- The presence of the dykes and faults may also influence the borehole yielding capacity in some areas. Dykes may lead to zones of high permeability if they are weathered or low permeability if they are persistent to weathering. Borehole SGM-B3 was drilled into a syenite dyke and the weathering of the syenite dyke is shallower than that of the surrounding gabbro. However, the syenite show more fracturing below the weathered part (in comparison with the surrounding gabbro aquifer) and three water strikes were intersected. The water level in SGM-B3 and SGM-B4 is also shallower than the average regional water level most probably due to the accumulation of ground water against the less permeable dyke.

The mining pits at Rhovan area will serve as drains within the weathered aquifer and a cone of depression will be present around the pits with lowered water levels. Current water levels measured around the pit is not deeper than about 21 m. The ground water gradient around the mining pits is estimated at about 10% over about a 200 m radius.

Furthermore, waste dumps with high water saturation lead to leachate beneath them if no impermeable liner is present. This increased leachate towards the saturated zone will lead to a rise in the water table and a significant mound could form in the case where a high amount of leachate is present. It is evident that water levels are shallower around the Slimes Dam. No definite higher water table could be observed around the current Calcine Dump.

3.5.2 Lateral Extent of Aquifers

Two types of aquifer boundaries exist around the Rhovan area:

- Physical aquifer boundaries such as (semi-)impermeable dolerite dykes and sills, or other geological discontinuities, for example ground water divides identified in the area or granite rock outcrops in the north-west.

- Hydraulic aquifer boundaries such as water sheds (no-flow boundaries) and streams, the latter which could act as either ground water discharge or recharge boundaries.

A map indicating the major lateral aquifer boundaries for the Rhovan area is shown in **Figure 3.5.2(A)** below:

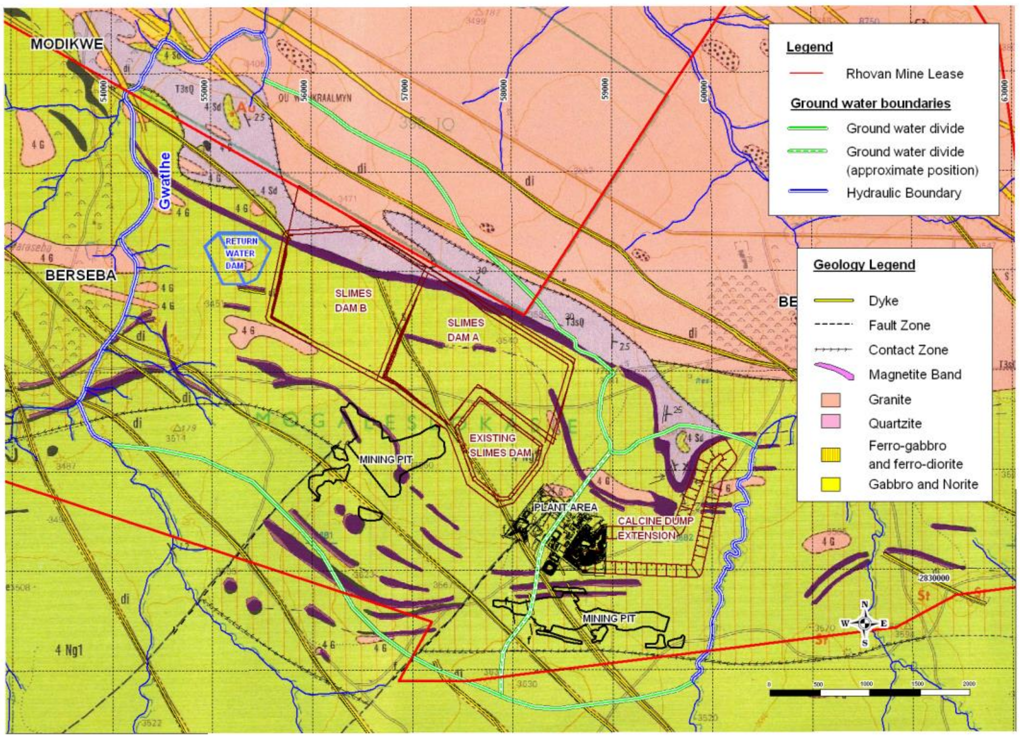


Figure 3.5.2(A): Geological aquifers and aquifer boundaries.

The following is important for delineating the Rhovan aquifer and understanding the ground water dynamic and hydraulic properties within the boundaries:

- The lateral extent of the perched aquifer zone is finite, varying as a function of the lateral extent of clay lenses in the soil. Although this zone undoubtedly exists in local areas at Rhovan, delineation of its lateral extent on a regional basis is part of the soil study performed at Xstrata Alloys Rhovan – see report Ref: XREMP/SSR/04/VER-01/2006.

- As discussed in **Section 3.5.1** above, ground water flow occurs within the weathered and fractured granite and gabbro aquifers. The ground water flow within aquifers will of course not continue infinitely in a certain direction and will be confined to boundaries due ground water's interaction with surface water, topography and geological features.

The natural boundaries of the Rhovan aquifers are:

1) Eastern side: the Tshukutswe River – recharge and/or discharge boundary.

2) Northern side: a ground water divide.

3) Western side: the Gwatlhe River – recharge and/or discharge boundary.

4) Southern side: a ground water divide.

- Within the larger aquifer boundaries as discussed above, the following ground water flow sub-boundaries exist within the larger Rhovan aquifer:

    1) Generally speaking, ground water flow within the aquifer is either to the west in the direction of the Gwatlhe River or towards the east in the direction of the Tshukutswe River. Therefore a groundwater divide exists that stretch from north to south almost parallel to these two rivers. According to the topographical contours, the approximate position of this ground water divide is shown in **Figure 3.5.2(A)** above with the divide going through the Plant Area.

    2) Dykes present within the aquifer boundaries may act as localized 1) no-flow boundaries or 2) preferential pathways depending on the degree of weathering of the dyke and fracturing associated with the intrusion. As discussed in **Section 3.5.1** above the syenite dykes are less permeable than the surrounding weathered gabbro aquifer. It is also evident at the Slimes Dam area that water levels are deeper on the west of the north-west/south-east stretching dyke than to the east of it.

    3) Faults in the area may have associated fractures with high permeability. The position of the faults in the area is shown in **Figure 3.5.2(A)** above. Contact zones (for instance between granite and gabbro) may also have fractures with higher permeability. No boreholes intersected faults or sub-vertical contact zones.

The lateral extent of the aquifer around Rhovan is important in order to set definable limits of any potential contaminant transport and lowering of water levels within the aquifer. The weathered and fractured aquifer zones are wherein contaminants derived from surface activities, e.g. from the Plant and the Calcine Dump, will migrate.

3.5.3 Thickness of Aquifers

Two aspects are relevant when discussing aquifer thickness:

- The thickness of the physical zone which forms the aquifer flow regime.

- The saturated thickness, which is a function of the degree of saturation within the physical zone.

From the data obtained during drilling of the geohydrological monitoring boreholes, the average thicknesses for the three different aquifer types as observed at Rhovan area is summarized in **Table 3.5.3(A)** below:

Table 3.5.3(A): Average thickness and saturated thickness of gabbro aquifer.

	Aquifer Type	Average Top (m)	Average Bottom (m)	Average Thickness (m)	Average Saturated Thickness (m)
Calcine Dump area (Water level = 12 m)	Shallow Perched	>0	<2.8	<2.8	Unknown
	Weathered gabbro	2.8	19	16	7
	Fractured gabbro	19	±36	±17	±17
Slimes Dam area (Water level = 13 m)	Shallow Perched	>0	<3.6	<3.6	Unknown
	Weathered gabbro	3.6	25	21	12
	Fractured gabbro	25	±31	±6	±6
Plant area (Water level = 15 m)	Shallow Perched	>0	<2.1	<2.1	Unknown
	Weathered gabbro	2.1	25	23	10
	Fractured gabbro	25	±46	±21	±21

The following comments could be made with regard to the aquifer thicknesses:

- The thickness of the saturated zone is calculated using the water table elevation as the top, the depth of weathering as the bottom of the weathered gabbro aquifer, and the contact between the gabbro and the magnetite gabbro as the bottom of the fractured aquifer.

- The bottom of the shallow perched aquifer is mostly present within the clayey Soil B horizon. The perched aquifer will mostly be saturated after times of high rainfall.

- The contact between the gabbro and the magnetite gabbro were taken as the bottom of the fractured aquifer. Although the fracturing was mostly logged shallower in the boreholes, some water make was observed in a few boreholes at this contact.

- Borehole SGM-B3 was drilled into a syenite dyke. The soil was 6 m deep, the weathering within the syenite was from 6 m to 12 m and the fracturing was logged from 12 m to 23 m. Below 23 m fresh syenite was present. The water table was at 6 m. It is evident that the granite and the syenite will be less weathered than the gabbro.

The depth to the water level in boreholes was discussed in detail in **Section 3.1.**

3.5.4 Porosity and Effective Porosity

Porosity of a rock is its property of containing pores or voids. The values proposed for aquifer porosity are based upon previous JMA experience on similar aquifers which were laboratory tested and/or verified through numerical models. The values below serve as a summary:

Lithological unit	Minimum	Maximum	Average
Gabbro (highly weathered)	0.08	0.20	**0.14**
Gabbro (slightly weathered)	0.005	0.08	**0.04**
Gabbro (fractured)	0.001	0.005	**0.002**

The large range in porosity for the gabbro aquifer is due to the degree of weathering. The total porosity includes all the voids within a rock, without indicating to what degree they are connected.

Aquifer effective porosity indicates the volume of water that can be released/the volume of connected pores that is present within an aquifer. Effective porosity is a crucial parameter to determine since it is used in ground water flow velocity and storativity calculations within the aquifer.

The effective porosity/aquifer storativity values chosen for the weathered and fractured aquifers area given below:

Lithological unit	Minimum	Maximum	Average
Gabbro (highly weathered)	0.04	0.10	**0.07**
Gabbro (slightly weathered)	0.0025	0.04	**0.02**
Gabbro (fractured)	0.0001	0.0005	**0.0002**

3.5.5 Hydraulic Conductivity

Hydraulic conductivity is the volume of water that can flow through a unit area of porous rock per unit time. The hydraulic conductivity was estimated by performing slug tests on all monitoring boreholes that was drilled at Rhovan.

Hydraulic conductivity values were calculated from the slug tests to determine the hydraulic conductivity distribution within the gabbro aquifer and all data for each area is shown in **Figures 3.5.5(A) to (D)** below.

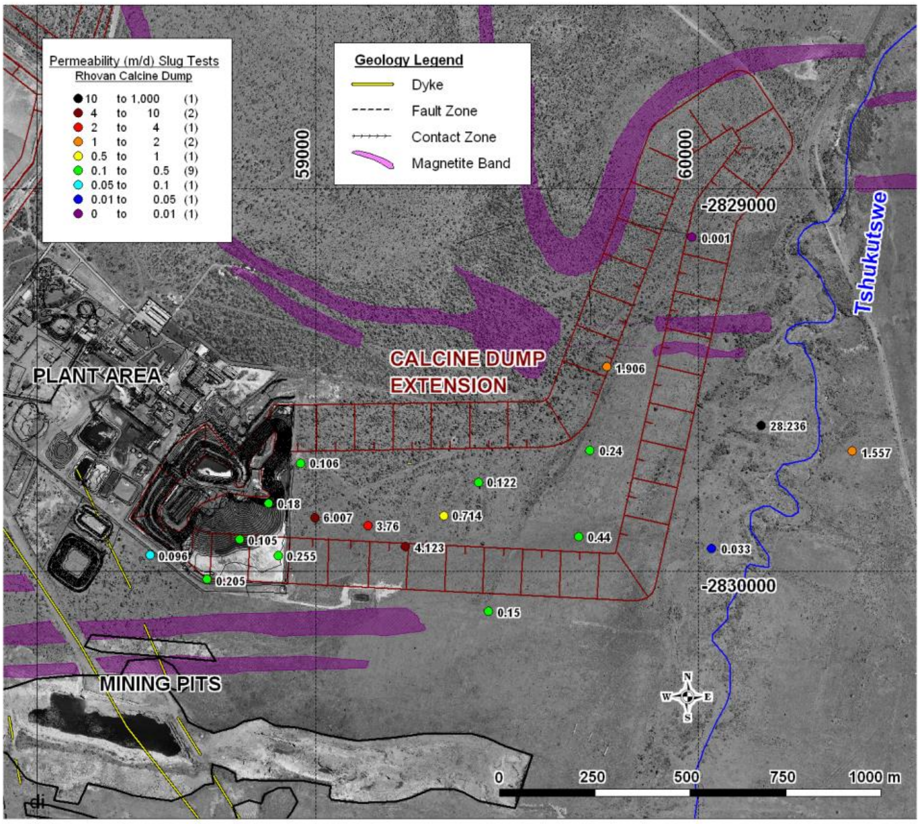


Figure 3.5.5(A): Permeability distribution at the Calcine Dump.

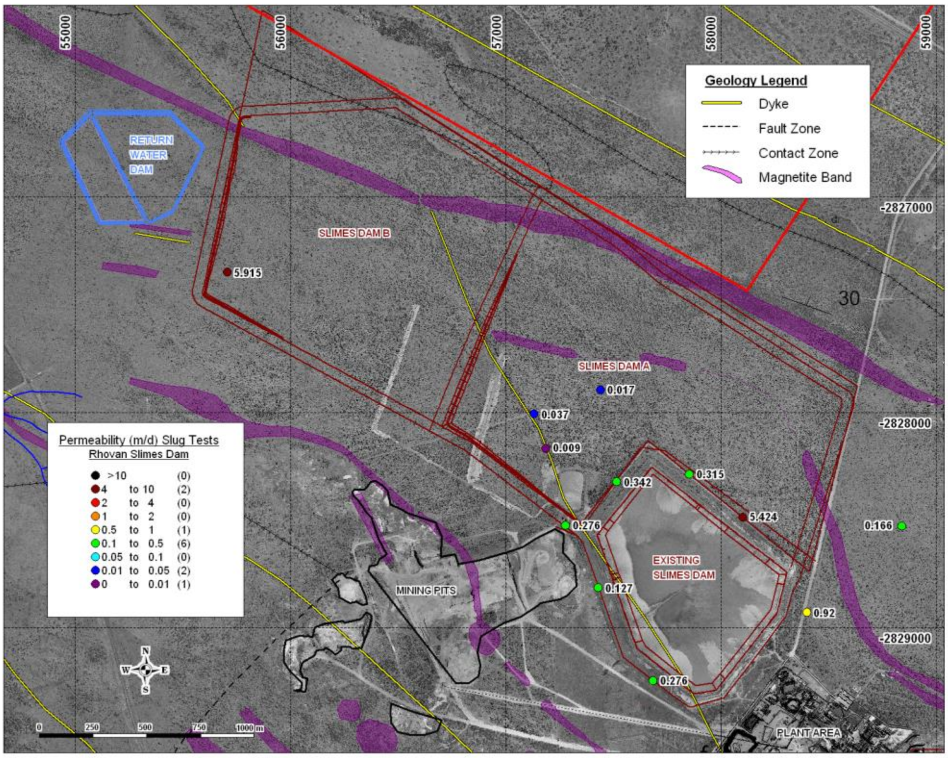


Figure 3.5.5(B): Permeability distribution at the Slimes Dam.

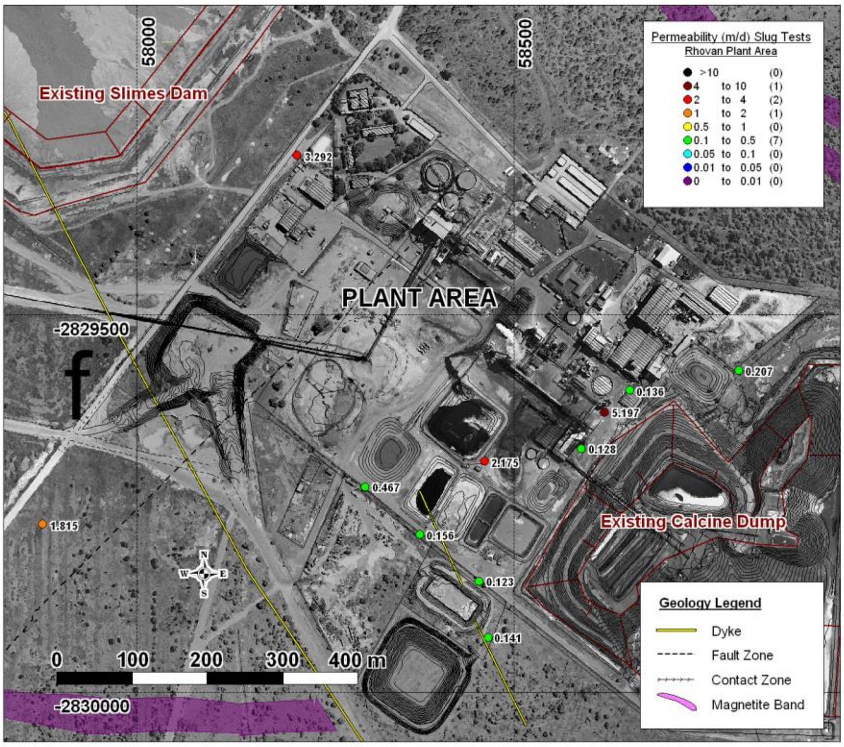


Figure 3.5.5(C): Permeability distribution at the Plant Area.

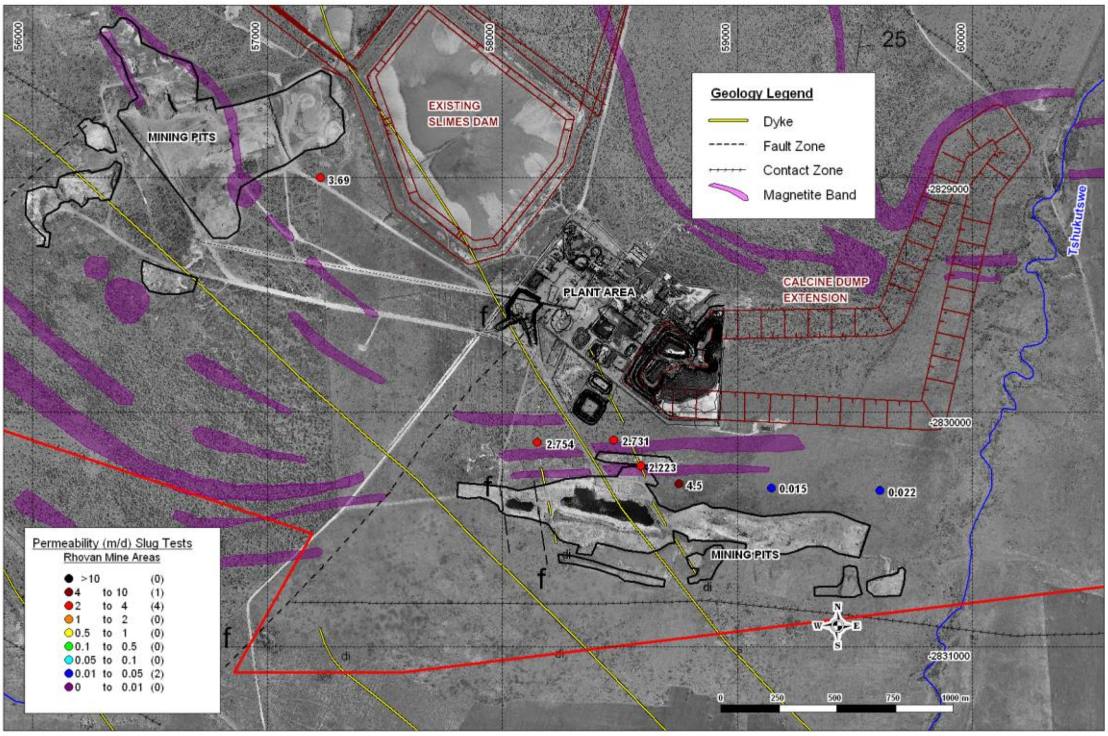


Figure 3.5.5(D): Permeability distribution at the Mine Area.

A statistical analysis of the data is given in **Table 3.5.5(A)** below:

Table 3.5.5 (A): Hydraulic conductivity statistical analyses.

Hydraulic conductivity (m/d)	Min	Max	Arithmetic Mean	Harmonic Mean	Geometric Mean
Calcine dump	0.001	28.236	2.539	0.017	0.359
Slimes dam	0.009	5.915	1.152	0.053	0.235
Plant areas	0.123	5.197	1.258	0.243	0.479
Mining areas	0.015	4.500	2.276	0.062	0.711

From **Figures 3.5.5(A) to (D)** and **Table 3.5.5(A)** the following observations could be made:

- The apparent extreme heterogeneity observed between the minimum and maximum conductivity values is because of the variation in weathering and fracturing.

- Overall the permeability within the gabbro aquifer is very high at Rhovan. It is at least an order of magnitude higher than the permeability observed in Karoo sedimentary rocks.

- The high permeability of the rocks can be attributed to the extensive weathering and fracturing of the gabbro.

It is a generally accepted approach to assume that the conductivity for the shallow weathered zone aquifer will be a value bounded by the harmonic mean and the geometric mean, although it will be nearer to the geometric mean. A statistical approach is therefore the only way in which to determine the permeability for a bulk aquifer zone that needs to be modelled. The average hydraulic conductivity chosen for the weathered gabbro aquifer is 0.4 m/d.

3.5.6 Ground Water Flow

The main mechanism for potential contaminant migration is convection, whilst the main aquifer zone through which contaminant migration and interaction with surface water resources will occur is the weathered zone aquifer. It is for these reasons that ground water flow through the weathered zone aquifer needs to be assessed.

The direction and velocity of ground water flow are governed *inter alia* by the ground water elevation distribution. In general it is a safe to assume that the ground water level elevation distribution within the shallow weathered zone aquifer will emulate the surface topography.

Subject to the above it can therefore be stated that ground water flow directions in areas not impacted by mining or Plant activities will be perpendicular to the surface topography contour lines - along the surface topographical gradient - form high ground towards the spruits and rivers.

A regional ground water flow direction map for the entire Xstrata Alloys Rhovan area's weathered zone aquifer is shown below in **Figure 3.5.6(A):**

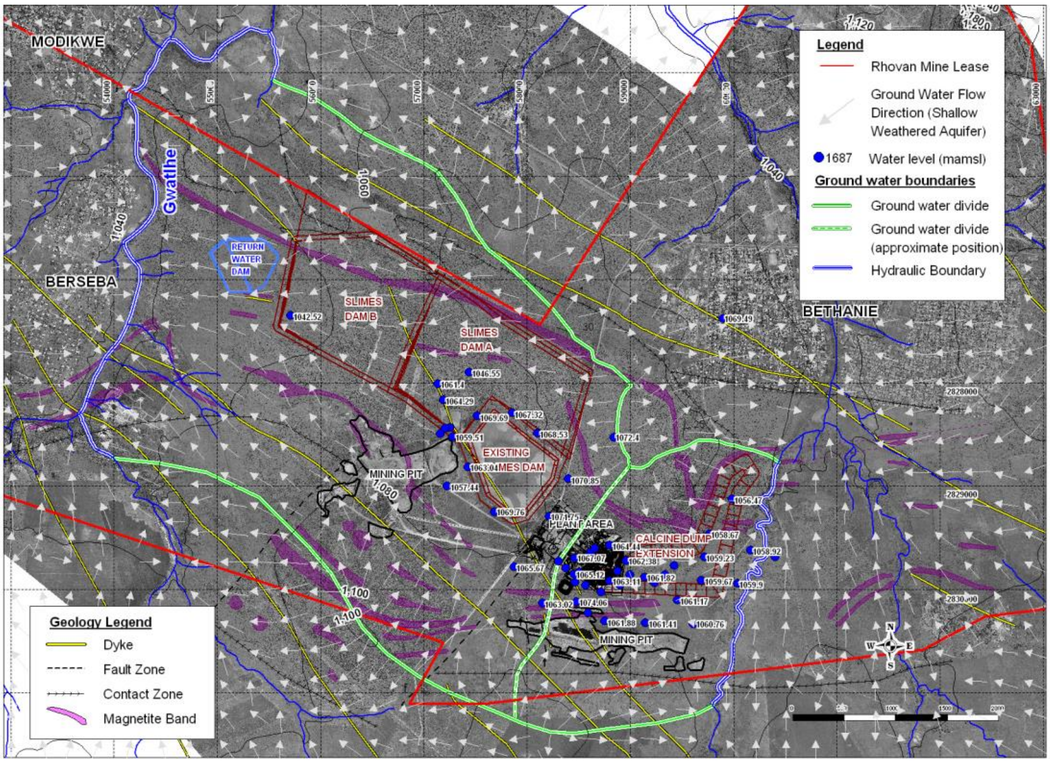


Figure 3.5.6(A): Ground water flow directions at Rhovan in the weathered zone aquifer.

From the above figure the following observations could be made:

- Locally the ground water directly around the mining pits will flow in the direction of the pits.

- Ground water flow will be away from the Slimes Dam and not towards it as water leaching towards the water table underneath this feature creates a ground water mound. This is also true for the Calcine Dump to a certain degree but the water levels below the Calcine Dump is not as shallow as those water levels measured around the Slimes Dam area. Please refer to **Section 3.1(A)** above for a discussion on the water level distribution. This may be due to the following: 1) less water may be leaching from the Calcine Dump and/or 2) the permeability is higher in the aquifer below the Calcine Dump and therefore does ground water not have the time to form a significant mound – the aquifer effectively drains the infiltration away.

- Ground water not influenced by mining and water leaching towards the aquifer from surface features (e.g. Slimes Dam and Calcine Dump) will flow perpendicular to topographical contours.

  Generally speaking, ground water flow within the aquifer is either to the west in the direction of the Gwatlhe River or towards the east in the direction of the Tshukutswe River. Therefore a groundwater divide must exist that stretch from north to south almost parallel to these two rivers. According to the topographical contours, the approximate position of this ground water divide is shown in **Figure 3.5.6(A)** above with the divide going through the Plant Area.

  Dykes present within the aquifer boundaries may act as localized 1) no-flow boundaries or 2) preferential pathways depending on the degree of weathering of the dyke and fracturing associated with the intrusion. As discussed in **Section 3.5.1** above the syenite dykes are less permeable than the surrounding weathered gabbro aquifer. It is also evident at the Slimes Dam area that water levels are deeper on the west of the north-west/south-east stretching dyke than on the east of it.

This map will be used as reference during the impact assessment **(Part 4)** to determine ground water flux boundaries and regional pollution migration routes.

3.5.7 Aquifer Classification

The shallow weathered zone aquifer underlying the Xstrata Alloys Rhovan study area was classified in accordance with ***"A South African Aquifer System Management Classification, December 1995."*** The special attributes of the aquifer related to structural features (such as fracturing along dyke/fault contact zones) have been incorporated into the classification through the "Second Variable Classification".

Classification has been done in accordance with the following definitions for Aquifer System Management Classes:

Sole Aquifer System:

An aquifer which is used to supply 50 per cent or more of domestic water for a given area, and for which there is no reasonably available alternative sources should the aquifer be impacted upon or depleted. Aquifer yields and natural water quality are immaterial.

Major Aquifer System:

Highly permeable formations, usually with a known or probable presence of significant fracturing. They may be highly productive and able to support large abstractions for public supply and other purposes. Water quality is generally very good (less than 150 *mS/m* Electrical Conductivity).

Minor Aquifer System:

These can be fractured or potentially fractured rocks which do not have a high primary permeability, or other formations of variable permeability. Aquifer extent may be limited and water quality variable. Although these aquifers seldom produce large quantities of water, they are important for local supplies and in supplying base flow for rivers.

Non-Aquifer System:

These are formations with negligible permeability that are regarded as not containing ground water in exploitable quantities. Water quality may also be such that it renders the aquifer unusable. However, ground water flow through such rocks, although imperceptible, does take place, and needs to be considered when assessing the risk associated with persistent pollutants.

Ratings for the Aquifer System Management and Second Variable Classifications:

Aquifer System Management Classification		
Class	**Points**	**Xstrata Rhovan Aquifers**
Sole Source Aquifer System:	6	-
Major Aquifer System:	4	-
Minor Aquifer System:	2	2
Non-Aquifer System:	0	-
Special Aquifer System:	0 - 6	-
Second Variable Classification - Weathering/Fracturing Along Contacts		
Class	**Points**	**Xstrata Rhovan Aquifers**
High:	3	-
Medium:	2	-
Low:	1	1
Note: Due to the local geology (potential preferential flow zones along dykes/faults), the second variable classification becomes relevant.		

Ratings for the Ground Water Quality Management Classification System:

Aquifer System Management Classification		
Class	**Points**	**Xstrata Rhovan Aquifers**
Sole Source Aquifer System: Major Aquifer System: Minor Aquifer System: Non-Aquifer System: Special Aquifer System:	6 4 2 0 0 - 6	- - 2 - -
Aquifer Vulnerability Classification		
Class	**Points**	**Xstrata Rhovan Aquifers**
High: Medium: Low:	3 2 1	- 2 -

The shallow weathered zone aquifers present at Xstrata Alloys Rhovan may, in terms of the above definitions, be classified as a **minor aquifer system**.

Level of ground water protection based on the Ground Water Quality Management Classification:

GQM Index = Aquifer System Management x Aquifer Vulnerability

GQM Index	Level of Protection	Xstrata Rhovan Aquifers
<1 1 - 3 3 - 6 6 - 10 >10	Limited Low Level Medium Level High Level Strictly Non-Degradation	- - 4 - -

Aquifer Vulnerability

The vulnerability, or the tendency or likelihood for contamination to reach a specified position in the groundwater system after introduction at some location above the uppermost aquifer, in terms of the above, is classified as **medium**.

Aquifer Susceptibility

Aquifer susceptibility, a qualitative measure of the relative ease with which a groundwater body can be potentially contaminated by anthropogenic activities and which includes both aquifer vulnerability and the relative importance of the aquifer in terms of its classification, in terms of the above, is classified as **medium**.

Aquifer Protection Classification

The ratings for the Aquifer System Management Classification and Aquifer Vulnerability Classification yield a Ground Water Quality Management Index of 4 for the Xstrata Alloys Rhovan Aquifers, indicating that **medium** level ground water protection may be required.

In terms of DWAF's overarching water quality management objectives which is ***(1)*** protection of human health and ***(2)*** the protection of the environment, the significance of this aquifer classification is that if any potential risk exist, measures must be triggered to limit the risk to the environment, which in this case is the protection of the Primary Underlying Aquifer and the External Users of ground water in the area.

4. IMPACT ASSESSMENT

4.1 IMPACT REGISTER

Two types of activities exist at Xstrata Rhovan that may potentially impact on the ground water environment, namely mining activities (Open Pits) and waste/effluent/water disposal/storage activities (Slimes Dams, Slimes Return Water Dams, Calcine Dump, Calcine Return Water Dam, Purge Dams, Scrubber Ponds, Storm Water Dams, etc.).

The Mining Pits

Mining at Xstrata Rhovan consists of historical talus mining and current open pit mining. The talus mining was not deeper than 2 m and current pit mining have a maximum depth of about 60 m. Five mining pits are present: Pit 1, 2, 4, 5 and 6; their current and future expanded positions are shown in **Figure 4.1(A)** below:

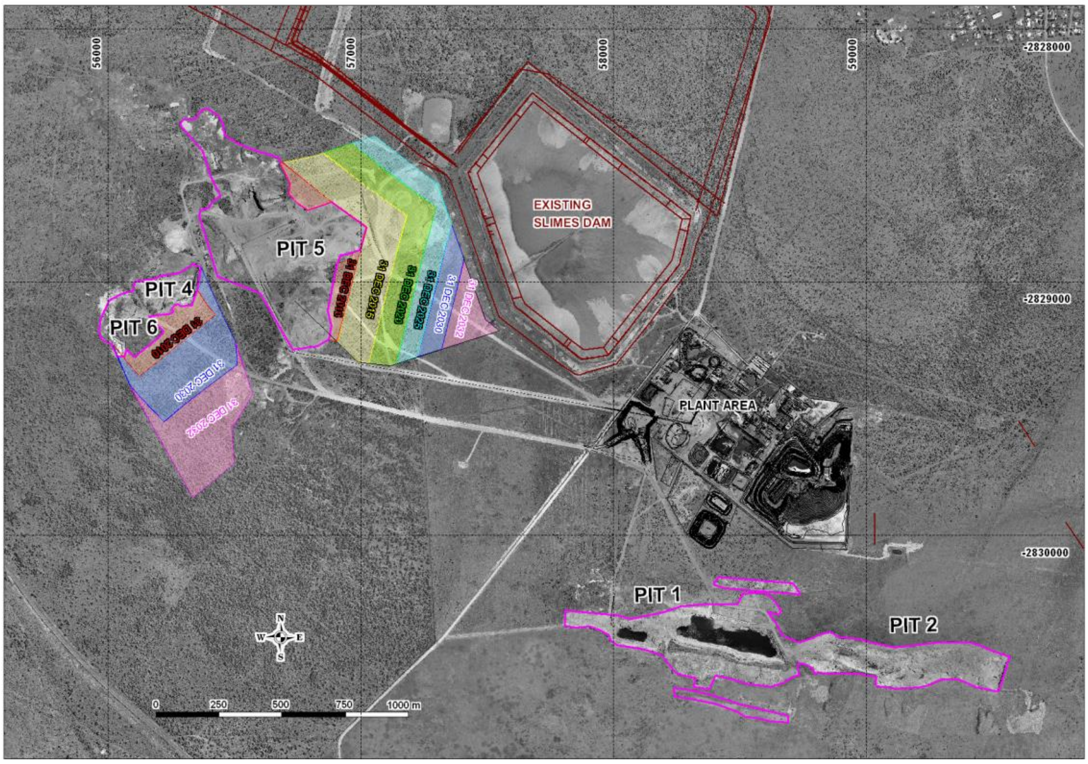


Figure 4.1(A): Location of current and future mining at Xstrata Alloys Rhovan.

Waste/Effluent/Water Dumps and Dams

Waste/Effluent/Water Dumps and Dams are present in or adjacent to the Plant Area. The positions of the above features are shown in **Figures 4.1(B) and (C)** below.

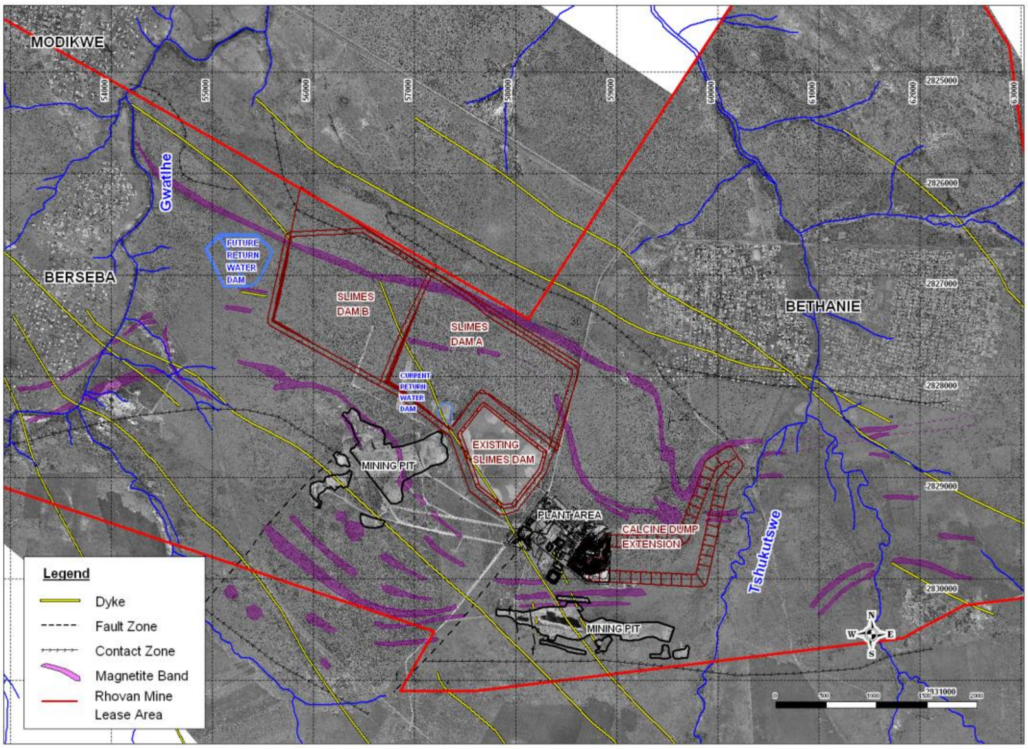


Figure 4.1(B): Position of the Slimes Dam, the Calcine Dump and the Plant Area at Xstrata Alloys Rhovan.

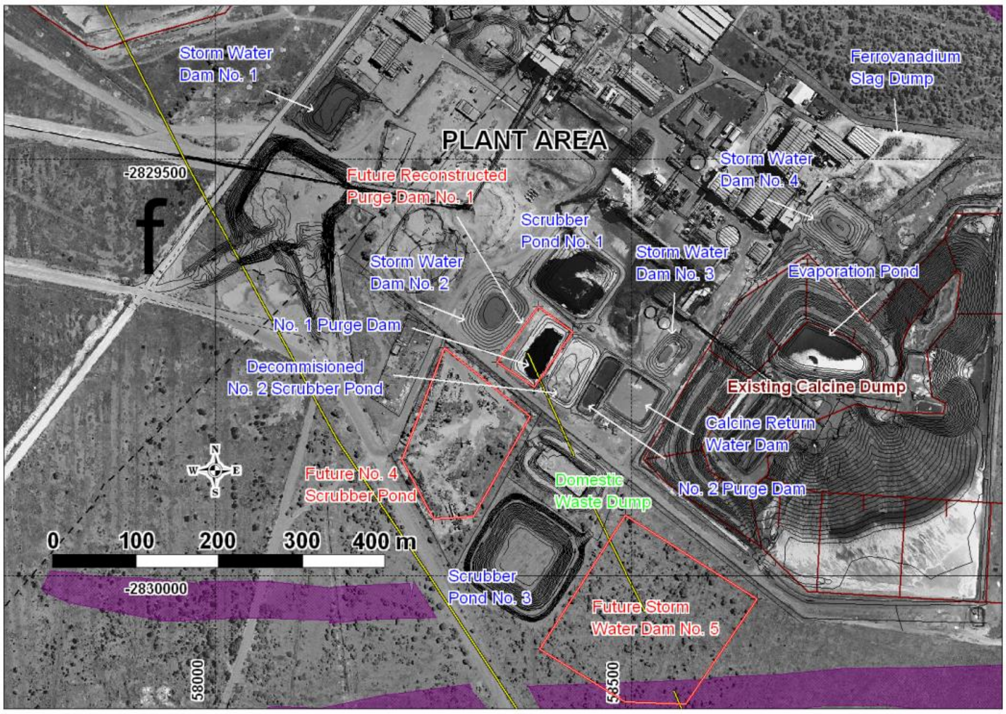


Figure 4.1(C): Position of Waste Dumps/ Effluent Ponds and Water Dams at the Xstrata Alloys Rhovan plant area.

Samples were taken in March 2005 of the liquid components of the Waste Dumps, Effluent Ponds and Water Dams. Acid Rain Leaching (ARLP) tests were also performed on all solid waste. All analyses and results are discussed in the Xstrata Alloys Rhovan Source Characterization report – Ref: XREMP/SSR/01/VER-01/2006.

Analyses have shown that the liquid component of the Slimes Dam, the Slimes Return Water Dam (RWD) and the Clean Storm Water Dam No. 1, are compliant in terms of the SABS 241 Drinking Water Standard and the Acceptable Environmental Risk (of the DWAF Minimum Requirements).

The Calcine Dump, the Calcine Return Water Dam (RWD), the Dirty Storm Water Dams (SWDs), the Purge Dams and the Scrubber Ponds all have liquid components that are non-compliant with respect to the same standards. Structures with non-compliant liquid components may potentially impact on the underlying ground water environment.

The Ferrovanadium Slag was the only waste product that did not have a liquid component that could be sampled. The ARLP performed on the slag however show that some components are also non-compliant in terms of the SABS 241 Drinking Water Standard and the Acceptable Environmental Risk of the DWAF Minimum Requirements. The results are discussed in the Xstrata Rhovan Source Characterization report – Ref: XREMP/SSR/01/VER-01/2006.

All Waste Dumps, Effluent Dams and Water Dams are operational except for Scrubber Pond No. 1 and 2. Scrubber Pond No. 1 was decommissioned in September 2005 and the footprint will be rehabilitated and concrete lined. The new additional Kiln will be constructed over the footprint. The Scrubber Pond No. 2 is already demolished and the footprint must still be rehabilitated.

4.2 DESCRIPTION OF IMPACT MECHANISM

The impacts on the ground water are both quantity and quality related.

The impact on the ground water quantity comprises the influx of ground water into the mining pits (water lost from the aquifer) and the flux of contaminated/non-contaminated leachate from Slimes Dams, Tailings Dumps, Effluent Ponds and Water Dams towards the underlying ground water environment (water added to the aquifer).

The impact on the ground water quality comprises of the influx of contaminated leachate from Slimes Dams, Tailings Dumps, Effluent Ponds and Water Dams towards the underlying unsaturated and saturated aquifer, and the influx of ground water into mining pits and the resultant potential contamination thereof with or by mining disturbed material.

<u>The Mining Pits</u>

The mining operations for the following 25 to 30 years will consist of the expansion of some operational pits. The operational pits will be kept dry during the operational phase and a resultant ground water gradient is created between the surrounding ground water aquifer and the mining pit floor. Ground water will therefore flow into the mine and the rate of influx will be a function of the gradient towards the mine, the hydraulic conductivity of the weathered gabbro and the influx area between the aquifer and the mining pits. Inflowing ground water will result in a cone of depression around the pit. Additionally, defunct pits will continue to residually impact on the surrounding ground water aquifer in much the same manner. The mining pits therefore create an effective mechanism for impacting on the ground water ***quantity***.

The inflowing ground water will also be in contact with mined material and may resultantly have an increased salt and suspended solids load. However, the mining have a low impact on the ground water ***quality*** because of the absence of reactive minerals in the geology.

Quantification of the mining impact will be discussed in the following **Sections 4.3**, **4.4** and **4.5**.

<u>Slimes Dams, Tailings Dumps, Effluent Ponds and Water Dams</u>

Potential leachate from these facilities, if they are unlined, will percolate through the underlying unsaturated zone towards the saturated aquifer. These facilities have therefore an effective potential mechanism of impacting on the ***quantity*** (water added to the aquifer) and ***quality*** of the underlying ground water aquifer.

Appropriate lining systems can effectively mitigate the impact of some of these facilities. The Calcine Tailings Dump and some of the Effluent Ponds are classified as Hazardous Waste Sites and the appropriate mitigation measures are therefore critical.

Quantification of these impacts will be discussed in the following **Sections 4.3**, **4.4** and **4.5**.

4.3 CURRENT SITUATION IMPACT ASSESSMENT

4.3.1 Current impact on ground water quantity

4.3.1.1 Current impact of Mining Pits on ground water quantity

At Xstrata Alloys Rhovan a total of 5 mining pits is currently present that extend over an area of some 100 ha (including talus mining and haul roads). The calculated ground water inflow into the existing pits is given in **Table 4.3.1.1(A)** below:

Table 4.3.1.1(A): Mining area and calculated ground water inflow.

Mining Pit	Total Ground Water Influx (m^3/a)	Total Ground Water Influx (m^3/d)
Pit 1	28 744	78.75
Pit 2	19 710	54.00
Pit 4	6 023	16.50
Pit 5	32 850	90.00
Pit 6	9 034	24.75
Total	**96 361**	**264.00**

Because of the small volumes of current ground water influx, the impact on the water quantity at Rhovan is small. A cone of depression does not extend more than 250 m from the mine. The depth to water level in the boreholes surrounding the mining area ranges between 10.62 m to 20.82 m, averaging at 17.94 m. The average depth to the ground water level is between 12 m and 15 m and it is therefore evident that mining activities are not depleting the ground water storage on a large scale.

The impact summary is given below:

IMPACT SUMMARY	**Current impact of Mining Pits on the Ground Water Quantity**	
Summary	**Rating**	**Comment**
Extent or Spatial Scale of Impact	LOW	Within Site Boundary.
Intensity	LOW	Cone of depression of <250 m around pits. Flux volume very small.
Duration	LONG-TERM	Excavated pit will remain ground water sink.
Mitigatory Potential	NONE	Void created will take very long time to fill at calculated influx rate.
Acceptability	ACCEPTABLE	No risk to public health or to any sensitive environment.

IMPACT SUMMARY	Current impact of Mining Pits on the Ground Water Quantity	
Summary	**Rating**	**Comment**
Degree of Certainty	DEFINITE	Mining must proceed in order to supply magnetite to Plant. Ground water inflow into the operational pit is a given.
Status of Impact	NEGATIVE	Water level lowered around pit and ground water removed from storage.
Significance Rating without Mitigation	LOW	Impact will have small effect on surrounding ground water environment.
Significance Rating with Mitigation	LOW	Although no mitigation possible, impact will still have a small effect on surrounding ground water environment.
Legal Requirements	REQUIRED	Water Use License.

4.3.1.2 Current quantity of leachate created by Slimes Dams, Tailings Dumps, Effluent Ponds and Water Dams

The quantity of leachate seeping through the facility footprints or lining systems, depends on the construction and type of footprint base or lining. Given the heterogeneity of the sources in terms of quality and quantity, the exact volumes and quantity per source is difficult to predict, although the total flux is estimated as 320 – 380 m^3/day for the Slimes Dam and associated infrastructure. However, when one takes the overall water balance into account, the Slimes Dam and Slimes Dam Return Water Dam has a very small impact.

The impact on the quantity of the ground water is therefore estimated as low for the Slimes Dam, the Slimes Return Water Dam (RWD) and the Clean Storm Water Dam No. 1 (SWD No. 1) mainly because leachate from these features is non-contaminated.

The impact summary is given below:

IMPACT SUMMARY	Current impact of the Slimes Dam, Slimes RWD and Clean SWD No. 1 on the Ground Water Quantity	
Summary	**Rating**	**Comment**
Extent or Spatial Scale of Impact	LOW	Within Site Boundary.
Intensity	LOW	Clean water added to aquifer.
Duration	MEDIUM TERM	Lifespan of facility.

IMPACT SUMMARY	**Current impact of the Slimes Dam, Slimes RWD and Clean SWD No. 1 on the Ground Water Quantity**	
Summary	**Rating**	**Comment**
Mitigatory Potential	HIGH	High potential to mitigate negative impact.
Acceptability	ACCEPTABLE	No risk to public health or to any sensitive environment.
Degree of Certainty	DEFINITE	For unlined facilities, leaching is taking place to underlying aquifer.
Status of Impact	NEUTRAL	No positive or negative results of impact.
Significance Rating without Mitigation	LOW	Impact will have small effect on surrounding ground water environment.
Significance Rating with Mitigation	LOW	Although mitigation measures such as leachate capturing and monitoring are in place, the impact will still have a small effect on surrounding ground water environment.
Legal Requirements	REQUIRED	Water Use License.

For the Calcine Tailings Dump, Scrubber Ponds and some of the Water Dams, the impact could be potentially high because the quantity of contaminated leachate introduced into the existing aquifer could be substantive. These include the FeV Slag Dump, the Calcine Tailings Dump, the Calcine Return Water Dam (RWD), the Dirty Storm Water Dams (SWDs), the Purge Dams and the Scrubber Ponds. Given the inefficiencies of some of the previous liner designs (limited compaction, bentonite liners cracking, etc), it was calculated that an average volume of 240m^3/day is leaching to the underlying aquifers. Given the heterogeneity of the sources in terms of quality and quantity, the exact volumes and quantity per source is difficult to quantify. However, when one takes the overall water balance into account, these facilities has a small impact in terms of ground water quantities.

More details on the mitigation measures for all these facilities are given in **PART 7** of this document. The impact summary is given below:

IMPACT SUMMARY	**Current impact of the FeV Slag Dump, the Calcine Tailings Dump, the Calcine RWD, the Dirty SWDs, the Purge Dams and the Scrubber Ponds on the Ground Water Quantity**	
Summary	**Rating**	**Comment**
Extent or Spatial Scale of Impact	MEDIUM	Impact will extend beyond local area of impact but still within site boundary.

IMPACT SUMMARY	**Current impact of the FeV Slag Dump, the Calcine Tailings Dump, the Calcine RWD, the Dirty SWDs, the Purge Dams and the Scrubber Ponds on the Ground Water Quantity**	
Summary	**Rating**	**Comment**
Intensity	HIGH	Contaminated leachate added to aquifer from Waste Sites – although small in terms of ground water quantities.
Duration	MEDIUM TERM	Lifespan of facilities. Remediation of current impact must be completed within lifespan of project.
Mitigatory Potential	HIGH	High potential to mitigate future negative impact. Current residue/plume must be remediated.
Acceptability	UNACCEPTABLE	Redesign dumps/lagoons/dams in order to remove ongoing impact.
Degree of Certainty	DEFINITE	Leaching is taking place to underlying aquifer.
Status of Impact	NEGATIVE	The impact is negative from a quality perspective and not a quantity perspective.
Significance Rating without Mitigation	HIGH	Impact has a negative effect on surrounding ground water environment.
Significance Rating with Mitigation	MODERATE	Although current mitigation measures such as leachate detection and monitoring is present, the impact will still have a negative effect on surrounding ground water environment. As soon as ground water abstraction is implemented as a mitigation measure, the overall impact will improve to Moderate.
Legal Requirements	REQUIRED	Lining beneath extensions of waste sites and leachate capturing according to DWAF Minimum Requirements. Remediation according to Section 19 of the National Water Act. Water Use License.

4.3.1.3 Current impact on ground water user's resource quantity

Bethanie, Berseba and Modikwe are respectively situated 1.6 km north-east, 4.6 km and 6 km north-west of the Rhovan Plant Area. These communities mainly rely on bulk water supply from Magalies Water Board since 1997. Boreholes are now used as standby for periods of technical problems with the main water supply. However, private boreholes are still used for domestic purposes such as laundry, garden watering etc.

Except for the external users' boreholes at Bethanie, Berseba and Modikwe, one borehole, GWE-6, is situated 2 km south of the Rhovan Plant Area.

Basic information of all external users' boreholes is given in **Table 3(B)** attached in **APPENDIX 3.**

There is currently no external users of ground water around Xstrata Alloys Rhovan within a 1 km radius. Because of the relative small scale of mining and because of the small volumes of current ground water influx, the impact on the ground water quantity at Rhovan is small. A cone of depression does not extend more than 250 m from the mine. The depth to water level in the boreholes at the mining area ranges between 10.62 m to 20.82 m, averaging at 17.94 m. The average depth to the ground water level is between 12 m and 15 m and it is therefore evident that mining activities are not depleting the ground water level on a large scale. The impact summary is given below:

IMPACT SUMMARY	**Current impact of Xstrata Rhovan mining activities on the quantity of ground water available to external user's**	
Summary	**Rating**	**Comment**
Extent or Spatial Scale of Impact	LOW	Impact small and within site boundary.
Intensity	LOW	Cone of depression <250 m from mine.
Duration	MEDIUM	Lifespan of project.
Mitigatory Potential	LOW	No mitigation measures applicable.
Acceptability	ACCEPTABLE	No risk to public health or to any sensitive environment.
Degree of Certainty	DEFINITE	It is definite that the cone of depression will not affect external ground water use.
Status of Impact	NEUTRAL	Impact currently doesn't have any positive or negative effects.
Significance Rating without Mitigation	LOW	Impact on ground water quantity in the site boundary is small.
Significance Rating with Mitigation	LOW	No mitigation measures applicable.
Legal Requirements	NO	None required.

4.3.1.4 Current impact on ground water quantity towards surface water features

No wetlands or pans exist in the area that is dependant on ground water flow. Because of the relative small scale of mining and because of the distance to the rivers, mining have no impact on the baseflow of ground water towards the rivers. Pit 4, 5 and 6 is situated more than 2 km east of the Gwathle River and Pit 1 and 2 more than 400 m west of the Tshukutswe River. The impact summary is given below:

IMPACT SUMMARY	**Current impact of Xstrata Rhovan on river baseflow**	
Summary	**Rating**	**Comment**
Extent or Spatial Scale of Impact	INSIGNIFICANT	Within Site Boundary.
Intensity	INSIGNIFICANT	No current impact is detected.
Duration	LONG TERM	Beyond lifespan of project.
Mitigatory Potential	NONE	-
Acceptability	ACCEPTABLE	No risk to public health or to any sensitive environment.
Degree of Certainty	DEFINITE	No current impact is detected.
Status of Impact	NEUTRAL	No positive or negative results of impact.
Significance Rating without Mitigation.	INSIGNIFICANT	No impact is identified.
Significance Rating with Mitigation.	INSIGNIFICANT	No mitigation measures applicable.
Legal Requirements	NOT APPLICABLE	None.

4.3.2 Current impact on ground water quality

4.3.2.1 Current impact of Mining Pits on ground water quality

Ground water flow is taking place towards the mining pit and not from it. It is therefore not possible that any significant volume of mine water is currently introduced into the ground water environment.

It is important to note that contaminated ground water from the Plant plume is flowing into Pit 1 and Pit 2 which result in a poor quality of water in these pits.

The mining itself, would as a worst case, slightly increase the Total Dissolved Solids of the water in the mine but the mine water quality would not be non-compliant with respect to the SABS 241 Drinking Water Standard, or the Environmental Risk Limit from the DWAF Minimum Requirements. The reason for an insignificant impact of mining on the water quality is because of the absence of reactive minerals in the mining horizons. To prove the absence of any significant impact of mining, a water sample was taken from Pit 5 and sent for analyses – the results are shown in **Table 4.3.2.1(A)** below:

Table 4.3.2.1(A): Chemical analyses of mine water of Pit 5 (March 05).

Parameter	Pit 5	SABS 241 Unacceptable Upper Limit (mg/l)	Acceptable Environ. Risk (ppm)
pH	8.0	4.0-10.0	-
EC (mS/m)	86.0	370	-
TDS (mg/l)	616	2400	-
Ca (mg/l)	91	300	-
Mg (mg/l)	40	100	-
Na (mg/l)	37	400	-
K (mg/l)	2.3	100	-
Si (mg/l)	25	-	-
TAlk (mg/l)	228	-	-
Cl (mg/l)	65	600	-
SO_4 (mg/l)	86	600	-
NO_3 as N(mg/l)	14.0	20	-
F (mg/l)	<0.2	1.5	-
Al (mg/l)	<0.100	0.5	0.39
Fe (mg/l)	<0.025	2	9
Mn (mg/l)	0.056	1	0.3
V (mg/l)	<0.04	0.5	1.3
Ti (mg/l)	<0.08	-	-
Zn (mg/l)	<0.025	10	0.7

An elevated concentration of NO_3 is present in the mine water, probably due to blasting. The presence of elevated NO_3 must be confirmed in future analyses. Overall the water in the pit is of good quality and complaint in terms with the SABS 241 Drinking Water Standard or the Environmental Risk Limit from the DWAF Minimum Requirements.

IMPACT SUMMARY	**Current impact of the Mining Pits on the Ground Water Quality**	
Summary	**Rating**	**Comment**
Extent or Spatial Scale of Impact	LOW	Within Mine Boundary.
Intensity	LOW	No reactive minerals in rock. Elevated concentration of NO_3 probably due to blasting. Mine water quality is however overall fully compliant. No outflow from pit.

IMPACT SUMMARY	**Current impact of the Mining Pits on the Ground Water Quality**	
Summary	**Rating**	**Comment**
Duration	LONG TERM	Beyond lifespan of project.
Mitigatory Potential	HIGH	Mine water can be pumped towards storage facilities or must be contained within confines of pit.
Acceptability	ACCEPTABLE	No risk to public health or to any sensitive environment.
Degree of Certainty	DEFINITE	Water samples tested.
Status of Impact	NEGATIVE	If water interferes with mining, it must be pumped towards storage facilities.
Significance Rating without Mitigation	LOW	Impact has small effect on inflowing ground water.
Significance Rating with Mitigation	LOW	Impact will prevail on inflowing water. Mine water pumped towards storage facilities will prevent flow of water towards surrounding aquifer.
Legal Requirements	REQUIRED	Water Use License.

4.3.2.2 Current impact of Slimes Dam, Calcine Tailings Dump, Effluent Ponds and Water Dams on ground water quality

The current contamination in the aquifer was discussed in **Section 3.3**. It was indicated that extensive contamination currently exists in parts of the aquifer at Xstrata Alloys Rhovan. A summary of existing contamination is given below.

<u>Extent of current pollution at Xstrata Alloys Rhovan</u>

The major contamination parameters at Xstrata Alloys Rhovan are summarized in **Table 4.3.2.2(A)** below:

Table 4.3.2.2(A): Summary of latest analysis of major contamination parameters at Xstrata Alloys Rhovan.

Area	Parameters	Minimum	Maximum	Arithmetic Mean	Number of Boreholes which are compliant or non-compliant with SABS 241 Drinking Water Standard*				
					Ideal	Acceptable	Allowable	Non-compliant	Total
Calcine Dump	TDS (mg/l)	542	48700	7518	0	2	5	12	19
	SO_4 (mg/l)	41	27301	4182	2	0	1	16	19
	V (mg/l)	0.010	839	103	9	1	1	8	19
	NO_3 (mg/l)	0.200	244	42.8	3	1	6	9	19
Slimes Dam	TDS (mg/l)	456	838	604	0	16	0	0	16
	SO_4 (mg/l)	21	168	102	16	0	0	0	16
	V (mg/l)	0.010	0.500	0.063	15	0	1	0	16
	NO_3 (mg/l)	0.010	8.000	4.221	11	5	0	0	16
Plant Area	TDS (mg/l)	252	321000	110137	1	2	0	9	12
	SO_4 (mg/l)	31	226318	69578	1	2	0	9	12
	V (mg/l)	0.010	7180	716	8	1	0	3	12
	NO_3 (mg/l)	0.900	1079	281	1	1	1	9	12
Mining Area	TDS (mg/l)	574	5336	1945	0	4	1	2	7
	SO_4 (mg/l)	47	2520	790	2	2	1	2	7
	V (mg/l)	0.010	1.150	0.240	4	1	1	1	7
	NO_3 (mg/l)	3.90	49.0	23.1	2	0	2	3	7

*** Ideal: TDS <450 mg/l, SO_4 <200 mg/l, V < 0.1 mg/l, NO_3 as N < 6 mg/l**

Acceptable: TDS 450-1000 mg/l, SO_4 200-400 mg/l, V 0.1-0.2 mg/l, NO_3 as N 6-10 mg/l

Allowable: TDS 1000-2400 mg/l, SO_4 400-600 mg/l, V 0.1-0.5 mg/l, NO_3 as N 10-20 mg/l

Non-compliant: TDS >2400 mg/l, SO_4 >600 mg/l, V >0.5 mg/l, NO_3 as N >20 mg/l

From the above table it is evident that contamination is present in areas of the Xstrata Alloys Rhovan aquifer. The existence of a plume in the ground water environment was identified through geophysical and hydro-chemical data collection. Contours were drawn for the plume and are shown for 1999, 2002 and 2005 respectively in **Figures 4.3.2.2(A) to (C)** below:

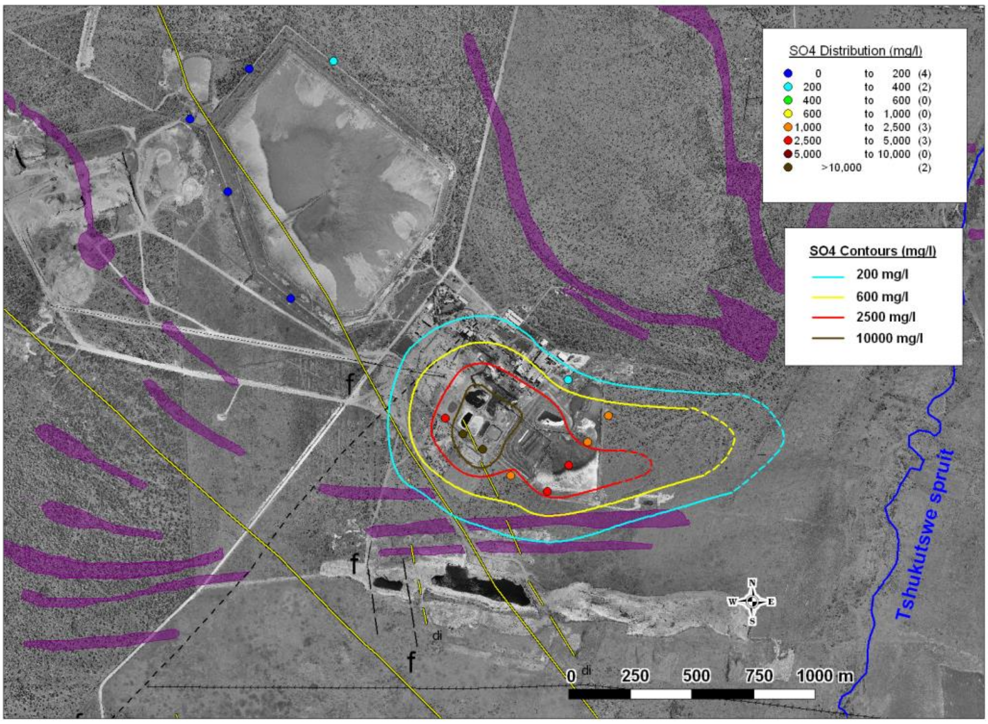


Figure 4.3.2.2(A): Extent of the Rhovan plume in 1999.

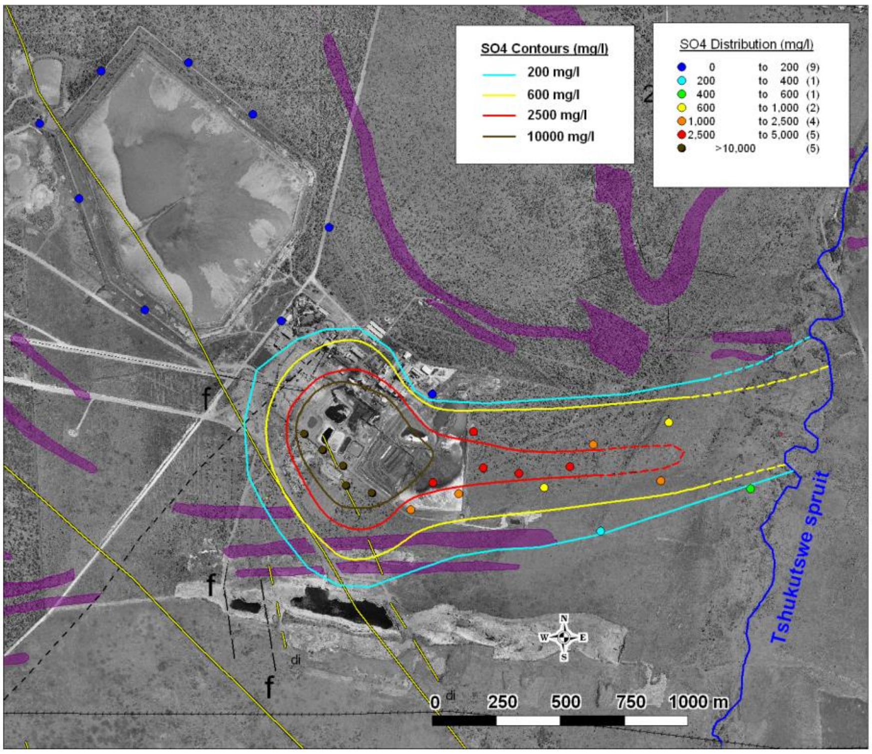


Figure 4.3.2.2(B): Extent of the Rhovan plume in 2002.

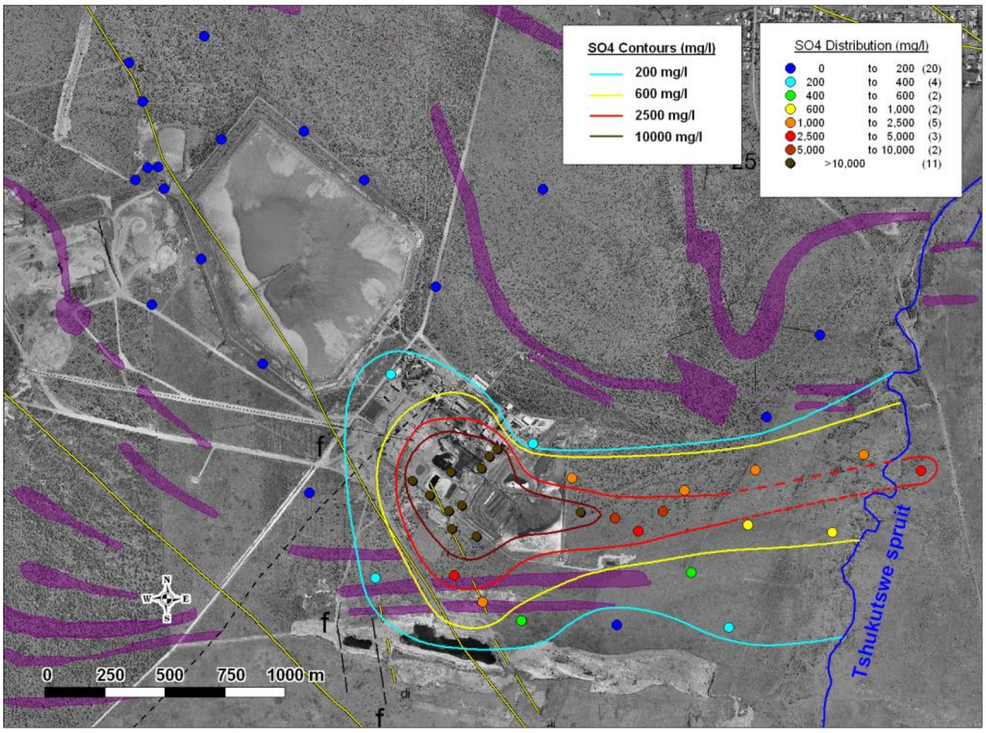


Figure 4.3.2.2(C): Extent of the Rhovan plume in 2005.

The change in the plume size and in the SO_4 concentration as observed from the above figures is illustrated in **Figure 4.3.2.2(D)** below:

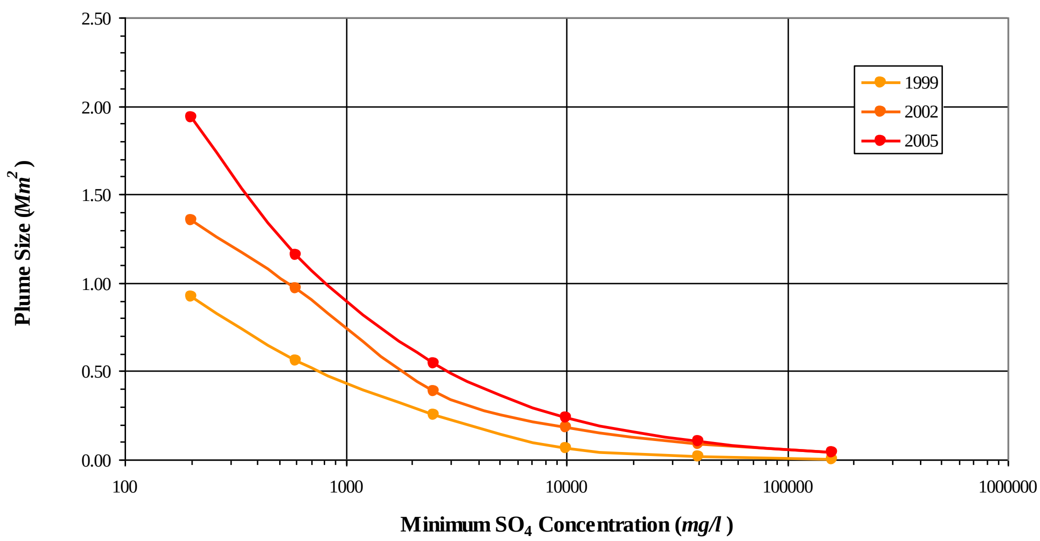


Figure 4.3.2.2(D): Change in plume size and SO_4 concentration over time.

From the above figures the following conclusions could be made:

- SO_4 is the best parameter to use in order to define the plume as it is identified as the dominant component of the total salt load. SO_4 is also more conservative than cations in the aquifer. V which is another parameter of concern, would easily adsorb to the aquifer matrix and don't have the same extent as the SO_4-plume. NO_3 is a more conservative anion that could be used to identify the plume but not all the sources have such extremities in NO_3 as with SO_4. Sulphuric Acid and sulphates (Sodium-, aluminium- and ammonium sulphates) are important additives in the metallurgical process used at the plant which explains the presence of SO_4 in the sources.

- A value of 200 mg/l SO_4 is seen as background as was calculated in **Section 3.3.1.** The 200 mg/l SO_4 contour line in **Figures 4.3.2.2(A) to (C)** could therefore be seen as the perimeter of the SO_4-plume.

- The Rhovan plant has been in operation from the early 90's. Since then the 200 mg/l SO_4 contour has increased from approximately 90 ha in 1999, to 135 ha in 2002, and to 194 ha in 2005. The 200 mg/l SO_4 contour has therefore doubled in aireal extent over the last six years. However, the 10 000 mg/l SO_4 contour has increased almost four-fold in extent from 1999 to 2005.

- It is evident that the plume has shown bigger development near the source area from 1999 to 2002. From 2002 to 2005 the plume has shown less development at the source area but has nonetheless increased substantially in overall extent.

Impact Summary

No impact is observed from **Table 4.3.2.2(A) and Figures 4.3.2.2(A) to (C)** at the Slimes Dam or the Slimes Return Water Dam (RWD) from chemistry samples taken from boreholes. The impact summary is given below:

IMPACT SUMMARY	**Current impact of the Slimes Dam and the Slimes RWD on the Ground Water Quality**	
Summary	**Rating**	**Comment**
Extent or Spatial Scale of Impact	LOW	Within Site Boundary.
Intensity	LOW	Clean water added to aquifer.
Duration	LONG TERM	Beyond lifespan of project.
Mitigatory Potential	NONE	Not required.
Acceptability	ACCEPTABLE	No risk to public health or to any sensitive environment.
Degree of Certainty	DEFINITE	Infiltration is taking place to underlying aquifer.

IMPACT SUMMARY	**Current impact of the Slimes Dam and the Slimes RWD on the Ground Water Quality**	
Summary	**Rating**	**Comment**
Status of Impact	NEUTRAL	No positive or negative results of impact.
Significance Rating without Mitigation	LOW	Impact will have small effect on surrounding ground water environment.
Significance Rating with Mitigation	LOW	Although mitigation measures such as seepage interception and monitoring are in place, the impact will still have a small effect on surrounding ground water environment.
Legal Requirements	REQUIRED	Water Use License.

It is evident from **Table 4.3.2.2(A) and Figures 4.3.2.2(A) to (C)** that an impact is present at the Plant Area and the Calcine Dump Area in the form of a plume that extends towards the Tshukutswe River.

Details on the mitigation measures for the Slimes, Tailings, Effluent and Water Holding facilities are given in **PART 7** of this document. The impact at Pits 1 and 2 of the Mining Area originates from the plume extending from the plant area and is not attributed to mining activities. The impact summary is given below:

IMPACT SUMMARY	**Current impact of the FeV Slag Dump, the Calcine Dump, the Calcine RWD, the Dirty SWDs, the Purge Dams and the Scrubber Ponds on the Ground Water Quality**	
Summary	**Rating**	**Comment**
Extent or Spatial Scale of Impact	MEDIUM	Impact will extend beyond local area of impact but still within site boundary.
Intensity	HIGH	Contaminated leachate added to aquifer from Waste/Effluent Facilities.
Duration	SHORT TERM	These facilities will be reconstructed to a large degree. Remediation of current impact must also be completed over short term.
Mitigatory Potential	HIGH	High potential to mitigate future negative impact. Current residue/plume must be remediated.
Acceptability	UNACCEPTABLE	Redesign dumps/ponds/dams in order to remove ongoing impact.

IMPACT SUMMARY	**Current impact of the FeV Slag Dump, the Calcine Dump, the Calcine RWD, the Dirty SWDs, the Purge Dams and the Scrubber Ponds on the Ground Water Quality**	
Summary	**Rating**	**Comment**
Degree of Certainty	DEFINITE	Leaching is taking place to underlying aquifer.
Status of Impact	NEGATIVE	Funds must be allowed for remediation of aquifer and upgrading of lining systems.
Significance Rating without Mitigation	HIGH	Impact has a negative effect on surrounding ground water environment.
Significance Rating with Mitigation	HIGH	Although current mitigation measures such as leachate detection and monitoring is present, the impact will still have a negative effect on surrounding ground water environment as long as the status quo prevails.
Legal Requirements	REQUIRED	Cleanup of current plume in accordance with Section 19. of the National Water Act. Water Use License.

4.3.2.3 Current impact on ground water resource quality

There are currently no external users of ground water around Xstrata Alloys Rhovan within a 1 km radius. Bethanie, Berseba and Modikwe are respectively situated 1.6 km north-east, 4.6 km and 6 km north-west of the Rhovan Plant Area. Except for the external users' boreholes at Bethanie, Berseba and Modikwe, one other borehole, GWE-6, is situated 2 km south of the Rhovan Plant Area. Basic information of all external users' boreholes is given in **Table 3(B)** attached in **APPENDIX 3.**

The results of the latest hydro-chemistry samples taken at external users, boreholes are given below:

Table 4.3.2.3(A): Summary of latest analysis of major contamination parameters at Xstrata Rhovan.

Area	Parameters	Minimum	Maximum	Arithmetic Mean	Number of Boreholes compliant or non-compliant with the SABS 241 Drinking Water Standard*				
					Ideal	Acceptable	Allowable	Non-compliant	Total
GWE-6	TDS (mg/l)	546	546	**546**	0	**1**	0	0	**1**
	SO_4 (mg/l)	23	23	**23**	**1**	0	0	0	**1**
	V (mg/l)	0.010	0.010	**0.010**	**1**	0	0	0	**1**
	NO_3 (mg/l)	7.88	7.88	**7.88**	0	**1**	0	0	**1**
Bethanie	TDS (mg/l)	172	2134	**514**	**14**	**4**	**2**	0	**20**
	SO_4 (mg/l)	4	120	**42**	**20**	0	0	0	**20**
	V (mg/l)	0.010	2.000	**0.110**	**19**	0	0	**1**	**20**
	NO_3 (mg/l)	0.010	190	**23.9**	**8**	**4**	**3**	**5**	**20**

*** Ideal: TDS <450 mg/l, SO_4 <200 mg/l, V < 0.1 mg/l, NO_3 as N < 6 mg/l**

Acceptable: TDS 450-1000 mg/l, SO_4 200-400 mg/l, V 0.1-0.2 mg/l, NO_3 as N 6-10 mg/l

Allowable: TDS 1000-2400 mg/l, SO_4 400-600 mg/l, V 0.1-0.5 mg/l, NO_3 as N 10-20 mg/l

Non-compliant: TDS >2400 mg/l, SO_4 >600 mg/l, V >0.5 mg/l, NO_3 as N >20 mg/l

From the chemistry-time data set, attached as **Dataset 3.3(A) - APPENDIX 3**, all parameters of GWE-6 have shown mostly ideal values except for NO_3 and TDS that is marginal and Fe and Mn that are sometimes marginal. GWE-6 shows a sideways trend in terms of its marginal compliance. It is therefore evident that the NO_3 contamination is persistent. The contamination could be most likely attributed to human/agricultural influences.

From **Dataset 3.3(A) - APPENDIX 3** the overall trend of pollution/contamination for the various boreholes at Bethanie could be established and are given in **Section 3.3.2**. From this it is shown that currently at Bethanie respectively 5 and 7 boreholes show sideways trends in terms of their non- and marginal compliance. It is therefore evident that the NO_3 contamination is persistent. All contamination could be most likely attributed to human/agricultural influences.

GWE-21 at Bethanie showed a NO_3 level of 190 mg/l and a V level of 2 mg/l. This borehole could unfortunately however only been accessed once (in 2002/09/11) and it could not be established by a follow-up whether this analysis was accurate. The impact summary is given below:

IMPACT SUMMARY	Current impact of Xstrata Alloys Rhovan activities on the quality of ground water available to external user's	
Summary	**Rating**	**Comment**
Extent or Spatial Scale of Impact	LOW	Impact small and within site boundary.
Intensity	LOW	No current users in site boundary. However, some of the ground water is not fit for use. Ongoing remediation will aim to adjust this.
Duration	MEDIUM	Lifespan of project.
Mitigatory Potential	HIGH	Active remediation measures will be put into place for aquifer clean-up.
Acceptability	MANAGEABLE	No risk to public health or to any sensitive environment currently. However remediation actions will be put into place for the remediation of the plume within the site boundary.
Degree of Certainty	SURE	No current impact is detected.
Status of Impact	NEUTRAL	No impact is currently present.
Significance Rating without Mitigation	LOW	No current risk to external user's.
Significance Rating with Mitigation	LOW	Remediation actions will be put into place for the remediation of the plume within the site boundary.
Legal Requirements	NO	-

4.3.2.4 Current impact of ground water on surface water quality

The largest concern is the ground water pollution plume that extends from the Plant/Calcine Area towards the Tshukutswe River as shown in **Figure 4.3.2.2(C)**. It was however found that the Tshukutswe River is not a discharge boundary for the weathered/fractured aquifer and that contaminated ground water is contained in the aquifer below the Tshukutswe River. Surface water monitoring points in the Tshukutswe River are shown in **Figure 4.3.2.4(A)** below. Statistics of chemical analyses of water samples from the Tshukutswe River are shown below in **Table 4.3.2.4(A).**

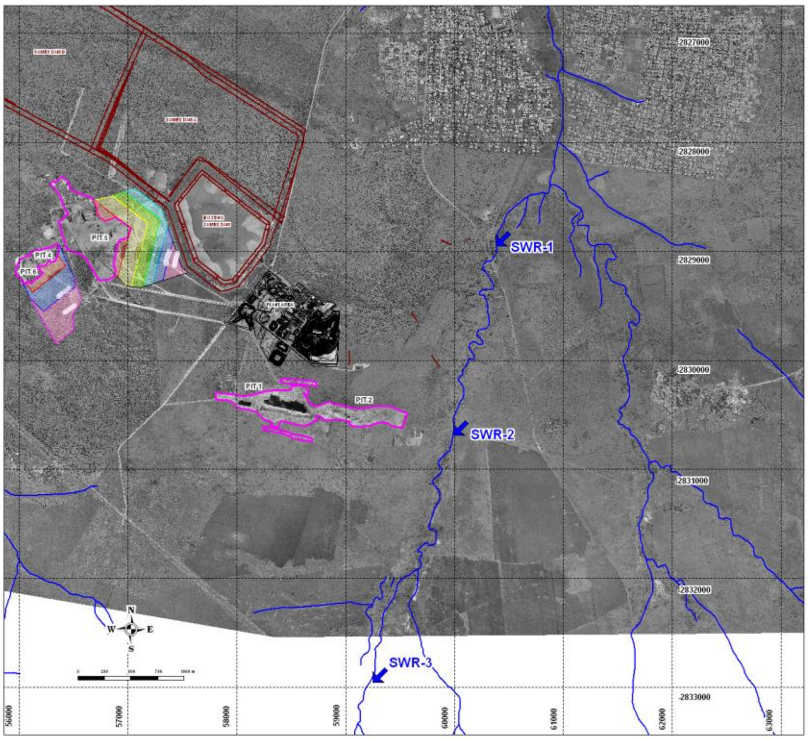


Figure 4.3.2.4(A): Surface monitoring points in the Tshukutswe River.

Table 4.3.2.4(A): Statistics of chemical analyses of water samples of the Tshukutswe River from Sept 2001 to March 2005.

Parameter	SWR-1 (12 samples)			SWR-2 (12 samples)			SWR-3 (12 samples)		
	Min	Max	Average	Min	Max	Average	Min	Max	Average
pH	7.5	8.3	7.9	6.9	8.4	7.8	7.2	8.4	7.9
EC	102.5	114.0	107.6	30.0	118.0	78.7	20.8	143.0	79.3
TDS	628	730	668	162	832	489	102	2166	609
Ca	58.0	93.6	79.0	24.2	76.0	49.4	19.0	214.0	58.1
Mg	43.0	62.0	51.0	9.0	56.3	36.1	7.0	221.0	61.7
Na	56.2	81.0	67.7	7.0	141.0	57.5	4.0	100.0	43.4
K	0.4	1.1	0.9	2.5	6.6	4.3	2.3	11.2	6.0
Si	20.6	25.0	22.9	3.8	11.3	6.5	7.1	23.0	14.1
T-Alk	345.0	392.5	366.9	122.8	340.0	244.8	73.0	630.6	317.3
Cl	78.4	97.0	91.1	4.1	126.0	71.9	5.0	99.0	39.7
SO_4	66.0	86.0	76.8	11.0	197.3	81.5	8.3	588.0	117.7
N	1.7	51.0	7.3	0.0	3.8	1.1	0.0	67.0	7.4
F	0.177	0.600	0.304	0.117	0.500	0.267	0.062	0.500	0.215
Fe	0.030	0.193	0.131	0.010	2.120	0.787	0.010	2.050	0.687
Mn	0.034	0.114	0.077	0.010	0.819	0.217	0.010	1.260	0.412
V	0.01	0.70	0.21	0.03	2.04*	0.35*	0.03	1.40	0.39

* Omitting an outlier of 32 mg/l measured on 2002/02/05

Finally it must be concluded that although no current impact exists on the Tshukutswe River, the water course must be protected from any contamination, especially since the river flows towards the Bethanie settlement. The protection of the river must be part of the long-term ground water remediation objectives at Xstrata Alloys Rhovan. No wetlands or pans exist that would be contaminated by the plume. The impact summary is given below:

IMPACT SUMMARY	**Current impact of the plume on the Tshukutswe River water quality**	
Summary	**Rating**	**Comment**
Extent or Spatial Scale of Impact	INSIGNIFICANT	Within Site Boundary.
Intensity	INSIGNIFICANT	No current impact is detected.
Duration	MEDIUM TERM	Lifespan of project.
Mitigatory Potential	NONE	-
Acceptability	ACCEPTABLE	No risk to public health or to any sensitive environment.
Degree of Certainty	DEFINITE	No current impact is detected.
Status of Impact	NEUTRAL	No positive or negative results of impact.
Significance Rating without Mitigation	INSIGNIFICANT	No impact is identified.
Significance Rating with Mitigation	INSIGNIFICANT	No mitigation measures applicable.
Legal Requirements	NOT APPLICABLE	-

4.4 ONGOING OPERATIONAL PHASE IMPACT ASSESSMENT

4.4.1 Ongoing impact on ground water quantity

4.4.1.1 Ongoing impact of Mining Pits on ground water quantity

Future mining will extend the pits with a further approximate 66 ha. The 30 Year Mine Plan of Xstrata Alloys Rhovan is shown in **Figure 4.1(A).** The open pit mining operations for the following 30 years will consist of the expansion of Pit 5 as well as Pit 4 and Pit 6. The operational pits will be kept dry during the operational phase. A resultant ground water gradient is created between the surrounding ground water aquifer and the mining pit floor. Ground water will therefore flow into the mine and the rate of influx will be a function of the gradient towards the mine, the hydraulic conductivity of the weathered gabbro and the influx area between the aquifer and the mining pits. Inflowing ground water will result in a cone of depression around the pit of not farther than 250 m.

The ground water inflows into Pit 1 and Pit 2 are given in **Table 4.4.1.1(A)** below. It is important to note that a large portion of the inflow into Pit 1 and Pit 2 is from the plume that extents from the Plant/Calcine Area.

Table 4.4.1.1(A): Ground water inflow into Pit 1 and Pit 2.

Mining Pit	Total Ground Water Influx (m^3/a)	Total Ground Water Influx (m^3/d)
Pit 1	28,744	78.75
Pit 2	19,710	54.00

The ground water balance calculations for Pit 5 are given in **Table 4.4.1.1(B)** below:

Table 4.4.1.1(B): Ground water balance for Pit 5.

Year of Mining	Area Mined (m^2)	Progressive Area Mined (m^2)	Total Water Liberated from Rock (m^3/a)	Total Ground Water Influx (m^3/a)	Total Ground Water Make (m^3/a)	Total Ground Water Make (m^3/d)
Existing Mining	315,000	315,000	0	32,850	32,850	90.00
2006	6,928	321,928	693	33,877	34,569	94.71
2007	6,928	328,857	693	34,903	35,596	97.52
2008	6,928	335,785	693	35,930	36,623	100.34
2009	6,928	342,713	693	36,956	37,649	103.15
2010	6,928	349,641	693	37,983	38,676	105.96
2011	26,420	376,061	2,642	39,009	41,651	114.11
2012	26,420	402,481	2,642	40,036	42,678	116.93
2013	26,420	428,900	2,642	41,063	43,704	119.74
2014	26,420	455,320	2,642	42,089	44,731	122.55
2015	26,420	481,740	2,642	43,116	45,758	125.36
2016	21,045	502,785	2,105	44,142	46,247	126.70
2017	21,045	523,830	2,105	45,169	47,273	129.52

Year of Mining	Area Mined (m^2)	Progressive Area Mined (m^2)	Total Water Liberated from Rock (m^3/a)	Total Ground Water Influx (m^3/a)	Total Ground Water Make (m^3/a)	Total Ground Water Make (m^3/d)
2018	21,045	544,875	2,105	46,195	48,300	132.33
2019	21,045	565,921	2,105	47,222	49,326	135.14
2020	21,045	586,966	2,105	48,248	50,353	137.95
2021	15,415	602,381	1,541	49,275	50,816	139.22
2022	15,415	617,795	1,541	50,302	51,843	142.04
2023	15,415	633,210	1,541	51,328	52,870	144.85
2024	15,415	648,625	1,541	52,355	53,896	147.66
2025	15,415	664,040	1,541	53,381	54,923	150.47
2026	7,633	671,673	763	54,408	55,171	151.15
2027	7,633	679,306	763	55,434	56,198	153.97
2028	7,633	686,939	763	56,461	57,224	156.78
2029	7,633	694,572	763	57,488	58,251	159.59
2030	7,633	702,205	763	58,514	59,277	162.40
2031	16,218	718,423	1,622	59,541	61,162	167.57
2032	16,218	734,641	1,622	60,567	62,189	170.38
Post Closure	**0**	**734,641**	**0**	**60,567**	**60,567**	**165.94**

The ground water balance calculations for Pit 4 and Pit 6 are given in **Table 4.4.1.1(C)** below:

Table 4.4.1.1(C): Ground water balance for Pit 4 and Pit 6.

Year of Mining	Area Mined (m^2)	Progressive Area Mined (m^2)	Total Water Liberated from Rock (m^3/a)	Total Ground Water Influx (m^3/a)	Total Ground Water Make (m^3/a)	Total Ground Water Make (m^3/d)
Existing Mining	74,754	74,754	0	10,950	10,950	30.00
2006	7,749	82,503	775	11,361	12,136	33.25
2007	7,749	90,252	775	11,771	12,546	34.37
2008	7,749	98,000	775	12,182	12,957	35.50
2009	7,749	105,749	775	12,593	13,367	36.62
2010	7,749	113,498	775	13,003	13,778	37.75
2011	0	113,498	0	13,414	13,414	36.75
2012	0	113,498	0	13,824	13,824	37.88
2013	0	113,498	0	14,235	14,235	39.00
2014	0	113,498	0	14,646	14,646	40.13
2015	0	113,498	0	15,056	15,056	41.25
2016	0	113,498	0	15,467	15,467	42.38
2017	0	113,498	0	15,878	15,878	43.50
2018	0	113,498	0	16,288	16,288	44.63
2019	0	113,498	0	16,699	16,699	45.75
2020	0	113,498	0	17,109	17,109	46.88
2021	0	113,498	0	17,520	17,520	48.00

Year of Mining	Area Mined (m^2)	Progressive Area Mined (m^2)	Total Water Liberated from Rock (m^3/a)	Total Ground Water Influx (m^3/a)	Total Ground Water Make (m^3/a)	Total Ground Water Make (m^3/d)
2022	0	113,498	0	17,931	17,931	49.13
2023	0	113,498	0	18,341	18,341	50.25
2024	0	113,498	0	18,752	18,752	51.38
2025	0	113,498	0	19,163	19,163	52.50
2026	19,337	132,835	1,934	19,573	21,507	58.92
2027	19,337	152,172	1,934	19,984	21,917	60.05
2028	19,337	171,509	1,934	20,394	22,328	61.17
2029	19,337	190,846	1,934	20,805	22,739	62.30
2030	19,337	210,183	1,934	21,216	23,149	63.42
2031	54,359	264,542	5,436	21,626	27,062	74.14
2032	54,359	318,900	5,436	22,037	27,473	75.27
Post Closure	**0**	**318,900**	**0**	**22,037**	**22,037**	**60.38**

The mining at Rhovan is of small to medium size. The future volumes of ground water flowing into the pits are also low due to the small scale of the different mining operations.

During the operational phase a backfilling and rehabilitation program will be followed for the mined pits.

The impact summary is given below:

IMPACT SUMMARY	**Ongoing impact of the Mining Pits on the Ground Water Quantity**	
Summary	**Rating**	**Comment**
Extent or Spatial Scale of Impact	LOW	Within Site Boundary.
Intensity	LOW	Cone of depression of <250 m around pits.
Duration	LONG TERM	Rock will permanently be changed in confines of mine.
Mitigatory Potential	NONE	No mechanism to mitigate the disturbance of the rock.
Acceptability	ACCEPTABLE	No risk to public health or to any sensitive environment.
Degree of Certainty	DEFINITE	Mining must proceed in order to supply magnetite to Plant. Ground water inflow into the operational pit is a given.
Status of Impact	NEGATIVE	Water level lowered around pit.

IMPACT SUMMARY	Ongoing impact of the Mining Pits on the Ground Water Quantity	
Summary	**Rating**	**Comment**
Significance Rating without Mitigation	LOW	Impact will have small effect on surrounding ground water environment.
Significance Rating with Mitigation	LOW	Although no mitigation possible, impact will still have a small effect on surrounding ground water environment.
Legal Requirements	REQUIRED	Mining License. Water Use License.

4.4.1.2 Ongoing quantity of leachate created by Slimes Dam, Calcine Dump, Effluent Ponds and Water Dams

If the correct lining systems are installed, the volume of leachate through the bases of these facilities would be much less than it is currently. Three aspects are important for the construction of any specific lining system:

- The quality of material and construction – permeability modification.

  The main function of a lining system is to minimize the permeability through the base of the facility. Care must therefore be taken in the placement of the geomembrane on the underlying material. A desiccation layer must be present over the geomembrane in order to protect it from the overlying material.

- The hydraulic head buildup on the liner – minimization of driving force.

  In a pond, dam or lagoon, the hydraulic head will typically be higher than in an unsaturated dump or stockpile. In general, the higher the head, the bigger the driving force for seepage.

- The distance towards the leachate collection drains.

  In order to collect most leachate and also to prevent a head build-up in the H:H and H:h lining systems, drainage layers form part of the lining system. The longer the distance towards the collection drain, the higher the head buildup will be and the higher the leachate volume through the liner will be.

  DWAF Minimum Requirements also specify that a Hazardous Waste lining system must be build at a 5% gradient and a G:L:B+ lining system at a gradient of 2% for the effective drainage of leachate towards the drains.

The Purge Dams and Scrubber Ponds will be constructed as H:H Lagoon systems or other appropriate configuration agreed upon with the authorities. The Calcine Dump is currently directly underlain with a geomembrane for the collection of leachate in order to be circulated back into the plant. The Calcine Dump could therefore currently also be seen as a H:H Lagoon system. The Calcine Return Water Dam should be constructed with the same lining (H:H Lagoon) as the Calcine Dump. The Dirty Storm Water Dams have almost the same chemicals of concern as the Calcine Return Water Dam and should therefore also be constructed similarly.

The Slimes Dam and the Slimes Return Water Dam should be constructed with nothing more than a G:L:B liner system because of the full compliance of the water quality of the Slimes Dam with water quality guidelines. The main requirement would be to install effective drainage systems for dam stability and safety considerations.

The final designs of the lining systems are contained in the design reports compiled as part of the Water Use License Application for these facilities – ref: **XREMP/SSR/20/VER-01/2006** and **XREMP/SSR/21/VER-01/2006**.

Modeling with Visual HELP

The volume of leachate expected for different lining systems for slimes, tailings, effluent and water holding facilities were modeled. The modeling was performed using the USEPA software program: Visual HELP. This model is generally used for predicting landfill hydrologic processes and testing the effectiveness of landfill designs, enabling the prediction of landfill design feasibility. HELP has become a requirement for obtaining landfill operation permits in the U.S.A.

The following input was used for the model:

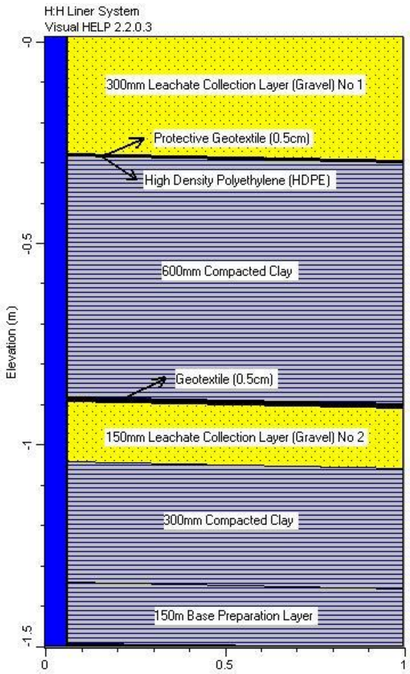
- All models were performed for liners as specified according to the DWAF Minimum Requirements specifications. The model profiles are given in **Figures 4.4.1.2(A) to (D)** below.

- The permeabilities of the clay and the slope towards the drains were taken from the specifications of the DWAF Minimum Requirements for the different lining systems:

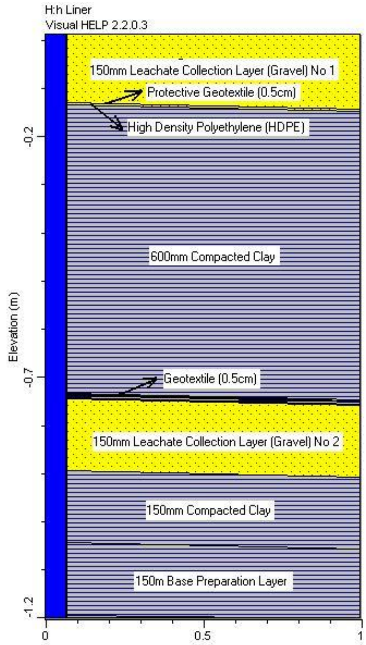
Lining Systems	**Clay Permeability (cm/s)**	**Drainage Slope**
G:L:B+	1×10^{-6}	2%
H:h liner	3×10^{-7}	5%
H:H Liner	1×10^{-7}	5%
H:H Lagoon	1×10^{-7}	5%

- The distances to the drains and the holes in the geomembranes were varied in order to set limits to the leachate expected. A total of 50 scenarios were modeled.

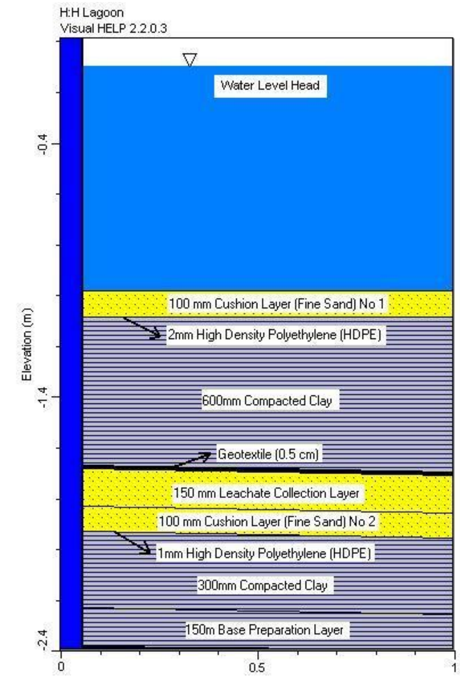
The representation of the H:H, the H:h, the H:H Lagoon and the G:L:B+ Lining Systems in Visual HELP are shown in **Figures 4.4.1.2(A) to (D)** below:



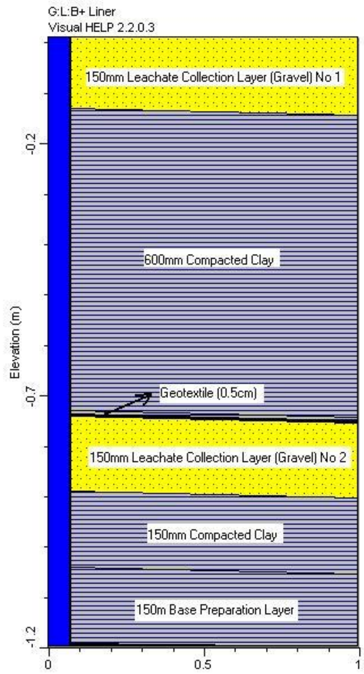
(A) H:H Liner



(B) H:h Liner



(C) H:H Lagoon



(D) G:L:B+ Liner

Figures 4.4.1.2(A) to (D): Modeled Lining systems in Visual HELP.

Model Results and Discussion

The simulated volume of leachate through the different lining systems is given below in **Tables 4.4.1.2(A) to (D)**:

Table 4.4.1.2(A): Leachate through H:H Lining system (mm/year).

Construction	Material	Average distance to drain				
	% Holes in 2 mm HDPE	10m	25m	50m	100m	200m
Bad	2.500%	0.00201	0.00385	0.00690	0.01435	0.05468
Poor	0.250%	0.00022	0.00041	0.00072	0.00168	0.00580
Good	0.025%	0.00005	0.00007	0.00010	0.00020	0.00063

Table 4.4.1.2(B): Leachate through H:h Lining system (mm/year).

Construction	Material	Average distance to drain				
	% Holes in 1 mm HDPE	10m	25m	50m	100m	200m
Bad	5.000%	0.00399	0.00767	0.01376	0.03034	0.11147
Poor	0.500%	0.00042	0.00079	0.00140	0.00332	0.00942
Good	0.050%	0.00007	0.00011	0.00017	0.00036	0.00120

Table 4.4.1.2(C): Leachate through H:H Lagoon system (mm/year).

Construction	Material		Average distance to drain				
	% Holes in 2 mm HDPE	% Holes in 1 mm HDPE	10m	25m	50m	100m	200m
Bad	2.500%	5.000%	31.536	31.536	31.536	31.536	31.536
Poor	0.250%	0.500%	8.345	8.345	8.345	8.345	8.345
Good	0.025%	0.050%	0.861	0.861	0.861	0.861	0.861

Table 4.4.1.2(D): Leachate through G:L:B+ Lining system (mm/year).

Average distance to cut-off drain				
10m	25m	50m	100m	200m
5.394	5.394	5.394	5.394	5.394

The volume of leachate through a H:H Liner and a H:h Liner is dependant on the average distance to the drain. The larger the distance the longer the leachate have time to build up a head on the geomembrane with a larger resultant flow.

Because of the large head on top of a H:H Lagoon, the leachate rate increases significantly through the upper geomembrane. Since there is no head build up in the percolation layer in order that horizontal flow can take place, vertical flow will be dominant in the lower layers.

The same is true for G:L:B+ lining systems; because of the larger vertical permeability (with respect to Hazardous Waste Liners) there is no head build up in the lower layers and vertical flow will be larger than the horizontal flow.

Model Conclusions

The following conclusions could be made with regard to the model results:

- The construction of lining systems must be according to the DWAF Minimum Requirements.
- The geomembrane and the overall liner construction must be of a good standard. Care must be taken in the placement of the geomembrane on the underlying material. On top a cushion layer or protective geotextile must be present in order to protect it from the overlying material.
- The minimum appropriate distance must exist towards drains.
- The H:H Lagoon and G:L:B+ is the liner systems that will probably be used the most at Xstrata Rhovan. For a good constructed H:H Lagoon system the drainage will be 0.861 mm/year per unit area (about 0.16% of rainfall – keep in mind that the lagoon have a nearly constant head on top and is independent of the meteorological water balance). For a G:L:B+ liner it will be 5.394 mm/year per unit area or nearly 1% of rainfall.

Impact Summary

As long as the status quo of the current sites proceed they will impact on the underlying aquifer as assessed in **Section 4.3.2.2**.

No impact is observed from **Table 4.3.2.2(A) and Figures 4.3.2.2(A) to (C)** at the Slimes Dam, the Slimes Return Water Dam (RWD) and the Clean Storm Water Dam (SWD) No. 1 from chemistry samples taken from boreholes and from the dams. The current lining and leachate collection system for the Slimes Dam and the Slimes RWD is therefore adequate. Future developments of the Slimes Dam, the Slimes RWD and the Clean SWDs can be constructed without special liner systems, provided that drainage systems are incorporated in the design for dam safety and stability purposes. The impact summary is given below:

IMPACT SUMMARY	**Current and ongoing impact of the Slimes Dam, the Slimes RWD and the Clean SWD No. 1 on the Ground Water Quantity**	
Summary	**Rating**	**Comment**
Extent or Spatial Scale of Impact	LOW	Within Site Boundary.
Intensity	LOW	Clean water added to aquifer.
Duration	MEDIUM TERM	Lifespan of project.
Mitigatory Potential	HIGH	High potential to mitigate negative impact.

Acceptability	ACCEPTABLE	No risk to public health or to any sensitive environment.
Degree of Certainty	DEFINITE	Leaching is taking place to underlying aquifer.
Status of Impact	NEUTRAL	No positive or negative results of impact.
Significance Rating without Mitigation	LOW	Impact will have small effect on surrounding ground water environment.
Significance Rating with Mitigation	LOW	Although mitigation measures such as leachate capturing and monitoring are in place, the impact will still have a small effect on surrounding ground water environment.
Legal Requirements	REQUIRED	Water use License.

It is evident from **Table 4.3.2.2(A) and Figures 4.3.2.2(A) to (C)** that an impact is currently present at the Plant Area and the Calcine Dump Area in the form of a plume that extends towards the Tshukutswe River. The impact at the Mining Area originates from the plume extending from the plant area and is not attributed to mining activities. As long as the status quo of the current waste sites at the Plant and Calcine Area proceeds, so long will they impact on the underlying aquifer as assessed in **Section 4.3.2.2**. The impact summary is given below:

IMPACT SUMMARY	**Current impact of the FeV Slag Dump, the Calcine Dump, the Calcine RWD, the Dirty SWDs, the Purge Dams and the Scrubber Ponds on the Ground Water Quantity before reconstruction**	
Summary	**Rating**	**Comment**
Extent or Spatial Scale of Impact	MEDIUM	Impact will extend beyond local area of impact but still within site boundary.
Intensity	HIGH	Contaminated leachate added to aquifer from Waste Sites.
Duration	MEDIUM TERM	Lifespan of project. Remediation of current impact must be completed within lifespan of project.
Mitigatory Potential	HIGH	High potential to mitigate future negative impact. Current residue/plume must be remediated.
Acceptability	UNACCEPTABLE	Redesign dumps/lagoons/dams in order to remove ongoing impact.
Degree of Certainty	DEFINITE	Leaching is taking place to underlying aquifer.

IMPACT SUMMARY	Current impact of the FeV Slag Dump, the Calcine Dump, the Calcine RWD, the Dirty SWDs, the Purge Dams and the Scrubber Ponds on the Ground Water Quantity before reconstruction	
Summary	**Rating**	**Comment**
Status of Impact	NEGATIVE	Funds must be allowed for remediation of aquifer and upgrading of lining systems.
Significance Rating without Mitigation	HIGH	Impact has a negative effect on surrounding ground water environment.
Significance Rating with Mitigation	HIGH	Although mitigation measures such as leachate detection and monitoring is present, the impact will still have a negative effect on surrounding ground water environment as long as the status quo prevails.
Legal Requirements	REQUIRED	Water use License.

It is recommended that the extension/expansion of the Purge Dams, the Scrubber Ponds, the Dirty Storm Water Dams (SWD), the Calcine Dump and the Calcine Return Water Dam (RWD) be constructed according to the DWAF Minimum Requirements Specifications. The construction of these waste sites according to appropriate lining systems would imply that the absolute minimum leachate will take place as modeled above. The FeV slag must be dumped on the Calcine Dump.

More details on the mitigation measures are given in **PART 7** of this document. The impact summary is given below:

IMPACT SUMMARY	Impact of future FeV Slag Dump, the Purge Dams, Scrubber Ponds, Dirty SWD, Calcine Dump and the Calcine RWD on the Ground Water Quantity. Sites constructed according to DWAF Minimum Requirements specifications.	
Summary	**Rating**	**Comment**
Extent or Spatial Scale of Impact	LOW	Within Site Boundary.
Intensity	LOW	Small quantity of leachate.
Duration	MEDIUM TERM	Lifespan of project.
Mitigatory Potential	LOW	Low potential to mitigate negative impact.
Acceptability	ACCEPTABLE	Full legal compliance of future constructed lining systems.

IMPACT SUMMARY	**Impact of future FeV Slag Dump, the Purge Dams, Scrubber Ponds, Dirty SWD, Calcine Dump and the Calcine RWD on the Ground Water Quantity. Sites constructed according to DWAF Minimum Requirements specifications.**	
Summary	**Rating**	**Comment**
Degree of Certainty	PROBABLY	The amount of leachate may be more/less than modeled depending on the construction integrity.
Status of Impact	NEGATIVE	Cost involved in leachate capturing and future lining construction.
Significance Rating without Mitigation	MEDIUM	The liner systems will require some management measures (e.g. leachate collection) without which the impact will increase.
Significance Rating with Mitigation	LOW	Mitigation measures such as leachate collection and monitoring is vital. However a small quantity of seepage towards the underlying aquifer will still be present as modeled.
Legal Requirements	REQUIRED	Water Use License.

4.4.1.3 Ongoing impact on ground water user's resource quantity

As discussed in **Section 4.3.1.3** there are currently no external users of ground water around Xstrata Rhovan in a 1 km radius. The impact on the ground water use therefore has post-closure/long term objectives. Future mining will only have a local impact on the ground water quantity and a cone of depression will not extend more than 250 m from the mine. As discussed in **Section 4.3.1.1** there is no extensive depletion of the ground water level around the pits and no increased depletion is expected from future mining. The impact summary is given below:

IMPACT SUMMARY	**Ongoing impact of Xstrata Rhovan activities on the quantity of ground water available to external user's**	
Summary	**Rating**	**Comment**
Extent or Spatial Scale of Impact	LOW	Impact small and within site boundary.
Intensity	LOW	Cone of depression <250 m from mine.
Duration	MEDIUM	Lifespan of project.
Mitigatory Potential	LOW	No mitigation measures applicable.

IMPACT SUMMARY	**Ongoing impact of Xstrata Rhovan activities on the quantity of ground water available to external user's**	
Summary	**Rating**	**Comment**
Acceptability	ACCEPTABLE	No risk to public health or to any sensitive environment.
Degree of Certainty	UNSURE	It is unsure if there will ever be an impact on external user's.
Status of Impact	POSITIVE	Impact currently doesn't have any negative effects.
Significance Rating without Mitigation	LOW	Impact on ground water quantity in the site boundary is small.
Significance Rating with Mitigation	LOW	No mitigation measures applicable.
Legal Requirements	NO	None.

4.4.1.4 Ongoing impact on ground water quantity towards surface water features

No wetlands or pans exist that is dependant on ground water flow. Because of the smaller scale of mining and because of the distance to the rivers, mining have no impact on the baseflow of ground water towards the rivers. Pit 4, 5 and 6 is situated more than 2 km east of the Gwathle River and Pit 1 and 2 more than 400 m west of the Tshukutswe River. Future mining will take place at Pit 4, 5 and 6 which is too far from the Gwathle River in order to deplete its base flow. The impact summary is given below:

IMPACT SUMMARY	**Ongoing impact of Xstrata Rhovan activities on river baseflow**	
Summary	**Rating**	**Comment**
Extent or Spatial Scale of Impact	INSIGNIFICANT	Within Site Boundary.
Intensity	INSIGNIFICANT	No current impact is detected and because the impact on the aquifer will decrease because of future remediation, no ongoing impact on the river is foreseen.
Duration	LONG TERM	Beyond lifespan of project.
Mitigatory Potential	NONE NECESSARY	-
Acceptability	ACCEPTABLE	No risk to public health or to any sensitive environment.
Degree of Certainty	DEFINITE	No current impact is detected.

IMPACT SUMMARY	**Ongoing impact of Xstrata Rhovan activities on river baseflow**	
Summary	**Rating**	**Comment**
Status of Impact	NEUTRAL	No positive or negative results of impact.
Significance Rating without Mitigation	INSIGNIFICANT	No impact is identified.
Significance Rating with Mitigation	INSIGNIFICANT	No mitigation measures applicable.
Legal Requirements	NOT APPLICABLE	None.

4.4.2 Ongoing impact on ground water quality

4.4.2.1 Ongoing impact of mining pits on ground water quality

No additional future impact than described in **Section 4.3.2.1(A)** for the current impact will be expected from the mining pits. Ground water flow is taking place towards the mining pit during ongoing operations and not from it. It is therefore not possible that mine water will be introduced into the ground water environment. The mining itself would as a worst case slightly rise the total dissolved solids of the water in the mine but the mine water quality would not be non-compliant with respect to the SABS 241 Drinking Water Standard or the Environmental Risk Limit from the DWAF Minimum Requirements.

The reason for an insignificant impact of mining on the water quality is because of the absence of reactive minerals in the mining horizons. To prove the absence of any significant impact of mining a water sample were taken from Pit 5 and sent for analyses as discussed in **Section 4.3.2.1(A)**. An elevated amount of NO_3 is present in the mine water probably due to blasting. The presence of elevated NO_3 must be confirmed in future analyses. Overall the water in the pit is of good quality and complaint in terms with the SABS 241 Drinking Water Standard or the Environmental Risk Limit from the DWAF Minimum Requirements.

It is important to note that contaminated ground water from the Plant plume is flowing into Pit 1 and Pit 2 which result in a poor quality of water in these pits.

The impact summary is given below:

IMPACT SUMMARY	**Ongoing impact of the Mining Pits on the Ground Water Quality**	
Summary	**Rating**	**Comment**
Extent or Spatial Scale of Impact	LOW	Within Mine Boundary.

IMPACT SUMMARY	Ongoing impact of the Mining Pits on the Ground Water Quality	
Summary	**Rating**	**Comment**
Intensity	LOW	No reactive minerals in rock. Elevated amount of NO_3 probably due to blasting. Mine water quality is however overall fully compliant. No outflow will occur from pit during the operational phase.
Duration	LONG TERM	Beyond lifespan of project.
Mitigatory Potential	HIGH	Mine water can be pumped towards storage facilities or must be contained within confines of pit.
Acceptability	ACCEPTABLE	No risk to public health or to any sensitive environment.
Degree of Certainty	DEFINITE	Water samples tested.
Status of Impact	NEGATIVE	If water interferes with mining, it must be pumped towards storage facilities.
Significance Rating without Mitigation.	LOW	Impact will have small effect on inflowing ground water.
Significance Rating with Mitigation.	LOW	Impact will prevail on inflowing water. Mine water pumped towards storage facilities will prevent flow of water towards surrounding aquifer.
Legal Requirements	REQUIRED	Water Use License.

4.4.2.2 Ongoing impact of Waste Dumps, Effluent Ponds and Water Dams on ground water quality

A detailed geochemical model has been performed by Jasper Müller Associates in order to model the impact of the future Waste Sites and Water Dams on the unsaturated zone. The model report is a stand-alone specialist report, Reference Number XREMP/SSR/17/VER-01/2006. A summary of the geochemical model is given below:

<u>Model Objective</u>

The objective of the geochemical modeling is to determine the hydro-chemical impact of leachate from the sources on the underlying unsaturated zone and to assess the performance of the different lining systems.

The interaction of the following parameters will be modeled:

- Estimated leachate from the different sources.
- Interstitial water in the underlying unsaturated zones.
- The adsorption potential (as determined by the mineralogy) of the host rock in the unsaturated zone.
- The resultant leachate quality to the saturated zone, after interaction between the three sources noted above.

Model Code

For the geochemical modeling the Geochemist' Workbench 6.0 suite was be used. This is the latest release of this internationally recognized software package and consists of 7 software modules: 2 plot programs (Aqplot and Gtplot), a program specifically for speciation calculations (SpecE8), a program for balancing of geochemical reactions (Rxn), 2 programs used to plot stability diagrams (Tact and Act), and a program for geochemical reaction modeling (React).

Model input and assumptions

The detailed model input can be found in the model report attached in the specialist report, Reference Number XREMP/SSR/17/VER-01/2006.

Model Assumption – 1. Unsaturated Zone Mineralogy

The *average* adsorptive mineralogical content of the respective Plant/Calcine Dump area and the Slimes Dam area were used as model input.

A whole rock sampling program was undertaken during the drilling of the geohydrological boreholes. The objective of the sampling was to sample all the major lithological and soil horizons in order to characterize the geochemical/mineralogical properties of the specific horizons for the purpose of the geochemical modeling.

Contamination from overlying sources will leach through the unsaturated zone and the geochemical/mineralogical assessment therefore defines the characteristics of the rock matrix through which contamination will be transported.

The XRD analyses were calibrated with the weighted average XRF analyses. The Fe specifically was corrected by increasing the hematite content. The results for the Plant and Calcine Tailings Dump area are shown in **Table 4.4.2.2(A)** and for the Slimes Dam area in **Table 4.4.2.2(B)** below:

Table 4.4.2.2(A): Comparison of calibrated mineralogy with XRD determined minerals at the Plant/Calcine Dump area.

Minerals	Weighted Average XRD Analyses (wt%)	Calibrated Mineralogy used in model
Calcite	1.68	1.00
Quartz	4.88	2.50
Anorthite	66.35	66.35
Augite	7.76	3.50
Smectite (High Fe, Mg)	5.58	5.58
Kaolinite	4.69	4.69
Clinochlore	1.35	1.35
Hematite	1.51	9.00
V_2O_5	-	0.07
Pyrolusite MnO_2	-	0.08
Rutile	0.27	0.10
Magnetite	4.08	4.08
Ilmenite	1.84	1.70
	100.00	**100.00**

Table 4.4.2.2(B): Comparison of calibrated mineralogy with XRD determined minerals at the Slimes Dam area.

Minerals	Weighted Average XRD Analyses (wt%)	Calibrated Mineralogy used in model
Quartz	28.79	10.53
Calcite	0.74	0.82
Kaolinite	18.35	20.35
Hematite	4.41	19.96
Anorthite	28.72	28.83
Augite	6.38	2.22
Rutile	0.72	0.18
Clinochlore	1.65	1.83
Magnetite	3.90	4.32
Smectite (High Fe, Mg)	1.24	1.37
Ilmenite	4.45	4.93
Lizardite	0.65	-
Gibbsite	-	4.44
V_2O_5	-	0.06
Pyrolusite MnO_2	-	0.17
	100.00	100.00

Model Assumption – 2. Interstitial Water

The chosen background ground water at Rhovan was used in the model as the interstitial water present in the unsaturated zone.

A discussion on the background ground water quality can be found in **Section 3.3.1** of this report.

The average background ground water is given in **Table 4.4.2.2(C)** below. The chosen average for the model is shown in the far right column.

Table 4.4.2.2(C): Background ground water at Xstrata Rhovan.

Parameter	Minimum	Probable Maximum	Average	Harmonic mean	Geometric mean	Chosen Average for Model
pH	6.6	8.8	7.8	7.8	7.8	7.8
EC (*mS/m*)	18	124	75	68	72	75
TDS (*mg/l*)	108	868	490	446	468	490
Ca (*mg/l*)	12	160	65	55	60	65
Mg (*mg/l*)	5	90	33	27	30	33
Na (*mg/l*)	11	106	37	30	33	37
K (*mg/l*)	0.4	11.9	3.2	1.8	2.4	3.2
Si (*mg/l*)	2	37	20	12	16	20
T-Alk (*mg/l*)	35	478	212	163	188	212
Cl (*mg/l*)	10	149	71	54	64	71
SO_4 (*mg/l*)	5	197	71	39	55	71
N (*mg/l*)	0.010	6.000	2.635	0.127	1.239	0.127
F (*mg/l*)	0.010	1.000	0.286	0.147	0.227	0.286
Al (*mg/l*)	0.010	0.250	0.089	0.024	0.051	0.051
Fe (*mg/l*)	0.010	116.000	11.284	0.041	0.361	0.361
Mn (*mg/l*)	0.010	0.770	0.129	0.027	0.057	0.027
V (*mg/l*)	0.010	0.500	0.092	0.027	0.044	0.092

Model Assumption – 3. Leachate Quality and Quantity From Source

The latest analyses (March 2005) of the fluid component of the sources are representative of the potential leachate quality from these sources. The leachate quantity from the source is that from DWAF specifications for lining systems as modeled with Visual HELP.

Table 4.4.2.2(D) gives the latest analyses of the fluid component of the sources. These qualities were used as the leachate quality from the sources in the geochemical model.

Table 4.4.2.2(D) Analyses of fluid component in sources March 2005

Parameter	Calcine Heap Leach	Slimes Dam (Return Water Dam)	Scrubber Pond No. 1	Purge Water Dam No. 1	Ericsson Return Water Dam	Storm Water Dam No. 3	SABS 241 Unacceptable Upper Limit (mg/l)	Acceptable Environ. Risk (ppm)
pH	10.2	8.0	4.2	5	9.7	9.7	4.0-10.0	-
EC (*mS/m*)	1938	69	27190	53800	1469	1497	370	-
TDS (*mg/l*)	20694	470	166282	448400	14834	15354	2400	-
TAlk as $CaCO_3$ (*mg/l*)	5400	84	<5	128	2900	3436	-	-
NH_4 as N(*mg/l*)	< 0.2	-	9660	35560	<0.2	<0.2	2	-
NO_3 as N(*mg/l*)	183	-	50	4425	258	159	20	-
Cl (*mg/l*)	239	70	14269	16750	201	191	600	-
SO_4 (*mg/l*)	6021	72	89795	312420	5393	6454	600	-
Si (*mg/l*)	66	11	97	87	49	46	-	-
F (*mg/l*)	20	0.2	959	78	15	13	1.5	-
Na (*mg/l*)	6172	51	37770	108300	4433	4547	400	-
K (*mg/l*)	26	2.8	513	4284	18.4	22	100	-
Ca (*mg/l*)	12	53	656	175175	62	41	300	-
Mg (*mg/l*)	51	21	1030	645	97	54	100	-
Al (*mg/l*)	0.085	<0.100	637	0.528	<0.100	0.471	0.5	0.39
Cr (*mg/l*)	0.085	<0.025	2.29	0.495	0.153	0.082	0.5	4.7 Cr(III)
Fe (*mg/l*)	0.177	0.036	1009	0.171	0.132	0.286	2	9
Mn (*mg/l*)	0.046	<0.025	32	0.773	0.03	0.033	1	0.3
Ti (*mg/l*)	3.6	<0.08	1.21	8.7	1.8	1.9	-	-
V (*mg/l*)	1732	<0.03	375	54	1277	1532	0.5	1.3
Zn (*mg/l*)	0.034	<0.025	3.4	7.73	0.037	0.056	10	0.7
%Balancing	85.3	97.3	95.1	99.2	86.8	90.8	-	-

The Visual HELP software was used to model the quantities of leachate from the sources. The HELP modeling was also discussed in **Section 4.4.1.2**. The H:H Lagoon and the G:L:B$^+$ is the liner systems that will probably be used the most at Xstrata Rhovan. For a good constructed H:H Lagoon system the drainage will be 0.861 mm/year per unit area (about 0.16% of rainfall – keep in mind that the lagoon have a nearly constant head on top and is independent on the meteorological water balance). For a G:L:B$^+$ liner it will be 5.394 mm/year per unit area or nearly 1% of rainfall.

Model Assumption – 4. Geometry of physical model

The chosen average geometry and physical parameters is representative of the whole area.

The model time was set to 20 Residence Times. One Residence Time is the time it will take for infiltrating leachate to replace the total volume of interstitial water.

The model results show the change in the average composition of the interstitial water in the unsaturated zone. It therefore also shows the quality of the water that percolates from the unsaturated zone towards the underlying saturated zone.

Model Assumption – 5. Adsorption as mechanism in the unsaturated zone

Because of the disequilibrium state of the infiltrating leachate from the sources, no precipitation, as a result of equilibrium reactions, were allowed and adsorption was taken as the only mechanism present in the unsaturated zone.

Adsorption was used as the only mechanism that would remove some contamination in the unsaturated zone. Because the fluid component of the sources is in a state of disequilibrium, precipitation, as a result of equilibrium reactions were not allowed. Adsorption is seen as an electrostatic property of the adsorption minerals in the unsaturated zone.

Model Results

The model time was set to 20 Residence Times. One Residence Time is the time it will take for infiltrating leachate to replace the total volume of interstitial water. The estimated time span of 20 Residence Times depends on the amount of leachate from the sources which is again dependant on the type of lining used. The estimated time span for G:L:B+ liners and Hazardous Waste liners is given in **Table 4.4.2.2(E)** below:

Table 4.4.2.2(E): Estimated Leachate and Residence Time for potential liners below the Waste Sites and Water Dams.

Liner/Liner system	Modeled Leachate (mm/a)	Estimated time span of one Residence Time (years)	Time span of 20 Residence Times (years)
G:L:B$^+$	5.394	250	5000
Hazardous Waste Lining System	0.861	1500	30000

The fraction of the fluid components adsorbed in the unsaturated zone beneath every Waste Site and Water Dam is given in **Figures 4.4.2.2(A) to (F)** below. Please refer to the geochemical specialist report, Reference Number XREMP/SSR/17/VER-01/2006 for other detailed model results.

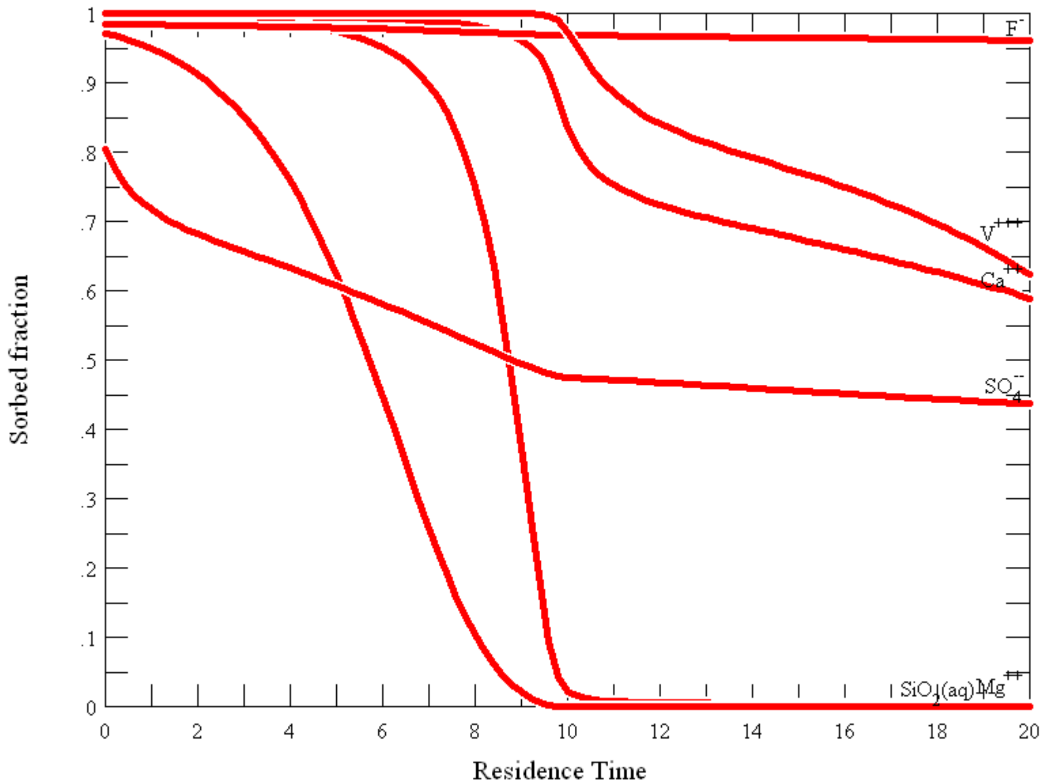


Figure 4.4.2.2(A): Fraction of some fluid components adsorbed in the unsaturated zone below the Calcine Dump.

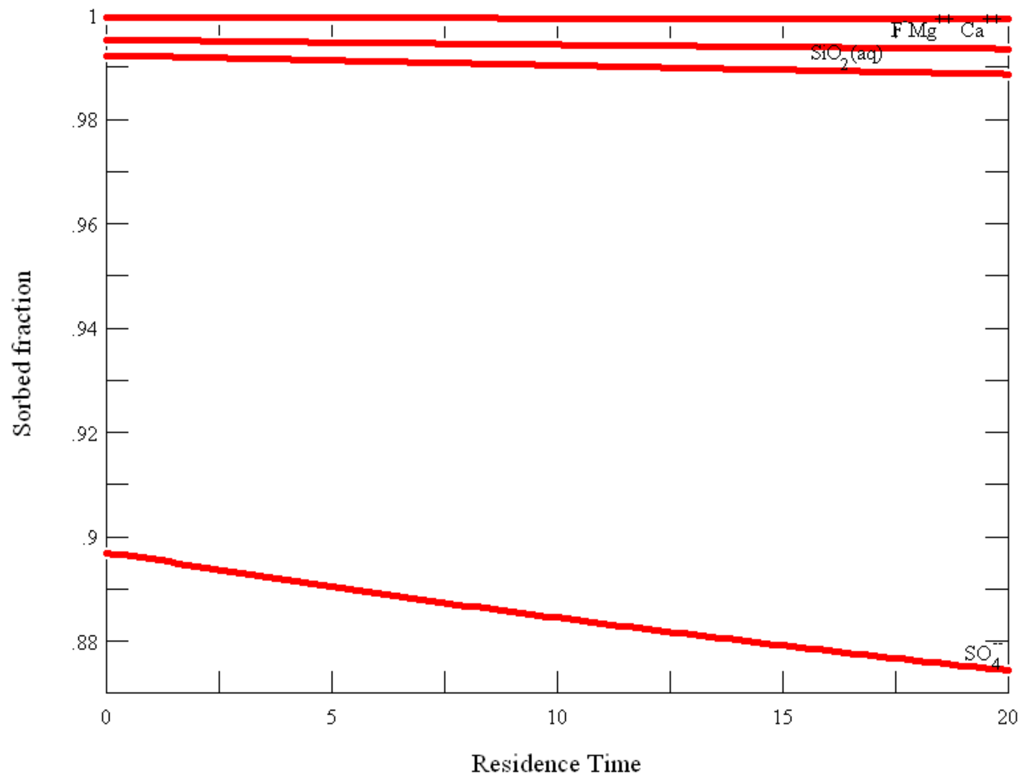


Figure 4.4.2.2(B): Fraction of some fluid components adsorbed in the unsaturated zone below the Slimes Dam.

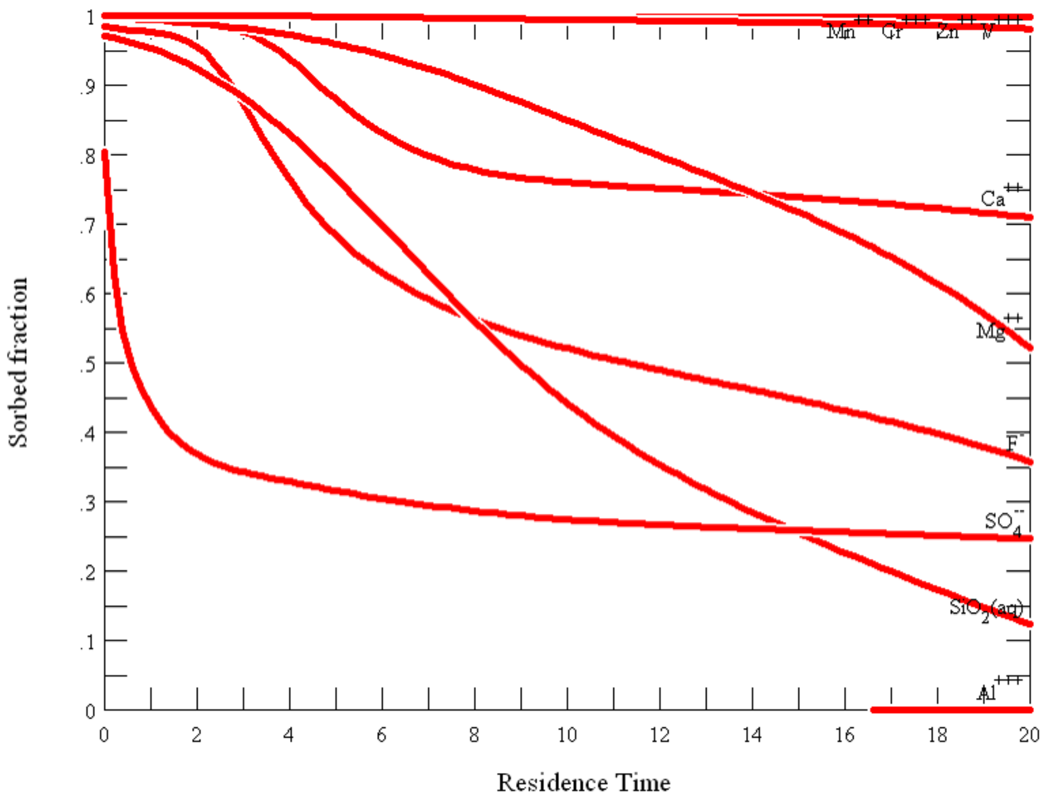


Figure 4.4.2.2(C): Fraction of fluid components sorbed in the unsaturated zone below the Scrubber Pond.

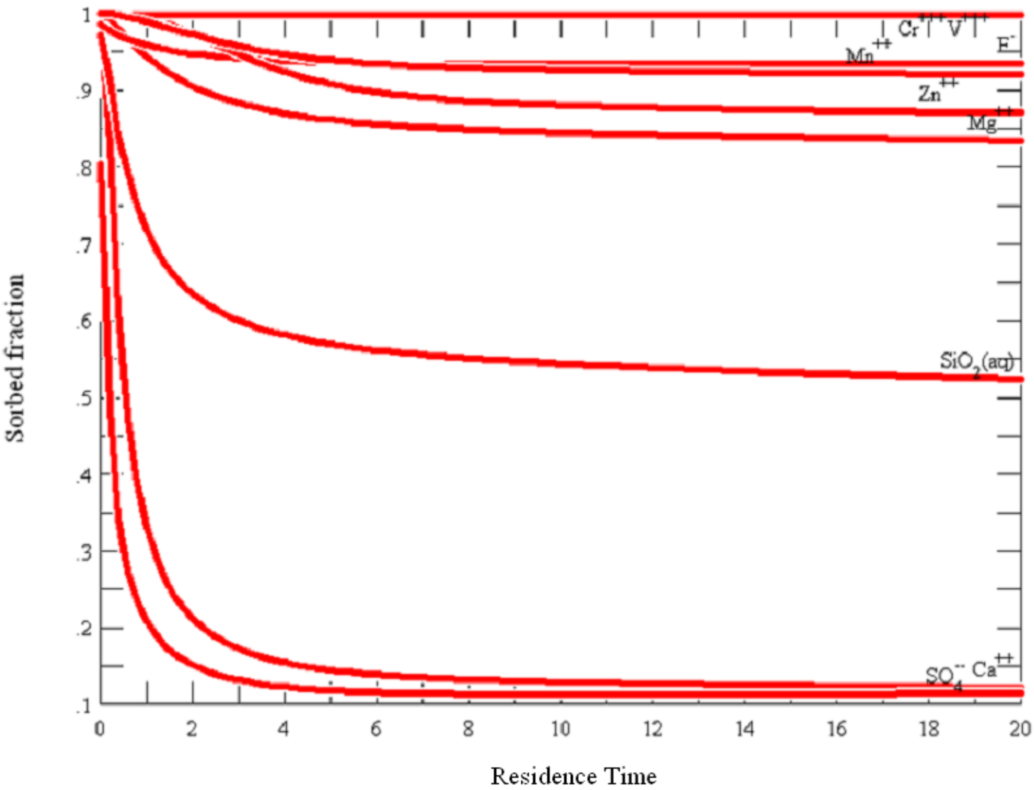


Figure 4.4.2.2(D): Fluid components sorbed in the unsaturated zone below the Purge Dam.

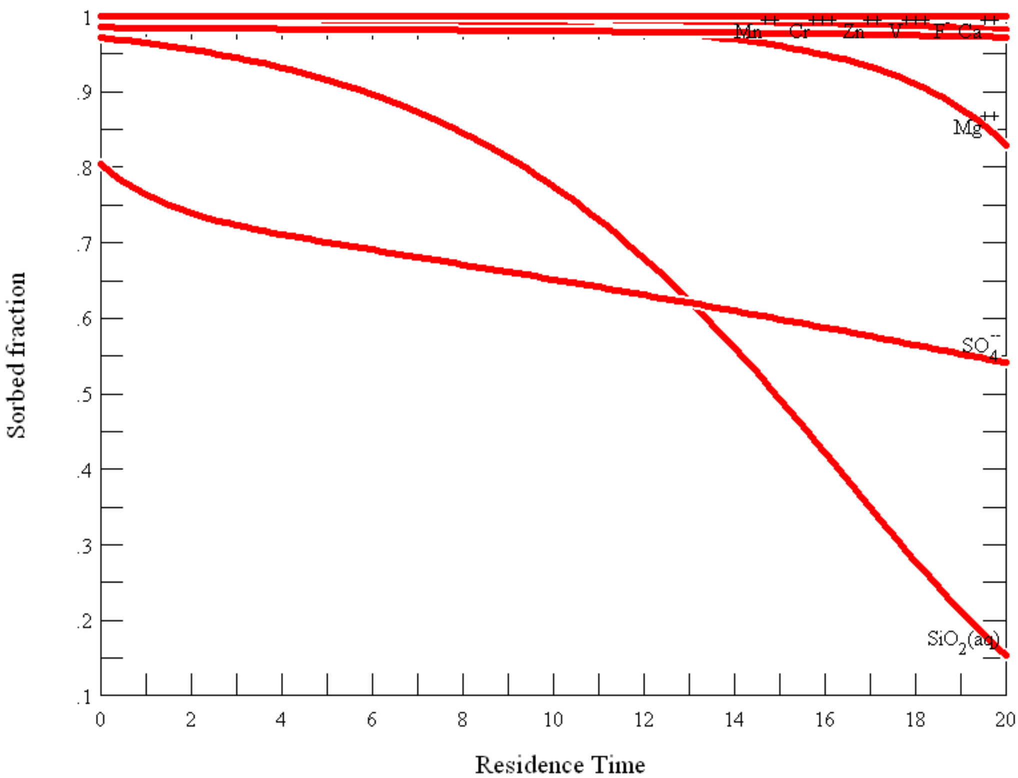


Figure 4.4.2.2(E): Fluid components sorbed in the unsaturated zone below the Ericsson Dam.

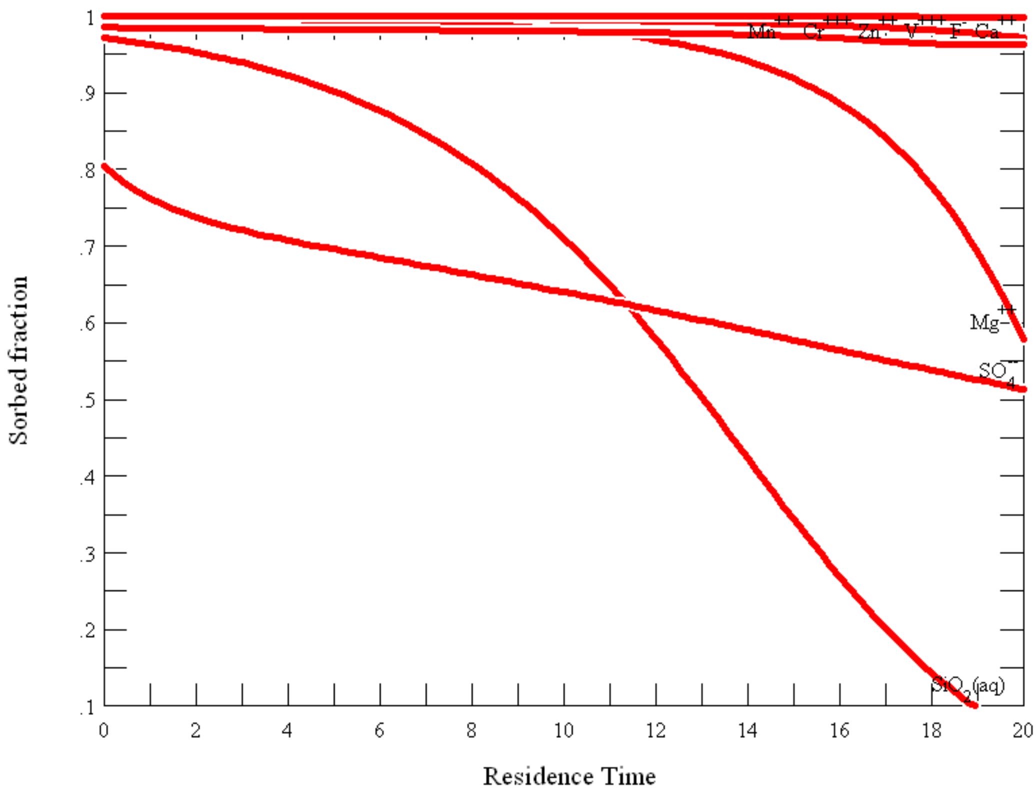


Figure 4.4.2.2(F): Fluid components sorbed in the unsaturated zone below the Dirty Storm Water Dams.

Model Conclusions

The following conclusions could be made with regard to the model results shown in **Table 4.4.2.2(E)** and in **Figures 4.4.2.2(A) to (F)** above, as well as those in the model attached in the specialist report, Reference Number XREMP/SSR/17/VER-01/2006:

- The volume of leachate is dependant on the type of the lining system used. The lower the grade of the liner (e.g. $G:L:B^+$ instead of Hazardous Waste Liner), the less contaminated leachate will be absorbed/collected by the lining system and therefore the higher the volume of leachate will be that infiltrates through the unsaturated zone towards the saturated zone. The final decision on the lining system used at Xstrata Rhovan must be agreed upon with the relevant authorities.

- The soil at Rhovan is suitable for the use in lining systems from a geochemical perspective. Not only does it contain clays that will reduce the permeability in the lining systems, but it also contains a fair amount of iron oxides, e.g. hematite, that could adsorb some contaminants, especially metals.

- The unsaturated zone below the Calcine Dump will adsorb V and F significantly and the only parameters of concern left are NO_3, SO_4 and Na. These parameters are not listed under the Acceptable Risk Limit of the DWAF Minimum Requirements. However, NO_3, SO_4 and Na must still be prevented to be introduced into the ground water environment in non-compliant quantities. It is therefore recommended that future developments of the Calcine Dump are therefore lined with a Hazardous Waste Site lining system.

- The Dirty Storm Water Dams and Calcine Return Water Dam have almost exactly the same Chemicals of Concern than the Calcine Dump. V and F will be significantly adsorbed in the unsaturated zone below these dams and the only Chemicals of Concern therefore are NO_3, SO_4 and Na. These dams must be treated the same as the Calcine Dump and it is also recommended that they are reconstructed with a Hazardous Waste Site lining system.

- The Scrubber Dams and Purge Dams are identified as the major polluters of the ground water environment currently at Xstrata Rhovan. V, Mn and Zn will be significantly adsorbed in the unsaturated zone below these ponds but various Chemicals of Concern, e.g. NH_4, NO_3, Cl, SO_4, F, Na, K, Al, can potentially reach the saturated zone. It is recommended that the existing ponds are reconstructed as Hazardous Waste Site lining systems.

- **Table 4.4.2.2(F)** below summarizes the recommended lining systems and the Chemicals of Concern of Waste sites and Water Dams at Xstrata Rhovan:

Table 4.4.2.2(F) Recommended lining systems and Chemicals of Concern of waste sites at Xstrata Rhovan.

Waste Site	**Identified Chemicals of Concern (CoC) in analyses**	**CoC significantly adsorbed in unsaturated zone***	**CoC that can potentially leach in non-compliant quantities towards the saturated zone****	**Recommended Lining*****
Calcine Dump	NO_3, SO_4, F, Na, V	V, F	NO_3, SO_4, Na	Hazardous Waste Site
Slimes Dam	None	-	None	Drains for stability
Slimes Return Water Dam	None	-	None	Drains for stability
Storm Water Dam No. 1	None	-	None	Drains for stability
Scrubber Ponds	NH_4, NO_3, Cl, SO_4, F, Na, K, Ca, Mg, Al, Fe, Mn, V, Zn	Mn, V, Zn	NH_4, NO_3, Cl, SO_4, F, Na, K, Al, Fe	Hazardous Waste Site
Purge Water Dams	NH_4, NO_3, Cl, SO_4, F, Na, K, Ca, Mg, Al, Mn, V, Zn	Mn, V, Zn	NH_4, NO_3, Cl, SO_4, Ca, F, Na, K, Al	Hazardous Waste Site

Waste Site	Identified Chemicals of Concern (CoC) in analyses	CoC significantly adsorbed in unsaturated zone*	CoC that can potentially leach in non-compliant quantities towards the saturated zone**	Recommended Lining***
Calcine Return Water (Ericsson) Dam	NO_3, SO_4, F, Na, V	V, F	NO_3, SO_4, Na	Hazardous Waste Site
Dirty Storm Water Dams	NO_3, SO_4, F, Na, Al, V	V, F	NO_3, SO_4, Na	Hazardous Waste Site

*At least 90% of the parameters are adsorbed during 10 modeled Residence Times in the unsaturated zone.

**These parameters reach non-compliance in the unsaturated zone within only 1 modeled Residence Times in numerical modeling. Non-compliance is either in terms of the Acceptable Risk Limit (from DWAF Minimum Requirements) or the SABS 241 Drinking Water Standard.

***The final decision on the lining system used at Xstrata Rhovan must be agreed upon with the relevant authorities.

- The final conclusion is that if proper lining systems are installed for future Waste Sites and Water Dams at Xstrata Rhovan, the impact on the underlying aquifer will be minute and acceptable.

Impact Summary

As long as the status quo of the current sites continue, they will impact on the underlying aquifer as assessed in **Section 4.3.2.2**.

No impact is observed from boreholes at the Slimes Dam or the Slimes Return Water Dam (RWD) as specified in **Table 4.3.2.2(A) and Figures 4.3.2.2(A) to (C),** or from the geochemical modeling. The current lining and leachate collection system for the Slimes Dam and the Slimes RWD is therefore adequate and future developments can be constructed according to similar designs. The main design criteria would be to incorporate drainage systems to achieve dam stability and safety. The impact summary is given below:

IMPACT SUMMARY	**Current and ongoing impact of the Slimes Dam and the Slimes RWD on the Ground Water Quality**	
Summary	**Rating**	**Comment**
Extent or Spatial Scale of Impact	LOW	Within Site Boundary.
Intensity	LOW	Clean water added to aquifer.

IMPACT SUMMARY	**Current and ongoing impact of the Slimes Dam and the Slimes RWD on the Ground Water Quality**	
Summary	**Rating**	**Comment**
Duration	LONG TERM	Beyond lifespan of project.
Mitigatory Potential	HIGH	High potential to mitigate negative impact.
Acceptability	ACCEPTABLE	No risk to public health or to any sensitive environment.
Degree of Certainty	DEFINITE	Leaching is taking place to underlying aquifer.
Status of Impact	NEUTRAL	No positive or negative results of impact.
Significance Rating without Mitigation	LOW	Impact will have small effect on surrounding ground water environment.
Significance Rating with Mitigation	LOW	Although mitigation measures such as leachate capturing and monitoring are in place, the impact will still have a small effect on surrounding ground water environment.
Legal Requirements	REQUIRED	Water Use License.

It is evident from **Table 4.3.2.2(A) and Figures 4.3.2.2(A) to (C)** that an impact is currently present at the Plant Area and the Calcine Dump Area in the form of a plume that extends towards the Tshukutswe River. A potential for the generation of large quantities was confirmed with geochemical modeling. As long as the status quo of the current waste sites at the Plant and Calcine Area proceeds, so long will they impact on the underlying aquifer as assessed in **Section 4.3.2.2**. The impact summary is given below for the continuation of the status quo:

IMPACT SUMMARY	**Current impact of the FeV Slag Dump, the Calcine Dump, the Calcine RWD, the Dirty SWDs, the Purge Dams and the Scrubber Ponds on the Ground Water Quality until reconstruction**	
Summary	**Rating**	**Comment**
Extent or Spatial Scale of Impact	MEDIUM	Impact will extend beyond local area of impact but still within site boundary.
Intensity	HIGH	Contaminated leachate added to aquifer from Waste Sites.
Duration	SHORT TERM	Extension of these waste sites will be reconstructured to a large degree. Remediation of current impact must be completed also over short term.

IMPACT SUMMARY	Current impact of the FeV Slag Dump, the Calcine Dump, the Calcine RWD, the Dirty SWDs, the Purge Dams and the Scrubber Ponds on the Ground Water Quality until reconstruction	
Summary	**Rating**	**Comment**
Mitigatory Potential	HIGH	High potential to mitigate future negative impact. Current residue/plume must be remediated.
Acceptability	UNACCEPTABLE	Redesign extensions dumps/lagoons/ dams in order to remove ongoing impact.
Degree of Certainty	DEFINITE	Leaching is taking place to underlying aquifer.
Status of Impact	NEGATIVE	Funds must be allowed for remediation of aquifer and upgrading of lining systems.
Significance Rating without Mitigation	HIGH	Impact has a negative effect on surrounding ground water environment.
Significance Rating with Mitigation	HIGH	Although mitigation measures such as leachate detection and monitoring is present, the impact will still have a negative effect on surrounding ground water environment as long as the status quo prevails. This will reduce to a low impact as the ground water abstraction scheme is implemented.
Legal Requirements	REQUIRED	Water Use License.

From the geochemical modeling attached in the specialist report, Reference Number XREMP/SSR/17/VER-01/2006, it is recommended that the Purge Dams, the Scrubber Ponds, the Dirty Storm Water Dams (SWD), the future Calcine Dump extension and the Calcine Return Water Dam (RWD) be constructed according to the DWAF Minimum Requirements Specifications for H:H and H:H Lagoon systems or another appropriate configuration agreed upon by DWAF for Hazardous Waste Sites.

More details on the mitigation measures are given in **PART 7** of this document. The reconstruction of these waste sites according to appropriate lining systems would imply that the absolute minimum leachate will take place as modeled above. The impact summary is given below:

IMPACT SUMMARY	**Impact of future FeV Slag Dump, the Purge Dams, Scrubber Ponds, Dirty SWD, Calcine Dump and Calcine RWD on the Ground Water Quality. Sites constructed according to DWAF Minimum Requirements specifications.**	
Summary	**Rating**	**Comment**
Extent or Spatial Scale of Impact	LOW	Within Site Boundary.
Intensity	MEDIUM	Small quantity of leachate.
Duration	MEDIUM/LONG TERM	Lifespan of project for all sites except for Calcine Dump.
Mitigatory Potential	LOW	High potential to mitigate negative impact.
Acceptability	ACCEPTABLE	Full legal compliance of constructed lining systems.
Degree of Certainty	PROBABLY	The amount of leachate may be more/less than modeled depending on the construction integrity.
Status of Impact	NEGATIVE	Cost involved in leachate capturing and future lining construction.
Significance Rating without Mitigation.	MEDIUM	The liner systems will require some management measures (e.g. leachate collection) without which the impact will increase.
Significance Rating with Mitigation.	LOW	Mitigation measures such as leachate collection and monitoring is vital. However a small quantity of seepage towards the underlying aquifer will still be present as modeled.
Legal Requirements	REQUIRED	Water Use License.

4.4.2.3 Ongoing impact on ground water resource quality

There is currently no external user's of ground water around Xstrata Rhovan in a 1 km radius as discussed in **Section 4.3.2.4.** Bethanie, Berseba and Modikwe are respectively situated 1.6 km north-east, 4.6 km and 6 km north-west of the Rhovan Plant Area. Except for the external user's boreholes at Bethanie, Berseba and Modikwe one borehole, GWE-6, is situated 2 km south of the Rhovan Plant Area.

No impact of Rhovan is currently present on external users. Since Xstrata Rhovan is committed to the remediation of current contamination on the site and mitigation of all future impact, the risk towards the external user's and towards the environment should be addressed during ongoing operations. The impact summary is given below:

IMPACT SUMMARY	**Ongoing impact of Xstrata Rhovan activities on the quality of ground water available to external user's**	
Summary	**Rating**	**Comment**
Extent or Spatial Scale of Impact	LOW	Impact small and within site boundary.
Intensity	LOW	No current user's in site boundary. However, some of the ground water is not fit for use. Ongoing remediation will aim to adjust this.
Duration	MEDIUM	Lifespan of project.
Mitigatory Potential	HIGH	Active remediation measures will be put into place for aquifer clean-up.
Acceptability	MANAGEABLE	No risk to public health or to any sensitive environment currently. However remediation actions will be put into place for the remediation of the plume.
Degree of Certainty	UNSURE	It is unsure if there will ever be an impact on external user's.
Status of Impact	NEUTRAL	No impact is currently present.
Significance Rating without Mitigation.	LOW	No current risk to external user's.
Significance Rating with Mitigation.	LOW	Remediation actions will be put into place for the remediation of the plume within the site boundary.
Legal Requirements	NO	None.

4.4.2.4 Ongoing impact of ground water on surface water quality

The largest concern is the plume that extends from the Plant/Calcine Area towards the Tshukutswe River as shown in **Figure 4.3.2.2(C)**. As discussed in **Section 4.3.2.4** it was however found that the Tshukutswe River is not a discharge boundary for the fractured aquifer and that contaminated ground water is contained only in the fractured aquifer.

Finally it must be concluded that although no current impact exist on the Tshukutswe River, the River must be protected from any contamination especially since the river flows towards the Bethanie settlement. The protection of the river must be part of the ground water remediation objectives at Xstrata Rhovan. No wetlands or pans exist that would be contaminated by the plume.

Since Xstrata Rhovan is committed to the remediation of current contamination on the site and mitigation of all future impact, the risk towards the environment should be addressed during ongoing operations. The impact summary is given below:

IMPACT SUMMARY	**Ongoing impact of the plume on the Tshukutswe River water quality**	
Summary	**Rating**	**Comment**
Extent or Spatial Scale of Impact	INSIGNIFICANT	Within Site Boundary.
Intensity	INSIGNIFICANT	No current impact is detected.
Duration	MEDIUM TERM	Lifespan of project.
Mitigatory Potential	NONE NECESSARY	-
Acceptability	ACCEPTABLE	No risk to public health or to any sensitive environment.
Degree of Certainty	DEFINITE	No current impact is detected.
Status of Impact	NEUTRAL	No positive or negative results of impact.
Significance Rating without Mitigation.	INSIGNIFICANT	No impact is identified.
Significance Rating with Mitigation.	INSIGNIFICANT	No mitigation measures applicable.
Legal Requirements	NOT APPLICABLE	None.

4.5 POST-CLOSURE PHASE (RESIDUAL/REMEDIAL) IMPACT ASSESSMENT

4.5.1 Post-closure impact on ground water quantity

4.5.1.1 Post-closure impact of Mining Pits on ground water quantity

At Xstrata Rhovan a total of 4 mining pits will be present post-closure. At the end of the operational phase the mine backfilling will be completed and the mines will be rehabilitated. The calculated ground water inflow into the existing pits is given in **Table 4.5.1.1(A)** below:

Table 4.5.1.1(A): Calculated post-closure ground water inflow into open pit mining.

Mining Pit	Total Ground Water Influx (m^3/a)	Total Ground Water Influx (m^3/d)
Pit 1	28,744	78.75
Pit 2	19,710	54.00
Pit 4 and 6	22,037	60.38
Pit 5	60,567	165.94
Total	**131,058**	**359**

A resultant ground water gradient is created during the operational phase between the surrounding ground water aquifer and the mining pit floor. Ground water will therefore flow into the mine post-closure and the rate of influx will be a function of the gradient towards the mine, the hydraulic conductivity of the weathered gabbro and the influx area between the aquifer and the mining pits. Inflowing ground water will result in a cone of depression around the pit of not further than 250 m.

As the mining pits are flooded post-closure, the pit water level will eventually reach the surface decant point of the mine. The position of the decant points are given in **Figure 4.5.2.1(A)**.

The impact summary is given below:

IMPACT SUMMARY	**Post-closure impact of the Mining Pits on the Ground Water Quantity**	
Summary	**Rating**	**Comment**
Extent or Spatial Scale of Impact	LOW	Within Site Boundary.
Intensity	LOW	Cone of depression of <250 m around pits.
Duration	LONG-TERM	Geology is permanently changed in confines of mine.

IMPACT SUMMARY	Post-closure impact of the Mining Pits on the Ground Water Quantity	
Summary	**Rating**	**Comment**
Mitigatory Potential	NONE	Mining is completed.
Acceptability	ACCEPTABLE	No risk to public health or to any sensitive environment.
Degree of Certainty	DEFINITE	Ground water inflow into the pit is a given.
Status of Impact	NEGATIVE	Water level lowered around pit.
Significance Rating without Mitigation	LOW	Impact will have small effect on surrounding ground water environment.
Significance Rating with Mitigation	LOW	Although no mitigation possible, impact will still have a small effect on surrounding ground water environment.
Legal Requirements	REQUIRED	Closure Certificate.

4.5.1.2 Post-closure quantity of leachate created by Waste Dumps, Effluent Ponds and Water Dams

Small Hazardous Waste Dumps, Effluent Ponds and Water Dams will be demolished and the surface will be rehabilitated during the decommissioning phase. This includes the Purge Dams, the Scrubber Ponds, the Storm Water Dams (SWD) and the Calcine Return Water Dam (RWD).

No impact is observed from **Table 4.3.2.2(A) and Figures 4.3.2.2(A) to (C)** at the Slimes Dam or the Slimes Return Water Dam (RWD) from chemistry samples taken from boreholes. The Slimes Dam will be rehabilitated in order to minimize the volume of infiltrating water. The leachate will be collected and be monitored post-closure. The impact summary is given below:

IMPACT SUMMARY	Post-closure impact of the Slimes Dam and the Slimes RWD on the Ground Water Quantity	
Summary	**Rating**	**Comment**
Extent or Spatial Scale of Impact	LOW	Within Site Boundary.
Intensity	LOW	Clean water added to aquifer.
Duration	MEDIUM TERM	Lifespan of project.

IMPACT SUMMARY	**Post-closure impact of the Slimes Dam and the Slimes RWD on the Ground Water Quantity**	
Summary	**Rating**	**Comment**
Mitigatory Potential	HIGH	High potential to mitigate negative impact.
Acceptability	ACCEPTABLE	No risk to public health or to any sensitive environment.
Degree of Certainty	DEFINITE	Leaching is taking place to underlying aquifer.
Status of Impact	NEUTRAL	No positive or negative results of impact.
Significance Rating without Mitigation	LOW	Impact will have small effect on surrounding ground water environment.
Significance Rating with Mitigation	LOW	Mitigation measures such as leachate capturing and monitoring will be performed until site closure.
Legal Requirements	REQUIRED	Closure certificate.

The large Calcine Dump will be constructed during the operational phase as an H:H facility, and will also be closed upon decommissioning to H:H standard. This would imply that the absolute minimum leachate will take place as modeled in **Section 4.4.1.2**.

The impact summary is given below:

IMPACT SUMMARY	**Post-closure impact of the Calcine Dump on the Ground Water Quantity**	
Summary	**Rating**	**Comment**
Extent or Spatial Scale of Impact	LOW	Within Site Boundary.
Intensity	LOW	Small quantity of leachate.
Duration	LONG TERM	Beyond lifespan of project.
Mitigatory Potential	LOW	Low potential to mitigate negative impact.
Acceptability	ACCEPTABLE	Full legal compliance of constructed lining system.
Degree of Certainty	PROBABLY	The amount of leachate may be more/less than modeled depending on the construction integrity.
Status of Impact	NEGATIVE	Cost involved in disposal to pollution control facilities.

IMPACT SUMMARY	Post-closure impact of the Calcine Dump on the Ground Water Quantity	
Summary	**Rating**	**Comment**
Significance Rating without Mitigation	MEDIUM	The liner systems will require some management measures (e.g. leachate collection) without which the impact will increase.
Significance Rating with Mitigation	LOW	Mitigation measures such as H:H capping, leachate capturing and monitoring will be performed until site closure.
Legal Requirements	REQUIRED	Closure certificate.

4.5.1.3 Post-closure impact on ground water resource quantity

Bethanie, Berseba and Modikwe are respectively situated 1.6 km north-east, 4.6 km and 6 km north-west of the Rhovan Plant Area. These communities mainly rely on bulk water supply from Magalies Water Board since 1997. Boreholes are now used as standby for periods of technical problems with the main water supply. However, private boreholes are still used for domestic purposes such as laundry, garden watering etc.

Except for the external user's boreholes at Bethanie, Berseba and Modikwe one borehole, GWE-6, is situated 2 km south of the Rhovan Plant Area.

Basic information of all external users' boreholes is given in **Table 3(B)** attached in **APPENDIX 3.**

There is no external user's of ground water around Xstrata Rhovan in a 1 km radius. The impact on the ground water use therefore has post-closure/long term objectives. Because of the small scale of mining and because of the small volumes of current ground water influx, the impact on the water quantity at Rhovan is small. A cone of depression will not extend more than 250 m from the mine.

The impact summary is given below:

IMPACT SUMMARY	Post-closure impact of Xstrata Rhovan activities on the quantity of ground water available to external user's	
Summary	**Rating**	**Comment**
Extent or Spatial Scale of Impact	LOW	Impact small and within site boundary.
Intensity	LOW	Cone of depression <250 m from mine.

IMPACT SUMMARY	**Post-closure impact of Xstrata Rhovan activities on the quantity of ground water available to external user's**	
Summary	**Rating**	**Comment**
Duration	LONG-TERM	Beyond lifespan of project.
Mitigatory Potential	LOW	No mitigation measures applicable.
Acceptability	ACCEPTABLE	No risk to public health or to any sensitive environment.
Degree of Certainty	UNSURE	It is unsure if there will ever be an impact on external user's
Status of Impact	NEUTRAL	Impact currently doesn't have any positive or negative effects.
Significance Rating without Mitigation	LOW	Impact on ground water quantity in the site boundary is small.
Significance Rating with Mitigation	LOW	No mitigation measures applicable.
Legal Requirements	NO	No impact expected.

4.5.1.4 Post-closure impact on ground water quantity towards surface water features

No wetlands or pans exist that is dependant on ground water flow. Because of the smaller scale of mining and because of the distance to the rivers, mining have no impact on the baseflow of ground water towards the rivers. Pit 4, 5 and 6 is situated more than 2 km east of the Gwathle River and Pit 1 and 2 more than 400 m west of the Tshukutswe River. The impact summary is given below:

IMPACT SUMMARY	**Post-closure impact of Xstrata Rhovan on river baseflow**	
Summary	**Rating**	**Comment**
Extent or Spatial Scale of Impact	INSIGNIFICANT	Within Site Boundary.
Intensity	INSIGNIFICANT	No current impact is detected and because the impact on the aquifer will decrease because of future remediation, no ongoing or post-closure impact on the river is foreseen.
Duration	LONG-TERM	Beyond lifespan of project.
Mitigatory Potential	NONE NECESSARY	-

IMPACT SUMMARY	Post-closure impact of Xstrata Rhovan on river baseflow	
Summary	**Rating**	**Comment**
Acceptability	ACCEPTABLE	No risk to public health or to any sensitive environment.
Degree of Certainty	DEFINITE	No future impact is possible.
Status of Impact	NEUTRAL	No positive or negative results of impact.
Significance Rating without Mitigation	INSIGNIFICANT	No impact is identified.
Significance Rating with Mitigation	INSIGNIFICANT	No mitigation measures applicable.
Legal Requirements	NOT APPLICABLE	-

4.5.2 <u>Post-closure impact on ground water quality</u>

4.5.2.1 Post-closure impact of Mining Pits on ground water quality

At Xstrata Rhovan a total of 4 mining pits will be present post-closure. At the end of the operational phase the mine backfilling will be completed and the mines will be rehabilitated. As the mining pits are flooded post-closure, the pit water level will eventually reach the surface decant point of the mine. The position of the decant points are given in **Figure 4.5.2.1(A)** below.

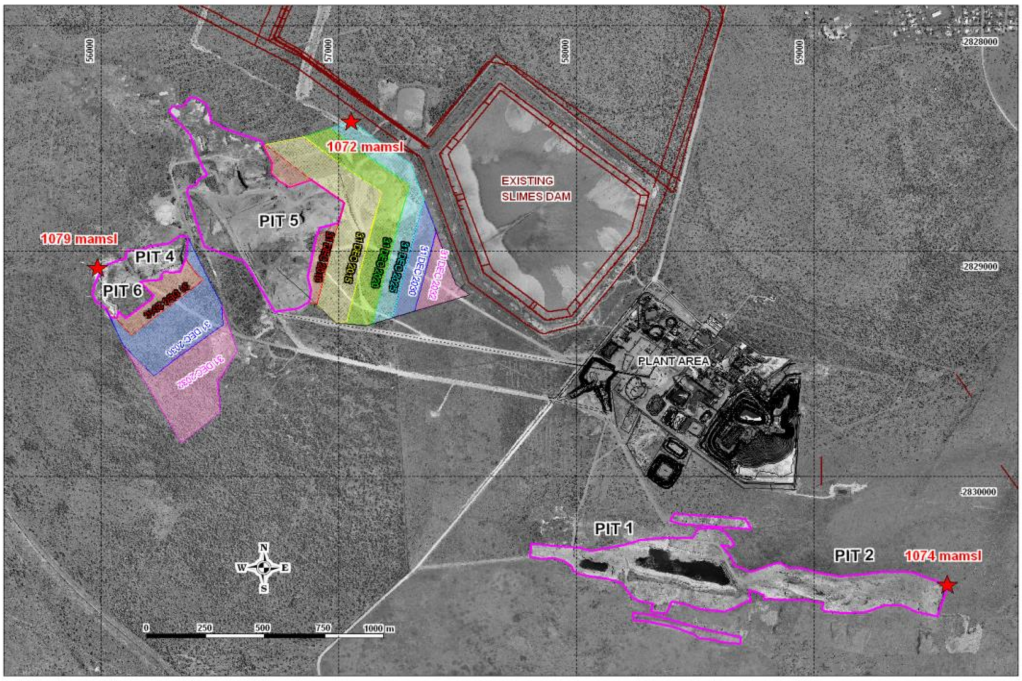


Figure 4.5.2.1(A): Position of mine surface decant points at Xstrata Rhovan.

As discussed in **Section 4.3.2.1** mine water from Pit 4, 5 and 6 will be of good quality similar to that measured in Pit 5 as given in **Table 4.3.2.1(A)**. The mine water in Pit 1 and Pit 2 will however be contaminated during the operational phase with ground water influx from the Plant plume. Water decanting from the pits, especially from Pit 1 and Pit 2, must be pumped towards pollution control facilities.

The impact summary is given below:

IMPACT SUMMARY	**Post-closure impact of Mining Pits on the Ground Water Quality**	
Summary	**Rating**	**Comment**
Extent or Spatial Scale of Impact	LOW	Within Mine Boundary.
Intensity	LOW	No reactive minerals in rock. Elevated amount of NO_3 probably due to blasting. Mine water quality is however overall fully compliant. Surface decant must be pumped towards pollution control facilities.
Duration	LONG TERM	Beyond lifespan of project.
Mitigatory Potential	HIGH	Mine water can be pumped towards storage facilities or must be contained within confines of pit.
Acceptability	ACCEPTABLE	No risk to public health or to any sensitive environment.
Degree of Certainty	DEFINITE	Water samples tested.
Status of Impact	NEGATIVE	Funds must be available for pumping of decant towards storage facilities.
Significance Rating without Mitigation	LOW	Impact has small effect on inflowing ground water.
Significance Rating with Mitigation	LOW	Mine water can be pumped towards storage facilities or must be contained within confines of pit.
Legal Requirements	REQUIRED	Closure certificate.

4.5.2.2 Post-closure impact of Waste Dumps, Effluent Ponds and Water Dams on ground water quality

Small Hazardous Waste Dumps, Effluent Ponds and Water Dams will be demolished and the surface will be rehabilitated and capped according to H:H specifications. This includes the Purge Dams, the Scrubber Ponds, the Dirty Storm Water Dams (SWD) and the Calcine Return Water Dam (RWD – Erickson Storage).

No impact is observed from **Table 4.3.2.2(A) and Figures 4.3.2.2(A) to (C)** at the Slimes Dam or the Slimes Return Water Dam (RWD) from chemistry samples taken from boreholes. The Slimes Dam will be rehabilitated in order to minimize the volume of infiltrating water. The leachate will be collected and continually be monitored. The impact summary is given below:

IMPACT SUMMARY	**Post-closure impact of the Slimes Dam and the Slimes RWD on the Ground Water Quality**	
Summary	**Rating**	**Comment**
Extent or Spatial Scale of Impact	LOW	Within Site Boundary.
Intensity	LOW	Clean water added to aquifer.
Duration	LONG TERM	Beyond lifespan of project.
Mitigatory Potential	HIGH	High potential to mitigate negative impact.
Acceptability	ACCEPTABLE	No risk to public health or to any sensitive environment.
Degree of Certainty	DEFINITE	Leaching is taking place to underlying aquifer.
Status of Impact	NEUTRAL	No positive or negative results of impact.
Significance Rating without Mitigation	LOW	Impact will have small effect on surrounding ground water environment.
Significance Rating with Mitigation	LOW	Mitigation measures such as leachate capturing and monitoring will be performed until site closure.
Legal Requirements	REQUIRED	Closure certificate.

The large Calcine Dump will be constructed during the operational phase as a H:H facility and will be rehabilitated and capped after decommissioning also to H:H specification. This would imply that the absolute minimum leachate will take place as modeled in **Section 4.4.1.2**. The leachate will be collected and continually be monitored. The impact summary is given below:

IMPACT SUMMARY	**Post-closure impact of the Calcine Dump on the Ground Water Quality**	
Criteria	**Rating**	**Comment**
Extent or Spatial Scale of Impact	LOW	Within Site Boundary
Intensity	LOW	Small quantity of leachate.

IMPACT SUMMARY	Post-closure impact of the Calcine Dump on the Ground Water Quality	
Criteria	**Rating**	**Comment**
Duration	LONG TERM	Beyond lifespan of project.
Mitigatory Potential	LOW	Low potential to mitigate negative impact.
Acceptability	ACCEPTABLE	Full legal compliance of constructed lining system.
Degree of Certainty	PROBABLY	The volume of leachate may vary from modeled results.
Status of Impact	NEGATIVE	Cost involved in leachate capturing.
Significance Rating without Mitigation.	MEDIUM	The liner systems will require some management measures (e.g. leachate collection) without which the impact will increase.
Significance Rating with Mitigation.	LOW	Mitigation measures such as leachate capturing and monitoring will be performed until site closure.
Legal Requirements	REQUIRED	Closure certificate.

4.5.2.3 Post-closure impact on ground water resource quality

There is currently no external user's of ground water around Xstrata Rhovan in a 1 km radius. No impact of Rhovan is currently present on external users. Since Xstrata Rhovan is committed to the remediation of current contamination on the site and mitigation of all future impact, the risk towards the post-closure external user's and towards the environment should be addressed during ongoing operations in order that no residual impact exist post-closure.

All leachate from the Slimes Dam and the Calcine Dump will be captured. The impact summary is given below:

IMPACT SUMMARY	Post-closure impact of Xstrata Rhovan activities on the quality of ground water available to external user's	
Summary	**Rating**	**Comment**
Extent or Spatial Scale of Impact	NONE	Historical impact remediated.
Intensity	NONE	No user's in site boundary. Ongoing remediation must be performed during the operational phase for the clean-up of the aquifer.

IMPACT SUMMARY	**Post-closure impact of Xstrata Rhovan activities on the quality of ground water available to external user's**	
Summary	**Rating**	**Comment**
Duration	HISTORICAL	Lifespan of project.
Mitigatory Potential	NOT APPLICABLE	Active remediation measures will be put into place for aquifer clean-up.
Acceptability	NOT APPLICABLE	No risk to public health or to any sensitive environment currently. Remediation actions during operational phase cleaned up the plume.
Degree of Certainty	UNSURE	It is possible that there will never be an impact on external user's.
Status of Impact	NEUTRAL	No impact is currently present.
Significance Rating without Mitigation	LOW	No current risk to external user's.
Significance Rating with Mitigation	LOW	No current risk to external user's.
Legal Requirements	Yes	Closure certificate.

4.5.2.4 Post-closure impact of ground water on surface water quality

The largest concern is the plume that extends from the Plant/Calcine Area towards the Tshukutswe River as shown in **Figure 4.3.2.2(C)**. As discussed in **Section 4.3.2.4** it was however found that the Tshukutswe River is not a discharge boundary for the weathered/fractured aquifer and that contaminated ground water is contained in the weathered/fractured aquifer below stretches below the Tshukutswe River.

The protection of the Tshukutswe River must be part of the ground water remediation objectives at Xstrata Rhovan. No wetlands or pans exist that would be contaminated by the plume.

Since Xstrata Rhovan is committed to the remediation of current contamination on the site and mitigation of all future impacts, the risk towards the environment should be addressed during the operational phase. In the light hereof it could be stated that no post-closure impact will exist on the River. The impact summary is given below:

IMPACT SUMMARY	**Post-closure impact of Xstrata Rhovan on river water quality**	
Summary	**Rating**	**Comment**
Extent or Spatial Scale of Impact	INSIGNIFICANT	Within Site Boundary.

IMPACT SUMMARY	Post-closure impact of Xstrata Rhovan on river water quality	
Summary	**Rating**	**Comment**
Intensity	INSIGNIFICANT	No current impact is detected.
Duration	MEDIUM TERM	Lifespan of project only.
Mitigatory Potential	NONE NECESSARY	-
Acceptability	ACCEPTABLE	No risk to public health or to any sensitive environment.
Degree of Certainty	DEFINITE	No future impact is possible.
Status of Impact	NEUTRAL	No positive or negative results of impact.
Significance Rating without Mitigation	INSIGNIFICANT	No impact is identified.
Significance Rating with Mitigation	INSIGNIFICANT	No mitigation measures applicable.
Legal Requirements	NOT APPLICABLE	-

5. RISK ASSESSMENT

5.1 RISK MECHANISM

The impact on the ground water induces a potential risk to Human Health and also to the surrounding Natural Environment.

The potential risk to Human Health relates to the following:

1) The exposure of people to the contaminated ground water as a primary risk.

   This would primarily be through the consumption of contaminated ground water for drinking and domestic purposes.

2) Depletion of ground water as a water resource for dependant user's as a secondary risk

Although there is currently no external user's of ground water at Xstrata Rhovan some parts of the ground water environment is contaminated to such a degree that it would be unfit for Human Consumption. Assessing the Risk to Human Health induced by contaminated ground water would therefore have post-closure/long term objectives.

The general potential risks to the Natural Environment involve the following:

1) The depletion of ground water flow towards surface water features.

2) Primary contamination of the ground water environment.

3) Secondary contamination of surface water features through ground water baseflow.

5.2 RISK ASSESSMENT

5.2.1 <u>Current Situation</u>

5.2.1.1 Current risk to Human Health

There is currently no external user's of ground water around Xstrata Rhovan within a 1 km radius. Bethanie, Berseba and Modikwe are respectively situated 1.6 km north-east, 4.6 km and 6 km north-west of the Rhovan Plant Area. Except for the external user's boreholes at Bethanie, Berseba and Modikwe, one other borehole, GWE-6, is situated 2 km south of the Rhovan Plant Area. Basic information of all external users' boreholes is given in **Table 3(B)** attached in **APPENDIX 3.**

A statistical analysis of the latest hydro-chemistry samples taken at external user's boreholes are given in **Table 4.3.2.3(A)** as part of the Impact Assessment.

From the chemistry time data set, attached as **Dataset 3.3(A) - APPENDIX 3**, all parameters of GWE-6 have shown mostly ideal values except for NO_3 and TDS that is marginal and Fe and Mn that are sometimes marginal. GWE-6 shows a sideways trend in terms of its marginal compliance. It is therefore evident that the NO_3 contamination is persistent. The contamination could be most likely attributed to human/agricultural influences.

From **Dataset 3.3(A) - APPENDIX 3** the overall trend of pollution/contamination for the various boreholes at the Bethanie could be established and are given in **Section 3.3.2**. From this it is shown that currently at Bethanie respectively 5 and 7 boreholes show sideways trends in terms of their non- and marginal compliance. It is therefore evident that the NO_3 contamination is persistent. All contamination is attributed to human/agricultural influences.

GWE-21 at Bethanie showed a NO_3 concentration of 190 mg/l and a V concentration of 2 mg/l. This borehole could unfortunately however only been accessed once (in 2002/09/11) and it could not be established by a follow-up whether this analysis were accurate.

The risk summary is given below:

RISK SUMMARY	**Current risk of Xstrata Rhovan activities on the quality of ground water available to external user's**	
Summary	**Rating**	**Comment**
Extent or Spatial Scale of Risk	LOW	Risk small and within site boundary.
Intensity	LOW	No current user's in site boundary. However, some of the ground water in the site boundary is not fit for use. Ongoing remediation will aim to adjust this.
Duration	MEDIUM	Lifespan of project.
Mitigatory Potential	HIGH	Active remediation measures will be put into place for aquifer clean-up.
Acceptability	MANAGEABLE	No risk to public health or to any sensitive environment currently. However remediation actions will be put into place for the remediation of the plume on the site.
Degree of Certainty	UNSURE	It is possible that there will never be a risk to any external user.
Status of Risk	NEUTRAL	No risk is currently present.
Significance Rating without Mitigation	LOW	No current risk to external user's.

RISK SUMMARY	Current risk of Xstrata Rhovan activities on the quality of ground water available to external user's	
Summary	**Rating**	**Comment**
Significance Rating with Mitigation	LOW	Remediation actions will be put into place for the remediation of the plume within the site boundary.
Legal Requirements	YES	Remediation of contamination on site. Water Use License.

5.2.1.2 Current risk to the environment

The ground water aquifer could be seen as the primary impact environment at Xstrata Rhovan and the surface water features as the secondary environment.

Current risk on environment by depletion of ground water resource quantity

Depletion of the ground water resource quantity is limited as discussed in the ground water balance of the Mining Pits in **Section 4.4.1.1**. The secondary impact on the surface water is therefore also negligible. No wetlands or pans exist that are dependant on ground water flow. Because of the small scale of mining and because of the distance to the rivers, mining have no impact on the baseflow of ground water towards the rivers. Pit 4, 5 and 6 is situated more than 2 km east of the Gwathle River and Pit 1 and 2 more than 400 m west of the Tshukutswe River.

Overall it could be stated that currently no significant risk is induced onto the quantity of the ground water resource. The risk summary is given below:

RISK SUMMARY	Current Risk on environment by depletion of ground water resource quantity	
Summary	**Rating**	**Comment**
Extent or Spatial Scale of Risk	INSIGNIFICANT	Within Site Boundary
Intensity	INSIGNIFICANT	No current impact is detected.
Duration	LONG TERM	Beyond lifespan of project.
Mitigatory Potential	NONE NECESSARY	-
Acceptability	ACCEPTABLE	No risk to public health or to any sensitive environment.
Degree of Certainty	DEFINITE	No current impact is detected.
Status of Risk	NEUTRAL	No positive or negative results of impact.

RISK SUMMARY	**Current Risk on environment by depletion of ground water resource quantity**	
Summary	**Rating**	**Comment**
Significance Rating without Mitigation.	INSIGNIFICANT	No impact is identified.
Significance Rating with Mitigation.	INSIGNIFICANT	No mitigation measures applicable.
Legal Requirements	NOT APPLICABLE	-

Current risk on environment by depletion of ground water resource quality

Extensive contamination is currently present in the ground water environment as discussed in **Section 3.3** and **Section 4.3.2.2**. A ground water pollution plume is shown in **Figure 4.3.2.2(C)** that extends from the Plant Area towards the Tshukutswe River. It was however found that the Tshukutswe River is not a discharge boundary for the fractured aquifer and that contaminated ground water is contained in the aquifer below the Tshukutswe River. Surface water monitoring points in the Tshukutswe River is shown in **Figure 4.3.2.4(A)**. Statistics of chemical analyses of water samples from the Tshukutswe River were given in **Table 4.3.2.4(A).** From these analyses it was shown that no risk induced by the plume on the Tshukutswe River currently exists.

No wetlands or pans exist direct that would be contaminated by the plume. The risk summary is given below:

RISK SUMMARY	**Current Risk on environment by depletion of ground water resource quality**	
Criteria	**Rating**	**Comment**
Extent or Spatial Scale of Risk	INSIGNIFICANT	Within Site Boundary.
Intensity	INSIGNIFICANT	No current risk is detected.
Duration	MEDIUM TERM	Lifespan of project.
Mitigatory Potential	NONE NECESSARY	-
Acceptability	ACCEPTABLE	No risk to public health or to any sensitive environment.
Degree of Certainty	DEFINITE	No current risk is detected.
Status of Risk	NEUTRAL	No positive or negative results of risk.
Significance Rating without Mitigation	INSIGNIFICANT	No impact is identified.

RISK SUMMARY	Current Risk on environment by depletion of ground water resource quality	
Criteria	**Rating**	**Comment**
Significance Rating with Mitigation	INSIGNIFICANT	No mitigation measures applicable.
Legal Requirements	NOT APPLICABLE	-

5.2.2 Risk induced during ongoing operation

5.2.2.1 Ongoing risk to Human Health

There is currently no external user's of ground water around Xstrata Rhovan within a 1 km radius as discussed in **Section 4.3.2.4.** Bethanie, Berseba and Modikwe are respectively situated 1.6 km north-east, 4.6 km and 6 km north-west of the Rhovan Plant Area. Except for the external user's boreholes at Bethanie, Berseba and Modikwe, one borehole, GWE-6, is situated 2 km south of the Rhovan Plant Area.

No risk will be present on external users during the operational phase of the site. Since Xstrata Rhovan is committed to 1) the remediation of current contamination on the site and 2) mitigation of all future impacts, the risk towards the external user's and towards the environment should be addressed during ongoing operations. The risk summary is given below:

RISK SUMMARY	Ongoing risk of Xstrata Rhovan activities on the quality of ground water available to external user's	
Summary	**Rating**	**Comment**
Extent or Spatial Scale of Risk	LOW	Risk small and within site boundary
Intensity	LOW	No current user's in site boundary. However, some of the ground water is not fit for use in the site boundary. Ongoing remediation will aim to adjust this.
Duration	MEDIUM	Lifespan of project.
Mitigatory Potential	HIGH	Active remediation measures will be put into place for aquifer clean-up.
Acceptability	MANAGEABLE	No risk to public health or to any sensitive environment currently. However remediation actions will be put into place for the remediation of the plume.
Degree of Certainty	UNSURE	It is possible that there will never be a risk on external user's

RISK SUMMARY	**Ongoing risk of Xstrata Rhovan activities on the quality of ground water available to external user's**	
Summary	**Rating**	**Comment**
Status of Risk	NEUTRAL	No risk is currently present.
Significance Rating without Mitigation	LOW	No current risk to external users.
Significance Rating with Mitigation	LOW	No current user's in site boundary. However, some of the ground water is not fit for use in the site boundary. Ongoing remediation will aim to adjust this.
Legal Requirements	YES	Remediation of contamination on site. Water Use License.

5.2.2.2 Ongoing risk to the environment

The ground water aquifer could be seen as the primary impact environment at Xstrata Rhovan and the surface water features as the secondary environment.

<u>Ongoing risk on environment by depletion of ground water resource quantity</u>

Depletion of the ground water resource quantity is limited as discussed in the ground water balance of the Mining Pits in **Section 4.4.1.1**. The secondary impact on the surface water is therefore also negligible. No wetlands or pans exist that are dependant on ground water flow. Because of the small scale of mining and because of the distance to the rivers, mining have no impact on the baseflow of ground water towards the rivers. Pit 4, 5 and 6 is situated more than 2 km east of the Gwathle River and Pit 1 and 2 more than 400 m west of the Tshukutswe River.

Overall it could be stated that currently no significant risk is induced onto the quantity of the ground water resource. The risk summary is given below:

RISK SUMMARY	**Ongoing Risk on environment by depletion of ground water resource quantity**	
Summary	**Rating**	**Comment**
Extent or Spatial Scale of Risk	INSIGNIFICANT	Within Site Boundary.
Intensity	INSIGNIFICANT	No current impact is detected.
Duration	LONG TERM	Beyond lifespan of project.
Mitigatory Potential	NONE NECESSARY	-

RISK SUMMARY	**Ongoing Risk on environment by depletion of ground water resource quantity**	
Summary	**Rating**	**Comment**
Acceptability	ACCEPTABLE	No risk to public health or to any sensitive environment.
Degree of Certainty	DEFINITE	No current impact is detected.
Status of Risk	NEUTRAL	No positive or negative results of impact.
Significance Rating without Mitigation	INSIGNIFICANT	No impact is identified.
Significance Rating with Mitigation	INSIGNIFICANT	No mitigation measures applicable.
Legal Requirements	NOT APPLICABLE	None.

<u>Ongoing risk on environment by depletion of ground water resource quality</u>

Extensive contamination is currently present in the ground water environment as discussed in **Section 3.3** and **Section 4.3.2.2**. A ground water pollution plume is shown in **Figure 4.3.2.2(C)** that extends from the Plant Area towards the Tshukutswe River. It was however found that the Tshukutswe River is not a discharge boundary for the fractured aquifer and that contaminated ground water is contained in the aquifer below the Tshukutswe River. Surface water monitoring points in the Tshukutswe River is shown in **Figure 4.3.2.4(A)**. Statistics of chemical analyses of water samples from the Tshukutswe River were given in **Table 4.3.2.4(A).** From these analyses it was shown that no risk induced by the plume on the Tshukutswe River currently exists.

No wetlands or pans exist that would be contaminated by the plume.

Since Xstrata Rhovan is committed to 1) the remediation of current contamination on the site and 2) mitigation of all future impact, the risk towards the environment should be addressed during ongoing operations. The risk summary is given below:

RISK SUMMARY	**Ongoing Risk on environment by depletion of ground water resource quality**	
Summary	**Rating**	**Comment**
Extent or Spatial Scale of Risk	INSIGNIFICANT	Within Site Boundary.
Intensity	INSIGNIFICANT	No current risk is detected.
Duration	MEDIUM TERM	Lifespan of project.
Mitigatory Potential	NONE NECESSARY	-

RISK SUMMARY	**Ongoing Risk on environment by depletion of ground water resource quality**	
Summary	**Rating**	**Comment**
Acceptability	ACCEPTABLE	No risk to public health or to any sensitive environment.
Degree of Certainty	DEFINITE	No current risk is detected.
Status of Risk	NEUTRAL	No positive or negative results of risk.
Significance Rating without Mitigation	INSIGNIFICANT	No impact is identified.
Significance Rating with Mitigation	INSIGNIFICANT	No mitigation measures applicable.
Legal Requirements	NOT APPLICABLE	None.

5.2.3 Residual risk during post-closure phase

5.2.3.1 Post-closure risk to Human Health

There is currently no external user's of ground water around Xstrata Rhovan within a 1 km radius as discussed in **Section 4.3.2.4.** Bethanie, Berseba and Modikwe are respectively situated 1.6 km north-east, 4.6 km and 6 km north-west of the Rhovan Plant Area. Except for the external user's boreholes at Bethanie, Berseba and Modikwe, one borehole, GWE-6, is situated 2 km south of the Rhovan Plant Area.

No risk will be present on external users during the post-closure phase of the site. Since Xstrata Rhovan is committed to the remediation of current contamination on the site and mitigation of all future impacts, the risk towards the external user's and towards the environment should be addressed during ongoing operations in order that no risk will be present residually. The risk summary is given below:

RISK SUMMARY	**Post-closure risk of Xstrata Rhovan activities on the quality of ground water available to external user's**	
Summary	**Rating**	**Comment**
Extent or Spatial Scale of Risk	NONE	Risk small and within site boundary.
Intensity	NONE	Continuous remediation will aim to adjust this.
Duration	MEDIUM	Lifespan of project.
Mitigatory Potential	HIGH	Active remediation measures will be put into place for aquifer clean-up.
Acceptability	MANAGEABLE	No risk to public health or to any sensitive environment currently.

RISK SUMMARY	Post-closure risk of Xstrata Rhovan activities on the quality of ground water available to external user's	
Summary	**Rating**	**Comment**
		However remediation actions will be put into place for the remediation of the plume.
Degree of Certainty	UNSURE	It is possible that there will never be a risk on external user's
Status of Risk	NEUTRAL	No risk is currently present.
Significance Rating without Mitigation	LOW	No current risk to external users. Because remediation actions during operational phase will be implemented, no risk to external users post-closure is foreseen.
Significance Rating with Mitigation	LOW	No mitigation necessary.
Legal Requirements	YES	Remediation of contamination on site. Water Use License.

5.2.3.2 Post-closure risk to the environment

The ground water aquifer could be seen as the primary impact environment at Xstrata Rhovan and the surface water features as the secondary environment.

Post-closure risk on environment by depletion of ground water resource quantity

The largest concern is the plume that extends from the Plant/Calcine Area towards the Tshukutswe River as shown in **Figure 4.3.2.2(C)**. As discussed in **Section 4.3.2.4** it was however found that the Tshukutswe River is not a discharge boundary for the weathered/fractured aquifer and that contaminated ground water is contained in the weathered/fractured aquifer below stretches below the Tshukutswe River.

The protection of the Tshukutswe River must be part of the ground water remediation objectives at Xstrata Rhovan. No wetlands or pans exist that would be contaminated by the plume.

Since Xstrata Rhovan is committed to the remediation of current contamination on the site and mitigation of all impacts, the risk towards the environment should be addressed during the operational phase. In the light hereof it could be stated that no post-closure impact will exist on the River.

The risk summary is given below:

RISK SUMMARY	Post-closure risk on environment by depletion of ground water resource quantity	
Summary	**Rating**	**Comment**
Extent or Spatial Scale of Risk	INSIGNIFICANT	Within Site Boundary
Intensity	INSIGNIFICANT	No current risk was detected.
Duration	MEDIUM TERM	Lifespan of project only.
Mitigatory Potential	NONE NECESSARY	-
Acceptability	ACCEPTABLE	No risk to public health or to any sensitive environment.
Degree of Certainty	DEFINITE	No future impact is possible.
Status of Risk	NEUTRAL	No positive or negative results of risk.
Significance Rating without Mitigation	INSIGNIFICANT	No impact is identified.
Significance Rating with Mitigation	INSIGNIFICANT	No mitigation measures applicable.
Legal Requirements	NOT APPLICABLE	None.

Post-closure risk on environment by depletion of ground water resource quality

No wetlands or pans exist that would be contaminated by the plume. Extensive contamination is currently present in the ground water environment as discussed in **Section 3.3** and **Section 4.3.2.2**. A ground water pollution plume is shown in **Figure 4.3.2.2(C)** that extends from the Plant Area towards the Tshukutswe River. It was however found that the Tshukutswe River is not a discharge boundary for the weathered/fractured aquifer and that contaminated ground water is contained in the aquifer below the Tshukutswe River. Surface water monitoring points in the Tshukutswe River is shown in **Figure 4.3.2.4(A)**. Statistics of chemical analyses of water samples from the Tshukutswe River were given in **Table 4.3.2.4(A).** From these analyses it was shown that no risk induced by the plume on the River currently exists. Since Xstrata Rhovan is committed to the remediation of current contamination on the site and mitigation of all impacts, the risk towards the environment should be addressed during the operational phase. In the light hereof it could be stated that no post-closure impact will exist on the Tshukutswe River.

The risk summary is given below:

RISK SUMMARY	**Post-closure risk on environment by depletion of ground water resource quality**	
Summary	**Rating**	**Comment**
Extent or Spatial Scale of Risk	INSIGNIFICANT	Within Site Boundary
Intensity	INSIGNIFICANT	No current risk is detected.
Duration	MEDIUM TERM	Lifespan of project.
Mitigatory Potential	NONE NECESSARY	-
Acceptability	ACCEPTABLE	No risk to public health or to any sensitive environment.
Degree of Certainty	DEFINITE	No current risk is detected.
Status of Risk	NEUTRAL	No positive or negative results of risk.
Significance Rating without Mitigation	INSIGNIFICANT	No impact is identified.
Significance Rating with Mitigation	INSIGNIFICANT	No mitigation measures applicable.
Legal Requirements	NOT APPLICABLE	None.

6. PROPOSED SITE SPECIFIC REMEDIATION AND MITIGATION OBJECTIVES

6.1 OBJECTIVES

Since Xstrata Rhovan is committed to the remediation of impacts, the risk induced by the impacts will be addressed during the operational phase. In the light hereof it could be stated that no post-closure risk will exist on Human Health and the Environment.

The following mitigation and remediation objectives exist for Xstrata Rhovan for the operational phase:

1) Mitigation measures must be applied during all phases in order to mitigate all current or future impacts.

2) Remediation of contamination in ground water in order that the ground water quality can support the post closure land use, or alternatively is compliant with Drinking Water Standards and the Environmental Risk Limit as specified in the DWAF minimum Requirements.

3) The reconstructuring/rehabilitation/demolishing of the sources of impact is seen as important indirect measures of remediation.

Ground water monitoring is seen as an inevitable part of the ongoing remediation program. The proposed monitoring scheme is discussed in **Part 9**.

6.2 IDENTIFICATION OF IMPACTS TO BE MITIGATED AND REMEDIATED

6.2.1 <u>The remediation of the ground water pollution plume</u>

As discussed in **Section 4.3.2.2** a plume is present in the aquifer that stretches from the Plant Area towards the Tshukutswe River. Contamination of the river is not taking place currently and is not foreseen for the ongoing operational phase if remedial measures are put into place.

Remediation of the plume in the aquifer at Rhovan Xstrata is seen as a priority and <u>immediate actions must be performed on detailed remediation planning and implementation</u>.

6.2.2 Mitigation of the sources of impact

The following existing sources of impact were identified in the impact assessment in **Part 4** that will form part of remediation measures:

Existing Source	Potential Impact
The Mining Pits	Current and future impact on Ground Water Quantity (water inflow from aquifer). Impact small and acceptable.
Slimes Dam, Slimes Return Water Dam and Clean Storm Water Dam	Current and future impact on Ground Water Quantity (clean water added to aquifer). Impact small and acceptable.
Scrubber Ponds and Purge Dams	Current impact on Ground Water Quality (contaminated leachate towards aquifer). Impact large and unacceptable. After reconstructuring the impact will be small and acceptable.
FeV Slag Dump Calcine Dump	Current impact on Ground Water Quality (contaminated leachate towards aquifer). Impact large and unacceptable. The FeV slag will be placed on top of the Calcine Dump. The impact of all future constructions at the Calcine Dump will be small and acceptable.
Calcine Return Water Dam and Dirty Water Storm Water Dams	Current impact on Ground Water Quality (contaminated leachate towards aquifer). Impact medium but unacceptable. After reconstructuring the impact will be small and acceptable.

Remediation of the plume in the aquifer would be a useless and costly exercise if contaminated leachate from sources is not substantially minimized.

7. PROPOSED REMEDIATION AND MITIGATION MEASURES

7.1 MITIGATION MEASURES

7.1.1 <u>Ongoing operational phase</u>

The mitigation measures must be actively implemented during the operational phase. All decommissioning and rehabilitation of sources must be completed before the closure phase. Ground water monitoring must be performed during operational and post-closure phase until final site closure in order to ensure that mitigation and remediation measures are effective.

The mitigation measures for the different sources are given in **Table 7.1.1(A)** below:

Table 7.1.1(A): Proposed mitigation measures for Rhovan Xstrata.

Source	Proposed Actions	Expected Outcome
The Mining Pits	Back-filling of pits where possible. Final rehabilitation. Ground water monitoring must be performed.	Smaller volume of total water make of pits.
Slimes Dam, Slimes Return Water Dam and Clean Storm Water Dam	Future developments constructed with stability drainage systems agreed upon with authorities. Leachate collection must be implemented During the decommissioning phase the Slimes Dam should be sloped and rehabilitated. All decommissioning must be completed before the closure of the site. The Clean Water Dam will be demolished with site decommissioning. The Slimes Dam will be operational until the Slimes Dam is finally closed with site closure. Ground water monitoring must be performed.	Small volume of clean water introduced into aquifer.
Scrubber Ponds and Purge Dams	Future developments constructed with Hazardous Waste Liners as agreed upon with authorities. Leachate collection must be implemented.	Minute volume of leachate introduced into aquifer.

Source	Proposed Actions	Expected Outcome
Scrubber Ponds and Purge Dams	During the decommissioning all contaminated soils must be removed and the site must be rehabilitated. All decommissioning must be completed before the closure of the site. Scrubber Pond No. 1 was decommissioned in September 2005. Final rehabilitation will remove it as a source. Scrubber Pond No. 2 is already decommissioned and final rehabilitation will clean-up all soils. A new Scrubber Pond No. 4 will be constructed according to the Minimum Requirements for such a facility. The current Purge Dam No. 1 and No. 2 will both be demolished and rehabilitated. Purge Dam No. 1 will be reconstructed according to the Minimum Requirements for such a facility. Ground water monitoring must be performed.	Minute volume of leachate introduced into aquifer.
Calcine Dump FeV Slag Dump	Future developments constructed as a Hazardous Waste Site or similar lining system agreed upon with authorities. Leachate collection must be implemented. During the decommissioning phase the Calcine Dump must be sloped and rehabilitated. The FeV Slag must be dumped on the Calcine Dump. The footprint of the FeV Slag Dump must be rehabilitated. Ground water monitoring must be performed.	Small volume of water introduced into aquifer.
Calcine Return Water Dam and Dirty Water Storm Water Dams	Future developments constructed as Hazardous Waste Lagoons or similar lining system agreed upon with authorities. Leachate collection must be implemented.	Minute volume of leachate introduced into aquifer.

Source	Proposed Actions	Expected Outcome
Calcine Return Water Dam and Dirty Water Storm Water Dams	During the decommissioning phase the sites must be demolished and rehabilitated. Ground water monitoring must be performed.	Minute volume of leachate introduced into aquifer.

7.1.2 Post-closure phase

All decommissioning and rehabilitation of sources must be completed before the closure phase. Ground water monitoring must be performed during the post-closure phase until final site closure in order to ensure that mitigation and remediation measures are effective.

The mitigation measures for the different sources are given in **Table 7.1.2(A)** below:

Table 7.1.2(A): Proposed post-closure mitigation measures for Rhovan Xstrata.

Source	Proposed Actions
The Mining Pits	Ground water monitoring must be performed during the post-closure phase until final site closure in order to ensure that mitigation and remediation measures are effective.
Slimes Dam, Slimes Return Water Dam and Clean Storm Water Dam	Leachate collection must be implemented until final site closure of Slimes Dam. Ground water monitoring must be performed post-closure until final site closure.
Scrubber Ponds and Purge Dams	Demolishing and final rehabilitation of these sites must already have been completed. Ground water monitoring must be performed post-closure until final site closure.
Calcine Dump FeV Slag Dump	Rehabilitation and sloping of these sites must already have been completed. Ground water monitoring must be performed post-closure until final site closure.
Calcine Return Water Dam and Dirty Water Storm Water Dams	Demolishing and final rehabilitation of these sites must already have been completed. Ground water monitoring must be performed post-closure until final site closure.

7.2 REMEDIATION OF CONTAMINATION IN AQUIFER

As discussed in **Section 4.3.2.2** a plume is present in the aquifer that stretches from the Plant Area towards the Tshukutswe River. Contamination of the river is not taking place currently and is not foreseen for the ongoing operational phase if remedial measures are put into place. It is important to note that the contamination at Xstrata Rhovan is contained within the aquifer.

Remediation of the plume in the aquifer at Rhovan Xstrata is seen as a priority and immediate actions must be performed on detailed remediation planning and implementation.

Ground water monitoring is seen as an inevitable part of the ongoing remediation program. The proposed monitoring scheme is discussed in **Part 9**.

Pump and treat is proposed as the most effective remediation measure for the clean-up of the plume at Xstrata Rhovan. This would involve the placement of abstraction and injection wells in the following areas:

Area	Proposed amount of boreholes	Placement
Plant Area	5 abstraction boreholes.	At source areas.
Calcine Area	10 abstraction boreholes.	South and east of plume.
	10 injection boreholes.	North and west of plume.

A total of 5 boreholes at the Plant Area and 10 boreholes at the Calcine Dump area will be used to pump out contaminated water from the plume, to be used as process water in the plant. A small volume of raw intake water will be used for injection and flushing into another 10 wells at the Calcine Dump area. In effect raw water will therefore be circulated through the contaminated aquifer for subsequent abstraction and final use in the plant.

This method has been used successfully at other sites and would be the most cost effective. It would however imply good planning and contaminant flow modeling must be performed of the site in order to find the most suitable scenarios for the placement of the pump and injection boreholes.

The legal requirement for the pump and treat remediation would involve a Water Use License from DWAF (Department of Water Affairs and Forestry).

The remediation of the plume in the aquifer will be a useless and costly exercise if contaminated leachate from sources is not substantially minimized.

It is important to note that the contamination at Xstrata Rhovan is contained within the aquifer and that the only impact is towards the ground water environment and not to any external users or to the surface water environment. Remediation will only better the current situation and all future impact will become smaller.

8. PRIORITIZATION OF PROPOSED REMEDIATION MEASURES

In terms of ground water remediation, a series of actions is/will be implemented during the operational phase, through to closure. These include, in order of priority:

- Improvement of liner systems of new dams and extension of waste dump footprints. These activities are currently underway at all facilities. The costs involved are considered as part of Operating Expenditure (OPEX) and the exact costs are not known.

- A comprehensive Ground Water abstraction scheme will be implemented to remediate the ground water pathway, and to prevent polluted ground water entering the receptor (rivers and external user's boreholes).

- During closure, the waste facilities will be rehabilitated, capped and shaped according to the required standards. This will remediate the ground water regime through source control.

The remediation of ground water is seen as integrated in the overall operation, closure and remediation of the total site.

9. PROPOSED ONGOING MONITORING

9.1 OBJECTIVES OF MONITORING

Ground water monitoring is seen as an inevitable part of the ongoing management and remediation program. The monitoring program at Xstrata Rhovan would have the following objectives:

- To monitor any contamination at Xstrata Rhovan in the ground water environment.

- To monitor the behavior of the plume at Xstrata Rhovan site and the effectiveness of remediation measures.

- To monitor any potential impact on external ground water users.

Although no external users of ground water exist within 1 km from the Rhovan operations, selective monitoring programs of external user's ground water would be needed in order to prove that no contamination is related to Xstrata Rhovan activities.

9.2 SITE SPECIFIC MONITORING MEASURES

9.2.1 Drilling of additional monitoring boreholes

Jasper Müller Associates (JMA) has been involved in the placement as well as the drilling of 51 monitoring boreholes (GWW-1 to GWW-45 and SGM-B1 to SGM-B6) at Rhovan from 1999 to 2005.

An additional number of boreholes will be needed in order to define the plume at certain areas, especially near the Tshukutswe River and in the central plume area towards the Tshukutswe River.

9.2.2 Sampling and analyses specifications

The monitoring of ground water boreholes on a regular basis at Xstrata Rhovan is important in order to monitor the effectiveness of remediation actions on the plume. This is critical in case where slight adjustments must be made on the remediation measures.

It is suggested that a broad ICP scan must be performed on ground water beneath the source area in order to identify the specific metals potentially present in the plume area. The identified metals must be continually analyzed for in future ground water samples taken.

No external users is present within 1 km radius from the operational Xstrata Rhovan area. The frequency of monitoring of the external user's could be on a lager time scale than at Rhovan.

The specifications for monitoring at Rhovan are given below:

Boreholes	Parameters to be analyzed for	Frequency
Ground Water Boreholes at Xstrata Rhovan	pH, EC, TDS Ca, Mg, Na, K, Si, Talk, SO_4, Cl, NO_3, F, Al, Mn, Fe, Cr, V and other metals identified with a once-off broad ICP scan performed on ground water below sources.	Quarterly
Bethanie External Users' Boreholes	pH, EC, TDS Ca, Mg, Na, K, Si, Talk, SO_4, Cl, NO_3, F, Al, Mn, Fe, Cr, V and other metals identified with a once-off broad ICP scan performed on ground water below sources.	Six-monthly

Respectfully submitted,

____
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APPENDIX D3

Soils Specialist Report

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DESCRIPTION OF THE PRE-MINING ENVIRONMENT:

- **SURFACE GEOLOGY,**
- **SOIL SURVEY,**
- **PRE-MINING LAND CAPABILITY,**
- **LAND USE,**
- **SITES OF ARCHAEOLOGICAL AND CULTURAL INTEREST AND**
- **SENSITIVE LANDSCAPES (INCLUDING WETLAND CLASSIFICATION AND DELINEATION),**

AS WELL AS

ENVIRONMENTAL IMPACT ASSESSMENT AND ENVIRONMENTAL MANAGEMENT PROGRAM

OF

THE LAND SURROUNDING THE INFRASTRUCTURE AND MINING AREAS OF RHOVAN MINE

(PORTION OF THE ORIGINAL FARMS LOSPERFONTEIN 405JQ, BERSEBA 397JQ AND NEWPEN 403JQ)

ODI 2 DISTRICT

Prepared for
JASPER MÜLLER ASSOCIATES CC
on behalf of
XSTRATA ALLOYS RHOVAN OPERATIONS

by
B.B. McLeroth

March 2006 **REMS37**

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TABLES AND FIGURES

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MAPS (Report Folder)

EXECUTIVE SUMMARY

Geology

Metasandstone/quartzite 2,13 %, Perthite 2,50 %, Granite 2,69 %, Norite 2,14 %, Anorthosite 1,09 %, Diabase/Dolerite 4,64 %, Gabbro 10,53 %, Ferrogabbro 22,60 %, Magnetite without surface outcrop 7,78 %, Magnetite with surface outcrop 9,10 %, Ferricrete 7,75 %, Colluvium 10,27 %, and 'man-made features' 16,78 %.

Soils

Broad Soil Group	Soil Forms	Area (ha)	%
Red apedal	Hutton, Bainsvlei, Bloemdal	268,40	15,27
Red structured	Shortlands	552,08	31,41
Pedocutanic	Swartland, Sepane, Valsrivier, Bonheim	118,88	6,76
Shallow (lithosols)	Mispah, Glenrosa, Dresden, Milkwood	270,26	15,38
Vertic	Arcadia, Rensburg	249,35	14,19
Prismacutanic	Sterkspruit	3,11	0,18
Man-made soils	Witbank	0,53	0,03
Man-made features	-	295,00	16,78
TOTAL		1757,61	100

Textures range from clay (geological types with a high content of weatherable minerals are highly dominant) to loamy-sand (geological types with a low content of weatherable minerals are extremely rare). The moderately and strongly structured soils have a high base status (eutrophic = very poorly leached), while the weakly structured soils frequently have a moderate base status (mesotrophic = poorly leached), this being due to both the low effective rainfall (621 – 651-mm per annum) as well as the dominantly base rich parent materials (geology) in the area. pH varies from 5,60 (medium acid) to 7,84 (moderately alkaline), while topsoil organic carbon is low (0,55 %) to moderate (1,54 %). The soils are neither saline nor sodic. The soil fertility status (agricultural purposes) for the deeper midslope soils is as follows: Potassium (sufficient), Magnesium (more than adequate), Phosphorus (seriously deficient) and Nitrogen (deficient).

Erosion Hazard and Slope

Erosion Hazard. Unacceptable erosion is likely to occur on bare soils with a slope of greater than:

- Undisturbed soils - 11,3 degrees,
- Rehabilitated soils overlying non-compacted discard rock - 9,1 degrees (red structured and red apedal soils) – 7,1 degrees (pedocutanic and vertic soils), and
- Dump cover soils overlying a compacted seal - 6,1 – 7,2 degrees (red structured and red apedal soils only).

Slope in the survey area varies as follows: majority :1 - 4 degrees (valley bottom - midslope),
: occasionally :4 - 14 degrees (midslope – hillslope), and
: rarely :14-20 degrees (hillslope – scarp).

Dryland Production Potential (Agriculture)

Dryland crops are not recommended in the area due to the low yields obtained (low effective rainfall) as well as the high associated risk (frequent droughts). The grazing potential for summer is approximately 2,0

– 2,8 ha/LAU while the year round average is approximately 4,0 ha/LAU (red structured, red apedal and pedocutanic soils) to 6,0 ha/LAU (vertic soils). However irrigated crops produce high yields on farms to the east of Bethanie. Frequently planted irrigated crops in the Bethanie to Brits area include maize, beetroot, carrots, swiss chard (spinach), wheat, cabbage, onions, sunflowers, soya beans and rarely tobacco.

Pre-mining Land Capability

Wetland 6,56 %, arable 30,06 %, grazing 28,48 %, wilderness 18,09 %,
rehabilitated land 0,03 %, and man-made features 16,78 %.

Present Land Use

Bush 59,86 %, scrub thorn grass veld 6,82 %, grassland 6,02 %, wetland vegetation (including scrub, grass and bush growing in wetlands) 6,35 %, cultivated 1,27 %,
rehabilitated land 0,02 %, and man-made features 19,66 % (in previous percentages small man-made features were not included).

Evidence of misuse from a land use perspective include the following: ponds (two) in wetlands, unnecessary disturbance of wetlands (haul truck brake testing ramp), numerous tallus inspection holes in the veld (not closed), the fact that rehabilitation operations have not commenced in any areas, and many unnecessary dirt roads.

Sensitive Landscapes (Wetlands)

The following measures are necessary in order to restore the wetlands to as close to their original condition as possible:

i) closure and rehabilitation of the 'eastern' pit where it bisects the wetland,

ii) the removal of the discard overlying the northern extent of the western wetland near the 'western' pit, once mining operations are completed in this area,

iii) the relocation and rehabilitation of the haul truck brake testing ramp in the 'western' wetland, and

iv) attending to the pollution sources which are presently infiltrating the wetland in contact (south-east) with the infrastructure area. Such pollution sources include the calcine tailings dump (requires intercept drains) and the polluted pond in the wetland (requires relocation or cladding).

Soil Utilization (Stripping) Guide and Rehabilitation Topsoil Budget

A total of 11 308230-m³ of suitable to marginal (for use as 'topsoil') soils are present *in-situ* in the undisturbed (1462,61-ha) sections of the survey area. In the rehabilitated scenario, at least the same percentage of arable and grazing land should exist as were present before disturbance. The rehabilitation 'topsoiling' depths of suitable 'topsoil' material are 0,6-m (arable), 0,25-m (grazing) and 0,15-m (wilderness and wetland), the pre-mining land capability of the disturbed area being evident from the trends on the periphery.

The broad soil groups which must be utilized for rehabilitation purposes include red apedal, red structured and pedocutanic for the 'western' pit, 'other' areas and dumps, while the vertic broad soil group should be utilized for the 'eastern' pit only.

Environmental Impact Assessment for Soils, Land Capability and Land Use

- Magnitude – very significant,
  since the existing soils, land capability and land use will be completely destroyed in the areas which are mined.
- Timing – intermediate,

as mining operations commence in an area.

- Duration – temporary,
  until rehabilitation operations (leveling of discard rock, regrading of slope, 'topsoiling', amelioration of topsoil fertility and re-vegetation) are completed.

Environmental Management Program

- Stripping recovery recommendations
  The soils must be stripped ahead of mining operations as per the Soil Utilization (Stripping) Guide, this 'topsoil' being redistributed immediately (if possible) in regraded areas.
  Soil compaction must be limited during these exercises, this best being achieved by stripping and 'topsoiling' when the soil moisture content is low (ie. during the dry winter season) as well as by the utilization of tracked vehicles.
- Dust pollution potential
  Wind erosion is not likely to be of major significance in the area, except on exposed sites (dumps and crests) where the vegetative cover has been removed.
- Storage life and stockpiling
  Soil material should be stock-piled only as a last resort, when it is impractical to redistribute such material promptly.
  However, if stock-piles are created these should ideally not exceed a maximum depth of one metre, as greater depths than this can lead to the following: anaerobic conditions developing in the pile, a reduction in soil fertility, the accelerated loss of the reproductive seedbank, and compaction. Should higher (than one metre) stock-piles be created, then extra attention must be given to ameliorating these soils when they are utilized. The soils must not be stock-piled or removed when they are wet.
- Topsoiling
  As per the recommendations made earlier in this summary, in the Soil Utilization (Stripping) Guide and Rehabilitation Topsoil Budget sections, these being based on the Pre-mining Land Capability map.
- Erosion and slope
  As per the slopes and broad soil groups, recommended earlier in this summary in the Erosion and Slope section.
  The pre-mining grade (slope), contours and drainage density should be implemented wherever possible. Concave (rather than convex) slopes should be maximized, while the creation of undulating 'basin and ridge' topography with frequent blind hollows should be avoided. Erosion control measures such as intercept drains, contour bank canals, grassed waterways and toe berms should be implemented where necessary.

Soil Fertility

Immediately after 'topsoiling', the soil fertility status of the top 15-cm must be determined (sampling) and ameliorated (fertilization) before re-vegetation. Thereafter the soils should be sampled on an annual basis until the required phosphorus and potassium levels have been built up. Thereafter, intervals of three or four years can be allowed between sampling.

Re-vegetation

Rehabilitate areas must be re-vegetated as soon after 'topsoiling' as possible, in order to limit raindrop and wind energy, as well as to slow and trap runoff. Indigenous (to the area) grassland species are preferred, given both their hardy nature, as well as their lower maintenance requirements.

1.0 INTRODUCTION (Maps 1 and 2)

A soil survey of the land surrounding the infrastructure and mining areas at Rhovan Mine was carried out in July (eastern half) and September – October (western half) 2005 by B.B. McLeroth of Red Earth cc. The area mapped (1757,61-ha) is comprised of portions of the original farms Losperfontein 405JQ, Berseba 397JQ and Newpen 403JQ. However, the soil-surveyed area (1462,61-ha) is less since a number of man-made features are present within the mapped area.

The objectives of this survey are:

- to produce a detailed surface geological plan of the survey area (add on service),
- to describe the soils (distribution, types, depth, surface features, wetness hazard and cultivation factors per horizon, suitability for agriculture and 'topsoil', physical and chemical characteristics, fertility, erodibility, dryland production potential and irrigation potential),
- to determine the pre-mining land capability (Chamber of Mines),
- to determine the present land use,
- to identify sites of potential archaeological and cultural interest,
- to identify the location of sensitive landscapes, as well as to classify and delineate the wetlands into the permanent/semi-permanent, seasonal and temporary classes,
- to produce a soil utilization (stripping) guide,
- to produce a rehabilitation topsoil budget,
- to conduct an environmental impact assessment for the soils, land capability, land use and sites of archaeological and cultural interest, and
- to propose mitigation measures for the same (environmental management program).

This study was conducted in order to both satisfy the EMPR requirements, as well as to comply with the Rehabilitation Guidelines as specified by the Chamber of Mines for any site which is to be disturbed.

2.0 DESCRIPTION OF THE PRE-MINING ENVIRONMENT

2.1 SURFACE GEOLOGY

The geology was recorded on a 150-m grid basis throughout the survey area (concurrently with the soil survey), while visual observations were also made between grid points. The geological classes (simplified) utilized on the geological plan were agreed between the mine geologist (Mr. Tony Mills) and myself before commencement of the soil survey, any problematic rocks encountered during the course of the survey being classified by the same.

Map 6 (geology theme) shows a complex surface geological pattern to exist in the survey area. The rock types encountered are the parent materials for the soils occurring, the soil properties generally reflecting the various parent material types.

The geology (parent material) at auger points was determined as follows:

- *in-situ* surface outcrops,
- rock (or weathering rock) sample from the bottom of the soil profile, up to a maximum depth (manual soil auger length) of 1,8-m, or less if the parent material was encountered at lesser depth, or
- in cases where the underlying lithology was not observed due to the following:
  - soil depth greater than 1,8-m,
  - impenetrable (to a manual soil auger) tallus or quartz stoneline, or alternatively
  - a sample of the solid rock encountered at depth could not be extracted for observation purposes;

  then the lithology was inferred (probable) from the soil properties. The geological plan indicates areas where the underlying lithology was inferred by the use of an additional symbol, namely *****. Furthermore, in soils derived from colluvium (also >1,8-m depth), the lithology underlying the colluvium is not known.

Based on the geological plan, the recommended (generalized) mining strategy, in terms of suitability (for mining) of geology type in descending order (to be refined by sampling by the mine) is as follows:

i) Magnetite with surface outcrop,
ii) Magnetite without surface outcrop,
iii) Ferrogabbro (>5-10% magnetics), and
iv) Tallus layer.
The tallus layer should be stripped where it occurs close (probably 0-0,3-m) to the surface (see Map 6) in both the aforementioned and other geological types. Such tallus layers frequently occur in non-suitable (mining perspective) geological types due to colluvial (gravity) action, downslope of a magnetite area. Such a stripping exercise has already been conducted in an area to the west of the ‘western’ pit, Map 6 indicating ‘scraped, tallus removed’. The economic feasibility of this exercise would be determined by the following variables: quality, depth below the soil surface and thickness of the tallus layer; the latter two variables being available on Map 6 and in the soils database (Appendix 1) respectively.

2.2 SOIL

2.2.1 SURVEY METHODS AND DATA COLLECTION (Appendix 1 and Map 1)

An intensive systematic grid survey was undertaken with sampling points 150-m apart throughout the entire survey area. However, extra auger points were occasionally conducted (not recorded in database) for clarification purposes. Furthermore, numerous visual observations aided in the compilation of the map set. Auger points were occasionally shifted off the pre-determined grid, in order to be conducted in meaningful positions or to avoid man-made obstacles. The distribution of the sample points examined with a 100-mm bucket soil auger are shown on Map 1.

Auger points were conducted to a maximum depth of 1,8-m, or less if a depth limiting material (for roots) such as hard rock, weathering rock (saprolite), hard plinthite, impenetrable (to a manual soil auger) tallus (loose colluvial magnetite gravel and stones) layers, soft plinthite or gleyed material was encountered at lesser depth.

Recorded per profile:	soil form/series, effective rooting depth, surface features, compaction, topsoil organic carbon, depth limiting material, lithology, ground roughness and remarks.
Recorded per horizon:	name/depth of horizons, clay content, sand grade, Munsell colour, structure, wetness hazard and cultivation factors.

The information recorded at the six-hundred-and-ninety-five auger points was entered into a D-base database (Appendix 1). Soils were classified as per the Soil Classification Working Group, 1991 (Taxonomic System for South Africa).

2.2.2 THE SOIL MAP (Table 1 and Map 2).

The different soil types identified were grouped together into soil-mapping units on the basis of soil form, effective soil depth for mining and cropping (ESD), surface features, depth limiting material and surface geology.

Each soil-mapping unit has a unique code, which describes these factors.

Table 1 summarises the information on Map 2 in terms of soil form.

Table 1. Summary of Soil Form

SOIL FORM (SUMMARY)							
BROAD SOIL GROUP	MAP NOTATION	FORM	HORIZONS	ha		% of total area	
Red apedal	Hu	Hutton	orthic A/red apedal B	225.74	268.40	12.84	15.27
	Bd	Bloemdal	orthic A/red apedal B/unspecified wet	5.05		0.29	
	Bv	Bainsvlei	orthic A/red apedal B/soft plinthic B	37.61		2.14	
Red structured	Sd	Shortlands	orthic A/red structured B	552.08	552.08	31.41	31.41
Pedocutanic	Va	Valsrivier	orthic A/pedocutanic B/unconsolidated non-wet	15.26	118.88	0.87	6.76
	Sw	Swartland	orthic A/pedocutanic B/saprolite	67.53		3.84	
	Se	Sepane	orthic A/pedocutanic B/unconsolidated wet	33.93		1.93	
	Bo	Bonheim	melanic A/pedocutanic B	2.16		0.12	
Shallow	Gs	Glenrosa	orthic A/lithocutanic B	43.93	270.26	2.50	15.38
	Ms	Mispah	orthic A/hard rock	220.65		12.55	
	Mw	Milkwood	melanic A/hard rock	0.87		0.05	
	Dr	Dresden	orthic A/hard plinthic B	4.81		0.27	
Vertic	Ar	Arcadia	vertic A/unspecified	134.11	249.35	7.63	14.19
	Rg	Rensburg	vertic A/G horizon	115.24		6.56	
Prismacutanic	Ss	Sterkspruit	orthic A/prismacutanic B	3.11	3.11	0.18	0.18
Man-made	Wb	Witbank	orthic A/man-made soil deposit	0.53	0.53	0.03	0.03
Mining				150.68	295.00	8.57	16.78
Infrastructure				63.66		3.62	
Slimes Dam & Surrounds				73.22		4.17	
Soil				4.04		0.23	
Pond				2.16		0.12	
Borrow Pit				0.40		0.02	
Stone Chips				0.84		0.05	
			TOTALS	1757.61ha		100%	

2.2.3 SOIL TYPES AND SUITABILITY FOR AGRICULTURE AND 'TOPSOIL'

The soils encountered in the survey area may be divided into seven broad groups, the relative abundance of which are as follows:

i)	Red apedal soils	Hutton, Bainsvlei, Bloemdal	268,40 ha (15,27 %)
ii)	Red structured soils	Shortlands	552,08 ha (31,41 %)
iii)	Pedocutanic soils	Swartland, Sepane, Valsrivier, Bonheim	118,88 ha (6,76 %)
iv)	Shallow soils	Mispah, Glenrosa, Milkwood, Dresden	270,26 ha (15,38 %)
v)	Vertic soils	Arcadia, Rensburg	249,35 ha (14,19 %)
vi)	Prismacutanic soils	Sterkspruit	3,11 ha (0,18 %)
vii)	Man-made soils	Witbank	0,53 ha (0,03 %).

The remaining 295,00-ha (16,78 %) of the survey area is comprised of mining operations ('western' pit, 'eastern' pit and 'other' small mined patches), infrastructure, the slimes dam and 'other' small features including soil piles, ponds, two borrow pits and one small patch of stone chips. The soils were mapped over many other man-made features (roads, conveyor, temporary infrastructure, power-lines, other soil stock-piles, drains, trenches and prepared surfaces) in order to simplify Maps 1-3 and 5-6, these features not being included in these totals. Map 4 (Present Land Use) provides more detailed land use totals.

(i) Red apedal soils

These well drained intermediate [depth] to very deep (majority 0,6 – >1,8-m) soils of the Hutton (dominant), Bainsvlei (occasional) and Bloemdal (rare) forms are widespread in gently sloping midslope positions. Textures are coarse (rarely medium) clay to sandy-loam in the topsoil and coarse (rarely medium) clay (dominant) to sandy-clay-loam in the subsoil. Sand grade is predominantly coarse in the majority of the survey area due to the abundance of magnetic particles in the soil.

Structure for all horizons is weak blocky (rarely apedal). Subsoil (B1-horizon) S-values (cmol (+)/kg^{-1} clay = leaching status) are mesotrophic (5-15 = moderate base status = poorly leached) to eutrophic (>15 = high base status = very poorly leached).

The soils in the area are poorly leached given both the low mean annual precipitation (approximately 621-651-mm per annum – source climate specialist report) and the high base reserve of the majority of the parent materials (rock types) in the area.

The variation in texture (dependant on the various parent material types as well as soil depth) shows that both texture and soil form should be considered in determining the suitability of the various soil materials for agricultural suitability, for rehabilitation purposes and for waste dump cover.

The ‘usable’ soil depth is dependant on the depth of the unsuitable underlying weathering rock, hard rock, hard plinthite (solid iron and manganese oxides layer), quartz, tallus, soft plinthite (hydromorphic horizon) or rarely unspecified wet horizons.

The red apedal soils have generally developed on basic (ferrogabbro, gabbro, diabase), intermediate (ferricrete), and acid (perthite and granite) parent materials, which have a high to moderate content of weatherable minerals and thus a high to moderate clay-forming potential. The clay mineral suites are dominated by non-swelling 1:1 types (hence the lack of structural development). The iron mineral hematite imparts the red pigment to the red apedal soils and is indicative of oxidizing conditions.

The high quality orthic A and red apedal B-horizons are suitable materials for annual cropping (good rooting medium) and use as ‘topsoil’, having very favourable structure (weak blocky) and consistence (dry – slightly hard to soft) as well as a generally favourable texture (clay subsoils have a high moisture holding capacity).

(ii) Red structured soils

These well drained intermediate [depth] to very deep (majority 0,5 - >1,8-m, rarely 0,3 – 0,4-m) soils of the Shortlands form are by far the most dominant and widespread soil form in the survey area, occurring in gently to moderately sloping midslope positions. Textures are coarse clay to sandy-loam in the topsoil and coarse clay to sandy-clay-loam in the subsoil, the variation in texture being parent material and depth related.

Structure is predominantly weak to moderate blocky in the topsoil and moderate or occasionally strong blocky in the subsoil, while consistence is slightly hard to hard. Subsoil (B1-horizon) S-values are predominantly eutrophic (occasionally mesotrophic).

The ‘usable’ soil depth is dependant on the depth of the unsuitable underlying tallus (most common), weathering rock, hard rock, concretions or occasionally quartz or hard plinthite.

The red structured soils have generally developed on the most basic (magnetite, ferrogabbro, gabbro and diabase) parent materials although they also occasionally occur in ferricrete, colluvium, perthite and granite areas. Red structured soils have occasionally developed on these intermediate to acid parent material types due to colluvial (gravity) movement of colloidal (clay) material and bases downslope from more basic areas. Thus there was not always a strong correlation between structural development and clay content on the one hand, with underlying parent material on the other, and particularly so in areas of non-basic parent material which occur downslope of basic parent material types.

Clay mineral suites are dominated by swelling 2:1 types.

The high quality orthic A and red structured B-horizons are suitable materials for annual cropping (good rooting medium) and use as 'topsoil' given their generally favourable texture (clay to sandy-clay-loam subsoils).

(iii) Pedocutanic soils

These relatively well ('red' as defined in soil matrix), moderately (brown), and occasionally poorly ('bleached' as defined in soil matrix) drained soils are generally shallow to deep (0,3 – 1,3-m) and occur in a number of patches in the survey area. Slope positions include the following:

- concave positions [gently sloping] (deep to intermediate in depth),
- footslope positions above the vertic soils (intermediate depth), and
- midslope positions downslope of extremely base rich parent material types (shallow).

Soil textures are generally clay-loam to clay in the topsoil and clay in the subsoil, except for those examples in the third slope position which occasionally have a sandy-clay-loam topsoil.

Structure varies from moderate to strong blocky in the topsoil and from strong to moderate blocky in the subsoil, while consistence is hard (rarely very hard) to slightly hard. Subsoil S-values are eutrophic.

The usable soil depth is dependant on the depth of the underlying unconsolidated wet material (majority), saprolite, hard rock, tallus or quartzite.

The pedocutanic subsoils are non-uniform in colour due to the presence of cutans (clay skins) on most ped surfaces, and both the presence of 2:1 clays and the generally high clay contents have given rise to the pedality (structure) of the soils.

The high to moderate quality orthic A and moderate to poor quality melanic A (rare) and pedocutanic B-horizons of these forms (Sepane, Valsrivier, Bonheim and Swartland) are suitable materials for use as 'topsoil' (not for dump cover), given their favourable texture (clay to clay-loam). However, many of these soils were deemed not to be suitable for annual cropping given either their limited depth or their slow permeability (probable high bulk density and low porosity in a number of cases).

(iv) Shallow soils

The relatively well ('red') to moderately (dark brown) drained shallow (0-0,4-m) soils of the Mispah (overlying hard rock -magnetite, tallus or metasandstone/quartzite) form [dominant] are widespread in rocky crest, scarp and moderately steep midslope positions, while the Glenrosa (overlying weathering rock – ferrogabbro and gabbro) form occurs to the south-west of the survey area on moderate slopes (not rocky). The Dresden (overlying hard plinthite) form occurs in two small patches only and is a desirable material for road surfacing. Two borrow-pits occur in the larger of these two areas.

These rocky and/or gravelly topsoils have a texture which varies from sandy-clay-loam (rarely sandy-clay or clay) on the basic parent material types to sandy-loam, loamy-sand or sand on the metasandstone/quartzite parent material types. Topsoil texture is both a function of parent material type and soil depth in these areas. Structure generally varies from weak blocky to apedal.

The orthic A horizon is unsuitable for annual cropping or forage plants. These rocky gravelly topsoils constitute a poor rooting medium with a very low total available moisture (drought prone). For the same reason these poor topsoils are generally not recommended for rehabilitation purposes, except as a last resort when more desirable material is not available (not the case in this area).

The 'shallow' soils in the mining areas (magnetite and ferrogabbro) are generally too shallow and too rocky (tallus and rock) to separate from the ore, this topsoil being lost. Topsoil stripping and stockpiling of the 'shallow' soils should only be attempted where the surface is not too rocky and where the topsoil overlies weathering rock (limited areas available), and not tallus. Should such topsoils be stripped, they should be replaced well below the soil surface (never at the surface) during rehabilitation, their contribution to rehabilitated depth not being considered. Other more suitable 'topsoil' material (red apedal, red structured or pedocutanic) is recommended for the rehabilitation of these areas.

(v) Vertic soils

Strongly structured dark calcareous and non-calcareous soils of the Arcadia form occur along the southern boundary of the survey area, these soils being derived from feldspar rich norite and anorthosite. Due to colluvial action these soils frequently overlie other parent material types (gabbro, ferrogabbro and occasionally diabase).

Downslope (north) of this area the Rensburg form (overlying a G-horizon = gleyed horizon) occurs in two gently concave drainage channels (permanent wetlands), the eastern of which drains into the floodplain of the Tshukutswe river (dry annual stream at this point), the soils of the floodplain also being of the Rensburg form. Two other small isolated patches of vertic topsoils occur to the north-west of the survey area.

These strongly structured clay textured vertic topsoils are intermediate [depth] to deep (0,5 – 1,2-m) in the non-rocky areas, and shallow (0,2 – 0,4-m) in the rocky areas. Topsoil colour is black to very-dark-grey.

Due to their high clay content and the predominance of smectitic clay minerals, vertic soils possess the capacity to swell and shrink markedly in response to moisture changes. Such expansive materials have a characteristic appearance: structure is strongly developed, ped faces are shiny, and consistence is highly plastic when moist and sticky when wet. Swell-shrink potential is manifested typically by the presence of conspicuous vertical cracks (dry state), and the presence of slickensides (polished or grooved glide planes produced by internal movement). Once the soils are moist, the permeability becomes very slow, and rainfall runs off laterally on the surface. Thus these soils are susceptible to erosion.

The poor quality vertic A-horizons have an unfavourable structure (strong blocky), consistence (very firm to firm) and permeability (slow once moist). These soils should be utilized to rehabilitate the ‘eastern’ pit area only, the pit being almost entirely (bar north-western boundary) surrounded by these soils, where they occur *in-situ*. The utilization of the vertic stock-piles which exist to the south of the pit will ensure soil and consequently vegetative continuity in the area.

(vi) Prismacutanic soils

Two very small patches of duplex (abrupt change in texture, structure and consistence from topsoil to subsoil) soils (Sterkspruit form) occur in the north-west of the survey area, this phenomenon generally being associated with a high exchangeable magnesium (most likely in this area) and/or sodium percentage. These soils are unsuitable for annual cropping, pastures or use as ‘topsoil’.

(vii) Man-made soils

One very small area of the Witbank form occurs to the south of the infrastructure area, where soil has been dumped into an old excavated area to a depth of 1,5-m, the undulating surface being approximately level with the surrounding surface.

Water-tables in augered depth were not present in the survey area at the time of the soil survey. Water-tables generally occur in summer after rainfall events, where there is a relatively impermeable horizon (hard plinthic B, soft plinthic B or G-horizon) below the A, B or E-horizon. Water tables largely disappear altogether in winter, except in the most low-lying positions.

The distribution and depths of areas where the soil was moist (rare) at the time of the soil survey are indicated on Map 2. These areas were: the soils surrounding, and an area extending to the north-west of the large ‘western’ pond; the soils surrounding, and the drainage line in the vicinity of the small ‘eastern’ pond; the deep soils between the slimes dam and the infrastructure area; and the small area of man-made soil on the south-western boundary of the infrastructure area.

2.2.4 SOIL ANALYTICAL DATA (Table 2)

Table 2 shows the analytical data for the topsoil (A-horizon) and subsoil (B-horizon) samples collected from modal examples of seven different soil forms. These samples represent five of the seven broad soil groups which occur in the survey area, samples not being collected from the two broad soil groups (prismacutanic and man-made) which together account for only 0,21 % of the area.

The analytical determinations were conducted in the laboratories of the Institute for Soil, Climate and Water (Agricultural Research Council) in Pretoria.

The interpretation of this data is discussed in the next section.

Table 2. Soil Analytical Data

SOIL SAMPLE AND GRID REFERENCE	PIT 1 (AUGER J27)				PIT 2 (AUGER V13)				PIT 3 (AUGER N28)				PIT 4 (AUGER J15)				PIT 5 (AUGER R17)			
HORIZON AND DEPTH	A(10cm)		B(50cm)		A(10cm)		B(60cm)		A(10cm)		B(60cm)		A(10cm)		B1(60cm)		A(10cm)		B(60cm)	
LABORATORY REFERENCE (ISCW)	M4282		M4283		M4284		M4285		M4290		M4291		M4288		M4289		M4286		M4287	
TEXTURE(%) Sand: Coarse	9,61]		6,69]		26,60]		17,79]		26,67]		24,12]		7,72]		7,19]		7,87]		10,30]	
Medium	12,71]	39,37	6,48]	24,80	16,80]	63,40	8,49]	38,66	21,04]	77,08	19,33]	67,67	4,67]	22,04	2,84]	16,11	8,70]	28,38	5,56]	24,75
Fine	12,40]		7,41]		14,85]		8,49]		21,87]		17,98]		5,89]		3,65]		8,39]		5,66]	
Very fine	4,65]		4,22]		5,15]		3,89]		7,50]		6,24]		3,76]		2,43]		3,42]		3,23]	
Silt : Coarse	4,13 }	13,58	4,32 }	17,08	3,25 }	8,87	3,02 }	8,85	2,55 }	5,31	1,46 }	5,41	7,26 }	25,84	6,03 }	18,95	3,52 }	21,74	7,42 }	25,05
: Fine	9,45 }		12,76 }		5,62 }		5,83 }		2,76 }		3,95 }		18,58 }		12,92 }		18,22 }		17,63 }	
Clay :	45,25 →	47,05	56,17 →	58,12	26,13 →	27,73	50,36 →	52,49	16,20 →	17,61	24,38 →	26,92	52,08 →	52,12	64,39 →	64,94	48,34 →	49,88	48,59 →	50,20
TEXTURE CHART	CoCl		CoCl		CoSaClLm		CoCl		CoSaLm		CoSaClLm		CoCl		CoCl		CoCl		CoCl	
EXCHANGEABLE																				
CATIONS Ca	5,130	1028	6,946	1392	3,678	737	7,116	1426	2,560	513	3,508	703	6,442	1291	6,876	1378	5,614	1125	4,157	833
(cmol (+) kg^{-1} soil Mg [ppm =	2,058	250	2,354	286	1,325	161	1,860	226	1,737	211	2,255	274	3,811	463	4,486	545	2,173	264	1,959	238
= meq 100g soil) K mg/kg]	0,844	330	0,194	76	0,189	74	0,102	40	0,153	60	0,069	27	0,650	254	0,348	136	0,964	377	0,488	191
Na	0,161	37	0,239	55	0,217	50	0,291	67	0,144	33	0,148	34	0,335	77	0,265	61	0,191	44	0,235	54
S-VALUE cmol (+)kg^{-1} soil	8,193		9,733		5,409		9,369		4,594		5,980		11,238		11,975		8,942		6,839	
cmol (+)kg^{-1} clay	17,4		16,7		19,5		17,8		26,1		22,2		21,6		18,4		17,9		13,6	
CEC at pH7 cmol (+)kg^{-1} soil	14,963		18,693		10,385		14,014		6,594		8,227		15,742		19,529		13,329		10,306	
cmol (+)kg^{-1} clay	31,8		32,2		37,5		26,7		37,4		30,6		30,2		30,1		26,7		20,5	
BASE SATURATION (%)	54,8		52,1		52,1		66,9		69,7		72,7		71,4		61,3		67,1		66,4	
ESP (%)	1,1		1,3		2,1		2,1		2,2		1,8		2,1		1,4		1,4		2,3	
SATURATION EXTRACT SOLUBLE CATIONS																				
(cmol (+) kg^{-1} soil Ca [ppm =	0,031	6,30	0,013	2,64	0,028	5,63	0,063	12,71	0,014	2,88	0,020	4,04	0,043	8,58	0,030	5,99	0,018	3,62	0,012	2,45
= meq 100g soil) Mg mg/kg]	0,019	2,29	0,006	0,70	0,015	1,87	0,027	3,27	0,013	1,56	0,018	2,22	0,035	4,27	0,024	2,93	0,011	1,37	0,007	0,90
K	0,016	6,27	0,002	0,74	0,004	1,53	0,002	0,59	0,003	1,26	0,001	0,49	0,009	3,58	0,003	1,28	0,015	5,94	0,005	1,97
Na	0,020	4,52	0,017	3,83	0,041	9,41	0,026	6,09	0,012	2,85	0,016	3,78	0,061	14,06	0,025	5,76	0,024	5,59	0,014	3,30
SAR	0,58		0,71		1,50		0,59		0,53		0,60		1,32		0,62		0,90		0,61	
EC (mS/m)	23		7		29		28		11		14		30		15		15		7	
RESISTANCE (ohms)	NOT DETERMINED																			
pH (1:2,5 H2O)	5,60		5,94		5,63		6,36		5,70		6,57		5,63		6,04		6,38		6,40	
ORGANIC CARBON (%) Walkley Black	0,82		0,58		0,77		0,56		0,55		0,46		1,31		0,68		1,33		0,66	
TOTAL N (TKN) (%)	0,052		0,036		0,030		0,024		0,028		0,023		0,058		0,036		0,050		0,027	
P (Bray P1) (ppm = mg/kg)	4,00		0,70		3,39		1,36		4,52		0,33		0,82		0,42		0,89		0,42	
SOIL FORM	Shortlands				Shortlands - Hutton				Shortlands				Bainsvlei				Hutton			
SOIL FAMILY	Bayala				Bolweni				Bolweni				Florida				Hayfield			
CODE	Sd2110				Sd2210				Sd2210				Bv3100				Hu2100			
DEGREE OF LEACHING	Eutrophic				Eutrophic				Eutrophic				Eutrophic				Mesotrophic			
DOMINANT PARENT MATERIAL	Magnetite				Magnetite				Ferrogabbro				Colluvium				Ferricrete			
PRESENT LAND USE	Bush				Bush				Bush				Bush				Grassland			
BROAD SOIL GROUP	RED STRUCTURED				RED STRUCTURED – RED APEDAL (TRANSITIONAL)				RED STRUCTURED				RED APEDAL				RED APEDAL			

Table 2. Soil Analytical Data (continued)

SOIL SAMPLE AND GRID REFERENCE	PIT 6 (AUGER I9)		PIT 7 (AUGER AB18)	PIT 8 (AUGER X9)	PIT 9 (AUGER N25 west)	PIT 10 (AUGER J31)
HORIZON AND DEPTH	A(5cm)	B(50cm)	A(40cm)	A(5cm)	A(5cm)	A(5cm)
LABORATORY REFERENCE (ISCW)	M4292	M4293	M4297	M4294	M4295	M4296
TEXTURE(%) Sand: Coarse	15,63]	10,13]	2,71]	24,17]	16,96]	22,52]
Medium	11,04] 43,33	6,01] 25,85	3,58] 17,68	18,49] 72,62	15,73] 59,14	25,05] 87,22
Fine	11,87]	6,65]	6,62]	22,21]	19,20]	32,35]
Very fine	4,79]	3,06]	4,77]	7,75]	7,25]	7,30]
Silt : Coarse	5,52 } 16,14	2,80 } 10,82	5,59 } 18,93	3,25 } 9,45	4,90 } 10,77	1,72 } 3,29
: Fine	10,62 }	8,02 }	13,34 }	6,20 }	5,87 }	1,57 }
Clay :	39,06 → 40,53	61,55 → 63,33	61,61 → 63,39	15,81 → 17,93	28,60 → 30,09	7,20 → 9,49
TEXTURE CHART	CoClLm	CoCl	FiCl	CoSaLm	CoSaClLm	CoSa
EXCHANGEABLE CATIONS (cmol (+) kg^{-1} soil = meq 100g soil) [ppm = mg/kg] Ca	7,111 1425	11,203 2245	50,624 10145	4,346 871	7,375 1478	1,312 263
Mg	2,757 335	3,531 429	10,510 1277	1,737 211	2,584 314	0,650 79
K	0,760 297	0,199 78	0,872 341	0,568 222	0,212 83	0,714 279
Na	0,161 37	0,231 53	0,278 64	0,130 30	0,248 57	0,087 20
S-VALUE cmol (+)kg^{-1} soil	10,789	15,164	62,284	6,781	10,419	2,763
cmol (+)kg^{-1} clay	26,6	23,9	98,3	37,8	34,6	29,1
CEC at pH7 cmol (+)kg^{-1} soil	14,863	17,107	54,492	8,908	9,417	3,711
cmol (+)kg^{-1} clay	36,7	27,0	85,9	49,7	31,3	39,1
BASE SATURATION (%)	72,6	88,6	114,3	76,1	110,6	74,5
ESP (%)	1,1	1,4	0,5	1,5	2,6	2,3
SATURATION EXTRACT SOLUBLE CATIONS (cmol (+) kg^{-1} soil = meq 100g soil) [ppm = mg/kg] Ca	0,015 3,05	0,020 4,02	0,137 27,53	0,009 1,83	0,185 37,14	0,006 1,15
Mg	0,009 1,09	0,010 1,22	0,044 5,36	0,006 0,73	0,108 13,15	0,002 0,29
K	0,009 3,35	0,002 0,90	0,006 2,19	0,009 3,40	0,005 2,01	0,035 13,71
Na	0,017 3,91	0,016 3,76	0,024 5,56	0,011 2,52	0,049 11,38	0,012 2,69
SAR	0,69	0,55	0,28	0,67	0,61	1,12
EC (mS/m)	10	8	23	11	71	24
RESISTANCE (ohms)	NOT DETERMINED					
pH (1:2,5 H2O)	6,20	6,33	7,84	6,29	6,32	6,81
ORGANIC CARBON (%) Walkley Black	1,54	0,80	0,84	1,10	0,97	0,74
TOTAL N (TKN) (%)	0,072	0,042	0,041	0,067	0,052	0,052
P (Bray P1) (ppm or mg/kg)	0,85	0,24	0,37	2,82	1,36	11,37
SOIL FORM	Sepane		Arcadia	Glenrosa	Mispah	Mispah
SOIL FAMILY	Katdoorn		Rietkuil	Tsende	Myhill	Myhill
CODE	Se1210		Ar2000	Gs1211	Ms1100	Ms1100
DEGREE OF LEACHING	Eutrophic		Calcareous	Eutrophic	Eutrophic	Eutrophic
DOMINANT PARENT MATERIAL	Colluvium		Norite Colluvium	Ferrogabbro	Magnetite	Metasandstone/Quartzite
PRESENT LAND USE	Scrub thorn grass veld		Scrub thorn grass veld	Bush	Bush	Bush
BROAD SOIL GROUP	PEDOCUTANIC		VERTIC	SHALLOW	SHALLOW	SHALLOW

NOTE: Textural rounding off discrepancies were added to the clay content.

2.2.5 SOIL ANALYTICAL CHARACTERISTICS AND SOIL FERTILITY (Table 2)

(i) Soil texture

Soil texture is considered to be a permanent property of soils and as such it is particularly important in determining soil behaviour. Many soil properties are dependent on the proportions of sand, silt and clay, including *inter-alia* nutrient and water holding ability, permeability, porosity, erodibility, and susceptibility to compaction.

The soils of the survey area have moderately low to high amounts of silt ranging from approximately 5 to 26 % in the topsoils and subsoils. These soils have moderate to high clay contents ranging from approximately 18 to 52 % (majority 41 to 52 %) (red apedal, red structured and pedocutanic soils) or 63 % (vertic soils) in the topsoils, and from approximately 27 to 65 % (majority 50 to 65 %) in the subsoils. The soils contain low to moderate, fine (including very fine) sand contents that generally range from approximately 10 to 29 % in both the topsoils and the subsoils.

All of these values exclude the shallow soils (approximately 9 to 30 % clay), which are not likely to be utilized for rehabilitation purposes, while they also exclude the small isolated patches of prismacutanic and man-made soils which will definitely not be utilized (also not analysed).

(ii) Soil pH (reaction)

Soil pH is the degree of acidity of a soil. Descriptive terms commonly associated with certain ranges in soil pH (van der Watt, 1995) measured in distilled water are:

extremely acid (< 4,5),	very strongly acid (4,5-5,0),	strongly acid (5,1-5,5),
medium acid (5,6-6,0),	slightly acid (6,1-6,5),	neutral (6,6-7,3),
mildly alkaline (7,4-7,8),	moderately alkaline (7,9-8,4),	strongly alkaline (8,5-9,0) and
very strongly alkaline (> 9,0).		

The soil pH has a direct influence on plant growth in a number of ways:

- through the direct effect of the hydrogen ion concentration on nutrient uptake;
- indirectly through the effect on trace nutrient availability; and by the
- mobilizing of toxic ions such as aluminium and manganese, which restrict plant growth.

The midslope (red apedal, red structured and pedocutanic broad soil groups) topsoils range in pH from 5,60 to 6,38 and subsoils from 5,94 to 6,57, while the vertic topsoil has a pH of 7,84, and the shallow soils topsoils range in pH from 6,29 to 6,81. The vertic pH reflects the presence of calcium carbonate which occurs in many of the vertic soils, and particularly so in the wetland area (Rensburg form) which was not analysed, but which is likely to have an even higher pH at certain locations.

(iii) Saturated extract

Saturated extracts are used to determine the amounts of easily water-soluble elements, especially the amounts of Ca (calcium), Mg (magnesium) and Na (sodium) in order to determine the salinity and sodicity of the soil.

<u>Background</u>

Electrical conductivity (EC: measured in millisiemens/m : mS/m) is a measure of the ability of a soil saturation extract to conduct electricity and is a measure of the concentration of salts in solution. For example low salinity irrigation waters have values less than 25 mS/m and high salinity irrigation waters have values greater than 75 mS/m.

Highly saline (high soluble salt content of which sodium forms a modest proportion [usually exchangeable sodium percentage or ESP < 15]) soils will result in the reduction of plant growth, caused by the diversion of plant energy from normal physiological processes to that involved in the acquisition of water under highly stressed conditions.

The sodium adsorption ratio (SAR) measures soil sodicity and is a measure of the quality of a solution (eg. saturation extract or an irrigation water regards sodium content). At high levels of exchangeable sodium, certain clay minerals, when saturated with sodium, swell markedly. With the swelling and dispersion of a sodic soil, pore spaces become blocked and infiltration rates and permeability are greatly reduced. The critical SAR for poorly drained grey soils is 6, for slowly draining black swelling clays is 10 and for well drained soils and recent sands 15. The exchangeable sodium percentage (ESP) [percentage of the cation exchange capacity (CEC) that is occupied by sodium] is also an indicator of soil sodicity. A sodic (low soluble salt content and a high exchangeable sodium percentage [usually ESP > 15] soil has sufficient adsorbed sodium to have caused significant deflocculation.

The Chamber of Mines specifies that for a soil to be defined as arable (or to be utilized as ‘topsoil’), that it must have an EC of less than 400 mS/m at 25°C and an ESP of less than 15 throughout the upper 0,75-m of soil.

<u>Survey Area</u>

Amounts of Ca, Mg and Na extracted are generally low to moderate for all soils, except for Pits 7, 4 and 2. Pit 7 is calcareous and so higher amounts of Ca and Mg were expected. The relatively high extractable Ca, Mg and Na, relative to the other non-calcareous soils, found in Pits 4 and 2 is anomalous and suggests that there are soluble carbonate minerals present in these soils, but insufficient to cause the pH to rise above the average. Pit 4 (Bainsvlei) is in a level footslope position, thus bases have probably accumulated in this area from upslope. The aforementioned notes apply to Pits 1-7, these soils being utilized for rehabilitation purposes.

The EC (concentration of salts in solution) for all soils is low to moderate. Thus the soils are not saline. Furthermore the ESP for all soils is very low (0,5-2,6). Thus neither are the soils sodic. This is confirmed by the SAR which too is very low (0,28-1,50) for all soils.

(iv) Organic carbon, nitrogen and phosphorus

Organic matter (indicated by the amount of organic carbon) is of vital importance in soil. It improves the structural condition of both coarse- and fine-textured soils and improves the water holding capacity, especially of sandy soils. It therefore greatly reduces the erodibility of soil. Organic matter supplies greater than 99 % of total soil N (nitrogen) and 33-67 % of total soil P (phosphorus). Humus, the active fraction of soil organic matter has a very high CEC (between 150 and 300 cmol(+) kg^{-1}) and can adsorb up to about 6 times its own weight in water. The C:N (carbon : nitrogen) ration of humus is often about 10:1 to 12:1.

In all the sloping midslope soils (Pits 1-3) the value for topsoil organic carbon is low (topsoils 0,55-0,82 %), while in the almost level footslope area (Pits 4-6) it is moderate (1,31-1,54 %). Subsoil organic carbon for the soils as a whole is low (0,46-0,80 %). Organic carbon for the vertic topsoil is 0,84 % while that for the shallow soils varies from 0,74-1,10 %.

Total N, as expected will generally follow the same trend as organic carbon with the highest amount being found in the topsoil of Pit 6, the remaining soils having lower levels of N. The topsoil C:N ratios exhibit a larger range than in the subsoil reflecting the more stable condition of the organic matter at depth.

Extractable P is always lower in the subsoil, reflecting the low solubility of this element in soil. The P values in the topsoil range from 0,37 (Pit 7) to 4,52 ppm (Pit 3) [bar an outlier of 11,37 for Pit 10 which is derived from metasandstone], and from 0,24 (Pit 6) to 1,36 ppm (Pit 2) in the subsoil. Bar Pit 10, the highest extractable P is generally found in the soils with the lowest pH, notably the topsoils of Pits 1, 2 and 3. This is probably due to the greater efficiency of the Bray 1 extractant at lower soil pH. The generally very low extractable P in the higher pH soils supports this interpretation. All soils thus have extremely low extractable P values below 4,52 ppm (bar Pit 10 outlier).

(v) Exchangeable cations

It is normal practice to determine what are known as the 'exchangeable bases' i.e., Ca, Mg, K (potassium) and Na because they include three of the major plant nutrients, and Na because it indicates the possible sodicity of the soil, especially in circumstances where saturated paste data are not available. Lack of organic matter and clay minerals, which provide exchange sites that serve as nutrient stores, results in the soil having a low ability to retain and supply nutrients for plant growth. The maximum potential of a soil to retain nutrients in an exchangeable form is assessed by measuring the cation exchange capacity (CEC). The percentage base saturation is then calculated as:

(sum of the four bases / CEC) x 100.

In general the amounts of exchangeable cations follow the same trend as outlined for pH, texture and saturated paste data. Thus Pit 7 (highest pH, as well as second highest clay content) contains the highest amount of exchangeable bases. In the majority of soils the cations follow the typical trend Ca > Mg > K > Na. Exceptions are: Ca > K > Mg > Na for the A-horizons of Pits 1, 5 and 10; and Ca > Mg > Na > K for the B-horizons of Pits 2 and 3. pH related exchangeable cation trends are not easily identified for the majority of soils (bar Pit 7 which has a pH of 7,84) since there is not a large range of pH for all horizons (5,60-6,81). Amounts of exchangeable sodium are relatively low and thus the exchangeable sodium percentage is negligible (all being less than about 2,6 %).

The base saturation values for Pits 1 to 6 as well as Pits 8 and 10 range from 52,1 to 88,6 % while that for Pits 9 and 7 range from 110,6 to 114,3 % respectively. These should be interpreted with some caution. The CEC value was measured at pH 7.0 and thus is only truly representative of the actual field value when the pH of the soil being analyzed is close to that value. The further the pH of the soil diverges from pH 7.0, then the less accurate the CEC determination becomes. In addition the S-value does not include any exchangeable acidity that may exist, especially in the more acid soils. A further constraint is apparent from the soils that have a base saturation >100 %. These are calcareous and it is probable that the extraction for exchangeable cations also dissolved some of the carbonate minerals, thus inflating the amount of apparent exchangeable bases, so resulting in an unrealistic base saturation value. In spite of these cautionary comments it is clear that the base saturation and CEC values generally follow the same trend as those for pH and texture with the coarser-textured, more acid soils having lower base saturation values and CEC than the finer-textured soils with higher pH. However, an exception to this general trend is the shallow soils which despite having relatively low clay contents, still have relatively high base saturation values and CEC.

(vi) Soil fertility

The comments that follow are based on the laboratory data discussed above and thus reflect the fertility of the soils as currently exists in the field, with the soils *in-situ*. It does not take into account any changes that may occur as a result of stripping, stock-piling and compaction, or the rehabilitation methods or purposes for which the soil may be used. It would be imperative that if any of the soils are to be used for rehabilitation purposes, that their fertility status be re-analyzed at that time prior to their use, in order that recommendations concerning possible ameliorative actions can be given, depending on the species to be planted. In addition different crops have different soil fertility requirements and so the discussion here can be of a general nature only, rather than specific to a particular crop.

None of the soils is either saline or sodic and the extremely low values of ESP (0,5-2,6) and SAR (0,28-1,50) show that salinity and sodicity will not be a problem in the cropping soils in the future. The amounts of soluble cations compared to the exchangeable fraction are extremely low suggesting that leaching of bases is not likely to be a serious problem and that the bases held in the soils are likely to remain available to plant roots.

If an optimum pH is assumed to be between about 6 and 7 (the range in which most nutrients are most available and the average range preferred by most crops), the pH values in all horizons range from being suitable for most crops (majority of samples), to being unsuitable either due to being too acid (topsoils of Pits 1, 2, 3 and 4 and subsoils of Pits 1 and 2) or being rather too high (Pit 7).

In terms of fertility for maize, the optimal levels of nutrients (exchangeable cations) are: K (120 ppm optimal – 100 ppm acceptable) and Mg (60 ppm). The values of K are sufficient for the majority of cropping soil topsoils (bar Pits 2 and 3 which are deficient). The subsoil samples (not rooting material except in rehabilitated areas) of Pits 1, 2, 3 and 6 were also deficient. Mg values are more than adequate for all of the horizons. All of the topsoil and subsoil samples are seriously deficient in P (optimum levels are 34 ppm). Levels of Ca should be in the range of 300 to 400 ppm, the soils having much higher values than these.

All the cropping soils (topsoils and subsoils) are also deficient in N (due to the generally low organic carbon percentages). The low amounts of organic matter would mean that fertilizer would have to be added regularly and often to maintain levels adequate for crops.

In terms of fertility for improved or natural pasture there are no accepted data for the elemental concentrations required in the soil to ensure optimum yields. Most of the available data is based on leaf analysis from various field experiments. The Guidelines for the rehabilitation of land disturbed by surface coal mining in South Africa (1981) suggest that optimal concentrations for P, K and Mg are 36, 120 and 50 mg kg^{-1}, respectively. Given these values it is clear that all the soils are seriously deficient in P. The values of K are sufficient for the majority of topsoil samples (bar Pits 2, 3 and 9, which are deficient). The subsoil samples of Pits 1, 2, 3 and 6 were also deficient in K. Mg values are more than adequate for all of the samples.

2.2.6 EROSION HAZARD AND SLOPE (Tables 2 and 3 and Figure 1)

It is necessary to determine the maximum critical slope (at which unacceptable soil erosion will begin to occur) for a site to be regarded as arable, for the range of broad soil groups that occur. To this end, minimum erosion slopes were calculated (for the topsoils and subsoils of the ten typical soil pits) from the soil erodibility nomograph of Wischmeier, Johnson and Cross (1971), based on the soil analytical data (Table 2) gathered during the soil survey.

The nomograph uses the following five soil parameters, which have been shown by research to have a major effect in determining erodibility:

i) The mass percentage of the fraction between limiting diameters of 0.1 and 0.002-mm (very fine sand plus silt) of the topsoil.

ii) The mass percentage of the fraction between 0.1 and 2.0-mm diameter (residue of sand fraction – fine, medium and coarse) of the topsoil.

iii) Organic matter content of the topsoil, obtained by multiplying the organic carbon content (in grams per 100 g soil, Walkley Black method) by a factor of 1.724.

iv) A numerical index of soil structure.

v) A numerical index of soil permeability of the soil profile as a whole.

Although topsoil permeability's vary from rapid to slow (majority rapid to moderate), the permeability classes refer to the permeability of the profile as a whole, which is determined by the controlling soil layer (horizon). Thus profiles overlying horizons of slow permeability (eg. hard plinthite, hard rock or a gleyed horizon) or luvic soils (with relatively permeable sandy topsoils overlying less permeable higher clay subsoils) are likely to reach field capacity relatively quickly, and particularly so when the soil depth is limited and the storm is heavy or of long duration. Therefore, the permeability classes cater for the worst scenario (heavy storm of long duration on a shallow example of the soil type). Other controlling soil horizons include slowly to very slowly (once moist) permeable vertic A-horizons and prismacutanic B-horizons (two small areas).

Both soil structure and soil permeability have a large influence on the soil erodibility factor (K) and thus the maximum slope for a site to be regarded as arable. The soil permeability index is the most subjective of the five parameters and is difficult to decide upon.

Figure 1 shows the nomograph while Table 3 is a summary of the data used and the results obtained.

Figure 1. The Soil Erodibility Nomograph of Wischmeier, Johnson and Cross (1971)

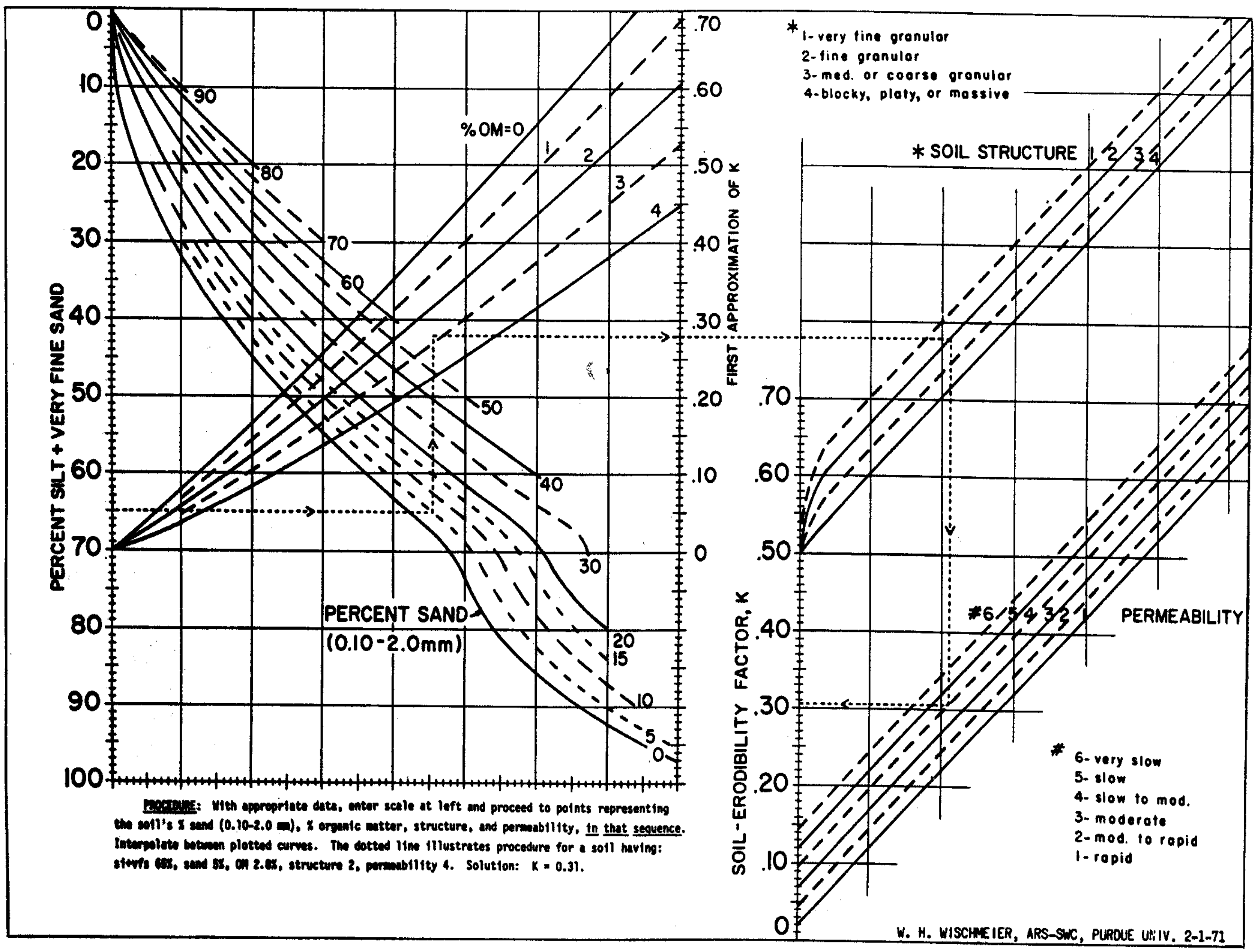

Table 3. Data Used and Results Obtained from the Soil Erodibility Nomograph

DATA USED						RESULTS OBTAINED		
SOIL SAMPLE	**MASS PERCENTAGE OF:**		**ORGANIC MATTER % (organic carbon x 1,724)**	**SOIL STRUCTURE (type and size)**	**SOIL PERMEABILITY BASED ON CONTROLLING SOIL HORIZON (profile as a whole)**	**SOIL ERODIBILITY FACTOR K (From nomograph)**	**MAXIMUM CRITICAL SLOPE FOR ARABLE (*IN-SITU*) REHABILITATION & DUMP-COVER**	
	vf sand & silt	**sand residue**					**%**	**Degrees**
PIT 1: SHORTLANDS **Orthic A**	18	35	1,4	Coarse granular (3)	*In-Situ*: Moderate (3)	0,100	20,0	11,3
Red structured B	21	21	1,0	Blocky (4)	Rehab: Moderate (3) Dump: Slow (5)	0,125 0,170	16,0 11,8	9,1 6,7
PIT 2: SHORTLANDS **Orthic A**	14	58	1,3	Coarse granular (3)	*In-Situ*: Moderate (3) (controlling-red structured)	0,095	21,1	11,9
Red structured B	13	35	1,0	Blocky (4)	Rehab: Moderate (3) Dump: Slow (5)	0,110 0,158	18,2 12,7	10,3 7,2
PIT 3: SHORTLANDS **Orthic A**	13	70	0,9	Coarse granular (3)	*In-Situ*: Moderate to rapid (2) (controlling-red structured)	0,085	23,5	13,2
Red structured B	12	61	0,8	Blocky (4)	Rehab: Moderate to rapid (2) Dump: Slow (5)	0,112 0,188	17,9 10,6	10,2 6,1
PIT 4: BAINSVLEI **Orthic A**	30	18	2,3	Coarse granular (3)	*In-Situ*: Slow- moderate (4) (controlling-dense clay B)	0,142	14,1	8,0
Red apedal B	21	14	1,2	Coarse granular (3)	Rehab: Slow–moderate (4) Dump: Slow (5)	0,115 0,135	17,4 14,8	9,9 8,4
PIT 5: HUTTON **Orthic A**	25	25	2,3	Coarse granular (3)	*In-Situ*: Moderate-rapid (2)	0,075	26,7	14,9
Red apedal B	28	22	1,1	Coarse granular (3)	Rehab: Moderate-rapid (2) Dump: Slow (5)	0,100 0,176	20,0 11,4	11,3 6,5

Table 3. Data Used and Results Obtained from the Soil Erodibility Nomograph (continued)

DATA USED						RESULTS OBTAINED		
SOIL SAMPLE	MASS PERCENTAGE OF:		ORGANIC MATTER % (organic carbon x 1,724)	SOIL STRUCTURE (type and size)	SOIL PERMEABILITY BASED ON CONTROLLING SOIL HORIZON (profile as a whole)	SOIL ERODIBILITY FACTOR K (From nomograph)	MAXIMUM CRITICAL SLOPE FOR ARABLE (*IN-SITU*) REHABILITATION & DUMP-COVER	
	vf sand & silt	sand residue					%	Degrees
PIT 6: SEPANE Orthic A	21	39	2,7	Fine granular (2)	*In-Situ*: Slow (5) (controlling-dense clay B)	0,128	15,6	8,9
Pedocutanic B	14	23	1,4	Blocky (4)	Rehab: Slow (5)	0,155	12,9	7,3
PIT 7: ARCADIA Vertic A	24	13	1,4	Blocky (4)	*In-Situ* / Rehab: Slow (5)	0,160	12,5	7,1
PIT 8: GLENROSA Orthic A	17	65	1,9	Coarse granular (3)	*In-Situ*: Slow-moderate (4) (controlling-hard lithocutanic B)	0,148	13,5	7,7
PIT 9: MISPAH Orthic A	18	52	1,7	Fine granular (2)	*In-Situ*: Slow (5) (controlling-hard rock)	0,142	14,1	8,0
PIT 10: MISPAH Orthic A	11	80	1,3	Very fine granular(1)	*In-Situ*: Slow (5) (controlling-hard rock)	0,125	16,0	9,1

Table 3 shows the K factor to increase, and the maximum slope for a site to be classed as arable to decrease with the following:

i) increasing very fine sand plus silt,
ii) decreasing organic matter percentage,
iii) increasing structure index, and
iv) decreasing permeability.

We regard the minimum slope for an unacceptable erosion hazard to exist, as the maximum slope for the site to be regarded as arable in terms of The Chamber of Mines land use capability (see PRE-MINING LAND CAPABILITY). The specification that the product of percent slope and soil erodibility factor (K) must not exceed 2.0 for land to be classed as arable, was the basis of calculating the maximum slope for arable in Table 3. Once the value of 2.0 is exceeded, an unacceptable erosion hazard exists and conservation measures are required.

***In-Situ* (undisturbed) soils**

Table 3 indicates the following critical slopes for the topsoils (orthic A and one Vertic A-horizon) of the following broad soil groups:

- Red structured and red apedal soils (Generally arable, occasionally grazing capability class, depending on depth and slope among other criteria) : Pits 1-3 and Pit 5 majority 20,0% (11,3 degrees) – 26,7% (14,9 degrees) : excluded Pit 4 14,1% (8,0 degrees) which is not representative of the majority of the red soils,
- Pedocutanic soils (Arable or grazing capability class) : Pit 6 : 15,6 % (8,9 degrees),
- Vertic soils (Majority grazing or wetland capability class, rarely wilderness - rocky areas) : Pit 7 : 12,5% (7,1 degrees),
- Shallow soils (Majority wilderness capability class, occasionally grazing) : Pits 8-10 : 13,5% (7,7 degrees) – 16,0% (9,1 degrees).

The subsoil values are not normally considered (not exposed) for the determination of the arable class.

The worst scenario critical arable slope for the red structured and red apedal (excluding pit 4) broad soil groups is thus 20,0 % (11,3 degrees), which is slightly steeper to that of Scotney *et al* (1987) for ferrallitic soils, vis 15,0 % (8,5 degrees). This slope is similar to that of pit 4 (worst scenario which is not representative of the majority of the red soils), vis 14,1 % (8,0 degrees).

Scotney *et al* (1987) [not considered in this report] makes use of the following critical arable slopes:

• Ferrallitic (highly weathered) soils	:	< 15,0 %	(8,5 degrees),
• Non-ferrallitic soils without a 'clay increase B horizon'	:	< 12,0 %	(6,8 degrees),
• Non-ferrallitic soils with a 'clay increase B horizon'	:	< 10,0 %	(5,7 degrees),
• Duplex soils	:	< 8,0 %	(4,5 degrees).

Slope in the survey area varies as follows:	majority :	1,8 % (1 degree) - 7,0 % (4 degrees) (valley bottom – midslope),
	: occasionally:	7,0 % (4 degrees) - 24,0 % (14 degrees) (hill slopes – midslope),
	: rarely :	24,0 % (14 degrees) – 36,4 % (20 degrees) (hill slope – scarp).

Slope was not a limiting factor in the majority of the survey area with regard to the determination of the arable capability class since the soils which were deep enough to qualify as arable (≥75-cm) generally occurred in areas where the slope was less than 14,1% (8,0 degrees). Other steeper sections display soils of shallow to intermediate (<75-cm) depth, and thus already classify as grazing areas.

It should be noted that the Department of Agriculture stipulates that conservation measures should be implemented on slopes of over 2,0 % (1,1 degrees) on disturbed (where the original grass cover has been removed) sites. These measures involve practices such as building contour banks, re-grassing and cultivating on the contour, etc. The maximum allowable slope for annual cropping is 12 % (6,8 degrees).

Rehabilitated (stripped) soils overlying discard rock (not compacted)

Table 3 indicates the following critical slopes for subsoils, at which an unacceptable erosion hazard will exist when stripped soil material is used for rehabilitation purposes:

- Red structured and red apedal soils : Pit 1: 16,0 % (9,1 degrees) – Pit 5: 20,0 % (11,3 degrees),
- Pedocutanic soils : Pit 6 : 12,9 % (7,3 degrees),
- Vertic soils : Pit 7 : 12,5 % (7,1 degrees).

The subsoils were considered since these B-horizons constitute the majority of the suitable available volume, and in practice subsoil (B-horizon) and topsoil (A-horizon) mixing is likely, despite the fact that it would be desirable to strip and topsoil these reserves separately (A-horizons replaced at the surface).

Given that the permeability of the discard rock will (nomograph exercise point of view) be rapid [360-3600-mm/hour], while the permeability of the 'topsoil' will on the whole be moderate [36-360-mm/hour] (red structured and red apedal subsoils) to slow [0,36-3,6-mm/hour] (pedocutanic subsoil and vertic topsoil), then the 'topsoil' itself becomes the controlling soil horizon.

Thus in rehabilitated areas (particularly of the rehabilitated arable capability class), **slopes of over 16,0 % (9,1 degrees)** should be **minimized** when utilizing **red structured and red apedal 'topsoil' material,** while **slopes of over 12,5 % (7,1 degrees)** should be **minimized** when utilizing **pedocutanic and vertic 'topsoil' material.** The determined maximum slopes are also similar to those determined by Scotney *et al* (1987) for ferrallitic soils, vis 15,0 % (8,5 degrees) and non-ferrallitic soils without a clay increase B-horizon, vis 12,0 % (6,8 degrees), which represent the two aforementioned scenarios.

Dump cover (stripped) soils (compacted)

In the case of dumps (eg. calcine tailings dump) where the objective is to limit the infiltration of rain water to avoid contamination of the ground water, a layer of compacted 'remoulded' soil is placed immediately overlying the dump. In such cases, the permeability of the controlling 'soil' horizon (compacted 'remoulded' soil) will from the nomograph exercise point of view, be defined as slow [0,36-3,6-mm/hour], then irrespective of the soil type used as dump cover material (overlying the compacted layer), the critical erosion slopes will be low for all suitable (for dump cover) soil types as follows:

- **Red structured and red apedal broad soil groups only : 10,6 % (6,1 degrees) – 12,7 % (7,2 degrees).**

The recommended maximum gradient (Chamber of Mines) for spoil dumped on level to gently sloping terrain is at least lv:3h (33,0 % or 18,4 degrees), the least erosion occurring if the slope angle reduces in the direction of the toe of the pediment (ie. concave). Given the minimum erosion slopes calculated in this exercise, 18,4 degree slopes appear to be too steep and would lead to unacceptable levels of soil erosion occurring after rehabilitation.

2.2.7 DRYLAND PRODUCTION POTENTIAL (Maps 2 and 3)

Agricultural potential of the various capability classes, as determined in the chapter PRE-MINING LAND CAPABILITY are discussed for the survey area as a whole.

DRYLAND

The agricultural yields mentioned in this section are those as per the following:

- Personal communication with Clifford Moshwane who leases land (vertic broad soil group) to the south of the mine.

- Personal communication with Johan Janse van Rensburg who farms near Brits. Brits lies approximately 10km to the south-east.

Given both the low effective rainfall in the area (approximately 621 [Brits] – 651-mm [Kareepoort] per annum) as well as the fact that the area has had approximately five years of drought (less than 75% of average rainfall) in the last seven years (between the years 1998 and 2004), dryland production is not recommended due to the low yields obtained as well as the high associated risk.

(i) **Arable** - Undisturbed : 528,38 ha (30,06 %)
- Rehabilitated : 0,53 ha (0,03 %)
: deeper (>75-cm) red structured, red apedal and pedocutanic (lower bulk density examples) broad soil groups

- Sunflowers (as cash crop) : 1,5 – 2,0 tons/ha average years, 0,8 tons/ha drought year, 3 tons/ha high rainfall year. In the 2004-2005 season Clifford Moshwane obtained a yield of 1 ton/ha

- Soya Beans : 1,5 – 1,8 tons/ha In the 2004-2005 season Clifford Moshwane obtained a yield of 1,5 tons/ha (20 ha planted)

- Wheat : 2,8 – 3,8 tons/ha

- Maize : maize is not planted in the area as a dryland crop on a commercial basis, since the high land prices do not justify the break-even or below yields obtained

- Potatoes : potatoes are never planted in the area, since according to the farmers, the soils have too much clay, causing the potatoes to remain green.

The aforementioned yields assume that the pH and nutrient status of the soils are optimum (ameliorated) for a particular crop. The yield variations are primarily rainfall dependant.

(ii) Grazing : 500,58 ha (28,48 %)
: shallower (25-75-cm) red structured, red apedal and pedocutanic broad soil groups, as well as the higher bulk density examples of the pedocutanic (>75-cm) broad soil group, and the less rocky (less than 50 % rock) examples of the vertic broad soil group.

- Grazing (natural veld)
  Summer : 2,0-2,8 ha/LAU
  Year round average : 4 (red/brown soils) – 6 (vertic soils almost bare in winter) ha/LAU.

Although a number of intermediate [depth] (0,4 –0,7-m) red structured, red apedal and pedocutanic grazing soils occur in the survey area (occasionally cultivated), the crop yield on these soils would be considered to be slightly below the long term financial break even. However, shallow patches inevitably occur within a land. Scotney *et al* (Soil Capability Classification, March 1987) defines such areas as arable, *albeit* with a lower potential.

(iii) Wetland : 115,24 ha (6,56 %)
: vertic broad soil group of the Rensburg form only (all soil depths).

Grazing may take place in these areas in summer, as per the carrying capacities indicated in the grazing capability class. In general however, wetland areas should be avoided for agricultural purposes, as is the case in the entire survey area (except for the grazing of cattle). Furthermore, these areas are largely bare of grass during winter and overgrazing at this time would leave the veld totally bare, thereby resulting in soil erosion when the rainy season commences.

(iv) Wilderness : 317,88 ha (18,09 %)
: shallow and prismacutanic broad soil groups and/or rocky (≥50 % rock from the surface to 25-cm) examples of other broad soil groups.

Large areas of the wilderness capability class occur in the survey area. Such areas are normally reserved for the conservation of wildlife and biodiversity, as well as recreation.

(v) Man-made features (Wilderness) : 295,00 ha (16,78 %)

The habitat and soils have been destroyed in these areas. Such areas will once again serve an ecological function after they are rehabilitated.

IRRIGATED

(i) Arable

The agricultural yields mentioned in this section are those as per the following:

- Personal communication with Christoff van der Merwe of 'Nick van der Merwe & Seuns Boerdery Bk' who farms approximately 2,5-km east of Bethanie.

In this agri-business, only the soils of the vertic broad soil group are cultivated since the core business is vegetable growing and these soils can easily be washed off the vegetables after harvesting, while vegetables grown on the red soils (red structured and red apedal broad soil groups) are stained red after harvesting and cannot easily be washed clean. However, cabbage and onions (both can be washed successfully) as well as wheat, maize and tobacco can also be grown on the red soils.

This business cultivates approximately 197-ha, frequently on a double cropping basis and currently produces the following:

• Maize	: 70-80 ha/year	: 14,8	tons/ha	(2000)
		: 12	tons/ha	(2001)
		: 13	tons/ha	(2002)
		: 13,8	tons/ha	(2004)
• Beetroot	: 115 ha/year	: 26,2	tons/ha	(2004)
• Carrots	: 85 ha/year	: 30,85	tons/ha	(2004)
• Swiss chard (spinach)	: 25 ha/year	: 7,3	tons/ha	(2004).

Other crops which have been planted in the past, include the following:

• Wheat	: 6,5-7,5	tons/ha
• Cabbage	: 135,0	tons/ha (30 000 plants/ha x 4,5 kg/head)
• Onions	: 85,0-95,0	tons/ha (8500-9500 bags/ha x 10,0 kg/bag).

Other farmers in the area have also planted the following irrigated crops:

• Tobacco (Johan Janse van Rensburg)	: 2,5-3,0	tons/ha Discontinued since the soils have too much clay and the tobacco would also not cure properly
• Sunflowers	: 3,8-4,0	tons/ha
• Soya Beans	: 3,0-3,5	tons/ha.

2.2.8 IRRIGATION POTENTIAL

The irrigation potential of the arable capability class varies from very high - high (Hutton and Shortlands forms) to moderate (Bainsvlei and Bloemdal forms) to moderate-low (Valsrivier, Swartland and Sepane forms). A number of deep pedocutanic soils were disqualified from the arable (downgraded to grazing) capability class due to a high bulk density (and consequently a low porosity).

The trend of very high - high, moderate and moderate-low potential is generally related to the bulk density of the soil, the depth of occurrence of the depth limiting horizon (thus effective rooting depth), the texture (clay content) and the organic matter content of the soil, which interact to influence the moisture holding capacity (readily and plant available water).

The allocation of soil forms to the various potentials is a guideline only, since there tends to be a large variation in effective rooting depth and a lesser variation in clay and organic carbon content within a particular soil form. Thus the irrigation potential of each polygon of cropping soils needs to be evaluated on it's own merits, irrespective of soil form. However, this is a separate exercise which is not covered by the scope of this report.

The remaining soils are shallow or drainage impaired, or have a high bulk density and clay content. Thus complex irrigation scheduling, drainage control and lower yields make them unfeasible for irrigation purposes.

Bearing in mind the mining operations in the area, water quality would have to be carefully evaluated before considering irrigation.

2.3 PRE-MINING LAND CAPABILITY (Tables 4 and 5 and Map 3)

Land capability classes were determined using the guidelines outlined in section seven of The Chamber of Mines Handbook of Guidelines for Environmental Protection (Volume 3, 1981), a summary of which follows. The further sub-division of the wetland capability class is discussed in the next chapter.

Table 4. Pre-Mining Land Capability Requirements

Criteria for Wetland

- Land with organic soils or
- An horizon that is gleyed throughout more than 50 % of its volume and is significantly thick, occurring within 750-mm of the surface.

Criteria for Arable Land

- Land, which does not qualify as a wetland,
- The soil is readily permeable to the roots of common cultivated plants to a depth of 750-mm,
- The soil has a pH value of between 4,0 and 8.4,
- The soil has a low salinity and SAR,
- The soil has a permeability of at least 1,5-mm per hour in the upper 500-mm of soil,
- The soil has less than 10 % (by volume) rocks or pedocrete fragments larger than 100-mm in diameter in the upper 750-mm,
- Has a slope (in %) and erodibility factor (K) such that their product is <2.0,
- Occurs under a climate regime which facilitates crop yields that are at least equal to the current national average for these crops, or is currently being irrigated successfully.

Criteria for Grazing Land

- Land, which does not qualify as wetland or arable land,
- Has soil, or soil-like material, permeable to roots of native plants, that is more than 250-mm thick and contains less than 50 % by volume of rocks or pedocrete fragments larger than 100-mm,
- Supports, or is capable of supporting, a stand of native or introduced grass species, or other forage plants, utilizable by domesticated livestock or game animals on a commercial basis.

Criteria for Wilderness Land

- Land, which does not qualify as wetland, arable land or grazing land.

Table 5 is extracted from Map 3 (Pre-mining land capability units) and summarises the information for the survey area.

Table 5. Summary of Pre-Mining Land Capability Units

LAND CAPABILITY					
MAP NOTATION	CAPABILITY CLASS	TOTALS			
		ha		%	
Wp	WETLAND : Permanent I	115.24	115.24	6.56	6.56
A	ARABLE : II	489.20	528.38	27.83	30.06
A-G		39.18		2.23	
G*	GRAZING : III	80.89	80.89	4.60	4.60
G-A	GRAZING : III	44.14	419.69	2.51	23.88
G		371.76		21.15	
G-L		3.79		0.22	
L-G	WILDERNESS : IV	17.64	317.88	1.00	18.09
L		300.24		17.08	
RA	REHABILITATED ARABLE	0.53	0.53	0.03	0.03
Mining	WILDERNESS : IV	150.68	295.00	8.57	16.78
Infrastructure		63.66		3.62	
Slimes Dam & Surrounds		73.22		4.17	
Soil		4.04		0.23	
Pond		2.16		0.12	
Borrow Pit		0.40		0.02	
Stone Chips		0.84		0.05	
	TOTALS	1757.61ha		100 %	

2.3.1 WETLAND CLASSIFICATION (Table 6)

The wetland sub-division utilized in this report is as per the draft document 'Wetland Overview and Recommendations for Mining' by B.B. McLeroth (May 2001), a brief summary of which is provided (Table 6). This wetland classification system has been used by Red Earth cc for all mining related soil surveys since August 2001. The B.B. McLeroth document was in turn largely based (adapted for The Chamber of Mines wetland definition) on the document 'Wetland/Riparian Habitats: A Practical Field Procedure for Identification and Delineation' by the Land-use and Wetland/Riparian Habitat Working Group, September 1999. The latter document was submitted by the working group to the Department of Water Affairs and Forestry (DWAF) as a proposal for a new wetland definition. After further adaptation by the Department, the Department made the new draft document (DWAF, 2002) available for comment. For continuity purposes, this system will continue to be used until DWAF finalizes the draft document on which it is presently working and the Chamber of Mines adopts the new wetland definition.

This further sub-division of The Chamber of Mines wetland capability class was deemed necessary, given the broad nature of the class at present.

For a site to be classified as a wetland, it must firstly, from a soil point of view, display a horizon which is gleyed (bleached dry colour) [and/or mottled] throughout at least 50 % of its volume, occurring within 750-mm (Chamber of Mines, 1981) of the soil surface. However, hydromorphic conditions occurring within 500-mm of the soil surface is now the accepted norm, and was the cut-off depth utilized in this exercise. Exceptions to this rule are the Rensburg, Katspruit, Champagne and Willowbrook forms which may be of any depth, the Rensburg and Champagne forms frequently being deeper (to the gleyed horizon) than 500-mm.

Once the site has been classified as a wetland, Wetland Indicators (soil form, soil wetness factor, vegetation and slope position) are used to further sub-divide the wetland into one of four types, viz.: permanent/ semi-permanent, seasonal, temporary and mining temporary as per Table 6. The first three wetland classes display anaerobic conditions within the top 500-mm of the soil surface while the mining temporary class displays such conditions between 500 and 750-mm of the surface. The latter class is necessary in order to cater for the Chamber of Mines wetland definition. This class will probably be dropped (in favour of the grazing capability class) by the Chamber of Mines once the final DWAF document is approved. Thus the mining wetland areas encountered, (none in current survey area) are included with the grazing capability class totals.

The only wetland soils which occur in the survey area are of the Rensburg form.

Table 6. Wetland Indictors and Corresponding Wetland Types

WETLAND INDICATOR	**WETLAND TYPE**			
	Permanent	**Seasonal**	**Temporary**	**Mining Temporary**
Soil Form	Katspruit, Rensburg, Champagne, Willowbrook (ANY VEGETATION) OR Kroonstad, Wasbank, Fernwood (VEGETATION INDICATOR REQUIREMENTS ARE MET)	Any form which incorporates wetness at the Form or Family level.		
Soil Wetness Factor	Wetness all year round	Wetness long periods (3-10 months p.a.) at < 50 cm	Wetness short periods (< 3 months p.a.) at < 50 cm	Wetness short periods (< 3 months p.a.) at 50-75 cm
Vegetation	Obligate Wetland species accounting for > 50 % of aerial cover	Obligate/Facultative Wetland species accounting for > 50 % of aerial cover	Facultative and Facultative Dryland species. (Facultative Wetland species accounting for <50 % of aerial cover)	Facultative Dryland and/or Facultative species mandatory.
Slope Position	Valley bottom mandatory	Typically lower footslope	Typically upper footslope	Typically lower midslope

VEGETATION DEFINITIONS:

Obligate Wetland species	–	almost always grow in wetland (> 99 % of occurrences)
Facultative Wetland species	–	usually grow in wetlands (67-99 % of occurrences) but occasionally are found in non-wetland areas.
Facultative species	–	are equally likely to grow in wetlands (34 –66 % of occurrences) and non-wetland areas.
Facultative dryland species	–	usually grow in non-wetland areas but sometimes grow in wetlands (1-34 % of occurrences)

NOTE: The Wetland Indicators of soil form and soil wetness factor are of over-riding importance, since the original vegetation may have either been removed or transformed by previous land use, drainage or mining practices.

2.4 LAND USE (Table 7 and Map 4)

Table 7 is extracted from Map 4 (present land use) and summarises the information for the survey area.

Map 4 also shows the location of natural vegetation communities in the survey area. The vegetative composition of these communities is addressed in more detail in the natural vegetation/plant life specialist report.

Table 7. Present Land Use

LEGEND							
MAP NOTATION	GROUP	SUB-GROUP	EXPLANATION	TOTALS			
				Group ha	Sub-Group ha	Group %	Sub-Group %
MINING	Mining	Mining	Current mining operations (pits, discard dumps, soil stockpiles)	150.68	150.68	8.57	8.57
INFRASTRUCTURE	Infrastructure	Mining related	Permanent (structures, electrical, earthworks, surfaces, ash dump, ponds, etc)	63.66	64.40	3.62	3.66
It		Temporary	Easily removed	0.49		0.03	
CONVEYOR		Conveyor		0.25		0.01	
Ia	Infrastructure cattle	Cattle kraals		0.65	0.65	0.04	0.04
SLIMES DAM	Water related	Slimes dam and surrounds	Slimes, wall, slurry, drain, piping	73.22	76.63	4.17	4.36
POND		Pond	Evaporative and treatment	2.16		0.12	
SLURRY		Slurry	Highly polluted ash fines and salts	0.70		0.04	
DRAIN		Drain	Water interception	0.33		0.02	
TRENCH		Trench	For observation of Tallus layer	0.22		0.01	
Rk	Road	District	Dirt	1.87	35.08	0.11	2.00
Rh		Haul	Dirt	16.97		0.97	
Rc		Concrete / tar	Leading to security entrance / offices	0.25		0.01	
Rd		Dirt, tracks	Internal dirt roads / tracks (not including cattle paths)	10.36		0.59	
Ru		Disused	Dirt	4.68		0.27	
Rb		Breaks		0.95		0.05	
Ss	Prepared surface	Soil	Surface prepared and levelled in order to facilitate trafficability by machinery and other vehicles	0.82	0.82	0.05	0.05
STONE CHIPS	Dumped	Small stones	Removed and levelled	0.68	0.68	0.04	0.04
POWERLINE	Powerline	Powerline	Disturbed area below lines	1.51	1.51	0.09	0.09
BORROW PIT	Borrow pit	Ferricrete	Road material	0.40	0.40	0.02	0.02
SOIL	Soil stockpile	Dump	Soil stockpiles which are not within or in contact with 'MINING' unit	14.62	14.62	0.83	0.83
C	Cultivated	Presently	Ploughed	2.43	22.32	0.14	1.27
Cp		Previously	Re-established grass	19.89		1.13	
B	Bush (in non-wetland area)	Undisturbed		936.29	1052.05	53.27	59.86
Bt		Thin	Thinned for firewood, or naturally thin (high bulk density soils)	95.03		5.41	
Bd		Degraded	Disturbed by machinery	11.84		0.67	
Be		Re-established	Naturally (by nature) re-established on a previously degraded area.	8.89		0.51	
S	Scrub (in non-wetland area)	Scrub thorn grass veld	Small shrubs in a grassland	119.97	119.97	6.82	6.82
G	Grassland	Undisturbed	Virgin grassland	60.66	105.85	3.45	6.02
Gd		Degraded	By machinery and man	28.91		1.64	
Ge		Re-established	Naturally (by nature) re-established on a previously degraded area.	9.64		0.55	
Gm		Mowed	Mowed veld grasses	1.38		0.08	
Gb		Bare	Largely bare soil surface	5.26		0.30	
Wg	Wetland vegetation	Grass		25.36	111.62	1.44	6.35
Ws		Scrub thorn grass veld	Small shrubs in a grassland	67.00		3.81	
Wb		Bush	Bush growing in a wetland	19.26		1.10	
Re	Rehabilitated	Re-established grasses	Naturally (by nature) re-established grasses on a rehabilitated area.	0.33	0.33	0.02	0.02
			TOTALS	1757.61Ha		100%	

NOTE : Although various combinations of Landuse Groups and Sub-Groups have been used, the legend totals include the first Group / Sub-Group only

: Abbreviations : / = and

( ) = occasionally

†9.8 : Location of Archaeological Sites and Reference Number (for Further Details see Report Document)

- **Pre-mining Land Use** is indicated on Map 4.

- **Historical Agricultural Production**

  Map 4 shows the presently (two small areas) and previously (four small areas) cultivated (cultivated for many years) areas, as well as the areas which are presently utilized for the grazing of cattle (grassland, scrub thorn grass veld [small shrubs in a grassland], wetland vegetation [grass, scrub thorn grass veld and bush] and bush [trees and grass] areas. Map 4 also shows the location of six currently utilized cattle kraals (fenced) in the bush. The cattle grazing in the area belong to the mine and are research herds being investigated by Onderstepoort University. Furthermore, cattle from the surrounding communities also stray onto the mine property.

  Predicted crop yields and livestock carrying capacities are discussed in the section DRYLAND PRODUCTION POTENTIAL.

- **Evidence of Misuse**

  From an agricultural perspective, there has been little evidence of misuse. The presently and previously cultivated areas fall outside of the wetlands.

  Issues of concern from a mining perspective include the following:

  i) Ponds in wetlands.
  From a historical perspective, two ponds (polluted water) are situated in (small one) or in contact with (large one) the permanent wetland (Rensburg form) to the south-east of the infrastructure area. Pollution (precipitated salts) is visible in the wetland surrounding the small pond, the source of this polluted water being the calcine tailings dump in the infrastructure area. The large pond has not been mapped since it is enclosed within the infrastructure area (eastern boundary).

  ii) Disturbance of wetlands.
  Wetland areas should not be disturbed unnecessarily in any way without a permit. The haul truck brake testing ramp which is presently being constructed from ‘topsoil’ and discard in the ‘western’ wetland should ideally be sited elsewhere. The same goes for any area which is not scheduled to be mined unless the mine is prepared to bear the costs of rehabilitating the area.

  iii) Wastage of topsoil.
  Topsoil and discard have in some cases not been stock-piled separately within the mining areas (‘western’ and ‘eastern’ pits). A topsoil survey needs to be undertaken within these areas (not within the scope of the current soil survey) in order to identify and conserve these resources. Topsoil reserves (separate from the mining areas) which are currently lying in dumps in the veld, and particularly the long narrow dumps to the north of the ‘western’ pit, should be collected for later use.

  iv) Tallus inspection holes in the veld.
  Numerous small holes and in some cases trenches (excavated by back-acter) exist in the bush (particularly south-western quarter of survey area) throughout the survey

area. These ‘tallus inspection’ holes need to be closed since they pose a threat to humans, domestic livestock and wildlife as well as being unsightly. These holes and trenches no longer serve any purpose and should be closed in order to reinstate the area to it’s former condition.

v) Rehabilitation operations have not commenced in any areas.
These operations should have commenced in the mined-out areas (‘eastern’ pit), whereby the discard is replaced in the pit, the area is graded to an acceptable slope (soil erosion point of view), the ‘topsoil’ reserves are replaced at the surface, the ‘topsoil’ material is analysed/ameliorated, and thereafter the area is re-vegetated.

vi) Unnecessary dirt roads.
The number of dirt roads, tracks and haul roads should be limited in the vicinity of the ‘western’ pit, and particularly so in areas which are not planned to be mined, since these will in the future have to be closed and rehabilitated.

- **Existing Structures**

Table 7 is a summary of the present land use, including the man-made features which are present in the area.

2.5 SITES OF ARCHAEOLOGICAL AND CULTURAL INTEREST (Map 4)

The areas displays numerous sites of archaeological and cultural interest, the majority of these being concentrated towards the southern boundary of the survey area, in the area occupied by the vertic broad soil group, as well as in the vicinity of rocky outcrops.

The following features are deemed to be of interest, their positions and reference numbers being recorded on Map 4. The findings of this survey were communicated to Dr. Julius Pistorius, the archaeologist on the project, for further investigation. See report reference XREMP/SSR/14/VER-01/2006.

1. Ceremonial site or other? (one site).

1.1 Approximately 40 circular or slightly oval stone foundations (approximate diameter 1,5-m) with entrances, arranged in a slight oval (approximate diameter 80-m x 60-m). These structures appear to be too small to sleep in. This site is worthy of preservation since it is unique in the area, the site lying on gabbro parent material next to (west) a magnetite kopje. This site should be investigated further by the relevant specialist.

A further site which displays similar structures (less in number) is recorded as site number 6.1. No pot shards were observed at either of these two sites.

2. Graves ? (two sites).

2.1 Two rock mounds (possibly graves).
2.2 Three rock mounds (probably graves).

3. Stone cattle kraal foundations [circular or irregular] (18 sites).

One stone kraal exists at each of the 18 sites, these sites being concentrated in four separate locations, with three kraals (sites 3.1 – 3.3) being present at the first location, five (sites 3.4 – 3.8) at the second, one (site 3.9) at the third and nine (sites 3.10 – 3.18) at the fourth. At the second (sites 3.4 – 3.8) of these four locations, the foundations of stone hut circles are also evident, while pot shards were observed at site 3.10 at the fourth location.

4. Stone livestock kraal foundations [rectangular] (five sites).

One stone kraal exists at each of the five sites, these sites being concentrated in two separate locations, with one kraal (site 4.1) being present at the first location, and four kraals (sites 4.2 – 4.5) being present at the second location.

5. Stone hut foundations [circular] (four sites).

5.1 Three foundations (small diameter).
5.2 One foundation (medium diameter).
5.3 One foundation (medium diameter).

5.4 Two to three foundations occur on the diabase/dolerite dyke overlooking the nine stone cattle kraal foundations (sites 3.10 – 3.18), which occur below this site. These stone hut foundations probably served as accommodation for the cattle herders who tended the livestock. These hut circles have a good view of the majority of the nine kraals at this location. A small agate (stone) was found (not taken) inside one of these huts, probably a plaything or charm belonging to one of the herders.

6. Very small stone hut foundations [circular] (one site).

6.1 At least eight small (1,8-2,0-m diameter) foundations extending into the rocky outcrop to the north-west. Similar structures to those at site 1.1.

7. Large walled terrace and stone kraal (one site).

7.1 A habitation site or village existed at this location. The site appears to be a man-made terrace which has been built up within a surrounding (now level) stone wall. A large cattle kraal is also present. This site requires further investigation.

8. Low stone foundations (or geological outcrop?) and pot shards (one site).

8.1 Numerous pot shards are present at this habitation site, the shards being of a similar age to those found at the other pot shard locations (see item 9).

9. Pot shards (20 sites).

With the exception of sites 9.1, 9.2 and 9.20 which occur on red soils, the majority of pot shard sites occur on the heavy black vertic soils along the southern boundary of the survey area. None of the pot shards displayed patterns, the shards being orange, grey or dark in colour. The shards are weathered (rounded edges) from lying on the surface.

The pot shards are almost never (exceptions sites 3.10 and 8.10) found at, or in proximity to the stone foundations (items 1-8 above), but rather lying on the surface (exception site 9.2 where the shards were buried 10-cm below the soil surface) away from the rocky outcrops where the stone foundations exist. Since there are no rock foundations at pot shard (ie habitation) sites, the homesteads were obviously built entirely of mud, wood and grass. Homesteads probably avoided the rocky outcrops due to the increased incidence of lightning in these areas.

Furthermore, given the absence (not seen) of pot shards at the sites with stone foundations, it is probable that the pot shards and stone foundations are from different periods in the iron age. Note that no glass or other ‘modern’ artifacts were found at any of the sites. Numerous fragments of a large orange pot are present on the surface at site 9.6, the pottery fragments in other areas being isolated.

2.6 SENSITIVE LANDSCAPES (Maps 2, 3, 4 and 5)

Wetlands are especially sensitive landscapes under statutory protection, and as such must not be disturbed, polluted, cultivated or overgrazed. Furthermore, the wetland capability class in the survey area is comprised of the vertic broad soil group which is relatively highly erodible (as determined in the chapter EROSION HAZARD AND SLOPE). The soils occurring in the wetland areas are indicated on Map 2 while the location of the natural vegetation communities are indicated on Map 4.

Although Maps 2 (Soil Mapping Units), 3 (Pre-Mining Land Capability) and 5 (Soil Utilization [Stripping] Guide) show wetland soils to presently occupy 115,24-ha (6,56 % of the survey area), Map 4 (Present Land Use) shows wetland vegetation to occupy a slightly lower area (111,62-ha or 6,35 % of the survey area). This is because alternative land uses, other than wetland vegetation exist in small portions of the wetland areas. Such alternative land uses include the following: soil pile (haul truck brake testing ramp), a patch of polluted slurry, haul roads, dirt roads, a district road, two power-lines, a drain and a section of the conveyor.

The permanent wetland which forms the eastern boundary of the survey area is the floodplain of the Tshukutswe river (dry annual stream at this point), which trends to the north through the town of Bethanie. Both calcareous and non-calcareous vertic soils of the Rensburg form are present in this floodplain which displays numerous meanders and old stream channels, the gleyed (permanent water-table) G-horizon occurring at between 0,5 to 1,2-m below the soil surface. The floodplain extends further to the east than is indicated on the soil map, a central donga being the limit of the soil survey.

The permanent wetlands, which occur in the study area to the west of the Tshukutswe floodplain, owe their existence to hillslope seepage (predominantly) and runoff (small component) into gently sloping concave areas, these soils also being of the Rensburg form.

The western permanent wetland in the survey area, has at it's northern extent had discard dumped on top of it. Given the small catchment associated with this wetland as well as the fact that it is 'blind' (ie. water naturally disappears underground – probably down a preferential recharge zone associated with the diabase dyke), causes it not to be an especially sensitive wetland.

The 'eastern' pit has mined through a permanent wetland which has a very small catchment above the mined area. Again this disturbance is acceptable given the small catchment. However, downslope (north-east) of the mined out area the wetland should be protected since the wetland trends into the Tshukutswe floodplain. **The pollution sources which are presently contaminating this wetland (polluted pond in the wetland and the calcine tailings dump in the infrastructure area) either require attention (intercept drains) or relocation (pond).**

Further disturbance of the wetlands on the mine property should not be necessary given that no further mining is planned in these areas (no magnetite or ferrogabbro). Furthermore, the disturbed wetland areas require rehabilitation as follows:

- closure and rehabilitation of the 'eastern' pit where it bisects the wetland,

- the removal of the discard overlying the northern extent of the western wetland near the ‘western’ pit, once mining operations are completed in this area,
- the relocation and rehabilitation of the haul truck brake testing ramp in the ‘western’ wetland, and
- attending to the pollution infiltrating the wetland in contact with the infrastructure area.

Provided that future mining operations/procedures are conducted appropriately (see ENVIRONMENTAL MANAGEMENT PROGRAM), then the impact to the wetlands will be minimized.

3.0 DETAILED DESCRIPTION OF THE PROPOSED PROJECT

3.1 SURFACE INFRASTRUCTURE (Map 4)

Map 4 (Present Land Use) indicates the existing surface infrastructure in the area.

3.2 CONSTRUCTION/OPERATIONAL PHASES

The activities which will be undertaken during these phases, and which will impact on the soils and land capability, are discussed.

Topsoil stripping will commence ahead of the opencast operation. This stripped material should ideally be redistributed immediately on mined out areas, where the leveling and regrading (slope) of discard rock is completed.

The immediate utilization of stripped topsoil material will have the following benefits:

i) reduced probability of compacting the soils,
ii) maintenance of soil fertility levels to a certain extent,
iii) preservation of the reproductive seed bank, and
iv) cost savings associated with a reduced number of handling operations.

Excess soil material may be stock-piled. However, given the section STORAGE LIFE AND STOCK-PILING, it is not desirable for stock-piles to be left unutilized for too long a period.

The amelioration of topsoil fertility and re-grassing will continue in areas undergoing rehabilitation.

3.3 SOIL UTILIZATION (STRIPPING) GUIDE (Map 5 and Table 8)

During the construction/operational phases, the soils must be stripped ahead of the mining operations as per the recommended stripping depth indicated on the soil utilization (stripping) guide (Map 5). The map summarises the soil map (Map 2) into broad soil groups and average usable depth. The broad soil groups indicated on the soil utilization (stripping) guide include cropping (i.e. mineral soils including red structured and red apedal), structured pedocutanic, shallow, vertic, duplex and man-made soils.

Table 8 is extracted from Map 5, and summarises the information for the survey area.
Table 8 shows that 11 308230-m^3 of suitable to marginal (for use as 'topsoil') soils are present *in-situ* in the undisturbed (1462,61-ha) sections of the survey area (1756,61-ha).

However, the cropping and structured pedocutanic soils (the former of which predominates in the survey area and is the most suitable) (8 809950-m^3) are the most suitable and are recommended for rehabilitation topsoiling purposes in the ‘western’ pit and ‘other’ (other disturbed areas bar the ‘western’ and ‘eastern’ pits) areas.

The vertic soils (2 250530-m^3) on the other hand should only be utilized to rehabilitate areas where these soils naturally occur *in-situ* (majority of ‘eastern’ pit). The topsoiling of the ‘eastern’ pit with vertic topsoils will also reduce the amount of rainfall and runoff which infiltrates into the pit. This is because vertic soils swell when they are wet, and consequently their permeability reduces. Furthermore, vertic stock-piles currently exist on the southern boundary of the pit. The utilization of this material will also ensure the continuity of soil, indigenous grassland and other flora species which have adapted to grow on these soils, as well as the fauna which depend on this vegetation.

A large proportion of the vertic volume is made up of soils of the Rensburg form (permanent wetlands), which must not be disturbed. The vertic areas which may be stripped are those of the Arcadia form.

‘Shallow’ soils (237600-m^3) are concentrated in patches throughout the survey area. The ‘shallow’ soils in the mining areas (magnetite and ferrogabbro areas) are generally too shallow (0-0,3-m) and too rocky (tallus) to separate from the ore, this topsoil being lost. Topsoil stripping and stock-piling of the ‘shallow’ soils should only be attempted where the surface is not too rocky and where the topsoil overlies weathering rock and not tallus (see Map 2 or 6). Given the rocky and/or gravelly nature of these topsoils, this material should not be replaced at the surface during rehabilitation operations, but rather deeper down in the rehabilitated soil profile.

Table 8. Summary of Soil Utilization (Stripping) Guide and Depth of Soil Suitable for 'Topsoil'

BROAD SOIL GROUP			AVERAGE USABLE DEPTH OR EFFECTIVE SOIL DEPTH (CM X 10)																				TOTALS FOR TABLE			
																						AREA		VOLUME	
MAP NOTATION	FORMS INCLUDED	SOIL CHARACTERISTICS	18+	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0	ha	%	m^3	%
C	Sd, Hu, Bv, Bd	Cropping Soils : well to moderately drained red apedal and red structured	54.98	7.67	8.76	14.67	3.36	1.26	102.90	60.67	34.56	95.55	40.72	110.73	55.55	88.66	93.29	24.90	22.25	-	-	-	820.48	46.68	7 786710	68.86
T	Sw, Se, Va, Bo	Structured Pedocutanic Soils: moderately to well drained pedocutanic	5.38	-	-	2.91	-	-	11.40	8.81	9.19	9.33	6.14	20.11	10.07	6.67	1.17	15.93	11.77	-	-	-	118.88	6.76	1 023240	9.05
S	Ms, Gs, Dr, Mw	Shallow Soils : overlying hard rock, lithocutanic or hard plinthite	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1.91	21.92	24.25	115.70	106.48	270.26	15.38	237600	2.10
V	Ar, Rg	Vertic Soils : black turf soils. Rg form is Permanent Wetland	2.89	-	-	-	-	-	-	34.66	45.17	29.83	13.66	83.80	1.42	11.10	17.40	4.15	3.86	1.18	-	0.23	249.35	14.19	2 250530	19.90
D	Ss	Duplex Soils : prismacutanic - dense	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1.40	-	1.71	-	3.11	0.18	5910	0.05
R	Wb	Man-made Soils : rehabilitated areas	-	-	-	-	-	-	-	-	-	-	-	0.53	-	-	-	-	-	-	-	-	0.53	0.03	4240	0.04
Mining																							150.68	8.57	0	0
Infrastructure																							63.66	3.62	0	0
Slimes Dam & Surrounds																							73.22	4.17	0	0
Soil																							4.04	0.23	Reserves Available	Reserves Available
Pond																							2.16	0.12	0	0
Borrow Pit																							0.40	0.02	0	0
Stone Chips																							0.84	0.05	0	0
TOTALS FOR TABLE																							1757.61ha	100%	11 308230 m^3	100%

3.4 REHABILITATION TOPSOIL BUDGET (Map 5)

All suitable topsoils stripped must be replaced on the disturbed surface during rehabilitation.

In the rehabilitated scenario, at least the same percentage of arable and grazing land should exist as were present before disturbance. Suitable topsoiling material should be utilized for rehabilitation purposes in the top 0,6-m (arable), 0,25-m (grazing) and 0,15-m (wilderness and wetland). The mixing of suitable/unsuitable materials in this zone should be avoided.

Although the pre-mining land capability (Map 3) and soils (Map 2) have been destroyed in the pit, infrastructure, slimes dam and pond areas, the pre-mining status is clear given the trends on the periphery. These clearly interpretable pre-mining land capabilities and soils in the disturbed areas form the basis for the rehabilitation which must take place in these areas.

- **Rehabilitation Scenario ('western' pit)**

  The south-western half of this area should at least be rehabilitated to the grazing standard (0,25-m of suitable 'topsoil'), the north-eastern half being rehabilitated to the arable standard (0,6-m of suitable 'topsoil'). Given that the north-western extremity of the south-western half was originally of the wilderness capability class, rehabilitation to grazing capability class standards will represent an improvement.

  Furthermore, careful topsoil planning (stripping the full available depth and stock-piling separately from the discard) should quickly lead to surplus 'topsoil' reserves developing, this being because the majority of the soils in the area are deep, while stock-piled 'topsoil' reserves already exist. Much of this area displays discard rock dumps and 'topsoil' stock-piles which have been dumped on un-mined land. Once these have been removed and replaced in the rehabilitated pit areas, the original underlying soils will once again be exposed.

  This area should be rehabilitated with the cropping and structured pedocutanic broad soil groups.

- **Rehabilitation Scenario ('eastern' pit)**

  The majority of this area should at least be rehabilitated to the grazing standard (0,25-m of suitable 'topsoil') using the vertic broad soil group stock-piles which are present to the south of the pit. A narrow strip along the north-western boundary of this area must be rehabilitated to at least the arable standard (0,6-m of suitable 'topsoil') using the cropping broad soil group.

- **Rehabilitation Scenario ('other' areas)**

  These areas include disturbed or mined sites other than the 'western' and 'eastern' pits. These areas must be rehabilitated to the land capability of the surrounds using the cropping and structured pedocutanic broad soil groups (unless these areas fall within the vertic broad soil group, of which there are only a few small sites).

A rehabilitation topsoil budget for the 'western' and 'eastern' pits can be worked out once these pits are separated from the 'mining' unit indicated on the map set, these areas having not been mapped from a present land use perspective (outside the scope of the survey).

Furthermore a 'topsoil' survey is required for the soil stock-piles which are scattered throughout these two areas.

4.0 ENVIRONMENTAL IMPACT ASSESSMENT

4.1 SOIL/LAND CAPABILITY/LAND USE

The impact of the opencast operation on the existing soils, land capability and land use are described collectively.

The impact to the area is described as follows:

VERY SIGNIFICANT, IMMEDIATE, TEMPORARY IMPACT.

- Very Significant
  The magnitude of the impact will be very significant since the existing soils, land capability and land use will be completely destroyed in the areas which are mined.

- Immediate
  The timing of the impact will be immediate as mining operations commence in an area. The commencement of the mining operation may be defined as the time that the 'topsoil' is stripped (before blasting or the removal of the rock).

- Temporary
  The duration of the impact will be temporary until rehabilitation operations (topsoiling, leveling, sampling and amelioration of topsoil fertility, and re-vegetation) are completed, which are ongoing behind the mining operations. Thus topsoils stripped from one area (ahead of mining operations) are generally replaced immediately in another area in close proximity, which is in the process of being rehabilitated (where the discard rock has been leveled behind the mining operations).

5.0 ENVIRONMENTAL MANAGEMENT PROGRAM

5.1 MITIGATION MEASURES – SOIL/LAND CAPABILITY/LAND USE

5.1.1 STRIPPING RECOVERY RECOMMENDATIONS (Map 5)

The soils should be stripped ahead of mining operations as per Map 5 (Soil Utilization [Stripping] Guide).

Apart from stripping, stock-piling (not recommended for long periods) and redistributing the suitable and unsuitable soils separately, the major issue of concern during this phase of the exercise is the limiting of surface compaction caused by the heavy machinery used.

Problems caused by compaction include the following:

- Drainage impedance.
  An increase in bulk density reduces the total porosity (reduced pore spaces and pore size), thus reducing the saturated flow of moisture through the soil. Halving the pore size would reduce the flow by a factor of 16.

- Root impedance.
  Since large pores also function in the aeration of the soil, compacted soils (reduced pore size) have a limited oxygen supply. Soil strength also increases with compaction. Thus roots will not elongate if large pores are absent (limited oxygen) or if soil strength is high (prevents active displacement of soil by root pressure). As a general guideline (varies from soil to soil), roots will fail to penetrate materials compacted to bulk densities greater than about 1500 kg/ m^3 for clayey (> 35 % clay), and about 1700 kg/m^3 for sandy (< 15 % clay) soils (Chamber of Mines Guidelines, 1981).

Factors affecting compaction:

- Fine sand and silt.
  Soils with high proportions of fine sand and silt are most susceptible to compaction and the formation of high bulk densities. If the soils in the survey area are handled (stripping and topsoiling) in the dry state, then they are likely to be only moderately to slightly susceptible to compaction.

- Moisture content.
  In order to avoid (stripping and topsoiling operations) or alternatively to achieve (compacted layer over dump) compaction (ie, bulk density), machinery should ideally operate at or near to the optimum moisture content required to achieve the desired compaction, which varies from soil to soil for the two extremes.

  Thus in order to limit compaction (stripping and topsoiling operations), machinery should ideally operate at a moisture content of below approximately 8 or 10 % (ie.

during the dry winter season). However, this practice is frequently not practical since topsoiling and rehabilitation operations progress behind the mining operations which are ongoing on a continual basis.

- Pressure and duration of pressure.
  Tracked vehicles are more desirable for the stripping and topsoiling operations, since tracked vehicles have a lower point loading and slip than wheeled vehicles. Vehicle speed should be maintained in order to reduce the duration of the applied pressure, thereby minimizing compaction.

5.1.2 DUST POLLUTION POTENTIAL

The particle sizes most at risk from wind erosion are clay and silt, despite the fact that they are themselves too small to be dislodged by the wind directly. However, fine and medium sand particles moving by saltation knock the clay and silt particles into the air to create what is termed ‘dust’. The soils most prone to wind erosion are those with high amounts of fine sand; the least liable are those with high clay contents. However, the soils most likely to cause dust pollution are those with both high fine sand and high silt contents.

The soils of the survey area have moderately low to high amounts of silt ranging from approximately 5 to 26 % in the topsoils and subsoils. These soils have moderate to high clay contents ranging from approximately 18 to 52 % (majority 41 to 52 %) (red apedal, red structured and pedocutanic soils) or 63 % (vertic soils) in the topsoils, and from approximately 27 to 65 % (majority 50 to 65 %) in the subsoils. The soils contain low to moderate, fine (including very fine) sand contents that generally range from approximately 10 to 29 % in both the topsoils and the subsoils.

All of these values exclude the shallow soils (approximately 9 to 30 % clay), which are not likely to be utilized for rehabilitation purposes, while they also exclude the small isolated patches of prismacutanic and man-made soils which will definitely not be utilized (also not analysed).

Given the above, wind erosion is not likely to be of major significance in the area, except on exposed sites (dumps and crests) where the vegetative cover has been removed.

In general the natural vegetation (grass cover) should be maintained for as long as possible prior to the commencement of mining, the topsoil stripping operation not being conducted earlier than required. Grass cover should also be re-established, as soon after topsoiling as possible. This is in order to prevent the erosion of topsoil organic matter, clay and silt.

5.1.3 STORAGE LIFE AND STOCK-PILING

The most critical and important part of the soil is the uppermost 20-cm as this is the repository for seeds, tubers, bulbs etc. Under natural conditions most grass seed remains viable for only about 1 year (reproductive seedbank life), with only few species having seed that can survive for up to 2-3 years.

Under stock-pile conditions it is probable that the seedbank life will be shorter than under natural conditions. Thus 'topsoil' stock-piles should ideally not exceed a maximum depth of one metre, as greater depths than this can lead to the following: anaerobic conditions developing in the pile; a reduction in soil fertility; the accelerated loss of the reproductive seedbank; and compaction.

However, a one metre deep stock-pile is not practical since such a stock-pile will have a large footprint, the stock-pile itself having a detrimental effect on the underlying (*in-situ*) soils, as well as killing the vegetation and reproductive seedbank which exist. From this perspective a high stock-pile with a small footprint will impact on a smaller surface area, although the soils within the stock-pile will be affected negatively. However, given the sections SOIL FERTILITY and RE-VEGETATION, the negative aspects associated with a high stock-pile may be largely mitigated.

In addition it is most advantageous if the soil is not stock-piled while wet since this can increase the risk of seeds etc rotting. Timing of stripping and stock-piling is also important since if the soil is stripped and stock-piled, and then moved and utilized before newly germinated grass on the stock-pile has seeded, then effectively the soil has gone 2 years without any new seed being added. It is therefore clearly not advisable to stock-pile the 'topsoil' at all, but to strip and use it immediately (ideally in winter).

All soil material (topsoils particularly, as well as subsoils) should be stock-piled only as a last resort, when it is impractical to redistribute such material promptly. Thus the mine should plan to utilize stripped 'topsoil' material immediately. However, provision should also be made for limited stock-piling of excess material for use in repair work.

5.1.4 TOPSOILING

The REHABILITATION TOPSOIL BUDGET section of the report should be consulted in this regard.

5.1.5 EROSION AND SLOPE

- Slope is one of the main parameters of erodibility.

  Given the findings of the section EROSION HAZARD AND SLOPE, the discard rock (and 'topsoil') in post-mining **rehabilitated areas** must be **graded** in order to ensure that **slopes** of over **16,0 % (9,1 degrees) [red structured and red apedal]** or over **12,5 % (7,1 degrees) [pedocutanic and vertic]** do not occur. This should not be difficult given the gentle (1,8-7,0 %; 1-4 degrees) slopes which presently dominate in the current mining areas. However, particularly careful planning will be required in probable future mining areas where moderately steep slopes of up to 24,0 % (14 degrees) occur.

  Compacted rehabilitated dumps (e.g. calcine tailings dump) should be topsoiled with the **red apedal and red structured soils only,** with **slopes** (soil erosion perspective) **above 12,7 % (7,2 degrees) being minimized.** Steeper slopes may be acceptable after re-vegetation, provided that this vegetation is maintained.

- The cropping (red structured and red apedal) and structured pedocutanic broad soil group soils must be utilized for rehabilitation purposes in the ‘western’ pit and ‘other’ areas, while the vertic broad soil group must be utilized in the majority of the ‘eastern’ pit, as per the determined maximum slopes applicable to these soils.

- The pre-mining grade (slope), contours and drainage density (not necessarily pattern) should be implemented where possible. Concave (rather than convex) slopes should be maximized while the creation of undulating ‘basin and ridge’ topography with frequent blind hollows should be avoided.

- Erosion control measures such as intercept drains, contour bank canals, grassed waterways and toe berms should be implemented where necessary.

- Rehabilitated areas must be revegetated.

5.1.6 SOIL FERTILITY

Soil analysis (top 15-cm) in order to provide corrective fertilization regimes is an ongoing procedure and is required periodically in order to facilitate vigorous plant growth for high levels of production.

This procedure should initially be carried out immediately after top-soiling and leveling, the soil fertility status being corrected before re-vegetation. Thereafter the soils should be sampled on an annual basis until the required phosphorus and potassium levels have been built up. Once the desired nutritional status has been achieved, intervals of three to four years can be allowed between sampling.

The section SOIL ANALYTICAL CHARACTERISTICS AND SOIL FERTILITY should be consulted in this regard.

5.1.7 RE-VEGETATION

Rehabilitated areas must be re-vegetated as soon after topsoiling as possible, in order to limit raindrop and wind energy, as well as to slow and trap runoff. Indigenous (to the area) grassland species are preferred, given both their hardy nature as well as their lower maintenance requirements.

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