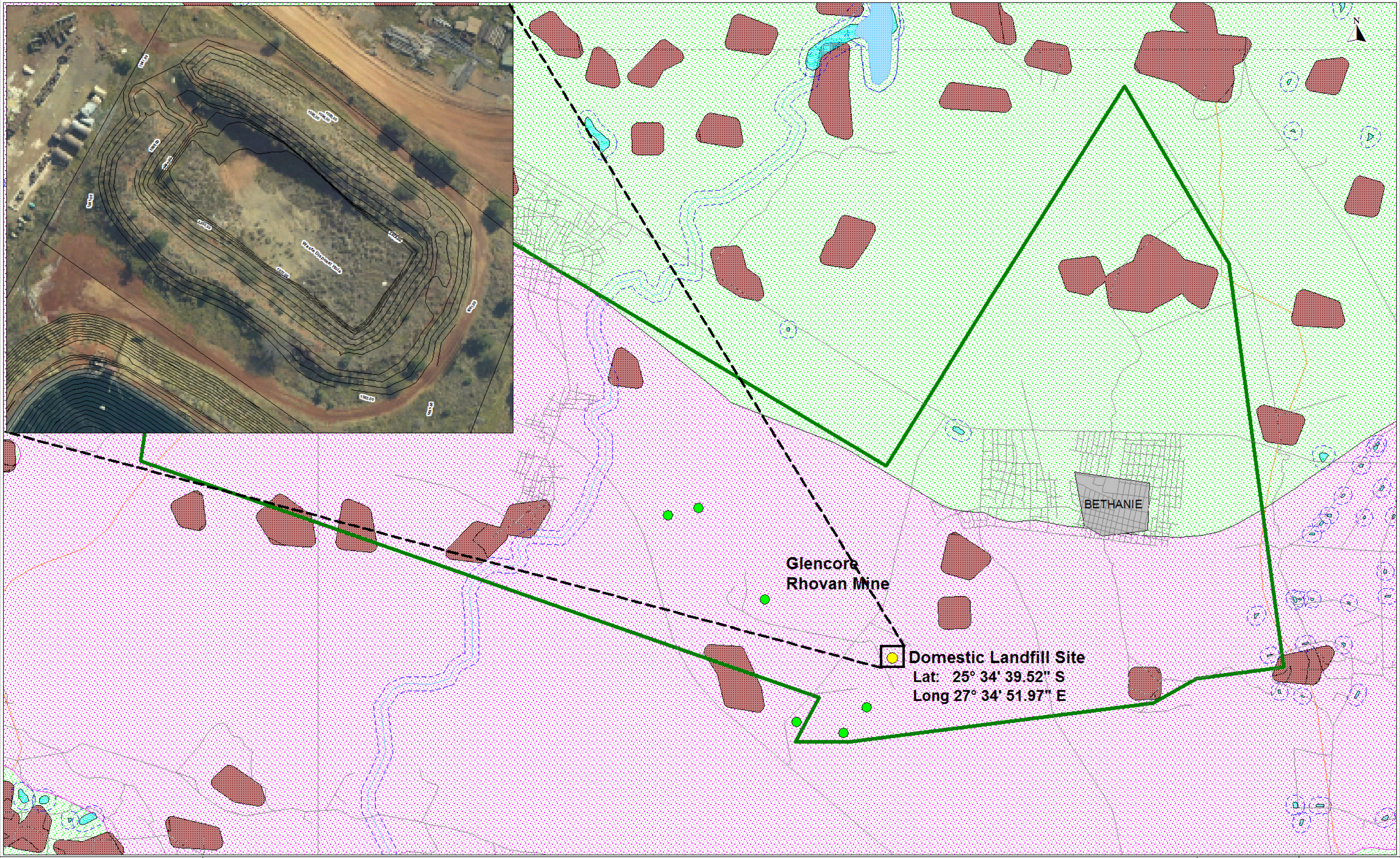
APPENDIX A3(ii)

A sensitivity map detailing the information listed below is attached as **Appendix A3(ii):**

- watercourses;
- the 1:100 year flood line (100m buffer around watercourses);
- ridges;
- for gentle slopes the 1 metre contour intervals must be indicated on the plan and whenever the slope of the site exceeds 1:10, the 500mm contours must be indicated on the plan; and
- cultural and historical features;
- ecosystem threat status



JMA CONSULTING (PTY) LTD.
Sustainable Environmental Solutions through Integrated Science and Engineering

Client: Glencore - Rhovan Mine
Project: Decommissioning of Domestic Landfill

LEGEND

- Rhovan Property Boundaries
- Roads
- Nearest Town
- Cultural/Historical Sites
- Hills and Ridges
- Wetlands
- Rivers & Streams
- 100m Buffer zone

Ecosystem Threat Status

- Least Threatened
- Vulnerable
- Endangered
- Critically Endangered

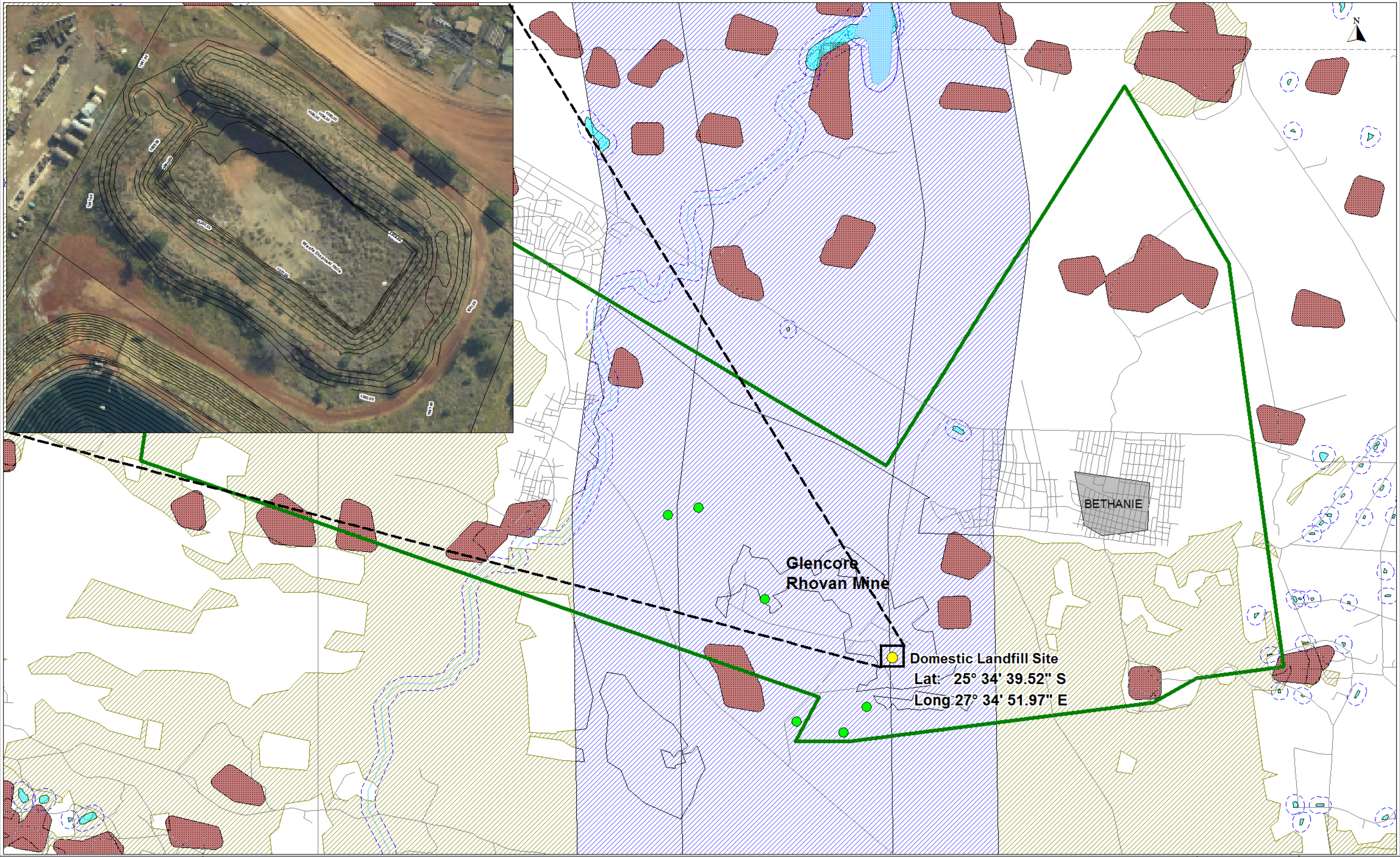
WGS84	DD
Date Compiled: **October 2014**	

Sensitivity Map: Ecosystem Threat Status

APPENDIX A3(iii)

A sensitivity map detailing the information listed below is attached as **Appendix A3(iii):**

- watercourses;
- the 1:100 year flood line (100m buffer around watercourses);
- ridges;
- for gentle slopes the 1 metre contour intervals must be indicated on the plan and whenever the slope of the site exceeds 1:10, the 500mm contours must be indicated on the plan; and
- cultural and historical features; and
- critical biodiversity areas (CBA)



JMA CONSULTING (PTY) LTD.

Sustainable Environmental Solutions through Integrated Science and Engineering

Client: Glencore - Rhovan Mine

Project: Decommissioning of Domestic Landfill

LEGEND

- Rhovan Property Boundaries
- Roads
- Nearest Town
- Cultural/Historical Sites
- Hills and Ridges
- Wetlands
- Rivers & Streams
- 100m Buffer zone

Critical Biodiversity Areas (CBA)

- Critical Biodiversity Area (CBA2)
- Critical Biodiversity Area (CBA1)
- Biodiversity Corridor (CBA2)

WGS84	DD
Date Compiled: **October 2014**	

Sensitivity Map: Critical Biodiversity Areas (CBA)

APPENDIX B

Colour Photographs of the Rhovan Domestic Landfill Facility

The Photographs were taken from the middle of the site in the eight major compass directions.

GPS coordinates: Latitude: 25°34'39.52"S
Longitude: 27°34'51.97"E

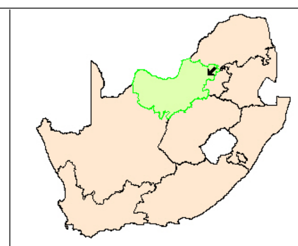
North	East
	
South	**West**
	
North East	**South East**
	

North West	South West
	

APPENDIX C

A detailed illustration of the activity is provided at a scale of 1:200 as **Appendix C**. The illustration gives a representative view of the activity.

LEGEND



Client: Glencore - Rhovan Mine

Project: Decommissioning of Domestic Landfill

JMA CONSULTING (PTY) LTD.

Sustainable Environmental Solutions through Integrated Science and Engineering

DATUM: WGS84	LO27
DATE: October 2014	

1:200 Scale view of Rhovan Landfill Site

APPENDIX D1

Geochemical Specialist Report.

FINAL

GEOCHEMICAL MODELING
OF THE
UNSATURATED ZONE BENEATH
WASTE SITES AND WATER DAMS AT
XSTRATA RHOVAN

REF : 10305
DATE : MARCH 2006

COMPILED FOR:

Xstrata South Africa (Pty) Ltd
Rhovan
P.O. Box 3620
Brits
0250

COMPILED BY:

Jasper Müller Associates CC
"at the edge of ground water innovation"

TABLE OF CONTENTS

SUMMARY

The unsaturated zone serves as the pathway for contaminated leachate from overlying waste sites and water dams towards the saturated ground water aquifer. This report describes the hydro-chemical impact of current and future sources of contamination through the unsaturated zone towards the saturated aquifer at Xstrata Rhovan.

Geochemical modeling is a useful tool in order to model the actual impact of leachate from waste sites and water dams on the underlying unsaturated zone. From the modeling results, recommendations on the type of lining systems to be constructed could be made. However the final decision on the lining system used at Xstrata Rhovan must be agreed upon with the relevant authorities.

The volume of leachate is dependant on the type of the lining system. The lower the grade of the liner (e.g. G:L:B$^+$ instead of H:H 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 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 the Calcine Dump be lined with a Hazardous Waste Site lining system.

The Dirty Storm Water Dams and Calcine Return Water Dam have almost 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 lined with a Hazardous Waste Site lining systems.

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.

The soil at Xstrata Rhovan is geochemically suitable for the use in lining systems. 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, significantly.

Respectfully submitted

____

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

1. BACKGROUND

1.1 INTRODUCTION

The unsaturated zone serves as the pathway for contaminated leachate from overlying waste sites, effluent ponds and water dams towards the saturated ground water aquifer. This report describes the hydro-chemical impact of current and future sources of contamination through the unsaturated zone towards the saturated aquifer at Xstrata Rhovan.

The aim of modeling the unsaturated zone is to quantify its adsorption potential and to understand the geochemical behaviour of the different contaminants in the unsaturated zone. Different lining systems also lead to differences in the volume/amount of contaminated leachate that occur towards the underlying unsaturated zone. The adsorption potential of the unsaturated zone is not constant and varies along with the amount and type of contaminants adsorbed. Geochemical modeling is an excellent predictive tool for the modeling of the changes in the adsorption potential during the infiltration of the contaminated leachate.

If an inadequate lining system is used, the volume of contamination leaching towards the unsaturated zone will be too high to be effectively adsorbed by the unsaturated zone. The unsaturated zone will also reach its adsorption limit more rapidly. Knowledge of the geochemical behaviour of the contaminants and the adsorption potential of the unsaturated zone will show the importance of using the correct lining system. The use of the correct lining system will become crucial for future construction of hazardous waste, effluent and water disposal/storage at Xstrata Rhovan.

1.2 OBJECTIVES

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 impact of contamination on the unsaturated zone at the following sources will be modeled:

1) The Calcine Tailings Dump

2) The Slimes Dam and Slimes Return Water Dam

3) Effluent Ponds and Water Dams at the Plant area:
3.1) Scrubber Ponds
3.2) Purge Dams
3.3) Calcine Return Water (Ericsson) Dam
3.4) Dirty Water Storm Water Dams

The positions of the above features are shown in **Figures 1.2(A) and (B)** below:

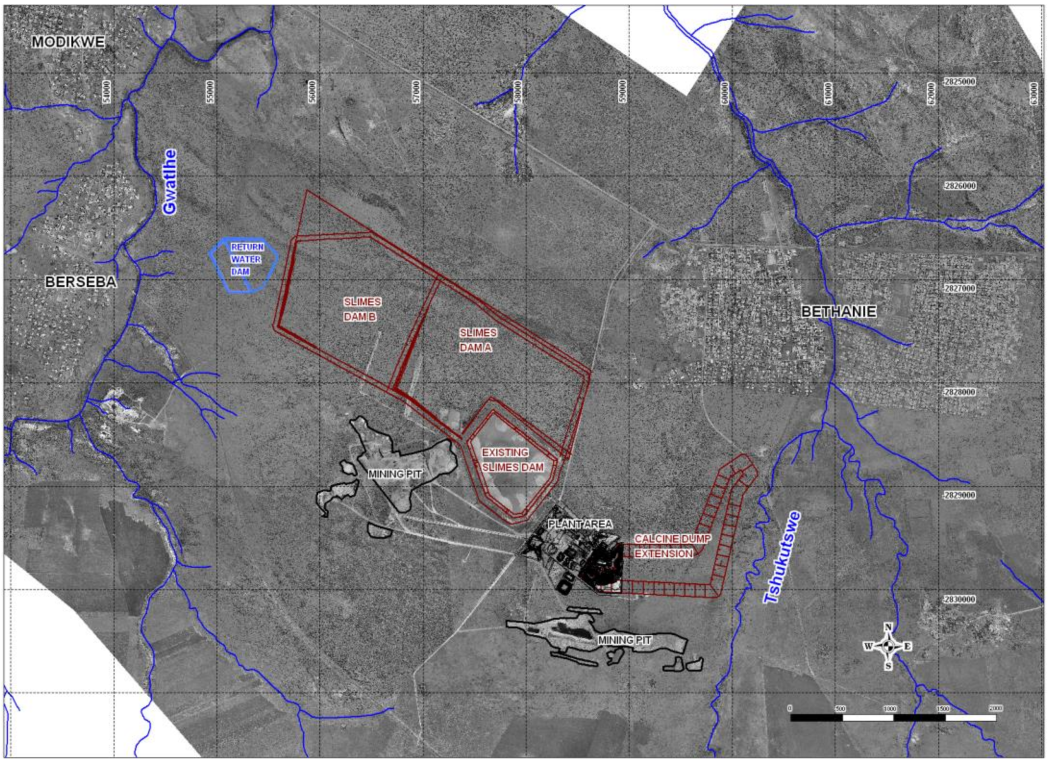


Figure 1.2(A): Position of the Slimes Dam, the Calcine Dump and the Plant Area at Xstrata Rhovan.

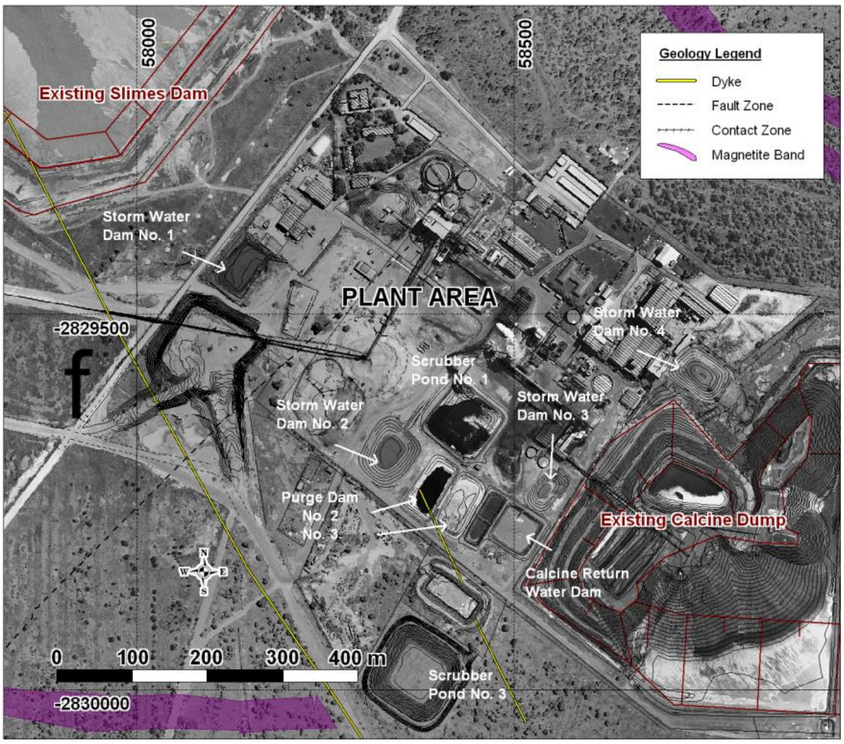


Figure 1.2(B): Position of effluent ponds and water dams in the Rhovan plant area.

At each of the above sites 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.

The model results will 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.

1.3 CONCEPTUAL MODEL

1.3.1 Source-pathway-receptor conceptual model

With reference to the geohydrological conceptual model the following aspects are summarized:

Source:

- A potential source of ground water quality impact is associated with the Calcine Dump, the Slimes Dam, the Scrubber Ponds, the Purge Dams, the Calcine Return Water Dam and Dirty Storm Water Dams. See **Figures 1.2(A) and (B)** above for the position of these features.
- Potential leachate will be introduced into the underlying unsaturated zone.

Pathway:

- The unsaturated zone will serve as a pathway for contamination between the overlying source and the ground water of the saturated zone aquifer.
- The contamination will perculate/filtrate through the unsaturated zone where some of the contamination will be adsorbed or will take part in other chemical reactions.

Receptors:

- The saturated zone is seen as a receptor of contamination as it is classified as a potential (ground) water resource.
- The contamination within the saturated zone does not currently affect any external ground water users or surface water features.

1.3.2 Description of the unsaturated zone at Xstrata Rhovan

It is important to describe the geology below the Calcine Tailings Dump, Slimes Dam and Plant Areas in order to understand the geological path that contamination will follow from the overlying sources. The unsaturated zone includes the soil horizons and part of the weathered gabbro.

From the drilled geohydrological boreholes at every area, a representative geological profile was constructed for each of the areas as shown in **Figures 1.3.2(A) to (C)** below:

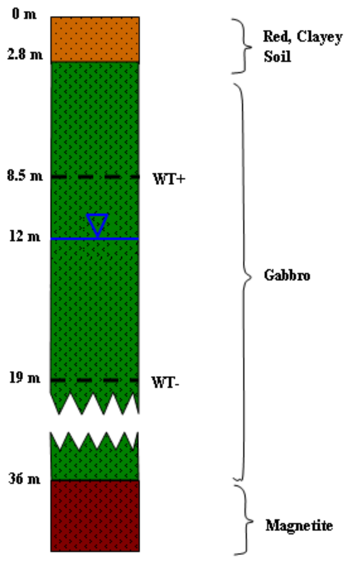


Figure 1.3.2(A): Representative geological profile at the Calcine Dump area.

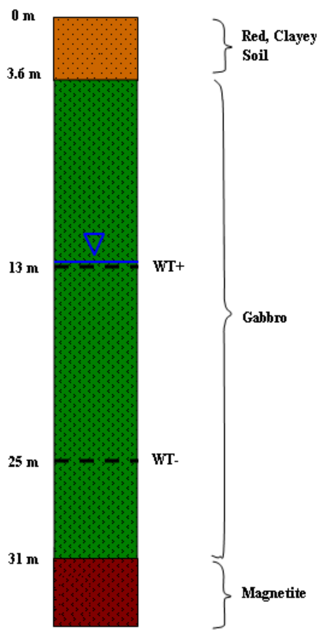


Figure 1.3.2(B): Representative geological profile at the Slimes Dam area.

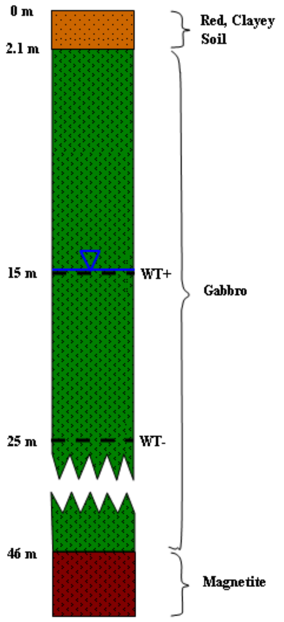


Figure 1.3.2(C): Representative geological profile at the Plant Area.

From **Figures 1.3.2(A) to (C)** the following conclusions can be made:

- The general geological profile consists of magnetite in depth, overlaid by gabbro and capped with a soil layer.

- The soil consists of an A- and a B-horizon. The A horizon is more loamy whereas the B-horizon is clayey. The mineralogy of the A-horizon indicates that this horizon have been subjected to a larger degree of weathering than the B-horizon. The B-horizon is situated on top of the highly weathered gabbro and formed in-situ. The B-horizon contains primary minerals originating from the gabbro as well as secondary minerals that formed from the weathering of the primary minerals. The well developed clayey soil is present over a large portion of the area and was identified in most of the boreholes. The depth of the soil layer varies at respectively 2.8 m, 3.6 m and 2.1 m for the Calcine, Slimes and Plant areas.

- The gabbro is extensively weathered. The weathering zone could be subdivided into a highly weathered and a slightly weathered zone. The highly weathered zone average respectively at 8.5 m, 13 m and 15 m for the Calcine, Slimes and Plant areas. The slightly weathered zone is respectively 19 m, 25 m and 25 m at the same respective areas.

- The gabbro is also fractured and most fractures largely coincide or are just below the slightly weathered horizon. The presence of the magnetite bands, dykes and faults are significant, as they might play an important role in the movement of contamination in ground water. Water make in some of the drilled boreholes were also find at the contact between the gabbro and the magnetite gabbro and the maximum depth of the fractured zone could be taken at this contact.

1.4 MODEL CODE

For the geochemical modeling the Geochemist' Workbench 6.0 suite was 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).

The modeled quantity of leachate from the waste sites was modeled using the USEPA software program Visual HELP. This software is 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.

2. MODEL INPUT AND ASSUMPTIONS

2.1 METHODOLOGY

In the program React, the following input will be specified:

- The relevant adsorption minerals (in weight) of the unsaturated/saturated zone.
- The ground water volume (liter) and quality (in concentration).
- The quality of the infiltrating water from the source (in concentration).
- The modeling time. The model time was set to 20 Residence Times. A Residence Time is the time it will take for the infiltrating leachate to replace the total volume of interstitial water.

The program React will perform the necessary numerical modeling and Gtplot will automatically plot the results as specified. The output will entail all the changes in the mineralogy and in the water quality over the modeled time.

2.2 MINERALOGY OF THE ROCK MATRIX

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.

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.

XRD and XRF results of rocks/soils at Plant/Calcine Dump area

A total of 16 samples were taken from four new boreholes (GWW-40 to GWW-43) drilled around the larger Plant and Calcine Dump area. On all the samples taken XRD, XRF major and XRF trace analyses were performed by the Department of Geology at the University of Pretoria. The results are given in **Tables 2.2(A) to (C)** below:

Table 2.2(A): XRD results of soils/rock at the larger Plant/Calcine Dump area.

Sample horizons	Sample Nr	Minerals wt %											
		QUARTZ	CALCITE	KAOLINITE	HEMATITE	ANORTHITE	AUGITE	RUTILE	CLINOCHLORE	MAGNETITE	MONTMORILONITE	ILMENITE	TOTAL
Soil A	GWW-40 0-1m	51.3	0.0	11.9	6.1	9.7	0.0	4.5	3.3	6.2	0.0	7.0	100.00
	GWW-41 0-1m	32.4	0.0	12.7	15.8	16.2	0.0	0.0	0.0	12.8	0.0	10.2	100.10
	GWW-42 0-1m	33.7	9.3	5.1	0.0	38.5	0.0	0.0	2.8	4.7	5.9	0.0	100.00
	GWW-43 2-3m	34.0	0.0	28.1	10.6	18.6	0.0	0.0	3.0	5.7	0.0	0.0	100.00
	Average wt%	**37.9**	**2.3**	**14.5**	**8.1**	**20.8**	**0.0**	**1.1**	**2.3**	**7.4**	**1.5**	**4.3**	100.03
	Percentage	**37.8**	**2.3**	**14.4**	**8.1**	**20.7**	**0.0**	**1.1**	**2.3**	**7.3**	**1.5**	**4.3**	100.00
Soil B	GWW-40 1-2m	0.0	0.0	16.9	3.6	56.4	0.0	0.0	4.6	3.1	15.4	0.0	100.00
	GWW-41 1-2m	0.0	0.0	4.0	0.0	93.9	0.0	0.0	0.6	0.7	0.8	0.0	100.00
	GWW-42 1-2m	0.0	8.3	2.1	0.0	50.5	23.4	0.0	1.7	5.3	8.7	0.0	100.00
	GWW-43 3-4m	15.9	0.0	11.7	3.7	46.5	0.0	0.0	2.4	3.6	12.5	3.7	100.00
	Average wt%	**4.0**	**2.1**	**8.7**	**1.8**	**61.8**	**5.9**	**0.0**	**2.3**	**3.2**	**9.4**	**0.9**	100.00
	Percentage	**4.0**	**2.1**	**8.7**	**1.8**	**61.8**	**5.9**	**0.0**	**2.3**	**3.2**	**9.4**	**0.9**	100.00
Gabbro (WT +)	GWW-40 3-4m	0.0	0.0	4.1	2.6	62.4	13.6	0.0	0.0	3.0	11.1	3.3	100.10
	GWW-41 8-9m	0.0	3.3	2.6	0.0	81.1	0.0	1.3	1.4	3.0	7.3	0.0	100.00
	GWW-42 7-8m	0.0	0.0	1.1	0.0	76.0	15.2	0.0	0.0	5.2	0.0	2.5	100.00
	GWW-43 7-8m	0.0	0.0	2.6	0.0	73.1	10.1	0.0	1.6	3.1	8.2	1.2	99.90
	Average wt%	**0.0**	**0.8**	**2.6**	**0.7**	**73.2**	**9.7**	**0.3**	**0.8**	**3.6**	**6.7**	**1.8**	100.00
	Percentage	**0.0**	**0.8**	**2.6**	**0.7**	**73.2**	**9.7**	**0.3**	**0.8**	**3.6**	**6.7**	**1.8**	100.00
Gabbro (WT -)	GWW-40 10-11m	0.0	0.0	0.8	0.3	88.8	4.7	0.0	0.0	2.3	2.6	0.6	100.10
	GWW-41 18-19m	0.0	5.4	3.0	0.0	77.2	0.0	0.0	3.1	5.1	6.2	0.0	100.00
	GWW-42 14-15m	0.0	5.3	1.8	0.0	86.2	0.0	0.0	0.0	4.5	0.0	2.2	100.00
	GWW-43 15-16m	0.0	0.0	4.8	0.0	50.2	29.3	0.0	3.0	3.6	6.9	2.2	100.00
	Average wt%	**0.0**	**2.7**	**2.6**	**0.1**	**75.6**	**8.5**	**0.0**	**1.5**	**3.9**	**3.9**	**1.3**	100.03
	Percentage	**0.0**	**2.7**	**2.6**	**0.1**	**75.6**	**8.5**	**0.0**	**1.5**	**3.9**	**3.9**	**1.2**	100.00

Table 2.2(B): Major elemental composition of soils/rock at the larger Plant/Calcine Dump area.

Sample horizons	Sample Nr	Oxides wt%															
		SiO_2	TiO_2	Al_2O_3	Fe_2O_3	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	Cr_2O3	NiO	V_2O_5	ZrO_2	LOI	TOTAL
Soil A	GWW-40 0-1m	29.05	10.59	10.07	43.94	0.27	0.25	0.46	0.15	0.55	0.05	0.05	0.03	0.17	0.03	4.38	100.05
	GWW-41 0-1m	9.32	11.23	5.87	68.20	0.20	0.49	0.52	0.06	0.05	0.00	0.28	0.02	1.53	0.00	2.14	99.90
	GWW-42 0-1m	40.55	5.19	13.30	23.14	0.23	2.74	7.09	1.20	0.27	0.01	0.02	0.01	0.38	0.01	4.62	98.79
	GWW-43 2-3m	33.57	7.12	16.60	33.19	0.27	1.59	1.49	0.51	0.32	0.01	0.02	0.00	0.44	0.00	5.51	100.64
	Average wt%	**28.12**	**8.53**	**11.46**	**42.12**	**0.24**	**1.27**	**2.39**	**0.48**	**0.30**	**0.02**	**0.09**	**0.01**	**0.63**	**0.01**	**4.16**	**99.84**
	Percentage	**28.17**	**8.55**	**11.48**	**42.18**	**0.24**	**1.27**	**2.39**	**0.48**	**0.30**	**0.02**	**0.09**	**0.02**	**0.63**	**0.01**	**4.17**	**100.00**
Soil B	GWW-40 1-2m	39.08	5.85	13.59	28.30	0.30	2.16	2.82	1.56	0.30	0.02	0.03	0.00	0.07	0.00	6.00	100.07
	GWW-41 1-2m	47.73	1.13	24.03	9.19	0.08	1.09	7.68	2.24	0.41	0.00	0.04	0.01	0.14	0.01	6.32	100.11
	GWW-42 1-2m	37.33	5.19	9.83	28.87	0.27	5.41	9.68	1.13	0.12	0.00	0.00	0.00	0.45	0.00	1.94	100.22
	GWW-43 3-4m	32.81	5.51	16.61	35.09	0.23	1.50	1.57	0.19	0.45	0.03	0.03	0.02	0.40	0.01	5.45	99.91
	Average wt%	**39.24**	**4.42**	**16.01**	**25.37**	**0.22**	**2.54**	**5.44**	**1.28**	**0.32**	**0.01**	**0.03**	**0.01**	**0.27**	**0.00**	**4.93**	**100.08**
	Percentage	**39.21**	**4.42**	**16.00**	**25.35**	**0.22**	**2.54**	**5.43**	**1.28**	**0.32**	**0.01**	**0.03**	**0.01**	**0.27**	**0.00**	**4.92**	**100.00**
Gabbro (WT +)	GWW-40 3-4m	46.03	2.37	13.28	21.80	0.30	4.76	8.19	1.92	0.24	0.00	0.01	0.00	0.04	0.00	1.53	100.46
	GWW-41 8-9m	48.46	0.88	21.54	11.86	0.12	2.84	8.81	2.58	0.30	0.02	0.04	0.03	0.08	0.01	2.61	100.17
	GWW-42 7-8m	33.20	7.44	17.51	31.38	0.14	1.27	6.21	2.29	0.26	0.00	0.01	0.01	0.63	0.00	0.63	100.96
	GWW-43 7-8m	41.21	3.62	15.01	25.14	0.21	3.49	6.74	2.01	0.29	0.00	0.00	0.00	0.27	0.00	1.92	99.92
	Average wt%	**42.22**	**3.58**	**16.84**	**22.55**	**0.19**	**3.09**	**7.48**	**2.20**	**0.27**	**0.01**	**0.01**	**0.01**	**0.26**	**0.00**	**1.67**	**100.38**
	Percentage	**42.06**	**3.56**	**16.77**	**22.46**	**0.19**	**3.08**	**7.46**	**2.19**	**0.27**	**0.01**	**0.01**	**0.01**	**0.26**	**0.00**	**1.66**	**100.00**
Gabbro (WT -)	GWW-40 10-11m	43.23	2.71	12.80	23.06	0.29	4.58	8.19	2.02	0.28	0.01	0.01	0.00	0.05	0.00	0.96	98.18
	GWW-41 18-19m	42.34	1.78	21.10	18.55	0.11	2.89	9.17	2.39	0.17	0.00	0.01	0.00	0.22	0.00	0.75	99.49
	GWW-42 14-15m	37.53	5.69	19.82	24.81	0.11	0.86	7.23	2.75	0.31	0.00	0.00	0.01	0.49	0.00	0.93	100.54
	GWW-43 15-16m	42.62	2.96	14.05	21.07	0.20	4.11	8.23	2.26	0.35	0.01	0.02	0.00	0.21	0.00	4.07	100.18
	Average wt%	**41.43**	**3.29**	**16.94**	**21.87**	**0.18**	**3.11**	**8.21**	**2.35**	**0.28**	**0.01**	**0.01**	**0.00**	**0.24**	**0.00**	**1.68**	**99.60**
	Percentage	**41.60**	**3.30**	**17.01**	**21.96**	**0.18**	**3.12**	**8.24**	**2.36**	**0.28**	**0.01**	**0.01**	**0.00**	**0.24**	**0.00**	**1.69**	**100.00**

Table 2.2(C): Trace elements in soils/rock at the larger Plant/Calcine Dump area.

Sample horizons	Sample ID	Trace Elements (ppm)										
		As	Cu	Ga	Mo	Nb	Ni	Pb	Rb	Sr	Th	U
Soil A	GWW-40 0-1m	16.0	90.6	30.5	9.9	19.8	72.4	16.5	53.4	48.1	25.6	16.6
	GWW-41 0-1m	46.7	183.5	47.3	16.0	24.6	306.7	12.0	33.6	80.5	37.4	24.4
	GWW-42 0-1m	11.4	397.8	24.5	2.4	9.7	125.3	8.5	22.6	216.2	10.2	5.9
	GWW-43 2-3m	14.2	371.9	41.1	10.3	20.8	195.1	12.3	49.6	30.0	28.4	17.3
	Average	**22.1**	**260.9**	**35.9**	**9.6**	**18.7**	**174.9**	**12.3**	**39.8**	**93.7**	**25.4**	**16.1**
Soil B	GWW-40 1-2m	3.8	96.9	24.6	4.5	9.5	53.3	16.3	27.9	180.5	14.4	6.5
	GWW-41 1-2m	10.0	138.4	24.1	1.0	4.3	98.3	8.9	16.6	296.4	3.0	3.0
	GWW-42 1-2m	9.0	493.0	21.3	6.9	11.3	154.7	8.6	15.6	197.0	17.7	10.8
	GWW-43 3-4m	18.8	481.5	36.3	5.9	14.8	136.9	13.8	38.8	117.8	19.9	12.7
	Average	**10.4**	**302.4**	**26.6**	**4.6**	**10.0**	**110.8**	**11.9**	**24.7**	**197.9**	**13.8**	**8.2**
Gabbro (WT +)	GWW-40 3-4m	6.1	78.0	24.3	4.4	7.0	36.0	9.3	17.1	318.7	10.6	7.0
	GWW-41 8-9m	12.5	320.0	23.2	1.0	3.5	243.8	4.7	12.6	337.7	4.7	3.0
	GWW-42 7-8m	5.8	849.7	36.6	5.9	10.6	174.3	7.4	19.9	368.7	19.1	14.4
	GWW-43 7-8m	12.9	440.4	24.8	3.9	6.5	60.5	14.1	19.0	314.3	13.9	8.5
	Average	**9.3**	**422.0**	**27.2**	**3.8**	**6.9**	**128.7**	**8.9**	**17.2**	**334.8**	**12.0**	**8.2**
Gabbro (WT -)	GWW-40 10-11m	14.2	128.7	23.8	4.4	7.7	54.1	4.0	19.4	344.7	13.8	8.1
	GWW-41 18-19m	7.6	304.9	27.4	3.3	5.9	60.8	8.3	12.2	390.0	11.3	7.4
	GWW-42 14-15m	6.3	578.0	33.9	4.7	8.2	147.0	8.2	17.5	408.9	15.8	10.5
	GWW-43 15-16m	10.5	435.6	21.6	3.6	8.3	97.1	7.4	19.7	312.9	11.3	5.6
	Average	**9.7**	**361.8**	**26.7**	**4.0**	**7.5**	**89.7**	**7.0**	**17.2**	**364.1**	**13.1**	**7.9**

Table 2.2(C): Trace elements in soils/rock at the larger Plant/Calcine Dump area…*continued.*

Sample horizons	Sample ID	Trace Elements (ppm)										
		W*	Y	Zn	Zr	Cl*	Co	Cr	F*	S*	Sc	V
Soil A	GWW-40 0-1m	97.4	21.9	148.9	140.0	202.4	135.4	174.8	100.0	279.6	33.7	587.8
	GWW-41 0-1m	88.6	21.8	186.9	48.0	98.6	164.7	700.4	100.0	281.7	21.3	5181.5
	GWW-42 0-1m	34.9	16.5	71.3	131.0	50.2	94.0	165.8	100.0	153.8	27.5	868.0
	GWW-43 2-3m	22.6	19.3	113.0	176.0	7.6	129.2	150.3	100.0	277.9	39.4	2079.7
	Average	**60.9**	**19.9**	**130.0**	**123.8**	**89.7**	**130.8**	**297.8**	**100.0**	**248.2**	**30.5**	**2179.3**
Soil B	GWW-40 1-2m	19.1	26.2	135.2	35.0	78.3	128.2	53.4	100.0	90.3	59.0	267.7
	GWW-41 1-2m	56.6	6.3	44.0	67.0	469.9	29.6	149.4	100.0	104.3	6.6	155.4
	GWW-42 1-2m	124.6	18.7	89.7	16.0	133.7	135.1	23.1	100.0	90.2	50.4	1133.0
	GWW-43 3-4m	6.1	22.7	91.3	95.0	64.9	129.8	91.1	100.0	174.6	46.0	1030.0
	Average	**51.6**	**18.5**	**90.0**	**53.3**	**186.7**	**105.6**	**79.3**	**100.0**	**114.9**	**40.5**	**646.5**
Gabbro (WT +)	GWW-40 3-4m	44.4	15.3	97.5	13.0	67.6	116.5	27.1	100.0	72.9	43.9	148.4
	GWW-41 8-9m	66.0	7.7	64.8	28.0	2860.8	80.4	182.8	100.0	36.6	7.0	264.8
	GWW-42 7-8m	85.1	10.8	73.1	10.0	67.5	97.3	10.6	100.0	112.4	7.8	1597.6
	GWW-43 7-8m	41.6	12.7	87.4	15.0	61.3	125.3	18.8	100.0	101.0	31.6	558.6
	Average	**59.3**	**11.6**	**80.7**	**16.5**	**764.3**	**104.9**	**59.8**	**100.0**	**80.7**	**22.6**	**642.3**
Gabbro (WT -)	GWW-40 10-11m	40.7	14.9	260.1	10.0	24.3	126.8	21.1	100.0	106.1	31.8	179.9
	GWW-41 18-19m	61.8	7.5	57.5	17.0	177.6	86.3	77.8	100.0	46.8	1.1	509.8
	GWW-42 14-15m	91.6	9.1	59.7	17.0	14.7	83.9	21.3	100.0	122.2	4.2	1177.2
	GWW-43 15-16m	9.8	13.4	101.8	15.0	176.2	143.9	19.5	100.0	4836.9	22.4	610.3
	Average	**51.0**	**11.2**	**119.8**	**14.8**	**98.2**	**110.2**	**34.9**	**100.0**	**1278.0**	**14.9**	**619.3**

<u>XRD and XRF results of rocks/soils at the Slimes Dam area</u>

A total of 12 samples were taken from 3 new boreholes (SGM-2, SGM-5 and SGM-6) drilled at the Slimes Dam area. On all the samples taken XRD, XRF Major and XRF Trace Analyses were performed by the Department of Geology at the University of Pretoria. The results are given in **Tables 2.2(D) to (F)** below:

Table 2.2(D): XRD results of soils/rock at the Slimes Dam area.

Sample horizons	Sample Nr	Minerals wt %												
		QUARTZ	CALCITE	KAOLINITE	HEMATITE	ANORTHITE	AUGITE	RUTILE	CLINOCHLORE	MAGNETITE	MONTMORILONITE	ILMENITE	LIZARDITE	Total
Soil A	SGM-B2 0-1m	45.9	0.0	22.1	6.3	11.5	0.0	0.0	0.0	6.1	0.0	8.1	0.0	100.00
	SGM-B5 0-1m	53.8	0.0	11.2	2.8	11.4	4.0	0.0	0.0	4.8	0.0	12.0	0.0	100.00
	SGM-B6 0-1m	28.3	8.0	26.7	4.9	17.0	6.1	3.8	2.0	3.2	0.0	0.0	0.0	100.00
	Average	**42.7**	**2.7**	**20.0**	**4.7**	**13.3**	**3.4**	**1.3**	**0.7**	**4.7**	**0.0**	**6.7**	**0.0**	100.00
	Percentage	**42.7**	**2.7**	**20.0**	**4.7**	**13.3**	**3.4**	**1.3**	**0.7**	**4.7**	**0.0**	**6.7**	**0.0**	100.00
Soil B	SGM-B2 1-2m	23.8	0.0	25.0	8.1	25.9	0.0	0.0	0.0	8.1	0.0	9.1	0.0	100.00
	SGM-B5 1-2m	0.0	0.0	0.9	0.0	68.7	16.1	0.0	2.0	2.7	5.1	1.6	2.8	99.90
	SGM-B6 2-3m	46.8	0.0	27.3	4.9	9.0	6.3	1.5	4.1	0.0	0.0	0.0	0.0	99.90
	Average	**23.5**	**0.0**	**17.7**	**4.3**	**34.5**	**7.5**	**0.5**	**2.0**	**3.6**	**1.7**	**3.6**	**0.9**	99.93
	Percentage	**23.5**	**0.0**	**17.7**	**4.3**	**34.6**	**7.5**	**0.5**	**2.0**	**3.6**	**1.7**	**3.6**	**0.9**	100.00
Gabbro (WT +)	SGM-B2 4-5m	0.0	0.0	1.4	0.0	63.5	23.8	0.0	0.0	2.8	5.5	2.0	1.0	100.00
	SGM-B5 5-6m	0.0	0.0	2.1	0.0	87.6	0.0	0.0	0.0	2.9	4.1	1.1	2.2	100.00
	SGM-B6 4-5m	1.8	0.0	0.0	0.0	75.2	15.2	1.2	3.0	0.0	3.5	0.0	0.0	99.90
	Average	**0.6**	**0.0**	**1.2**	**0.0**	**75.4**	**13.0**	**0.4**	**1.0**	**1.9**	**4.4**	**1.0**	**1.1**	99.97
	Percentage	**0.6**	**0.0**	**1.2**	**0.0**	**75.5**	**13.0**	**0.4**	**1.0**	**1.9**	**4.4**	**1.0**	**1.1**	100.00
Gabbro (WT -)	SGM-B2 12-13m	0.0	0.0	2.8	0.0	54.8	23.6	0.0	0.0	5.3	5.6	5.8	2.0	99.90
	SGM-B5 14-15m	0.0	0.0	2.7	2.0	85.0	0.0	0.0	0.0	3.1	4.9	2.3	0.0	100.00
	SGM-B6 12-13m	0.0	0.0	3.0	0.0	72.9	17.1	0.0	1.6	0.0	5.4	0.0	0.0	100.00
	Average	**0.0**	**0.0**	**2.8**	**0.7**	**70.9**	**13.6**	**0.0**	**0.5**	**2.8**	**5.3**	**2.7**	**0.7**	99.97
	Percentage	**0.0**	**0.0**	**2.8**	**0.7**	**70.9**	**13.6**	**0.0**	**0.5**	**2.8**	**5.3**	**2.7**	**0.7**	100.00

Table 2.2(E): Major elemental composition of soils/rock at the Slimes Dam area.

Sample horizon	Sample Nr	Oxides wt%															
		SiO_2	TiO_2	Al_2O_3	Fe_2O_3	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	Cr_2O3	NiO	V_2O_5	ZrO_2	LOI	TOTAL
Soil A	SGM-B2 0-1m	36.57	9.03	13.99	31.90	0.26	0.22	0.24	0.06	0.50	0.08	0.07	0.01	0.11	0.03	6.88	99.93
	SGM-B5 0-1m	22.75	11.98	9.08	50.90	0.34	0.57	0.60	0.02	0.28	0.33	0.03	0.02	0.29	0.02	2.73	99.95
	SGM-B6 0-1m	44.00	3.15	18.17	19.93	0.22	1.18	2.17	0.28	0.58	0.02	0.04	0.01	0.23	0.01	9.73	99.73
	Average	**34.44**	**8.05**	**13.75**	**34.25**	**0.28**	**0.66**	**1.00**	**0.12**	**0.45**	**0.14**	**0.05**	**0.01**	**0.21**	**0.02**	**6.45**	**99.87**
	Percentage	**34.49**	**8.07**	**13.77**	**34.30**	**0.28**	**0.66**	**1.00**	**0.12**	**0.45**	**0.14**	**0.05**	**0.01**	**0.21**	**0.02**	**6.46**	**100.03**
Soil B	SGM-B2 1-2m	27.55	8.22	12.63	42.34	0.43	1.10	1.74	0.33	0.26	0.05	0.07	0.04	0.11	0.01	5.45	100.32
	SGM-B5 1-2m	33.89	6.27	13.04	36.35	0.26	2.57	3.67	1.53	0.32	0.14	0.01	0.00	0.05	0.00	1.79	99.90
	SGM-B6 2-3m	41.07	5.34	17.93	22.75	0.23	0.66	0.47	0.18	0.78	0.06	0.05	0.01	0.25	0.02	11.15	100.96
	Average	**34.17**	**6.61**	**14.53**	**33.82**	**0.30**	**1.44**	**1.96**	**0.68**	**0.45**	**0.08**	**0.04**	**0.02**	**0.14**	**0.01**	**6.13**	**100.39**
	Percentage	**34.15**	**6.61**	**14.52**	**33.79**	**0.30**	**1.44**	**1.96**	**0.68**	**0.45**	**0.08**	**0.04**	**0.02**	**0.14**	**0.01**	**6.13**	**100.32**
Gabbro (WT +)	SGM-B2 4-5m	43.26	3.22	12.44	23.12	0.24	5.11	9.40	1.71	0.17	0.00	0.01	0.00	0.07	0.00	0.90	99.64
	SGM-B5 5-6m	36.43	6.76	14.65	31.60	0.26	2.46	4.57	2.34	0.26	0.06	0.01	0.00	0.04	0.00	1.26	100.69
	SGM-B6 4-5m	49.63	1.86	14.72	13.40	0.22	5.23	8.29	2.68	0.42	0.13	0.03	0.01	0.06	0.02	3.19	99.90
	Average	**43.11**	**3.94**	**13.94**	**22.71**	**0.24**	**4.27**	**7.42**	**2.24**	**0.28**	**0.06**	**0.01**	**0.00**	**0.05**	**0.01**	**1.78**	**100.08**
	Percentage	**42.94**	**3.93**	**13.89**	**22.62**	**0.24**	**4.25**	**7.39**	**2.24**	**0.28**	**0.06**	**0.01**	**0.00**	**0.05**	**0.01**	**1.77**	**99.70**
Gabbro (WT -)	SGM-B2 12-13m	42.58	3.44	11.47	24.14	0.26	5.55	9.23	1.56	0.15	0.00	0.01	0.00	0.07	0.00	0.69	99.15
	SGM-B5 14-15m	30.89	7.08	11.47	41.20	0.34	2.04	4.14	0.97	0.20	0.01	0.01	0.00	0.11	0.00	1.43	99.90
	SGM-B6 12-13m	43.68	2.62	14.14	20.74	0.21	4.87	8.54	1.80	0.26	0.00	0.01	0.00	0.13	0.00	2.64	99.63
	Average	**39.05**	**4.38**	**12.36**	**28.69**	**0.27**	**4.15**	**7.30**	**1.44**	**0.20**	**0.00**	**0.01**	**0.00**	**0.10**	**0.00**	**1.59**	**99.56**
	Percentage	**39.21**	**4.40**	**12.41**	**28.81**	**0.27**	**4.17**	**7.33**	**1.45**	**0.21**	**0.00**	**0.01**	**0.00**	**0.10**	**0.00**	**1.59**	**99.97**

Table 2.2(F): Trace elements in soils/rock at the Slimes Dam area.

Sample horizons	Sample ID	Trace Elements (ppm)										
		As	Cu	Ga	Mo	Nb	Ni	Pb	Rb	Sr	Th	U
Soil A	SGM-B2 0-1m	17.2	112.3	31.8	6.6	16.7	70.9	11.6	53.8	24.8	18.9	11.1
	SGM-B5 0-1m	17.3	146.0	33.6	13.1	23.6	50.0	18.8	49.9	56.7	32.1	22.5
	SGM-B6 0-1m	17.8	169.9	25.0	2.1	12.3	122.8	15.1	40.4	66.0	9.3	3.0
	Average	**17.5**	**142.7**	**30.1**	**7.3**	**17.5**	**81.2**	**15.2**	**48.0**	**49.2**	**20.1**	**12.2**
Soil B	SGM-B2 1-2m	32.6	170.7	31.4	9.5	18.0	69.3	16.0	36.7	72.0	23.7	14.7
	SGM-B5 1-2m	21.0	95.2	30.8	5.7	11.3	23.3	10.6	21.4	332.2	21.1	14.3
	SGM-B6 2-3m	7.1	179.2	30.1	3.0	14.3	126.6	20.8	53.1	41.4	11.4	4.0
	Average	**20.2**	**148.4**	**30.8**	**6.1**	**14.5**	**73.1**	**15.8**	**37.1**	**148.5**	**18.7**	**11.0**
Gabbro (WT +)	SGM-B2 4-5m	6.0	141.4	21.5	4.3	8.4	29.3	9.1	13.2	266.0	12.8	7.8
	SGM-B5 5-6m	21.0	90.7	27.8	5.9	8.9	12.9	3.0	17.4	361.3	17.8	11.9
	SGM-B6 4-5m	10.3	117.3	23.4	2.0	12.0	111.3	12.4	20.6	270.2	5.9	3.0
	Average	**12.4**	**116.4**	**24.2**	**4.1**	**9.8**	**51.1**	**8.1**	**17.1**	**299.2**	**12.2**	**7.6**
Gabbro (WT -)	SGM-B2 12-13m	23.5	152.9	20.5	5.5	8.5	27.4	12.2	14.0	228.0	15.2	9.6
	SGM-B5 14-15m	22.7	115.5	29.3	9.2	12.2	17.6	13.0	19.6	305.1	23.6	15.0
	SGM-B6 12-13m	3.0	51.1	24.5	4.0	6.7	45.3	10.8	15.4	317.0	9.3	6.2
	Average	**16.4**	**106.5**	**24.8**	**6.2**	**9.1**	**30.1**	**12.0**	**16.3**	**283.4**	**16.0**	**10.3**

Table 2.2(F): Trace elements in soils/rock at the Slimes Dam area…*continued.*

Sample horizons	Sample ID	Trace Elements (ppm)										
		W*	Y	Zn	Zr	Cl*	Co	Cr	F*	S*	Sc	V
Soil A	SGM-B2 0-1m	42.6	21.0	105.9	148.0	214.4	136.0	203.1	100.0	207.7	42.2	522.3
	SGM-B5 0-1m	52.1	28.5	190.9	119.0	342.6	147.3	96.3	100.0	201.9	20.5	519.5
	SGM-B6 0-1m	6.0	22.5	97.7	123.0	97.7	107.8	220.1	100.0	108.9	31.2	1054.2
	Average	**33.6**	**24.0**	**131.5**	**130.0**	**218.2**	**130.4**	**173.2**	**100.0**	**172.9**	**31.3**	**698.7**
Soil B	SGM-B2 1-2m	34.3	22.8	91.7	71.0	156.0	205.6	195.4	100.0	168.2	38.6	685.9
	SGM-B5 1-2m	28.3	15.3	104.7	26.0	64.2	112.2	38.3	100.0	113.4	8.9	118.6
	SGM-B6 2-3m	6.0	22.3	94.4	152.0	88.7	119.1	264.0	100.0	235.5	35.1	1191.2
	Average	**22.9**	**20.1**	**96.9**	**83.0**	**103.0**	**145.6**	**165.9**	**100.0**	**172.4**	**27.5**	**665.2**
Gabbro (WT +)	SGM-B2 4-5m	62.6	14.6	64.5	13.0	28.8	130.3	33.1	100.0	70.9	49.7	222.7
	SGM-B5 5-6m	64.3	11.2	119.2	10.0	96.3	125.3	22.6	100.0	76.5	7.8	99.0
	SGM-B6 4-5m	36.3	21.6	96.6	110.0	127.1	99.4	126.6	100.0	62.5	22.8	388.1
	Average	**54.4**	**15.8**	**93.4**	**44.3**	**84.1**	**118.4**	**60.8**	**100.0**	**70.0**	**26.8**	**236.6**
Gabbro (WT -)	SGM-B2 12-13m	107.2	16.7	93.8	10.0	51.9	131.7	37.8	100.0	83.7	42.6	284.4
	SGM-B5 14-15m	61.4	11.7	224.4	10.0	88.1	177.7	19.4	100.0	100.3	12.1	151.8
	SGM-B6 12-13m	33.7	14.5	98.7	14.0	103.2	119.9	40.6	100.0	47.5	26.3	406.3
	Average	**67.4**	**14.3**	**138.9**	**11.3**	**81.0**	**143.1**	**32.6**	**100.0**	**77.2**	**27.0**	**280.9**

Geochemical/Mineralogical Assessment

The following minerals were identified in the soils and rocks:

- Quartz SiO_2

  Quartz is mostly present within the Soil A-horizon. The A-horizon has been subjected to a larger degree of weathering than the Soil B-horizon. Secondary quartz may be formed in-situ from the weathering of anorthite and augite.

  Quartz is a tectosilicate with a slow weathering rate and is therefore very resistant to weathering. Some quartz may also originate from the weathering of the granite to the north and also the granite inliers within the gabbro.

  Less quartz occurs within the Soil B-horizon as the clayey B-horizon show less weathering and external influences than the Soil A-horizon. Almost no quartz occurs within the weathered gabbro.

- Calcite $CaCO_3$

  Calcite is a carbonate mineral that may be formed from the weathering of anorthite or augite. More calcite occurs within the Soil A-horizon than in the Soil B-horizon as the former have been subjected to a higher degree of weathering.

- Kaolinite $Al_2Si_2O_5(OH)_4$

  Kaolinite is a 1:1 phyllosilicate mineral that may form from the weathering of anorthite or any of the other primary or secondary Al containing minerals. More kaolinite occurs within the Soil A-horizon than in the Soil B-horizon as the former have been subjected to a higher degree of weathering.

- Magnetite $Fe(II)Fe(III)_2O_4$, ilmenite $Fe(II)TiO_3$, hematite Fe_2O_3 and rutile TiO_2

  Magnetite and ilmenite are minerals typically present in gabbro. These two minerals are also therefore present in all the horizons but are concentrated in the soil horizons because of their resistance to weathering. Hematite is present almost only in the soil horizons and specifically the Soil A-horizon as a weathering/oxidation product of the Fe-minerals. Rutile formed from the weathering of ilmenite and is concentrated in the Soil A-horizon but absent in the slightly weathered gabbro at the bottom.

- Anorthite $CaAl_2Si_2O_8$

  Anorthite is a dominant mineral present in gabbro and its concentration increase downwards in the weathering profile from the Soil horizons throughout the highly weathered gabbro to the slightly weathered gabbro. The weathering of anorthite leads to several products actually observed within the soil horizons according to the following reactions:

Anorthite + 8 H^+ → 4 H_2O + Ca^{2+} + 2 Al^{3+} + 2Quartz

Anorthite + H_2O + 2 H^+ → Ca^{2+} + Kaolinite

If HCO_3 is present in the system the following reactions will occur:

Anorthite + H_2O + H^+ + HCO_3^- → Calcite + Kaolinite

It is therefore evident that the bulk of the soil at Rhovan was formed from the weathering of the gabbro whether colluvial or in-situ.

- Augite $(Ca,Na)(Mg,Fe,Al,Ti)(Si,Al)_2O_6$

  Augite is a Ca clinopyroxene and contains also other elements as shown in its formula above. Augite is a major mineral of the ferrogabbro. Weathering of augite may lead to secondary minerals that may contain Ca and Mg as chlorite, montmorillonite, serpentine, calcite etc. The reaction below shows the weathering of augite in terms of calcite, lizardite (a serpentine mineral) and quartz:

  $CaMgSi_2O_6$ + H^+ + HCO_3^- → Calcite + 1/6Lizardite + 1/3H_2O + 4/3Quartz

  Augite is easily weathered (more easily than anorthite for instance) and almost no augite occurs within the Soil A-horizon.

- Chlinochlore $(Mg,Fe{+}{+})_5Al(Si_3Al)O_{10}(OH)_8$

  Chlinochlore is a chlorite mineral and formed from the weathering of the various Mg and Fe silicate minerals of the ferrogabbro.

- Montmorillonite $(Na,Ca)_{0,3}(Al,Mg)_2Si_4O_{10}(OH)_2{\cdot}n(H2O)$

  Montmorillonite is a clay mineral (2:1 clay) formed from the weathering of the various Mg and Fe silicate minerals of the ferrogabbro. In contrast with kaolinite, which is associated with a higher degree of weathering (in soil A-horizon), montmorillonite is a more direct weathering product of the ferrogabbro and occur in higher quantities in the Soil B-horizon and in the weathered gabbro, than in the Soil A-horizon.

- Lizardite $Mg_6Si_4O_{10}(OH)_8$

  Lizardite is a serpentine mineral (1:1 phyllosilicate) and results from the weathering/alternation of dark minerals e.g. augite. It was identified only at the slimes dam area and only within the soil B-horizon and gabbro.

The following conclusions could be made with regard to the mineralogical results given in **Table 2.2(A)** for the larger Calcine and Plant Area and in **Table 2.2(D)** for the Slimes Dam area:

- It is evident that the bulk of the soil at Rhovan formed from the weathering of the gabbro whether colluvial or in-situ.

- In most of the soils an A- and B-horizon are present.

  Minerals that are evident of a high degree of weathering occur within the Soil A-horizon like quartz, kaolinite, hematite and rutile. Magnetite and ilmenite is concentrated in this horizon due to their resistance to weathering.

  In the Soil B-horizon minerals occur that are more evident of a lesser degree of weathering and the bottom of the B-horizon overlap with the highly weathered gabbro. In contrast to the Soil A-horizon, the Soil B-horizon has a larger quantity of the original silicate minerals of the gabbro namely anorthosite and augite. Montmorillonite occurs as the dominant clay mineral in the Soil B-horizon instead of kaolinite, which is the dominant clay in the Soil A-horizon.

- In the highly and slightly weathered gabbro, less secondary minerals occur and down the profile, the mineralogy became more typical that of gabbro. For instance is no quartz present.

- It is evident from a mineralogical perspective that a slightly higher degree of weathering is present in the samples taken at the larger Plant and Calcine Tailings Dump area (**Table 2.2(A)**) than those of the Slimes Dam area (**Table 2.2(D)**).

The following conclusions could be reached in terms of the XRF major and trace elements tabled in **Tables 2.2(B), (C), (E) and (F)**:

- The major elements from the dominant and major silicates in the gabbro typically increase downwards in the geochemical profile. These elements are SiO_2, MgO, CaO and Na_2O.

- In the soil horizons several Fe-minerals have been concentrated by weathering and therefore are the associated elements much higher in the soil e.g. Fe_2O_3, TiO_2, Cr_2O_3 and V_2O_5. K_2O is higher in the soil than in the underlying gabbro because K_2O is typically not associated with gabbro.

- Of the trace elements, Rb and Pb are associated with K and therefore show an increase upwards in the geochemical profile. All other trace elements analyzed except W, Cl, F, S and Sr are elevated in the soil horizons because of their association with the concentrated iron minerals. Sr is associated with the Ca silicate minerals and increase therefore downwards in the geochemical profile.

<u>Chosen mineralogy for unsaturated zone geochemical model</u>

From the above mineralogical and elemental analyses a representative average mineralogy must be chosen to incorporate into the geochemical model. It is important to note the following before choosing a representative mineralogy:

- The XRF is a quantitive determination of the major elements and for most of the trace elements. In contrast is the XRD only semi-quantitive/qualitative.

- The Fe determined by the XRF major analysis is much higher than the Fe from the total Fe-containing minerals identified by XRD. The reason why the Fe is much lower from the XRD minerals is because most of the Fe is actually contained within amorphous Fe-hydroxide and Fe-oxides in the weathered profile. These amorphous phases can't be determined by the XRD because of the absence of a crystal form. It is however important to determine the correct amount of Fe-minerals present as Fe-hydroxide and Fe-oxides can adsorb contamination that leach into the unsaturated zone.

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 **Tables 2.2(G) and (H)** and for the Slimes Dam area in **Tables 2.2(I) and (J)** below:

Table 2.2(G): Comparison of calibrated mineralogy with XRD determined minerals at the Plant/Calcine Dump area.

Minerals	Weighted Average XRD Analyses (wt%)	Calibrated Mineralogy
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 2.2(H): Comparison of the elemental composition of the calibrated mineralogy with XRF results at the Plant/Calcine Dump area.

Major Element	Weighted Average XRF Analyses (wt%)	Elements in calibrated Mineralogy (wt%)
Si	33.46	32.65
Al	15.28	15.32
Fe	31.34	31.84
Mn	0.27	0.28
Mg	3.06	3.29
Ca	8.76	9.18
Na	2.60	2.60
K	0.44	0.09
V	0.29	0.29
Ti	4.51	4.45
	100.00	**100.00**

Table 2.2(I): Comparison of calibrated mineralogy with XRD determined minerals at the Slimes Dam area.

Minerals	Weighted Average XRD Analyses (wt%)	Calibrated Mineralogy
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**

Table 2.2(J): Comparison of the elemental composition of the calibrated mineralogy with XRF results at the Slimes Dam area.

Major Element	Weighted Average XRF Analyses (wt%)	Elements in calibrated Mineralogy (wt%)
Si	29.34	29.80
Al	13.89	13.02
Fe	43.51	43.57
Mn	0.41	0.39
Mg	1.35	1.41
Ca	2.22	3.05
Na	0.71	0.76
K	0.69	0.02
V	0.16	0.16
Ti	7.71	7.82
	100.00	**100.00**

2.3 INTERSTITIAL WATER QUALITY

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 the Geohydrological Specialist Report for Xstrata Rhovan of March 2006, done by Jasper Müller Associates – ref: XREMP/SSR/10/VER-01/2006.

The average background ground water is given in **Table 2.3(A)** below. The chosen average for the model is shown in the far right column.

Table 2.3(A): 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

2.4 LEACHATE QUALITY AND QUANTITY FROM SOURCE

Model Assumption – 3. Leachate 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.

Leachate quality from source

Table 2.4(A) gives the latest analyses of the fluid component of the sources. These qualities will be used as the leachate quality from the sources in the geochemical model.

Table 2.4(A): 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

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)
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	-	-

<u>Modeled Leachate Quantity from Source</u>

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

Jasper Müller Associates calculated the volume of leachate expected for different lining systems for waste sites. The modeling was performed using the USEPA software program: Visual HELP. This model is 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:

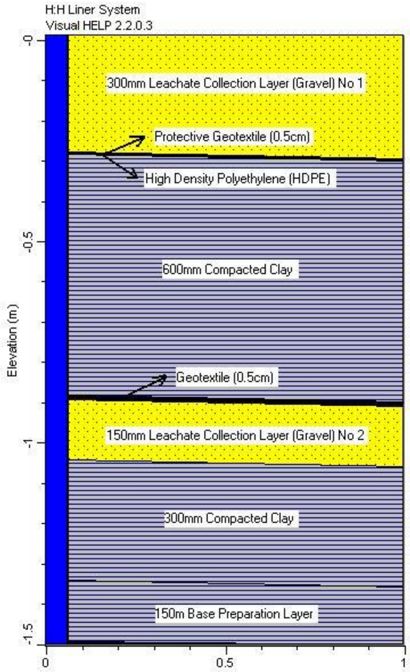
- All models were performed according to the DWAF Minimum Requirements specifications. The model profiles are given in **Figures 2.4(A) to (D)** below.

- 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:

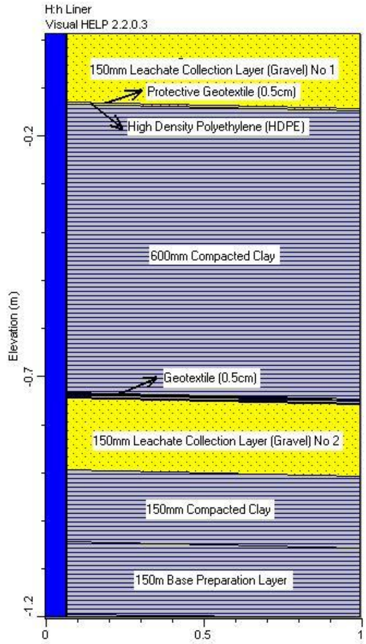
Lining Systems	**Clay Permeability (cm/s)**	**Drainage Slope**
$G:L:B^+$	1×10^{-6}	2%
H:h liner	3×10^{-7}	5%
H:H Liner	1×10^{-7}	5%
H:H Lagoon	1×10^{-7}	5%

- The distances to the drains and the holes in the geomembranes were varied in order to set limits to the leachate expected and a total of 50 models were run.

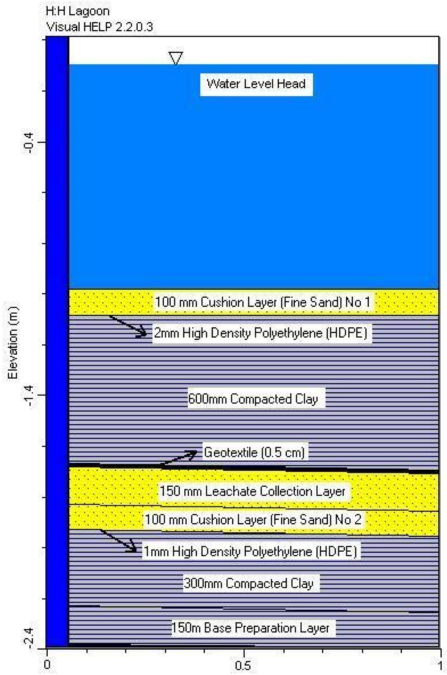
The construction of the H:H, the H:h, the H:H Lagoon and the $G:L:B^+$ Lining Systems in Visual HELP are shown in **Figures 2.4(A) to (D)** below:



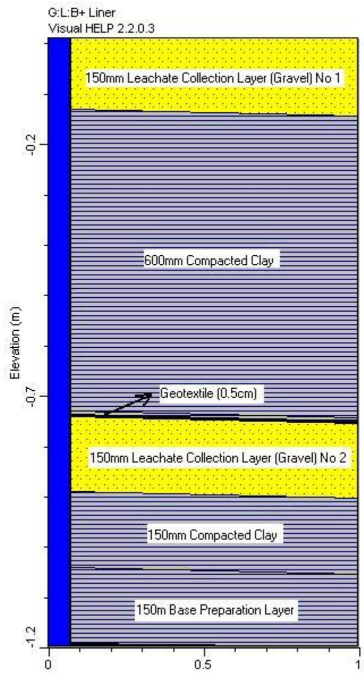
(A) H:H Liner



(B) H:h Liner



(C) H:H Lagoon



(D) G:L:B$^+$ Liner

Figures 2.4(A) to (D) Modeled Lining systems in Visual HELP.

The amount of leachate through the different lining systems is given below in **Tables 2.4(B) to–(E)**:

Table 2.4(B): 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 2.4(C): 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 2.4(D): 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 2.4(E): 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 amount 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 increase 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 or on a similar concept agreed upon with the authorities.
- 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, H:H and G:L:B^{+} are 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 good constructed H:H Liner system the drainage will be 0.0.00063 mm/year per unit area (about 0.00012% of mean annual rainfall – keep in mind that the material on the H:H Liner will be placed fairly dry and that the hydraulic head will be dependent 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.

2.5 GEOMETRY OF PHYSICAL MODEL AND MODEL TIME

Model Assumption – 4. Geometry of physical model

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

The following physical parameters were assigned to the unsaturated zone:

Parameter	Calcine Dump	Slimes Dam	Plant Area	
Unit Area	1.00	1.00	1.00	m^2
Weighted Average Porosity	0.18	0.18	0.16	fraction
Water Content	0.11	0.09	0.08	fraction
Average Thickness	12.00	13.00	15.00	m
Total Volume	12.00	13.00	15.00	m^3
Volume Rock	9.87	10.60	12.56	m^3
Volume Moisture	1.34	1.23	1.24	m^3
Volume Air	0.79	1.16	1.20	m^3

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.

2.6 CHEMICAL REACTIONS IN UNSATURATED 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.

3. UNSATURATED ZONE GEOCHEMICAL MODEL

The unsaturated zone below the waste sites, effluent ponds and water dams extends from the bottom of the liner to the water table of the aquifer. This includes the Soil A- and B-horizon and a part of the weathered gabbro below the soil as described in **Section 1.3.2**. The average thickness of the unsaturated zone below the Calcine Tailings Dump, the Slimes Dam area and the Plant Area are 12 m, 13 m and 15 m respectively. Unsaturated zone geochemical modeling was performed on all existing and future waste dumps, effluent ponds and water dams at Rhovan incorporating the various input discussed in **Section 2**.

3.1 CALCINE TAILINGS DUMP

<u>Introduction</u>

The unsaturated zone below the Calcine Tailings Dump has an average thickness of 12 m. The existing Calcine Dump covers an area of about 14 ha (see **Figure 1.2(B)**) while future expansions will extend the dump with a further 79 ha (see **Figure 1.2(A)**).

<u>Chemicals of Concern</u>

In **Table 2.4(A)** an analysis is given of the Calcine Heap Leach. Hydro-chemical parameters that are non-compliant in terms of the SABS 241 Drinking Water Standard or the Acceptable Environmental Risk (from DWAF Minimum Requirements) are **NO_3, SO_4, F, Na and V**. The geochemical model will especially focus on the behavior of these chemicals in the unsaturated zone.

<u>Model Time</u>

The model was run over 20 Residence Times and therefore simulates the change in chemistry that takes place while contaminated leachate from the overlying source replaces the water in the unsaturated zone 20 times.

The volume of leachate and therefore *the actual years* to reach one Residence Time is dependant on the *type of the lining system used*. The lower the grade of the liner (e.g. (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 into the unsaturated zone. The higher the volume of leachate created, the quicker the interstitial water in the unsaturated zone will be replaced by contaminated leachate.

The estimated leachate volume and time span of Residence Time for various lining systems at the Calcine Dump are given in **Table 3.1(A)** below:

Table 3.1(A): Estimated Leachate and Residence Time for various potential liners below the Calcine Dump.

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

A bentonite liner was used in the first developments of the Calcine Dump and currently a double HDPE geomembrane is used. Only G:L:B$^+$ and Hazardous Waste Lining Systems are permissible lining systems prescribed by DWAF. Bentonite and HDPE liners don’t have any leachate collection systems. In the case where only HDPE liners are used, pollutants cannot be adsorbed by clay or collected by leachate collection systems. The performance of HDPE liners is therefore less reliable than that of Hazardous Waste Lining Systems.

The estimated leachate quantity and the resultant Residence Time, as tabulated in **Table 3.1(A)**, could be validated and calibrated as soon as site specific permeability tests are done during the construction of the liners.

The model results are given in terms of 20 Residence Times; for G:L:B$^+$ and Hazardous Waste Lining Systems the respective time spans are estimated at 5000 years and 30000 years, as tabulated in **Table 3.1(A)** above.

Model Results

The quality of the Calcine Heap Leach, as given **Table 2.4(A)**, was used as input in the model. 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.

Take note that the NO_3 and NH_4 in the model are expressed respectively in terms of NO_3 and NH_4 and not as N. The conversion factor from NO_3-NO_3 to NO_3-N is 0.23 and from NH_4-NH_4 to NH_4-N is 0.78.

The model results are shown in **Figures 3.1(A) to (F)** below:

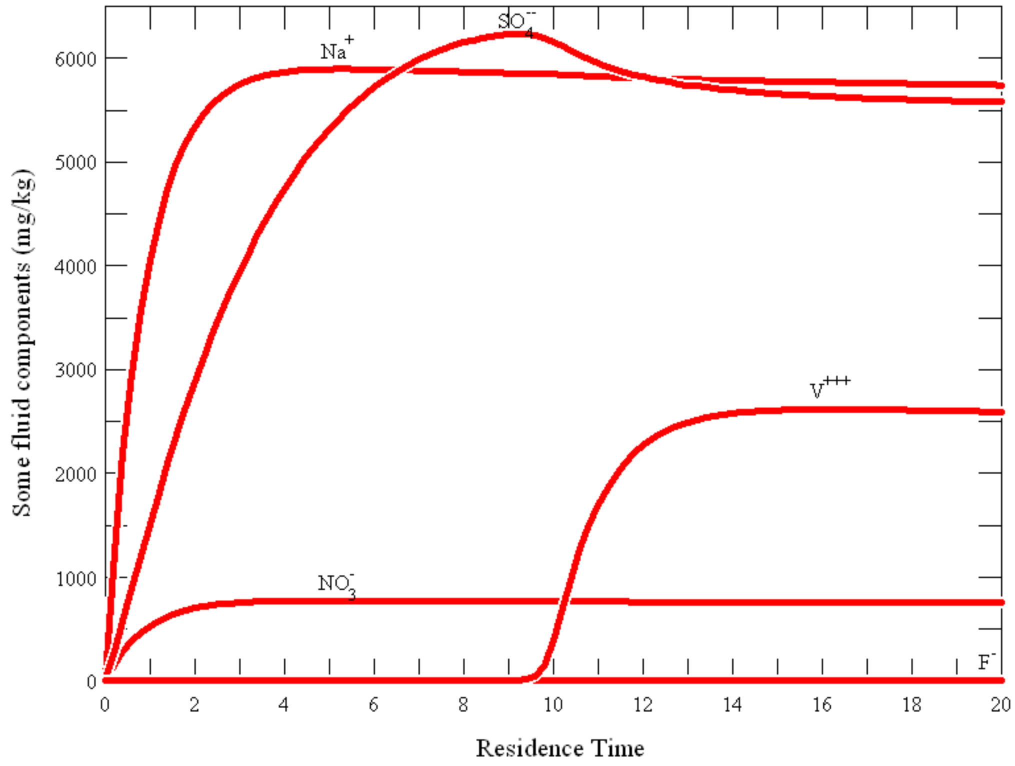


Figure 3.1(A): Fluid components in the unsaturated zone below the Calcine Dump.

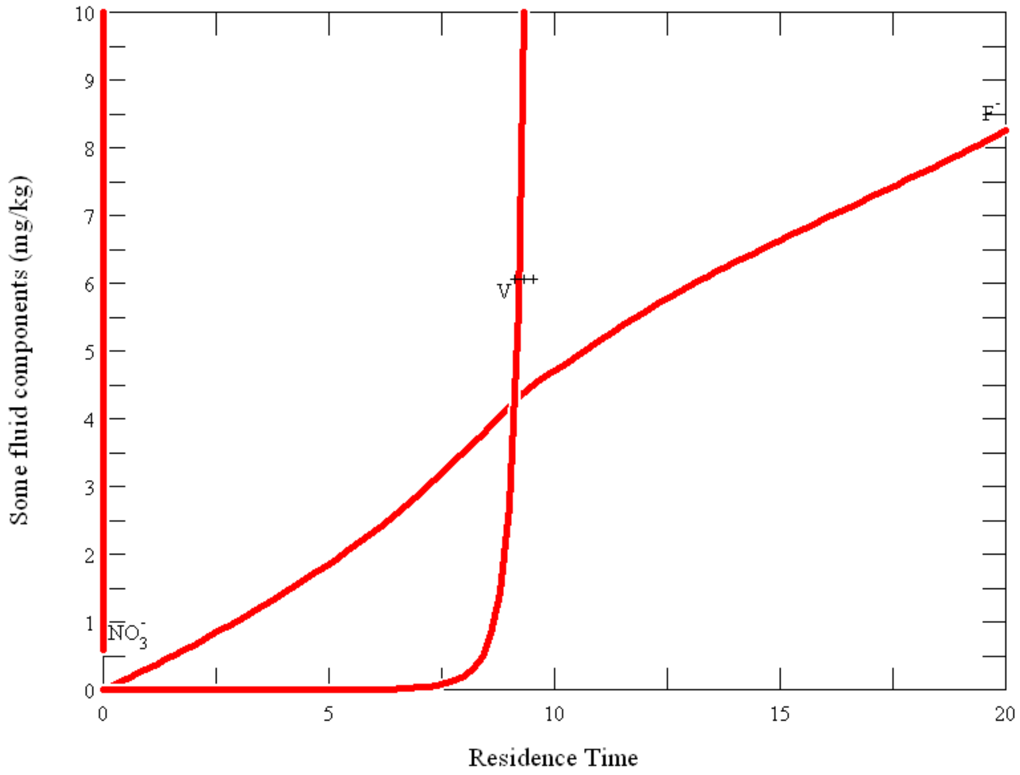


Figure 3.1(B): Fluid components in the unsaturated zone below the Calcine Dump.

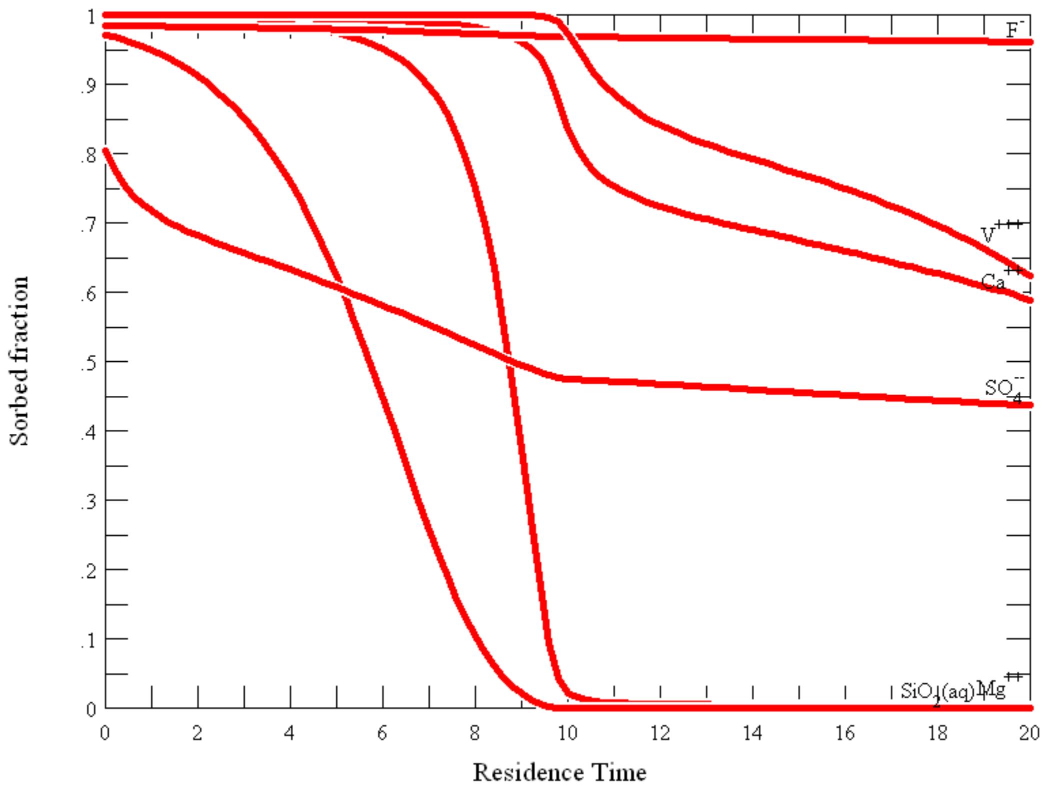


Figure 3.1(C): Fraction of some fluid components adsorbed in the unsaturated zone below the Calcine Dump (Na and NO_3 not sorbed).

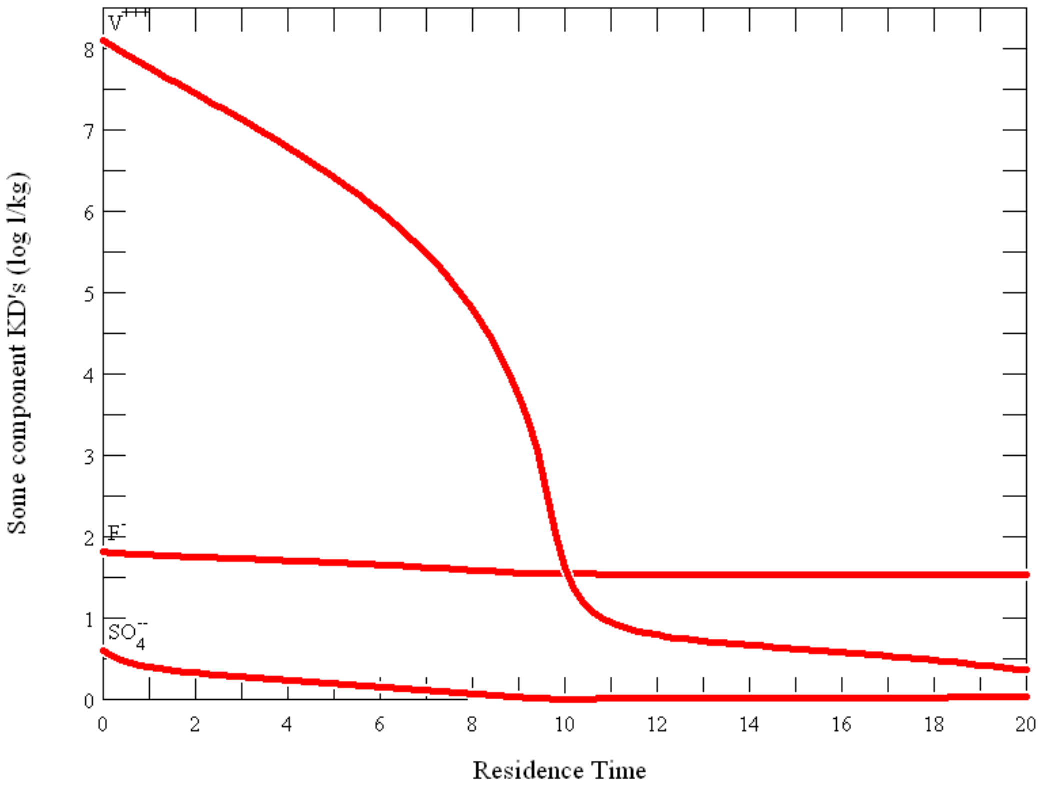


Figure 3.1 (D): Change in KD of some components in the unsaturated zone below the Calcine Dump.

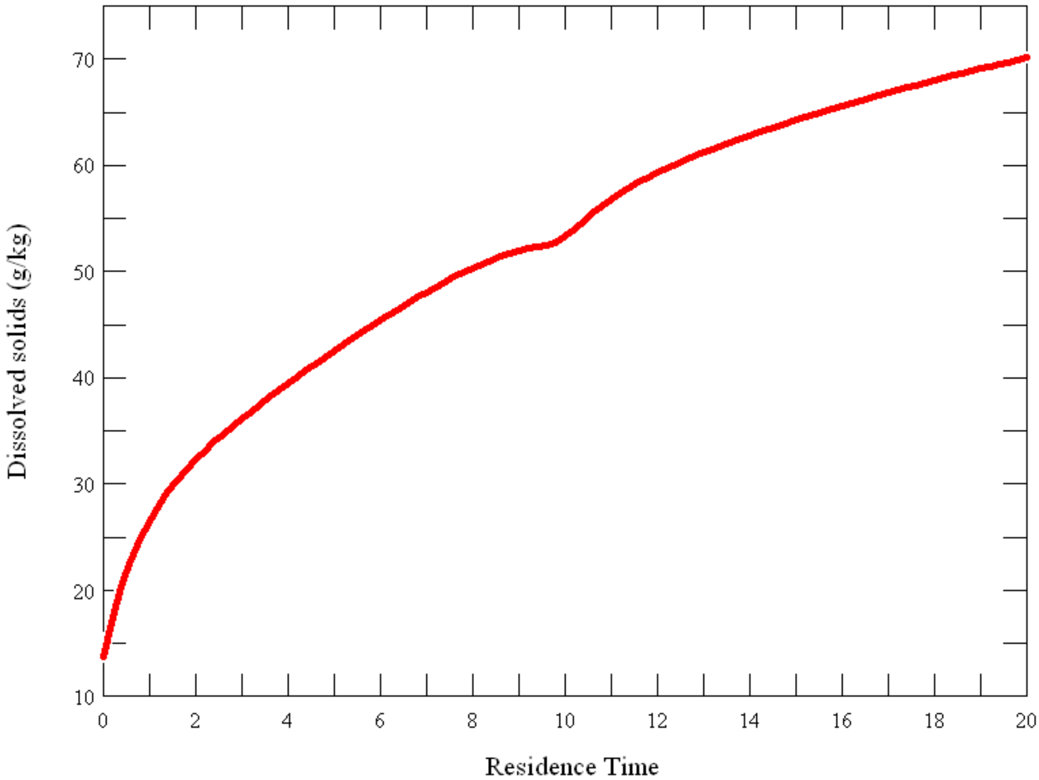


Figure 3.1(E): Change in TDS in the unsaturated zone below the Calcine Dump.

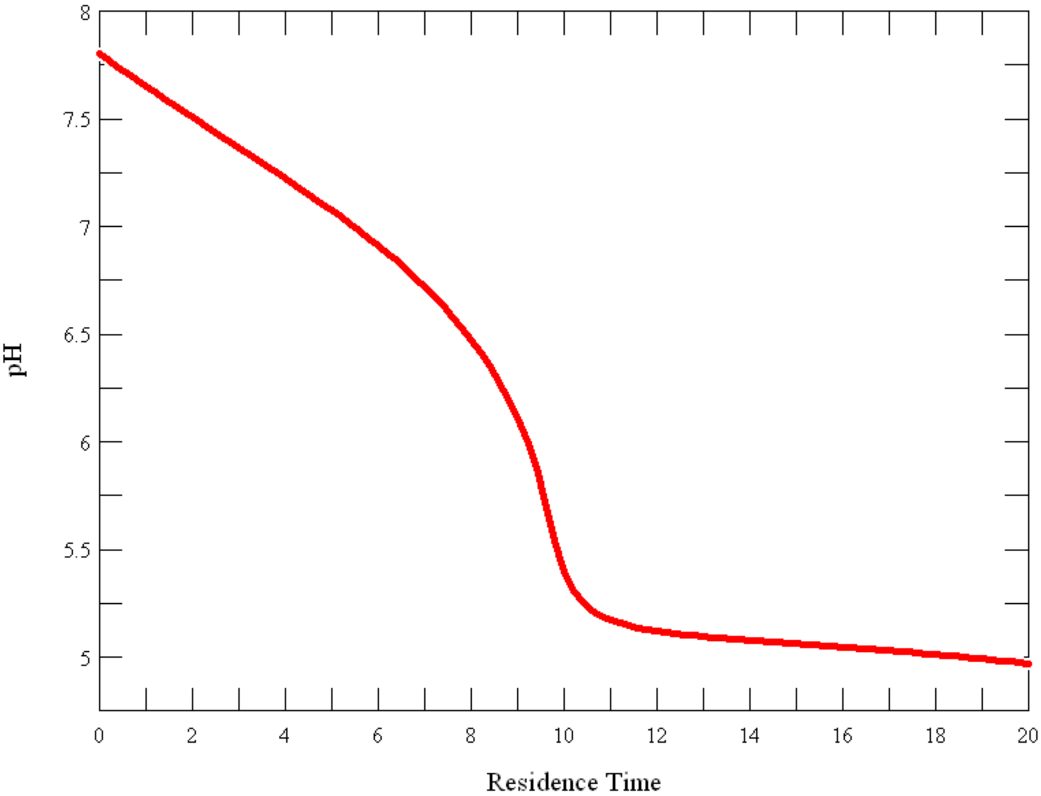


Figure 3.1(F): Change in pH in the unsaturated zone below the Calcine Dump.

Discussion of Model Results

From the results shown in **Figures 3.1(A) to (F)** above, the following observations could be made:

- In **Figure 3.1(A)** it is shown that Na and NO_3 reach their respective maximum values in less than 4 Residence Times. The maximum concentration of these parameters is nearly the same as the concentration in the source. These parameters are not adsorbed in the unsaturated zone.

  SO_4 is moderately adsorbed and reaches its highest concentration, which is equal to that of the source, after about 9 Residence Times.

  Figures 3.1(A) and (B) shows that V is initially strongly adsorbed in the unsaturated zone. V starts to increase in solution after about 6 Residence Times and reaches a concentration of 2500 mg/kg after 13 Residence Times. The F concentration increases steadily over the model time and its maximum lies outside the 20 residence Times modeled.

- From **Figure 3.1(C)** it is evident that SiO_2(aq) and Mg are poorly adsorbed in the unsaturated zone. As the adsorption sites are filled, Mg is removed in favour of Ca. SO_4 is only moderately adsorbed in the unsaturated zone. V is strongly adsorbed in the unsaturated zone because of its high valence state and will only show in solution at values of above 0.1 mg/l (the background) after 6 Residence Times. Between 10 and 20 Residence Times, the fraction V adsorbed will decrease from 96% to 59%. F is adsorbed strongly and over 95% of it is adsorbed throughout the model.

  NO_3 is a very conservative parameter and is not adsorbed in the unsaturated zone. Because Na is mono-valent, it stays in solution and the bivalent ions Mg and especially Ca are rather adsorbed in its place.

- **Figure 3.1(D)** shows the change in Kd of V, F and SO_4 which corresponds to the sorbed fractions of the parameters shown in **Figure 3.1(B)**. V is initially strongly adsorbed, and its Kd decrease until about 10 Residence Times. The Kd of F stays fairly constant over the model time. The Kd of SO_4 is small and decrease further over the model time. The Kd of Na and NO_3 is zero since these parameters are not adsorbed in the unsaturated zone.

- The TDS in the unsaturated zone, shown in **Figure 3.1(E)**, increases throughout the model and don’t reach its maximum within the 20 Residence Times modeled.

- Hydrogen ions are also adsorbed onto the adsorption minerals and the more the contamination replaces the H-ions, the more H-ions are released in solution with the result of a drop in pH over the model time as shown in **Figure 3.1(F)**.

- After comparing **Table 3.1(A)** with the model results, it is evident that the better the type and the grade of the lining system, the longer it will take for any contamination from the overlying Calcine Dump to reach the saturated zone in non-compliant quantities. When using a Hazardous Waste Lining System, it will take thousands of years but when using only a bentonite liner, the unsaturated zone and therefore the saturated zone will be polluted within a much shorter time span.

3.2 SLIMES DAM AND SLIMES RETURN WATER DAM

Introduction

The unsaturated zone below the Slimes Dam has an average thickness of 13 m. The existing Slimes Dam covers an area of about 74 ha while future expansions will extend the dump with a further 366 ha (see **Figure 1.2(A)**).

Chemicals of Concern

In **Table 2.4(A)** an analysis is given of the water from the Slimes Return Water Dam. Since excess water from the Slimes Dam is pumped towards the Slimes Return Water Dam, it is assumed leachate from the Slimes Dam and water in the Slimes Return Water Dam must be of the same quality. An Acid Rain Analyses of the slimes confirmed that leachate from the slimes will not be of a worse quality than that analyzed in the Slimes Return Water Dam.

In the analyses of the water in the Slimes Return Water Dam, **no hydro-chemical parameters that are non-compliant in terms of the SABS 241 Drinking Water Standard or the Acceptable Environmental Risk (from DWAF Minimum Requirements) were found**. All metals were also found below detection limit. Overall it could be stated that the Slimes Dam and also the Slimes Return Water Dam do not create leachate of poor quality.

A geochemical model was however still performed in order to show the changes, if any, brought by the introduction of clean leachate in the underlying aquifer. This geochemical model could be used as reference for all dams that only introduce clean water into the underlying aquifer.

Model Time

The model was run over 20 Residence Times and therefore simulates the change in chemistry that takes place while contaminated leachate from the overlying source replaces the water in the unsaturated zone 20 times.

The volume of leachate and therefore *the actual years* to reach one Residence Time 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 into the unsaturated zone. The higher the volume of leachate created, the quicker the interstitial water in the unsaturated zone will be replaced by contaminated leachate.

The estimated leachate volume and time span of one Residence Time for various lining systems at the Slimes Dam are given in **Table 3.2(A)** below:

Table 3.2(A): Estimated Leachate and Residence Time for various potential liners below the Slimes Dam.

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

Currently, monitoring around the Slimes Dam also indicates that no parameters are non-complaint in the groundwater. No parameters of concern have been observed in the Slimes Return Water Dam. Therefore will the Slimes Dam and the Slimes Return Water Dam not be classified as Hazardous Waste Sites.

The estimated leachate quantity and the resultant Residence Time, as tabulated in **Table 3.2(A)**, could be validated and calibrated as soon as site specific permeability tests are done during the construction of the liners.

The model results are given in terms of 20 Residence Times; for G:L:B$^+$ and Hazardous Waste Lining Systems the respective time spans are estimated at 5000 years and 30000 years, as tabulated in **Table 3.2(A)** above.

<u>Model Results</u>

The quality of the water analyzed in the Slimes Return Water Dam was used as input in the model as given in **Table 2.4(A)**. 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.

The model results are shown in **Figures 3.2(A) to (D)** below:

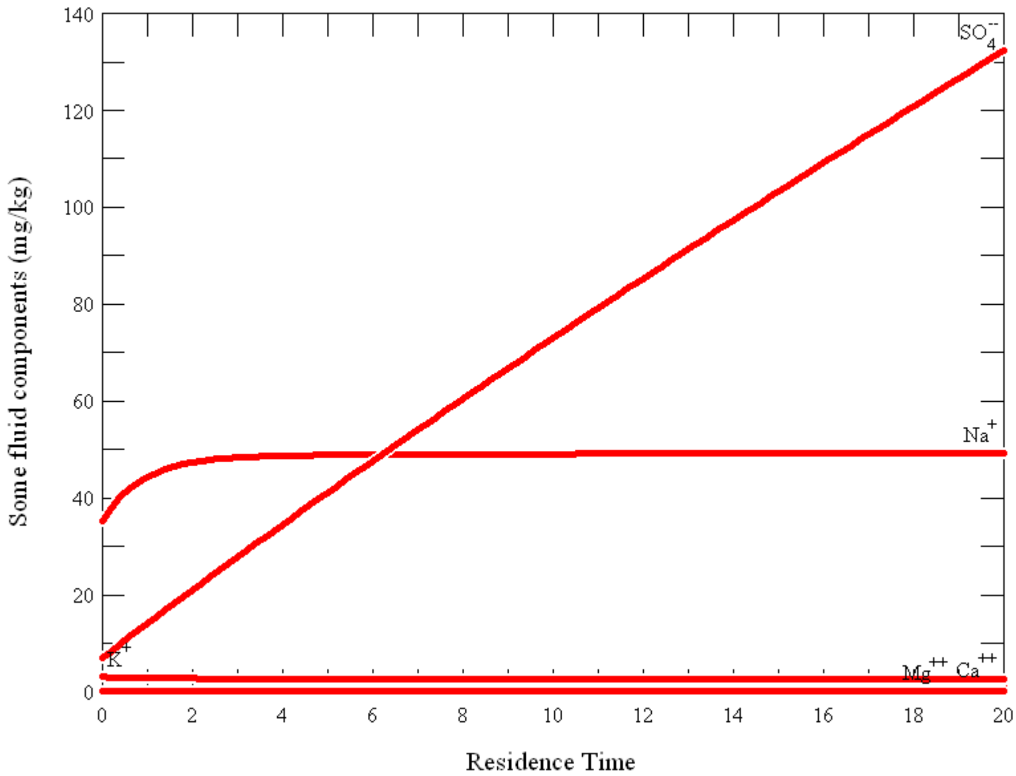


Figure 3.2(A): Fluid components in the unsaturated zone below the Slimes Dam.

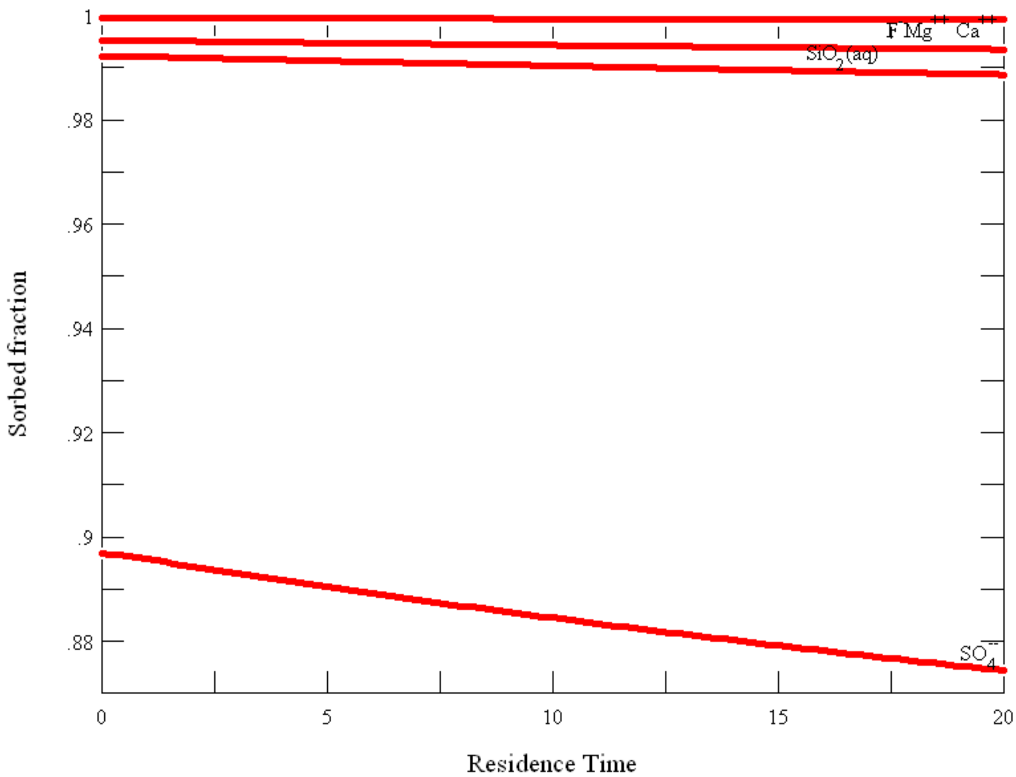


Figure 3.2(B): Fraction of some fluid components adsorbed in the unsaturated zone below the Slimes Dam.

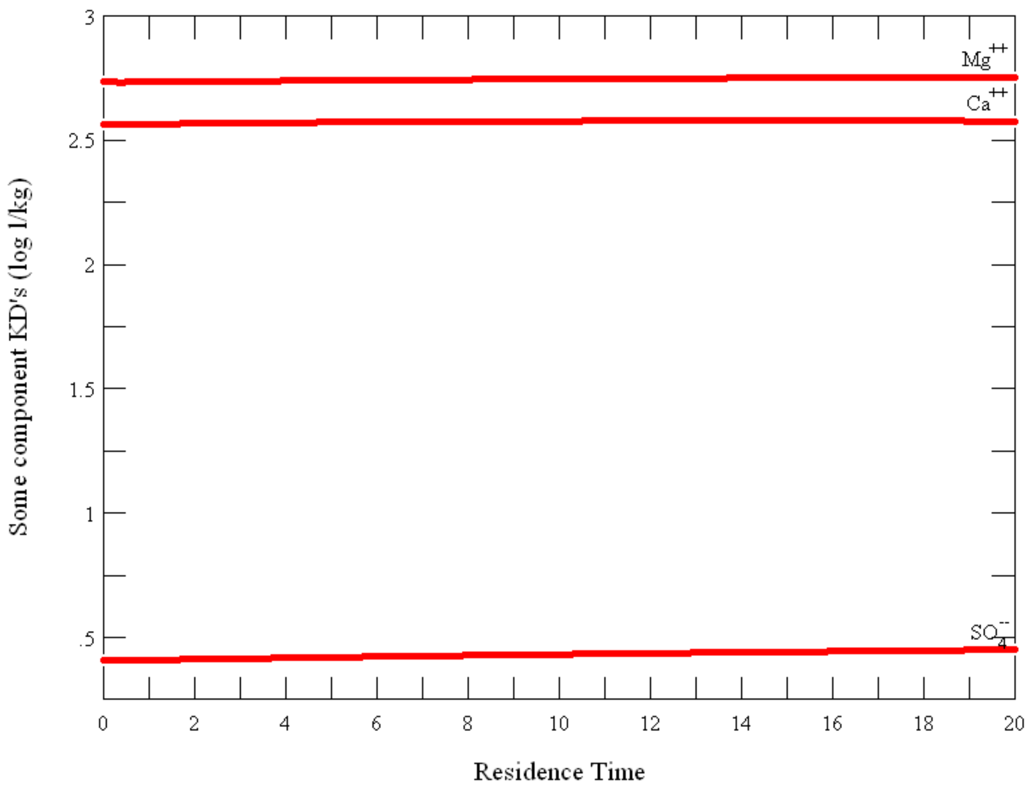


Figure 3.2(C): Change in Kd of some elements in the unsaturated zone below the Slimes Dam.

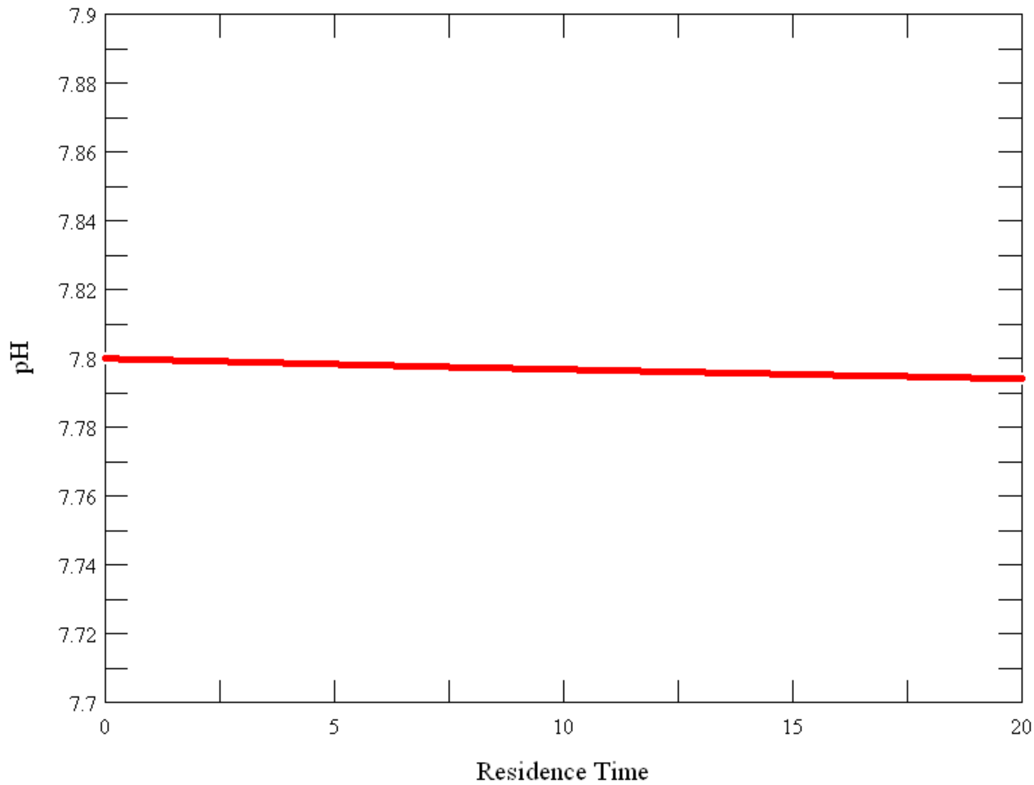


Figure 3.2(D): Change in pH in the unsaturated below the Slimes Dam.

Discussion of Model Results

From the results shown in **Figures 3.2(A) to (D)** above, the following observations could be made:

- In **Figure 3.2(A)** it is shown that SO_4 is the only parameter that shows significant change over the modeled Residence Times. All other parameters stay fairly constant. SO_4 however does not reach non-compliant status in the unsaturated zone and reach a concentration of only 132 mg/kg after 20 Residence Times.

- From **Figure 3.2(B)** it is shown that about 10% of SO_4 is not adsorbed which result in the slight increase of SO_4 in solution observed. Because Na is mono-valent, it stays in solution and the bivalent ions Mg and especially Ca are rather adsorbed.

- **Figure 3.2(C)** shows that Kd stay fairly constant in the case of dilute solutions as with the leachate from the Slimes Dam.

- Because of the dilute leachate from the overlying Slimes Dam, only a small amount of H-ions is replaced from the adsorption sites with a small resultant decrease in pH as shown in **Figure 3.2(D)**.

- After comparing **Table 3.2(A)** with the model results, it is evident that neither the Slimes Dam nor the Slimes Return Water Dam could be classified as Hazardous Waste Sites. It is important that the Slimes Dam must not be used for any hazardous waste in order to keep it classified as a waste site with the minimum impact on the surrounding ground water environment. Currently the only impact of the Slimes Dam and the Slimes Return Water Dam are the addition of (clean) water into the ground water aquifer.

3.3 PLANT AREA

Introduction

The unsaturated zone below the Plant Area has an average thickness of 15 m. The position of the Processing Plant with the various waste ponds and dams is shown in **Figure 1.2(A)**. None of the ponds or dams are larger than 1 ha, however, most contain high concentrations of various contaminants; the ponds and dams, although small, are considered the major contributors of current ground water pollution at Xstrata Rhovan. The Scrubber and Purge Dams contain process water from the plant and the Calcine Return Water (Ericsson) Dam is used to temporarily store heap leach water from the Calcine Dump before it is returned to the plant. Storm Water Dam No. 1 contains clean run-off water, whereas the Storm Water Dams No. 2, 3 and 4 are dirty water Storm Water Dams.

Chemicals of Concern

In **Table 2.4(A)** analyses are given of the water/fluid component of the 1) Scrubber Pond No. 1, 2) the Purge Water Dam No. 1, 3) the Calcine Return Water (Ericsson) Dam and 4) the Storm Water Dam No. 3. Hydro-chemical parameters that are non-compliant in terms of the SABS 241 Drinking Water Standard or the Acceptable Environmental Risk (from DWAF Minimum Requirements) are listed below:

Dam/Effluent Pond	Chemicals of Concern
Scrubber Pond No. 1	NH_4, NO_3, Cl, SO_4, F, Na, K, Ca, Mg, Al, Fe, Mn, V, Zn
Purge Water Dam No. 1	NH_4, NO_3, Cl, SO_4, F, Na, K, Ca, Mg, Al, Mn, V, Zn
Calcine Return Water (Ericsson) Dam	NO_3, SO_4, F, Na, V
Storm Water Dam No. 3	NO_3, SO_4, F, Na, Al, V

The geochemical model will specifically focus on the behavior of the above chemicals in the unsaturated zone.

Model Time

The model was run over 20 Residence Times and therefore simulates the change in chemistry that takes place while contaminated leachate from the overlying source replaces the water in the unsaturated zone 20 times.

The volume of leachate and therefore *the actual years* to reach one Residence Time 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 into the unsaturated zone. The higher the volume of leachate created, the quicker the interstitial water in the unsaturated zone will be replaced by contaminated leachate.

The estimated leachate volume and time span of one Residence Time for various lining systems are given in **Table 3.3(A)** below:

Table 3.3(A): Estimated Leachate for various potential liners below effluent ponds/water dams at the Plant Area.

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

It is recommended that the Scrubber Ponds, the Purge Dams, the Dirty Water Storm Water Dams and Calcine Return Water Dam (Ericsson Dam) are all treated as Hazardous Waste Sites. The Dirty Water Dams would not generally be classified as Hazardous Waste Sites but since some have been used as a overflow for the Calcine Return Water Dam, it must be treated the same as the latter. Storm Water Dam No. 2, -3 and -4 showed various non-compliant parameters.

The estimated leachate quantity and the resultant Residence Time, as tabulated in **Table 3.3(A)**, can be validated and calibrated as soon as site specific permeability tests are done during the construction of the liners.

The model results are given in terms of 20 Residence Times; for $G:L:B^+$ and Hazardous Waste Lining Systems the respective time spans are estimated at 500 years and 16000 years, as tabulated in **Table 3.3(A)** above.

3.3.1 Scrubber Ponds

Model Results

The quality of the fluid component in Scrubber Pond No. 1, as given in **Table 2.4(A)**, was used as input for the model. The ionic strength of the fluid component in the Scrubber Dam is too strong in order for the activity to be accurately modeled by the Debye-Hückel method used by the Geochemist Workbench model. However, although the model results are only semi-quantitive it still shows the general characteristics of the contaminants in the unsaturated zone.

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.

Take note that the NO_3 and NH_4 in the model are expressed respectively in terms of NO_3 and NH_4 and not as N. The conversion factor from NO_3-NO_3 to NO_3-N is 0.23 and from NH_4-NH_4 to NH_4-N is 0.78.

The model results are shown in **Figures 3.3.1(A) to (H)** below:

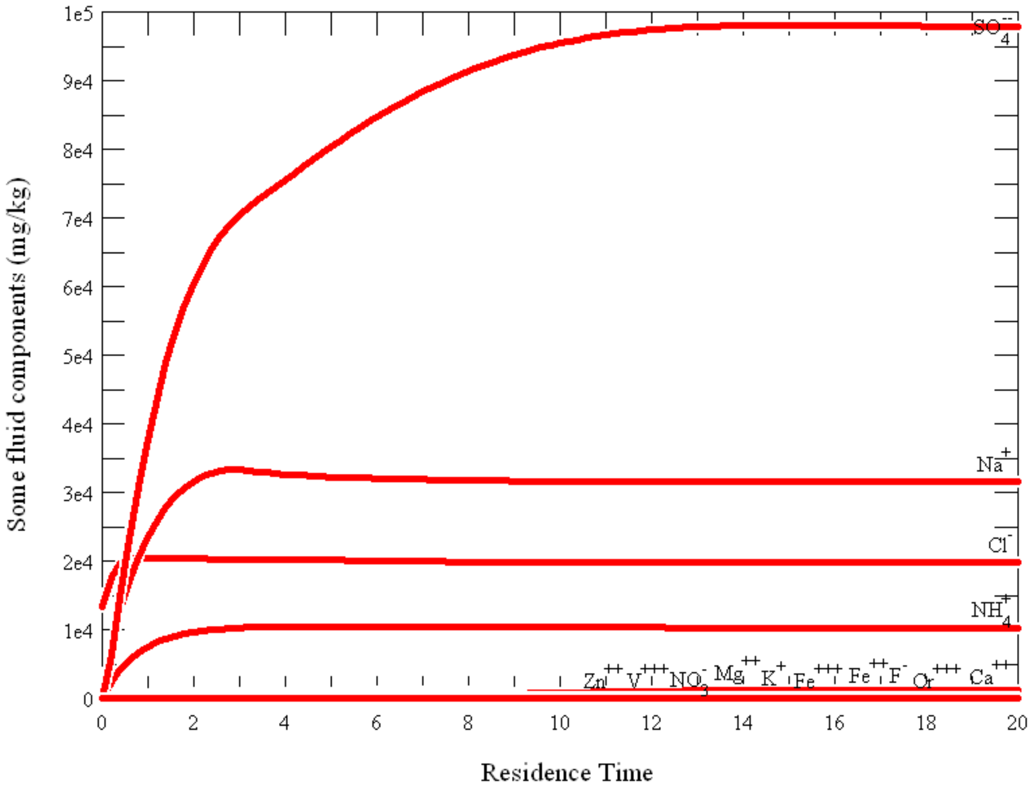


Figure 3.3.1(A): Fluid components in the unsaturated zone below the Scrubber Pond.

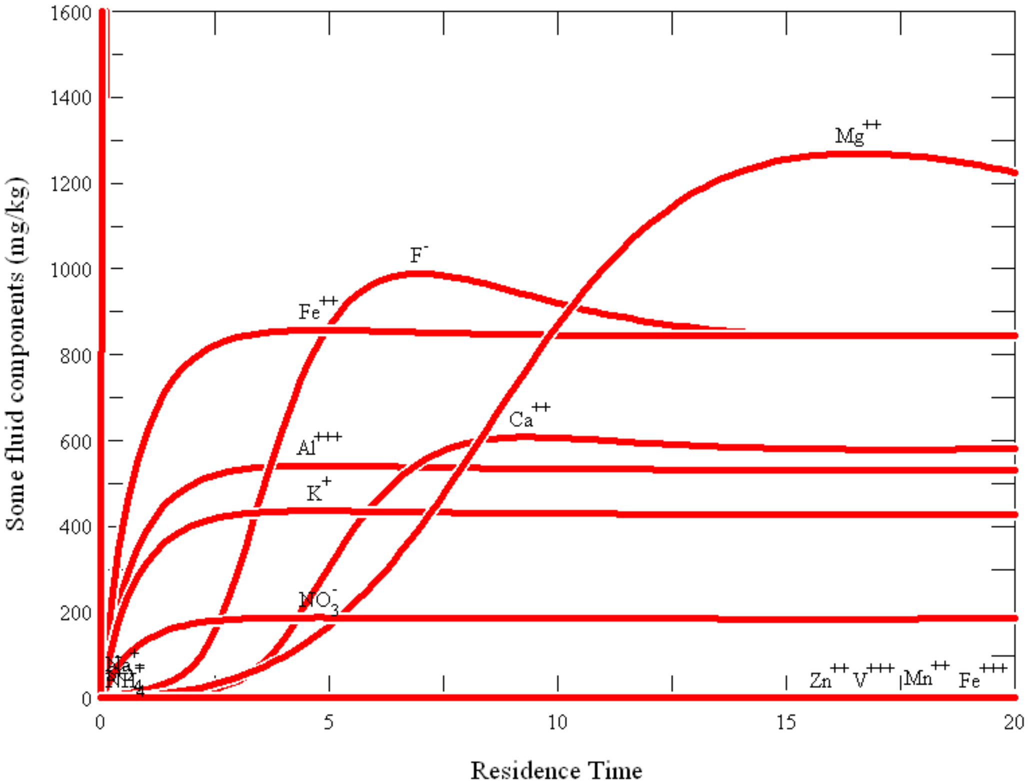


Figure 3.3.1(B): Fluid components in the unsaturated zone below the Scrubber Pond.

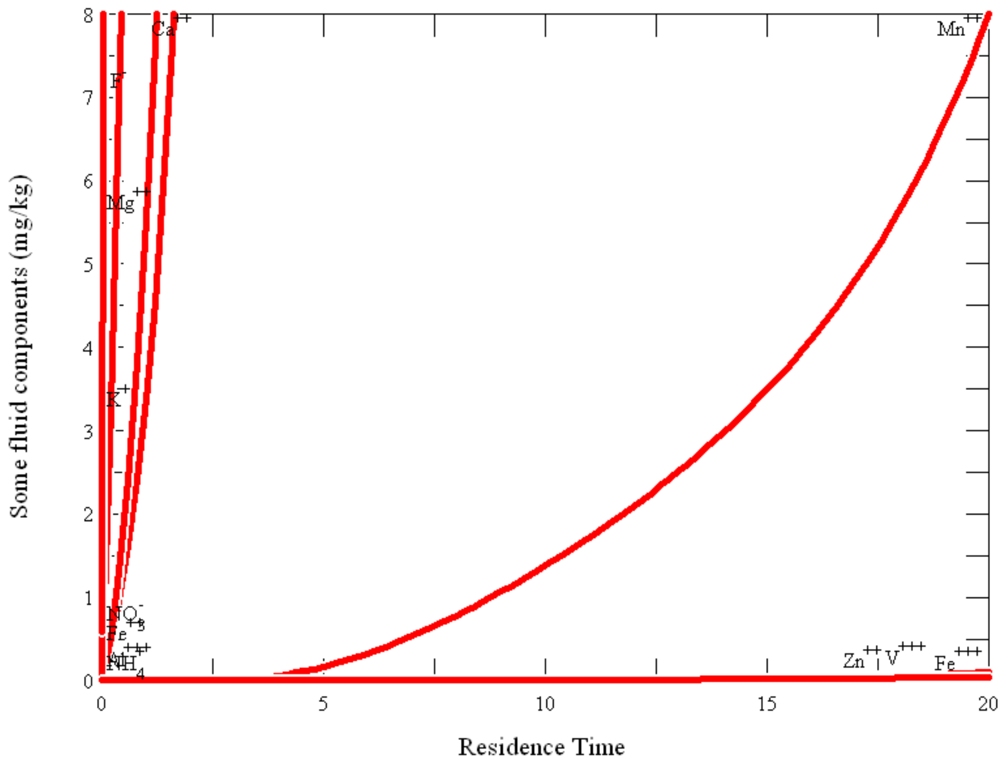


Figure 3.3.1(C): Fluid components in the unsaturated zone below the Scrubber Pond.

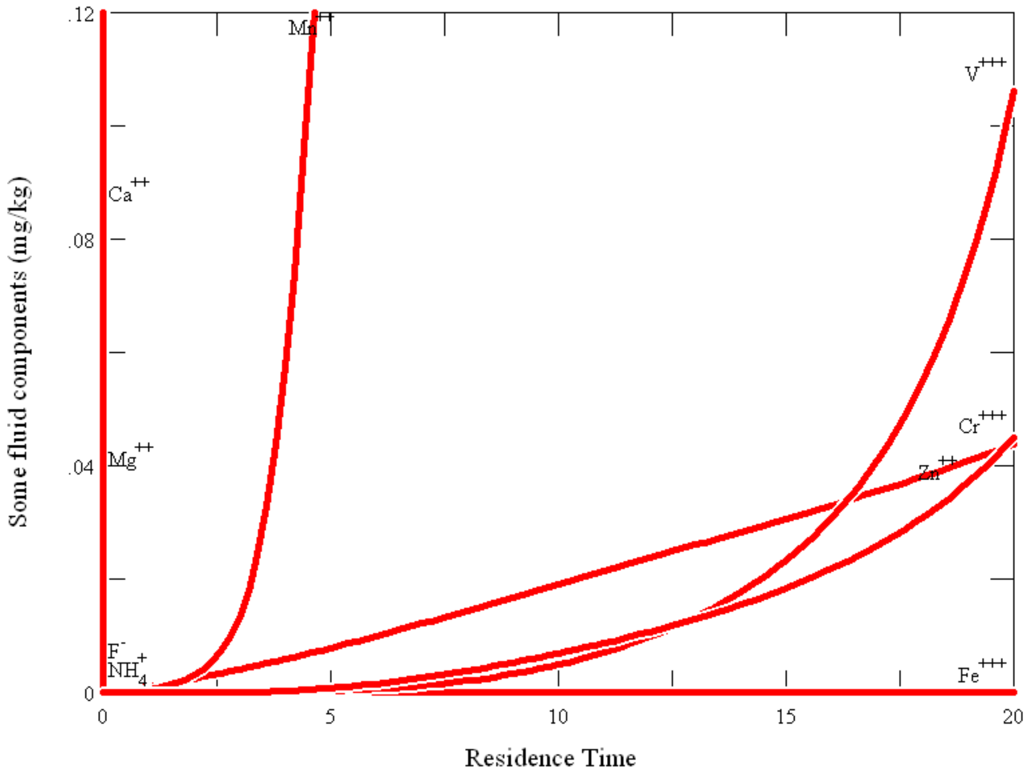


Figure 3.3.1(D): Fluid components in the unsaturated zone below the Scrubber Pond.

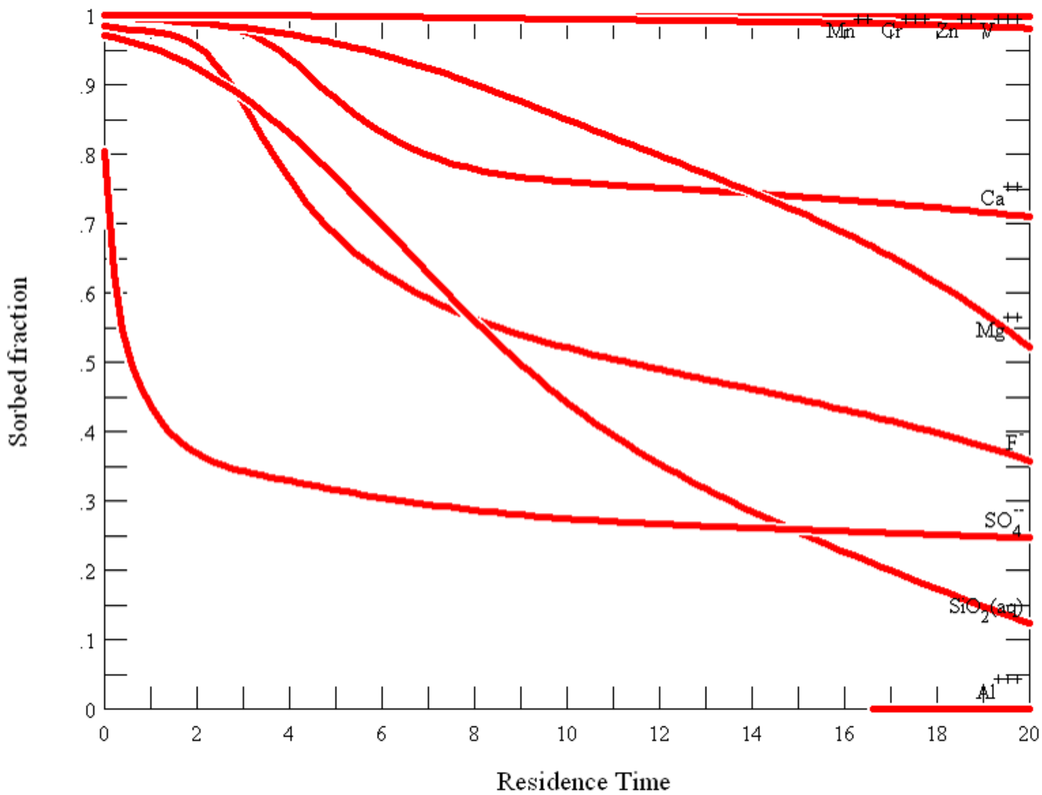


Figure 3.3.1(E): Fraction of fluid components sorbed in the unsaturated zone below the Scrubber Pond (NH_4, NO_3, Cl, Na, K and Fe not sorbed).

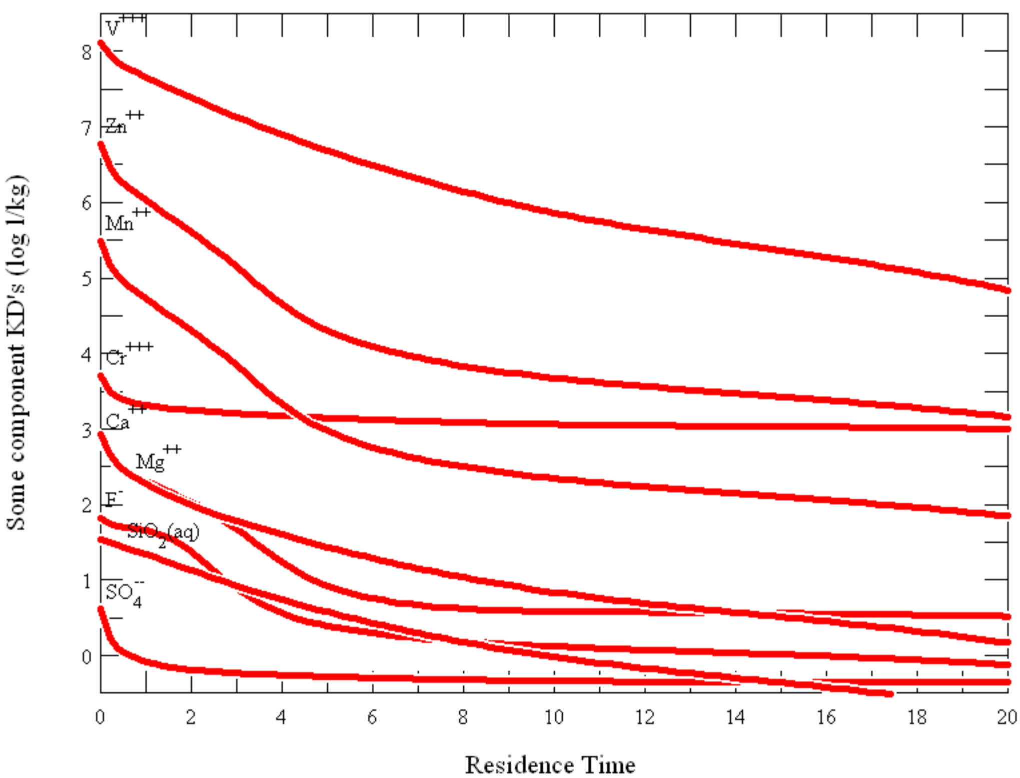


Figure 3.3.1(F): Change in Kd of elements in the unsaturated zone below the Scrubber Pond.

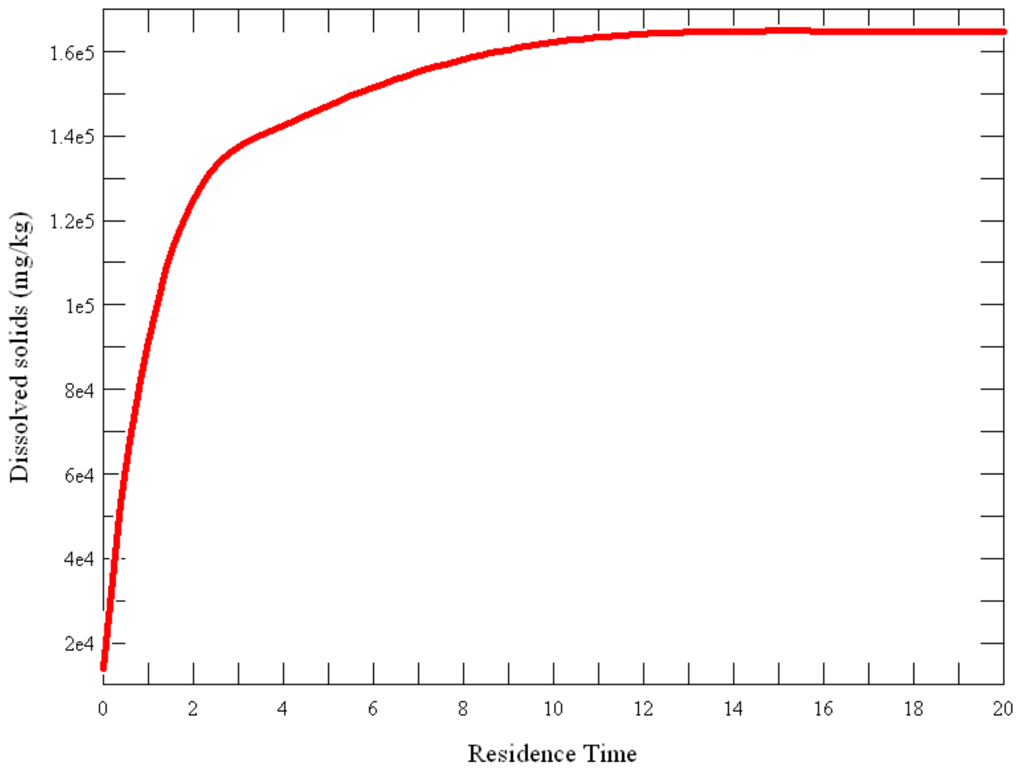


Figure 3.3.1(G): Change in TDS in the unsaturated zone below the Scrubber Pond.

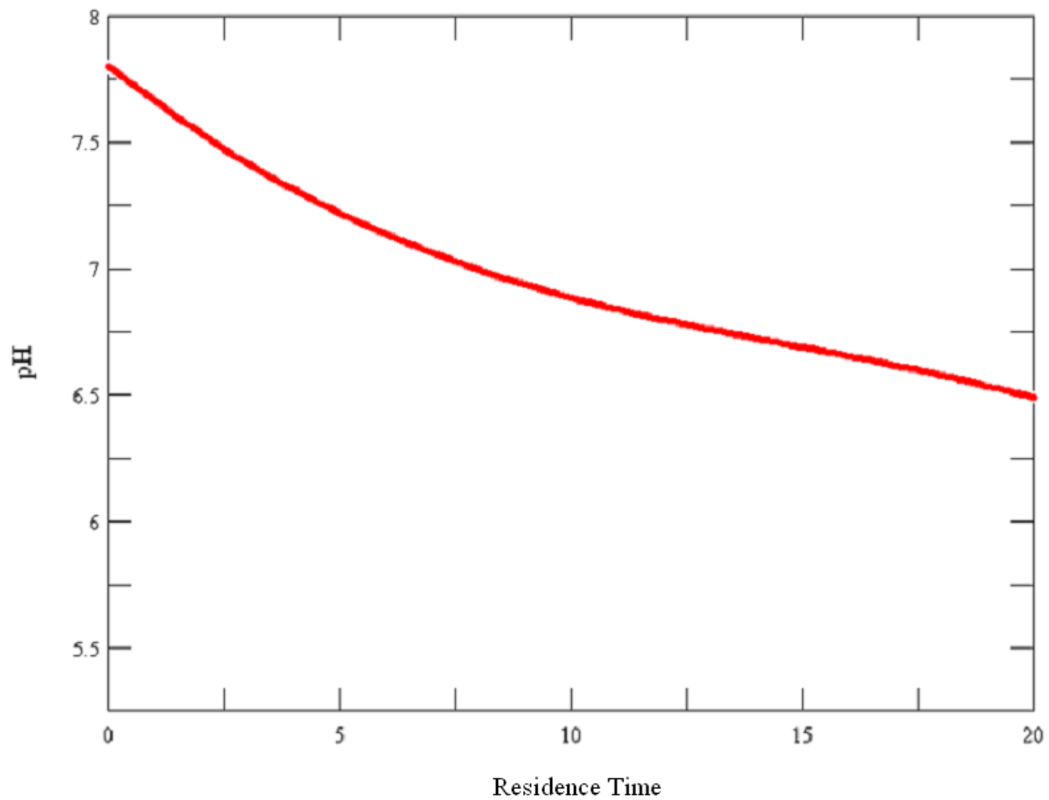


Figure 3.3.1(H): Change in pH in the unsaturated zone below the Scrubber Pond.

Discussion of Model Results

From the results shown in **Figures 3.3.1(A) to (H)** above, the following observations could be made:

- In **Figures 3.3.1(A) to (D)** it is shown that SO_4, Na, Cl, NH_4, NO_3, Fe, Al, K and NO_3 reach their respective maximum values within 6 Residence Times. The maximum concentration of these parameters is nearly the same as the concentration in the source. These parameters are not adsorbed or are only weakly adsorbed in the unsaturated zone.

  F, Ca and Mg are moderately adsorbed and it takes longer for these parameters to reach their respective maximum values.

  V, Zn and Cr are strongly adsorbed in the unsaturated zone and their respective concentrations start to increase significantly in the interstitial water only after about 10 Residence Times. After 20 Residence Times their concentration is still much lower than that of the overlying source. Mn is also strongly adsorbed but shows a significant increase in solution after about 3 Residence Times.

- From **Figure 3.3.1(E)** it is evident that SiO_2(aq) and SO_4 are poorly adsorbed in the unsaturated zone. As the adsorption sites become occupied, Mg is removed in favor of Ca. F is initially 95% adsorbed but after 20 Residence Times only 35% of F species are adsorbed. More than 95% of V, Mn, Cr and Zn are adsorbed in the unsaturated zone throughout the model time.

  Na, Cl, NH_4, NO_3, Fe, Al, K and NO_3 are not adsorbed in the unsaturated zone.

- Initially, the TDS in the unsaturated zone, shown in **Figure 3.3.2(D)**, increases rapidly but its rate slows down after about 10 Residence Times as it becomes nearly the same as the TDS of the source.

- Hydrogen ions are also adsorbed onto the adsorption minerals and the more the contamination replaces the H-ions, the more H-ions are released in solution with the result of a drop in pH over the model time as shown in **Figure 3.3.2(E)**.

- After comparing **Table 3.3(A)** with the model results, it is evident that the better the type and the quality of the lining system, the longer it will take for any contamination from the overlying Scrubber Pond to reach the saturated zone in non-compliant quantities.

3.3.2 Purge Dams

Model Results

The quality of the fluid component in Purge Dam No. 1, as given **Table 2.4(A)**, was used as input in the model. The ionic strength of the leachate of the Purge Dams is too strong in order for the activity to be accurately modeled by the Debye-Hückel method used by the Geochemist Workbench model. However, although the model results are only semi-quantitive it still shows the characteristics of the contaminants in the unsaturated zone.

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.

Take note that the NO_3 and NH_4 in the model are expressed respectively in terms of NO_3 and NH_4 and not as N. The conversion factor from NO_3-NO_3 to NO_3-N is 0.23 and from NH_4-NH_4 to NH_4-N is 0.78.

The model results are shown in **Figures 3.3.2(A) to (H)** below:

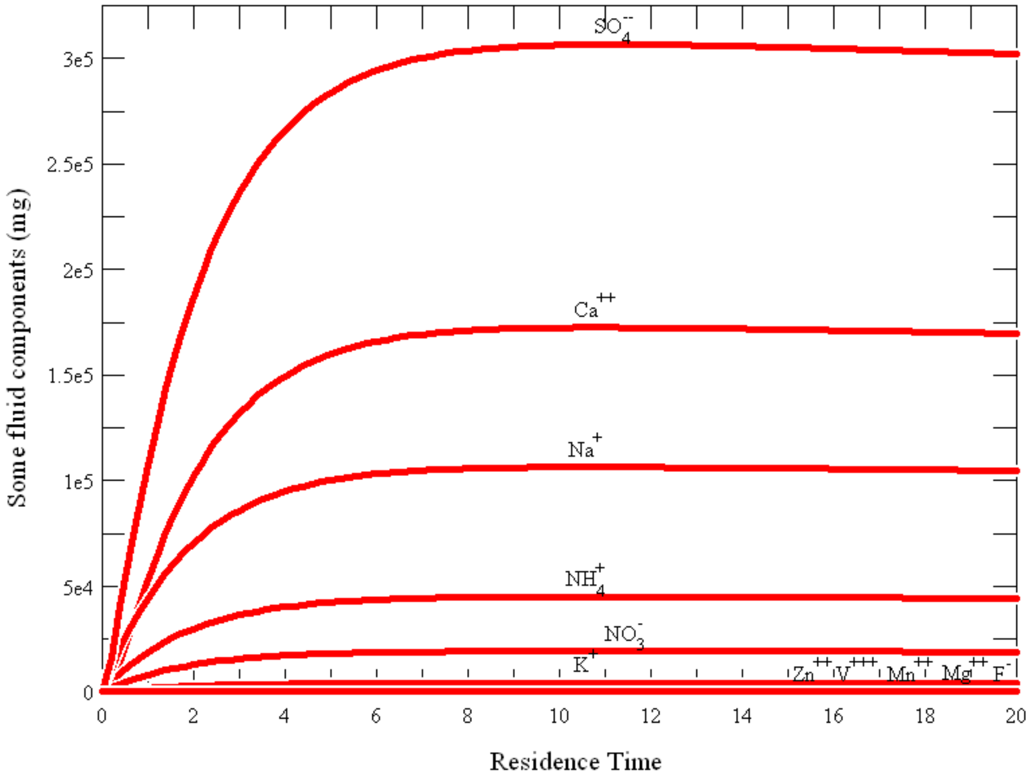


Figure 3.3.2(A): Fluid components in the unsaturated zone below the Purge Dam.

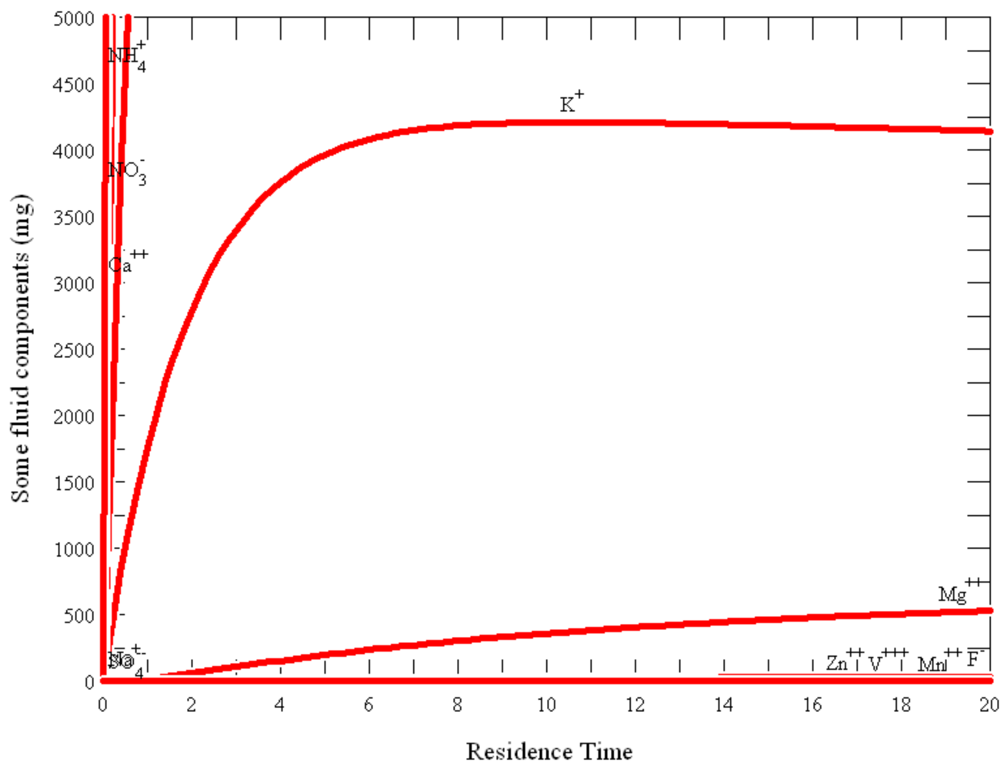


Figure 3.3.2(B): Fluid components in the unsaturated zone below the Purge Dam.

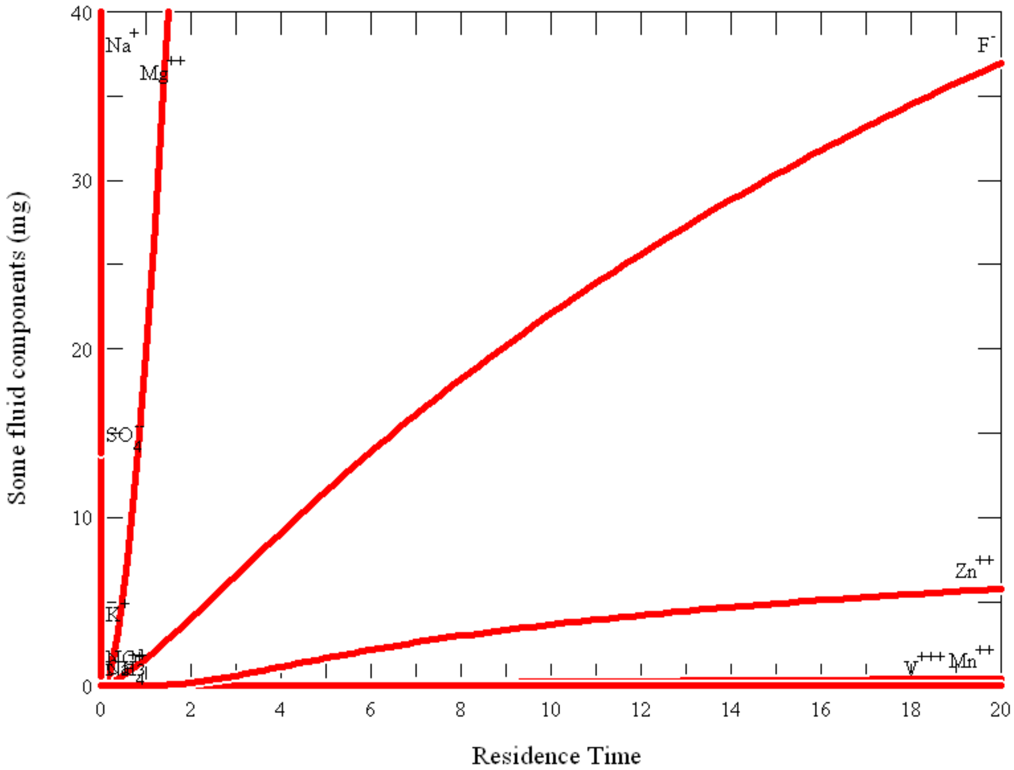


Figure 3.3.2(C): Fluid components in the unsaturated zone below the Purge Dam.

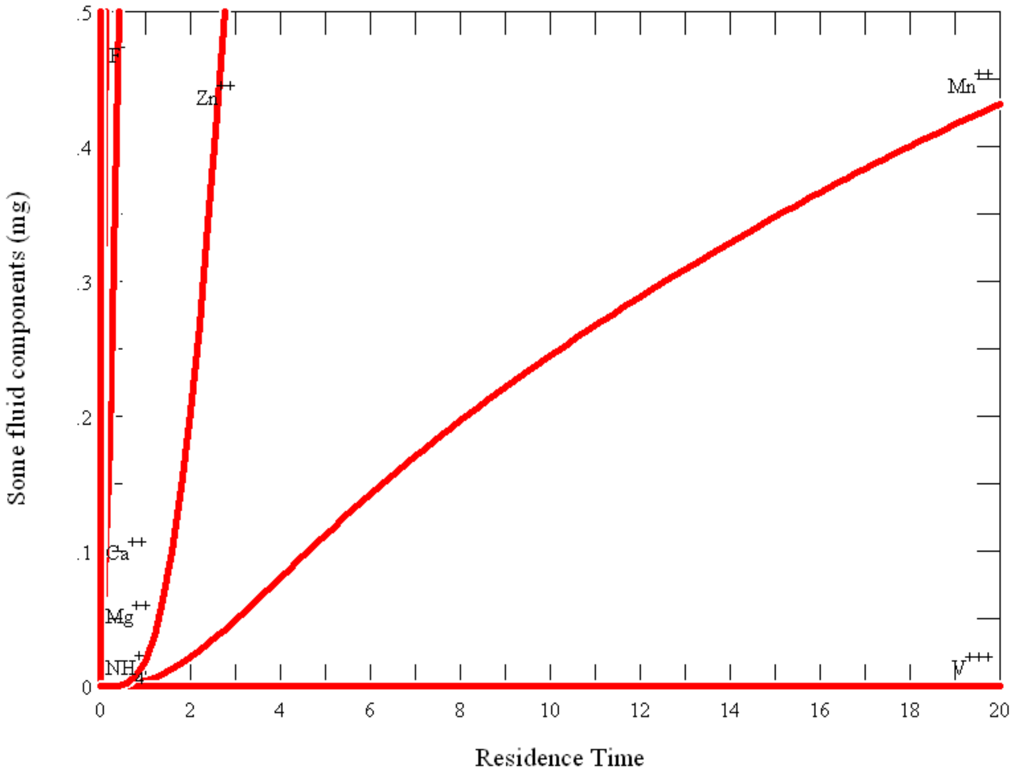


Figure 3.3.2(D): Fluid components in the unsaturated zone below the Purge Dam.

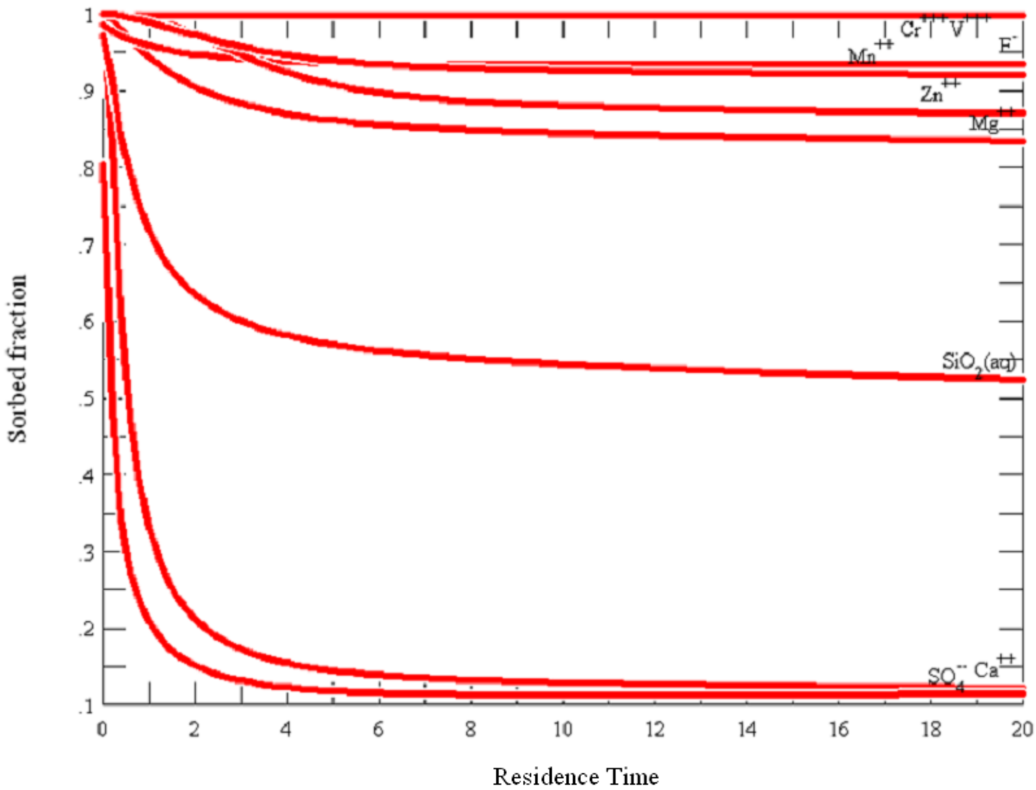


Figure 3.3.2(E): Fluid components sorbed in the unsaturated zone below the Purge Dam.

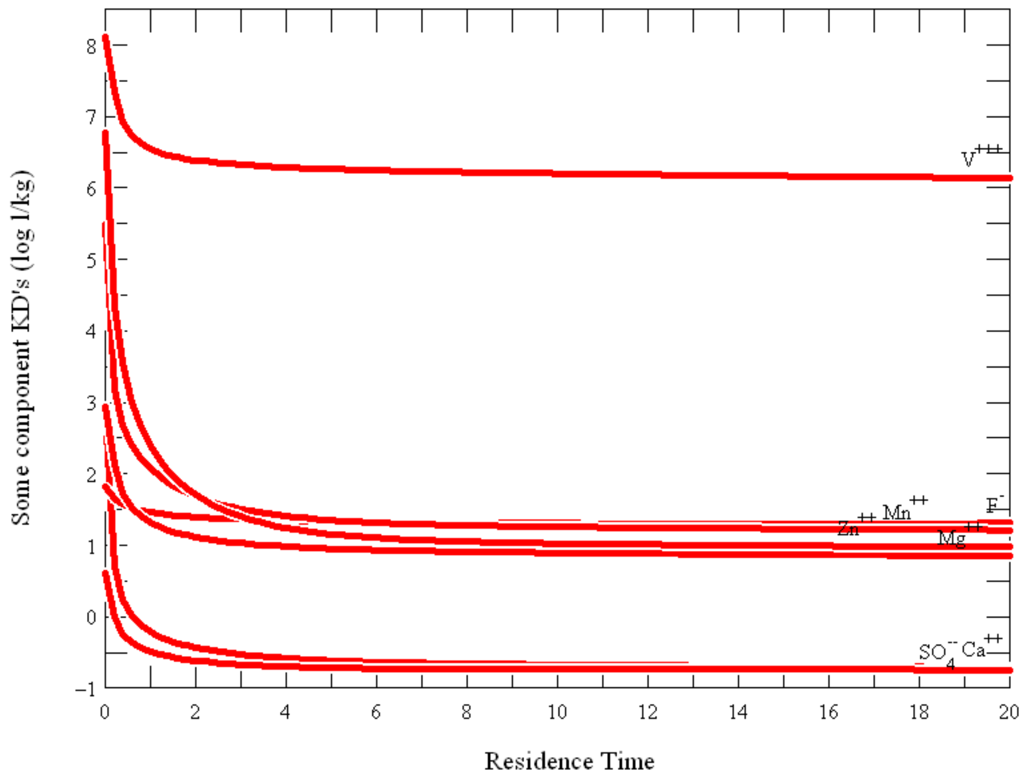


Figure 3.3.2(F): Change in Kd of some compounds in the unsaturated zone below the Purge Dam.

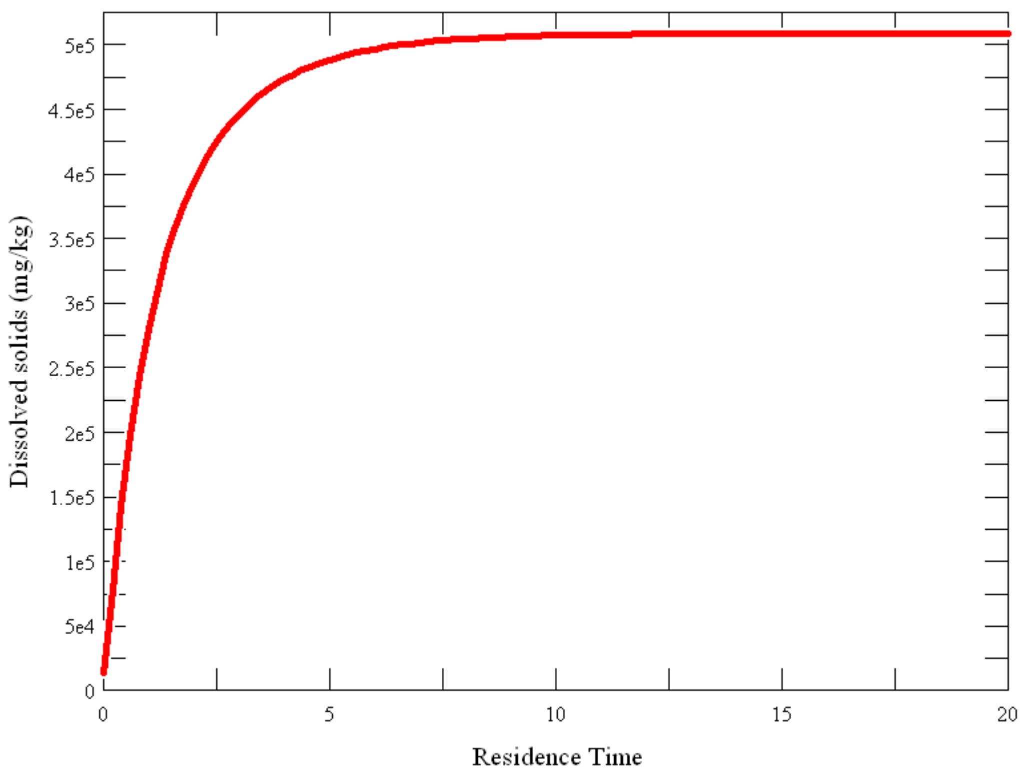


Figure 3.3.2(G): Change in TDS in the unsaturated zone below the Purge Dam.

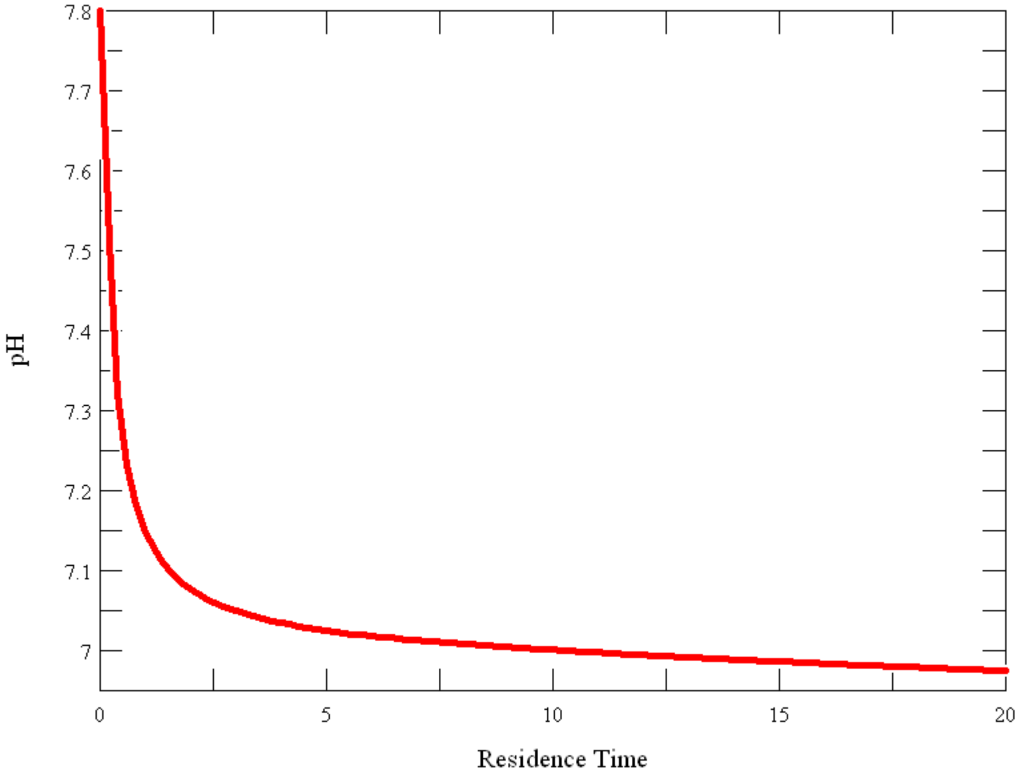


Figure 3.3.2(H): Change in pH in the unsaturated zone below the Purge Dam.

Discussion of Model Results

From the results shown in **Figures 3.3.2(A) to (H)** above, the following observations could be made:

- In **Figures 3.3.2(A) to (D)** it is shown that SO_4, Na, Ca, NH_4, NO_3, K and NO_3 reach their respective maximum values in less than 8 modeled Residence Times. The maximum concentration of these parameters is nearly the same as the concentration in the source. These parameters are not adsorbed or are only weakly adsorbed in the unsaturated zone.

  F and Mg are moderately adsorbed and it takes longer for these parameters to reach their respective maximum values. V, Zn and Mn are strongly adsorbed in the unsaturated zone and reach their respective maximum concentrations only after 20 Residence Times.

- From **Figure 3.3.2(E)** it is evident that SO_4, Ca and SiO_2(aq) are poorly adsorbed in the unsaturated zone. Mg is adsorbed in favor of Ca as the latter have an extremely high concentration in the leachate from the source. More than 85% of V, Mn, F and Zn are adsorbed in the unsaturated zone throughout the model time.

  Na, NH_4, NO_3, Fe, Al and K are not adsorbed in the unsaturated zone.

- Initially, the TDS in the unsaturated zone, shown in **Figure 3.3.2(D)**, increases rapidly but its rate slow down after about 10 Residence Times as it becomes nearly the same as the TDS of the source.

- Hydrogen ions are initially adsorbed onto the adsorption minerals and the more the contamination replaces the H-ions, the more H-ions are released in solution with the result of a drop in pH over the model time as shown in **Figure 3.3.2(E)**.

- After comparing **Table 3.3(A)** with the model results, it is evident that the better the type and the quality of the lining system, the longer it will take for any contamination from the Purge Dams to reach the saturated zone in non-compliant quantities.

3.3.3 <u>Calcine Return Water (Ericsson) Dam</u>

<u>Model Results</u>

The quality of the water in the Ericsson Dam, as given **Table 2.4(A)**, was used as input in the model. 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. Take note that the NO_3 and NH_4 in the model are expressed respectively in terms of NO_3 and NH_4 and not as N. The conversion factor from NO_3-NO_3 to NO_3-N is 0.23 and from NH_4-NH_4 to NH_4-N is 0.78.

The model results are shown in **Figures 3.3.3(A) to (F)** below:

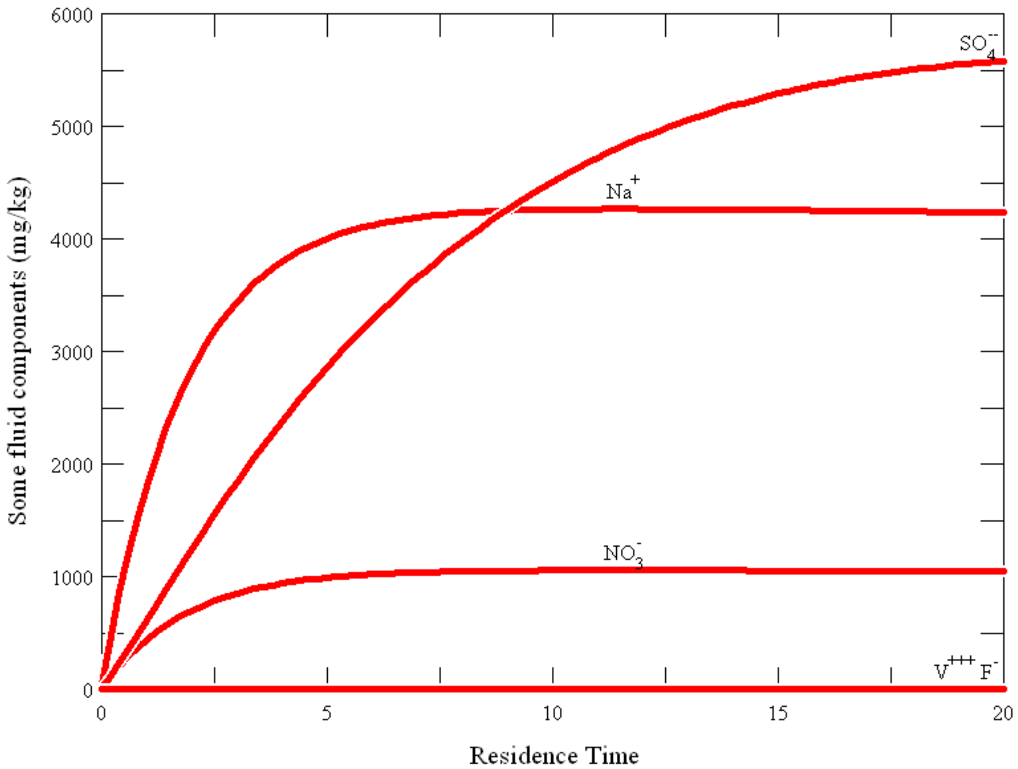


Figure 3.3.3(A): Fluid components in the unsaturated zone below the Ericsson Dam.

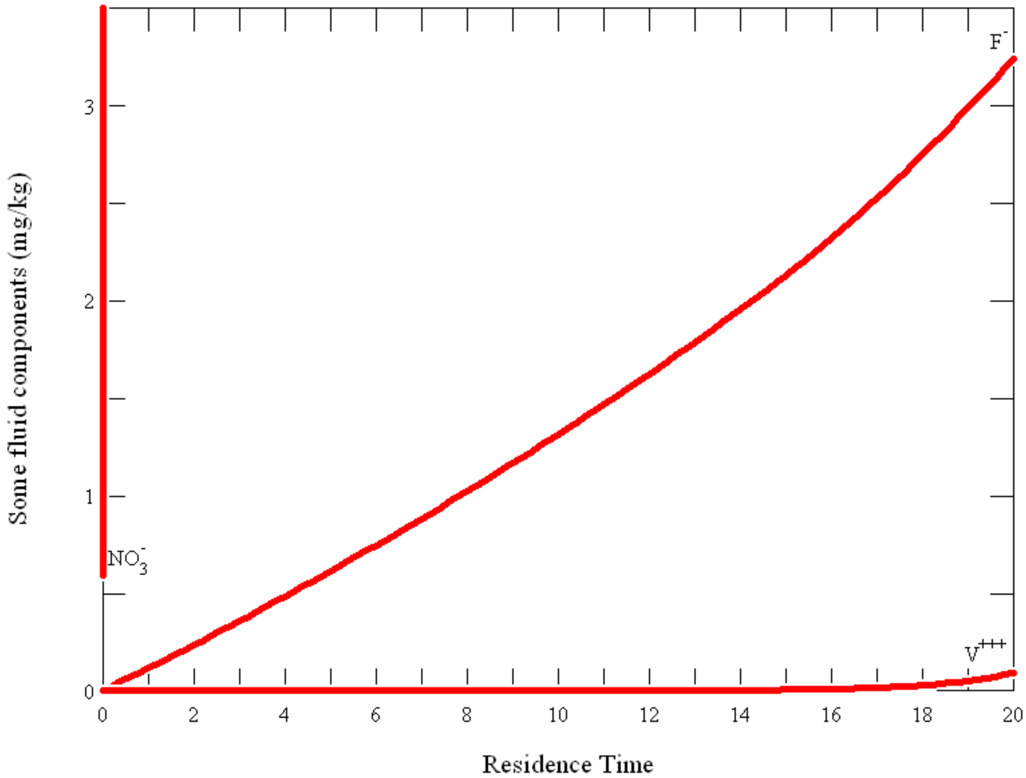


Figure 3.3.3(B): Fluid components in the unsaturated zone below the Ericsson Dam.

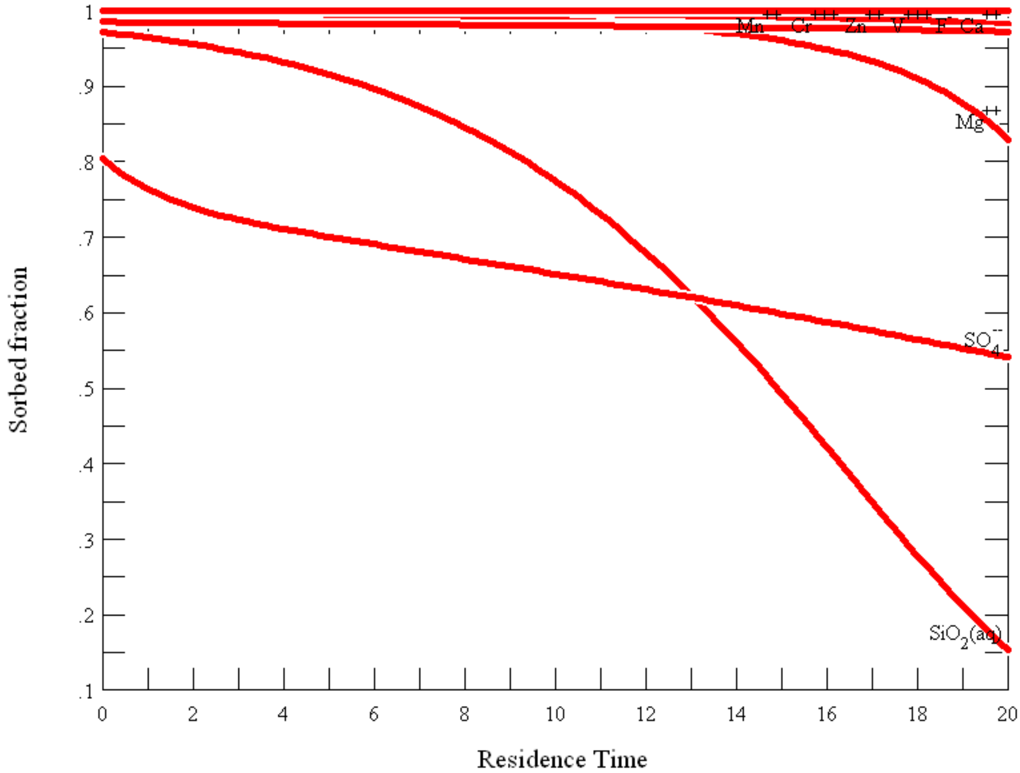


Figure 3.3.3(C): Fluid components sorbed in the unsaturated zone below the Ericsson Dam.

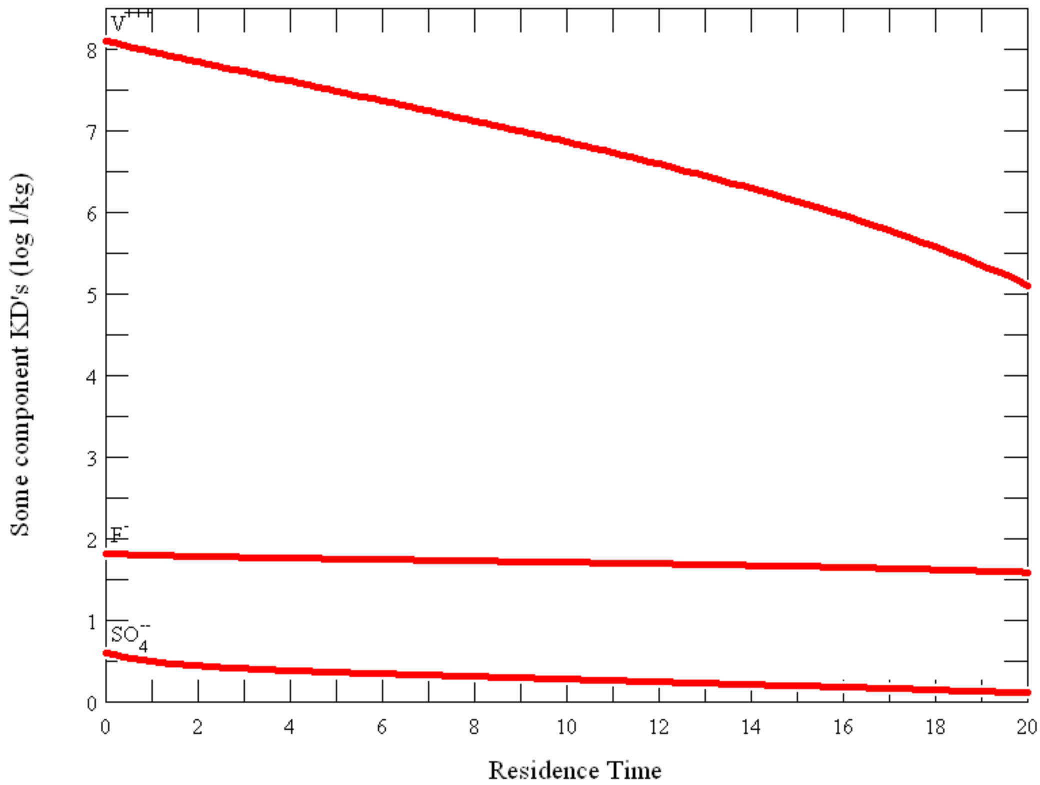


Figure 3.3.3(D): Change in Kd of elements in the unsaturated zone below the Ericsson Dam.

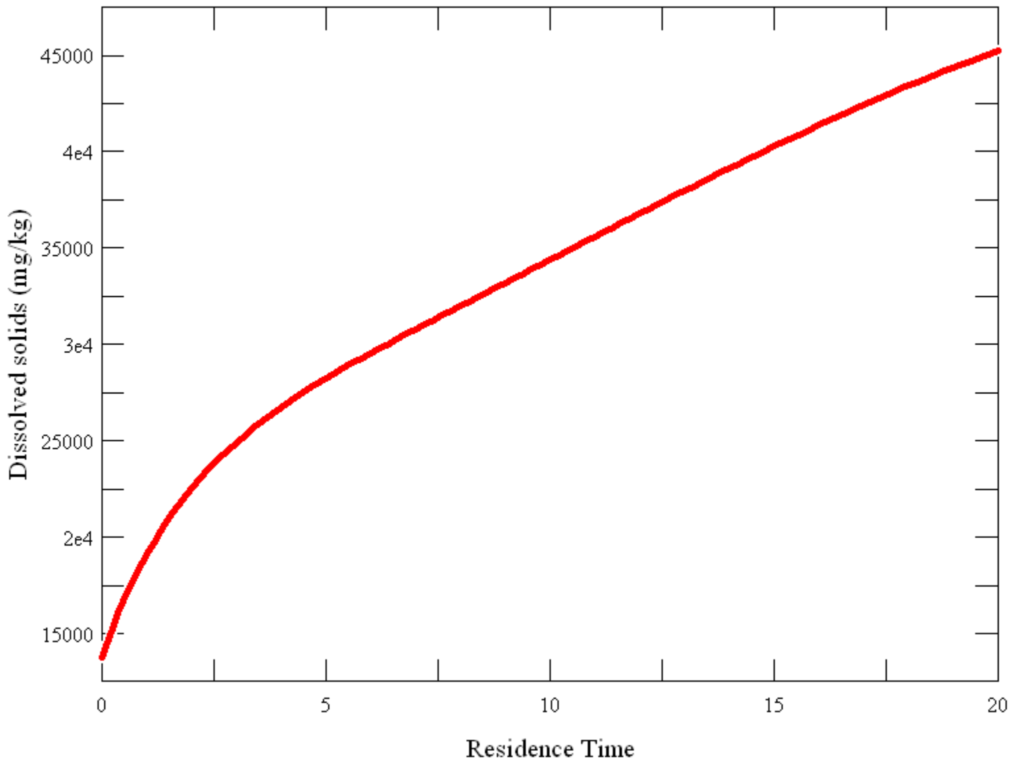


Figure 3.3.3(E): Change in TDS in the unsaturated zone below the Ericsson Dam.

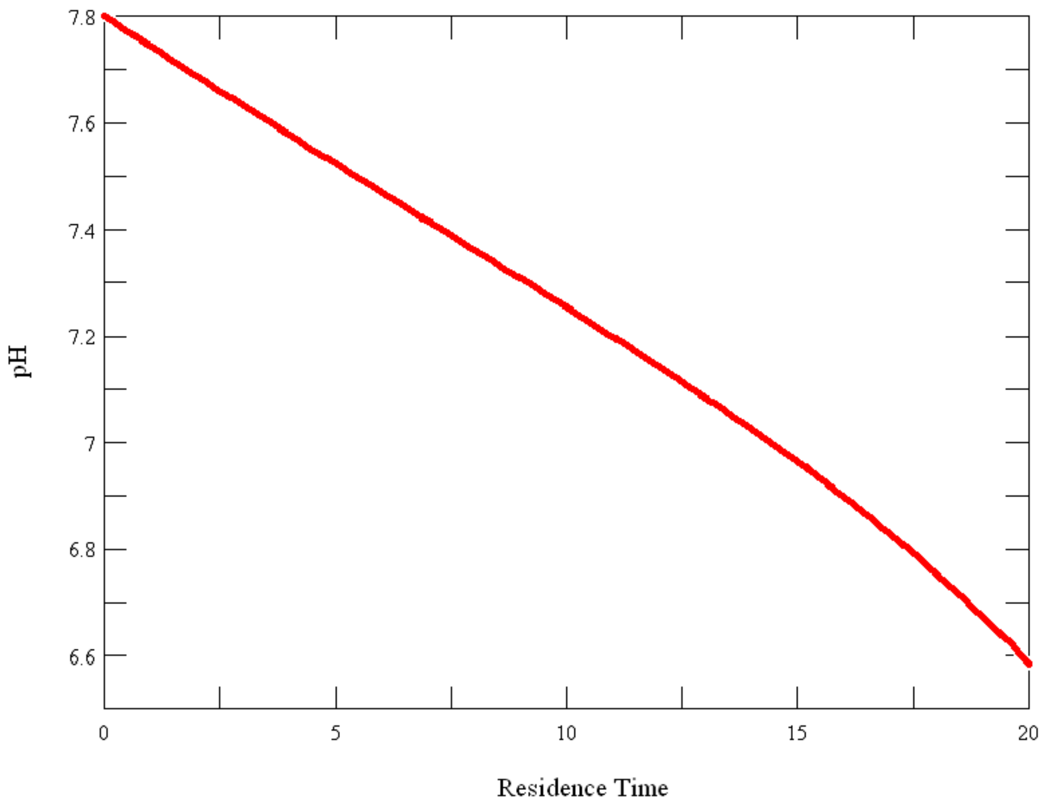


Figure 3.3.3(F): Change in pH in the unsaturated zone below the Ericsson Dam.

<u>Discussion of Model Results</u>

From the results shown in **Figures 3.3.3(A) to (F)** above, the following observations could be made:

- In **Figures 3.3.2(A) and (B)** it is shown that Na and NO_3 reach their respective maximum values in less than 8 modeled Residence Times. The maximum concentration of these parameters is nearly the same as the concentration in the source. These parameters are not adsorbed in the unsaturated zone.

  SO_4 is moderately and V, Zn and Mn are strongly adsorbed in the unsaturated zone. These parameters do not reach their respective maximum concentrations during 20 Residence Times.

- From **Figure 3.3.3(C)** it is evident that SiO_2(aq) is poorly adsorbed in the unsaturated zone. SO_4 and Mg are moderately adsorbed but more than 90% of V, Zn, F, Ca and Mn are adsorbed in the unsaturated zone.

  NO_3 is a very conservative parameter and are not adsorbed in the unsaturated zone. Because Na is mono-valent, it stays in solution and the bivalent ions Mg and especially Ca are rather adsorbed.

- **Figure 3.3.3(D)** shows the change in Kd of V, F and SO_4 which corresponds to the sorbed fractions of the parameters shown in **Figure 3.3.3(B)**. V is strongly adsorbed throughout the model. The Kd of F stays fairly constant over the model time. The Kd of SO_4 is small and decrease further over the model time. The Kd of Na and NO_3 is zero since it is not adsorbed in the unsaturated zone.

- The TDS in the unsaturated zone, shown in **Figure 3.3.3(E)**, increases throughout the model and don't reach its maximum during the modeled 20 Residence Times.

- Hydrogen ions are also adsorbed onto the adsorption minerals and the more the contamination replaces the H-ions, the more H-ions are released in solution with the result of a drop in pH over the model time as shown in **Figure 3.3.3(F)**.

- After comparing **Table 3.3(A)** with the model results, it is evident that the better the type and the quality of the lining system, the longer it will take for any contamination from the waste dumps/lagoons to reach the saturated zone in non-complaint quantities.

3.3.4 Storm Water Dams

Model Results

The quality of the water in Storm Water Dam No. 3, as given **Table 2.4(A)**, was used as input in the model. 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.

Take note that the NO_3 and NH_4 in the model are expressed respectively in terms of NO_3 and NH_4 and not as N. The conversion factor from NO_3-NO_3 to NO_3-N is 0.23 and from NH_4-NH_4 to NH_4-N is 0.78.

The model results are shown in **Figures 3.3.4(A) to (F)** below:

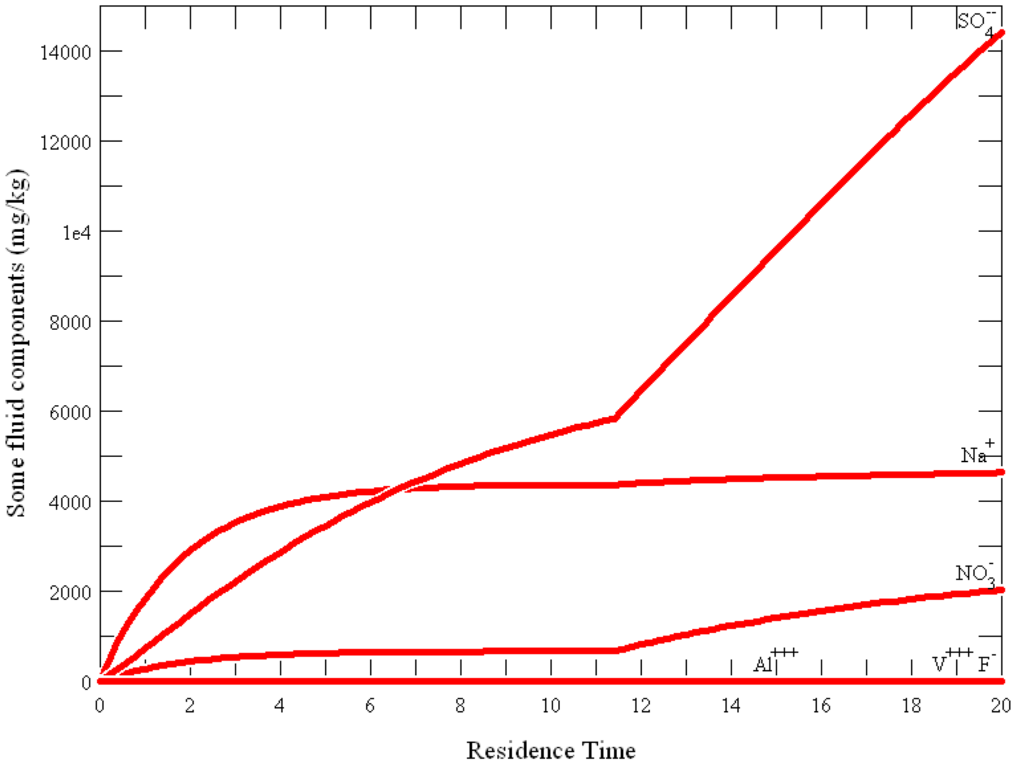


Figure 3.3.4(A): Fluid components in the unsaturated zone below the Storm Water Dam.

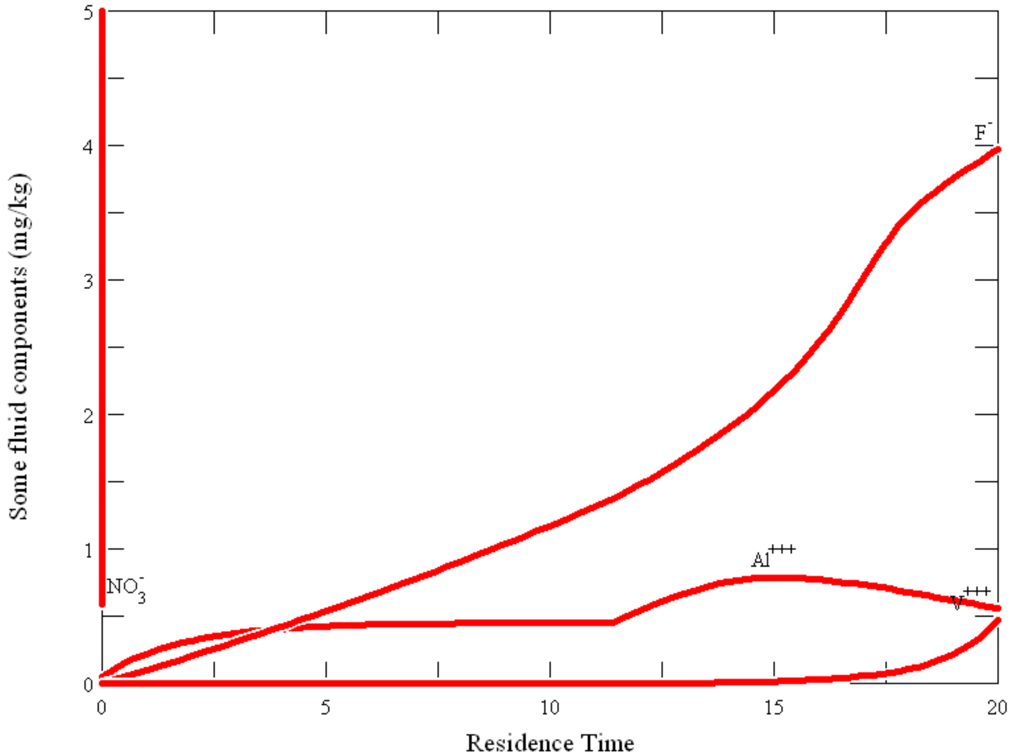


Figure 3.3.4(B): Fluid components in the unsaturated zone below the Storm Water Dam.

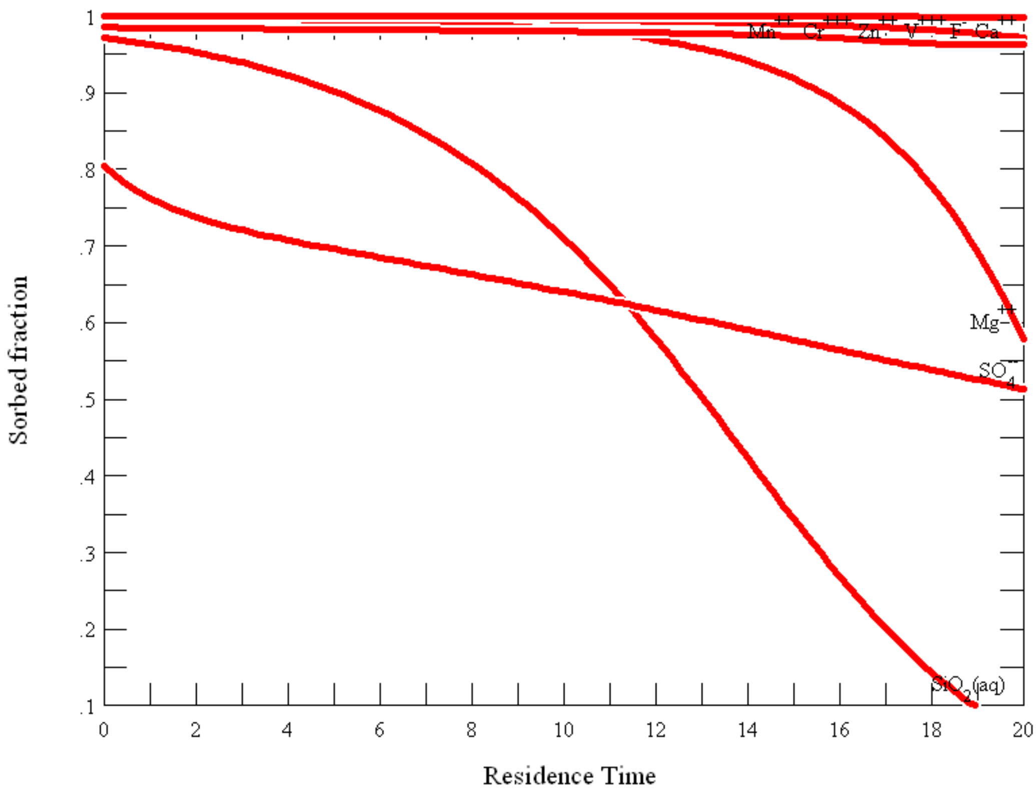


Figure 3.3.4(C): Fluid components sorbed in the unsaturated zone below the Storm Water Dam.

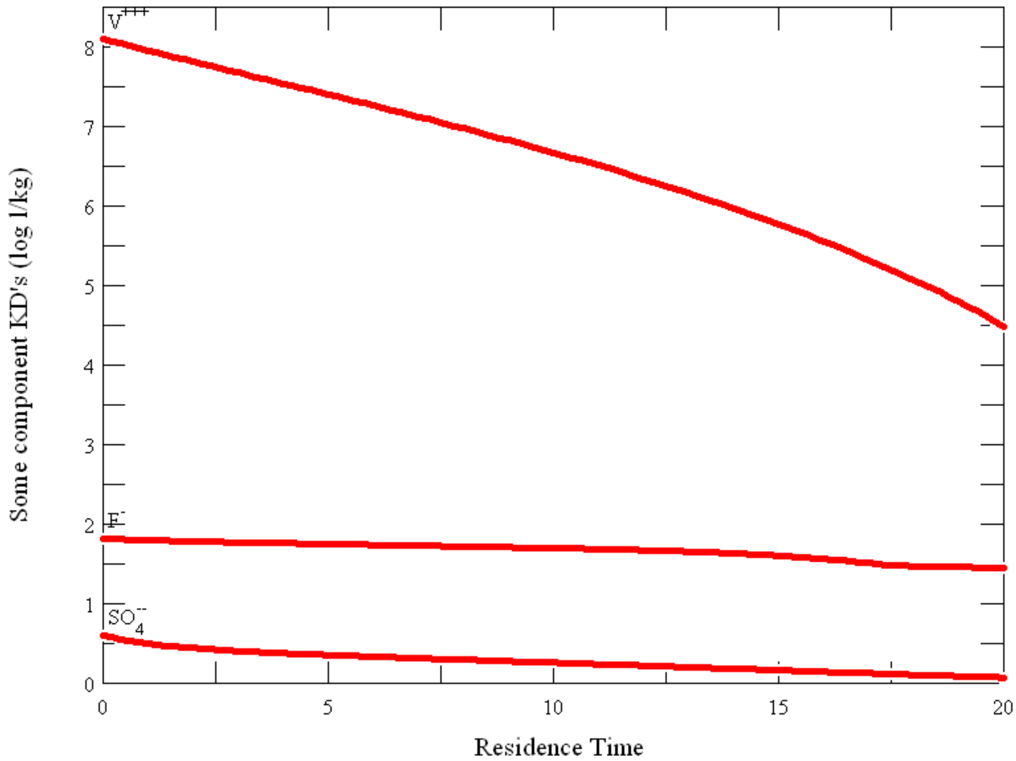


Figure 3.3.4(D): Change in Kd of elements in the unsaturated zone below the Storm Water Dam.

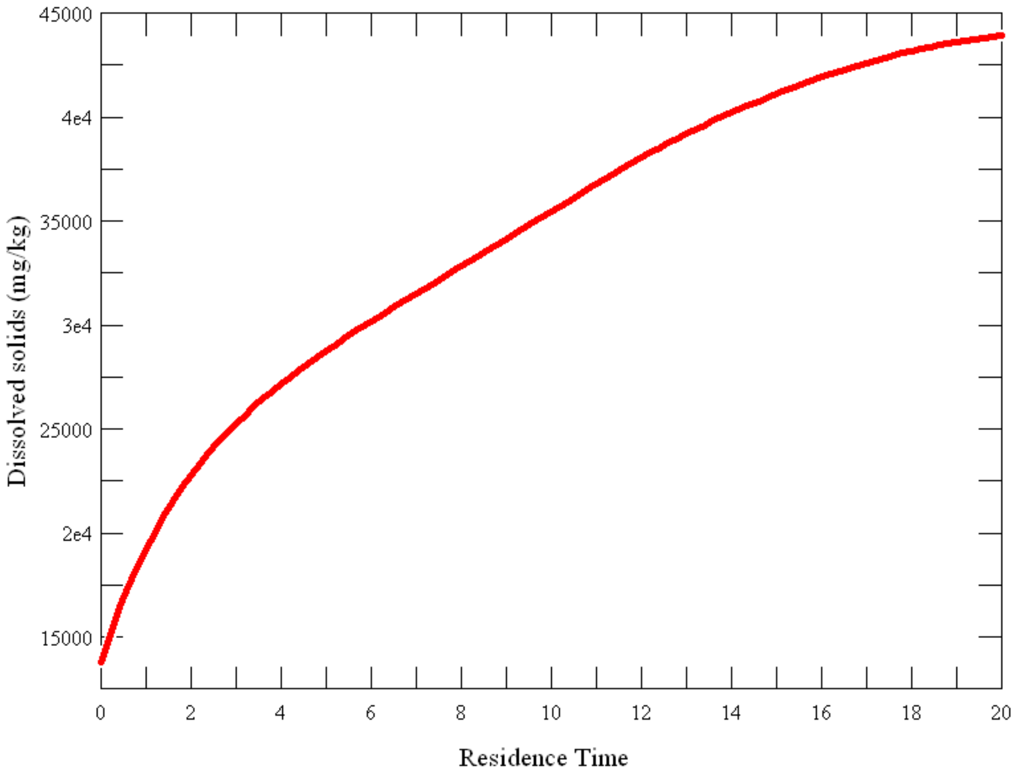


Figure 3.3.4(E): Change in TDS in the unsaturated zone below the Storm Water Dam.

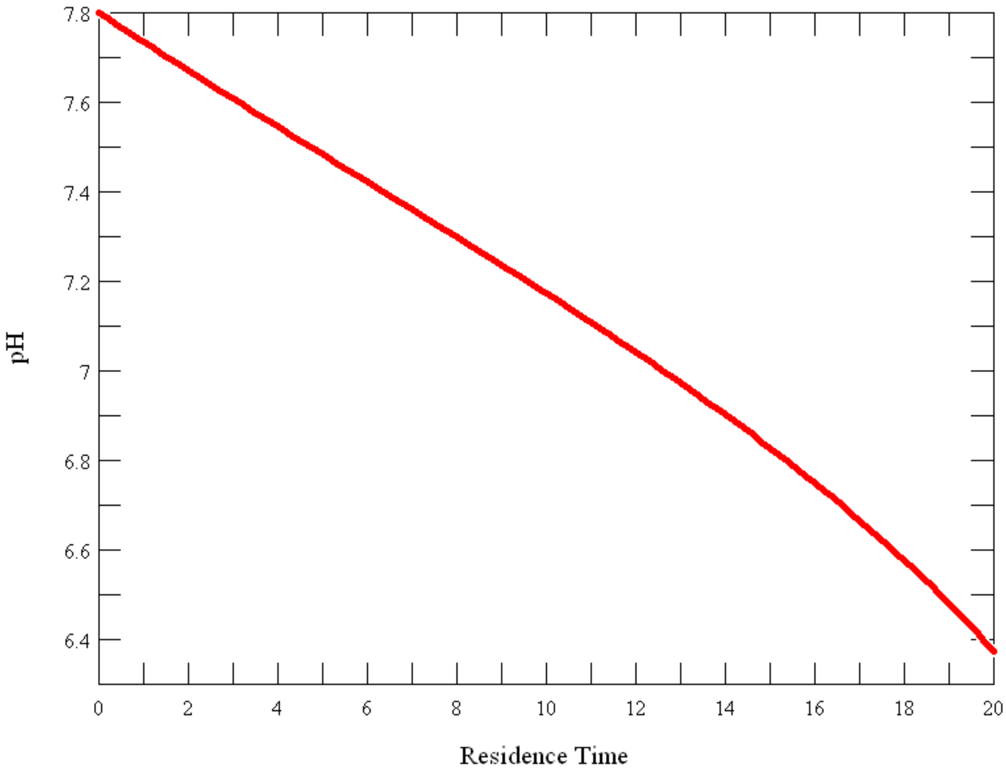


Figure 3.3.4(F): Change in pH in the unsaturated zone below the Storm Water Dam.

Discussion of Model Results

From the results shown in **Figures 3.3.4(A) to (F)** above, the following observations could be made:

- In **Figures 3.3.4(A) and (B)** it is shown that Na and NO_3 reach the same concentration that is present in the source in less than 8 modeled Residence Times. These parameters are not adsorbed in the unsaturated zone.

  SO_4 is only moderately adsorbed and reach the same concentration than the source in about 12 Residence Times. V and F are strongly adsorbed in the unsaturated zone. These parameters do not reach their respective maximum concentrations during 20 Residence Times.

- From **Figure 3.3.4(C)** it is evident that SiO_2(aq) is poorly adsorbed in the unsaturated zone. SO_4 and are moderately adsorbed but more than 90% of V, Zn, F, Ca and Mn are adsorbed in the unsaturated zone. Mg is initially strongly adsorbed but is eventually mostly replaced by Ca on the adsorption sites.

  NO_3 is a very conservative parameter and is not adsorbed in the unsaturated zone. Because Na is mono-valent, it stays in solution and the bivalent ions Mg and especially Ca are rather adsorbed.

- **Figure 3.3.4(D)** shows the change in Kd of V, F and SO_4 which corresponds to the sorbed fractions of the parameters shown in **Figure 3.3.4(B)**. V is strongly adsorbed throughout the model. The Kd of F stays fairly constant over the modeled Residence Times. The Kd of SO_4 is small and decrease further over the model time. The Kd of Na and NO_3 is zero since it is not adsorbed in the unsaturated zone.

- The TDS in the unsaturated zone, shown in **Figure 3.3.4(E)**, increases throughout the model and don't reach its maximum within the modeled 20 Residence Times.

- Hydrogen ions are also adsorbed onto the adsorption minerals and the more the contamination replaces the H-ions, the more H-ions are released in solution with the result of a drop in pH over the model time as shown in **Figure 3.3.4(F)**.

- After comparing **Table 3.3(A)** with the model results, it is evident that the better the type and the quality of the lining system, the longer it will take for any contamination from the dirty water Storm Water Dams to reach the saturated zone in non-complaint quantities. When using a Hazardous Waste Lining System, it will take thousands of years but when using only a bentonite liner, the unsaturated zone and therefore the saturated zone will be polluted within a few decades to severe conditions with resultant high costs of remediation.

4. CONCLUSIONS

The following conclusions could be made with regard to the modeling of the leachate from surface sources through the unsaturated zone towards the saturated zone at Xstrata Rhovan:

- 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 geochemically suitable for the use in lining systems. 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, significantly.

- **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 the Calcine Dump is 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 saturated 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 lined 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 saturated 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 with Hazardous Waste Site lining systems.

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

- **Table 4(A)** below summarizes the recommended lining systems and the Chemicals of Concern of Waste sites, Effluent Ponds and Water Dams at Xstrata Rhovan:

Table 4(A): Recommended lining systems and Chemicals of Concern of waste sites, effluent ponds and dirty water dams 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	H:H Liner
Slimes Dam	None	-	None	Drains for dam safety and stability only
Slimes Return Water Dam	None	-	None	Drains for dam safety and stability only
Storm Water Dam No. 1	None	-	None	Drains for dam safety and stability only
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	H:H Lagoon Liner
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	H:H Lagoon Liner
Calcine Return Water (Ericsson) Dam	NO_3, SO_4, F, Na, V	V, F	NO_3, SO_4, Na	H:H Lagoon Liner
Dirty Storm Water Dams	NO_3, SO_4, F, Na, Al, V	V, F	NO_3, SO_4, Na	H:H Lagoon Liner

*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.

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