

## TABLE OF CONTENTS

	<u>Page No.</u>
<b>EXECUTIVE SUMMARY</b> .....	i
<b>1 INTRODUCTION</b> .....	1
1.1 STATEMENT OF PROBLEM.....	1
1.2 PROJECT PHILOSOPHY .....	1
1.3 RESEARCH OBJECTIVES AND REPORT STRUCTURE .....	2
1.4 LIMITATIONS OF THIS PROJECT .....	3
<b>2 PHASE 1 FINDINGS AND LITERATURE REVIEW</b> .....	5
2.1 SUMMARY OF THE PHASE 1 REPORT .....	5
2.1.1 Background and objectives .....	5
2.1.2 Methodology .....	5
2.1.3 Impact on unsaturated zone.....	6
2.1.4 Geochemical load index .....	6
2.1.5 Geotechnical Investigations.....	7
2.1.6 Impact on the saturated zone .....	7
2.1.7 Conclusions and Recommendations .....	7
2.2 INFORMATION GAPS HIGHLIGHTED BY REPORT .....	10
2.2.1 Investigate gold mine tailings dams.....	10
2.2.2 Preliminary guideline .....	10
2.3 SPECIALIST LITERATURE REVIEWS.....	10
2.3.1 Risk Assessment Procedure.....	10
2.3.2 Geohydrological Processes .....	13
2.3.3 Potential Remediation Strategies Related to Land Surface.....	15
<b>3 METHODS</b> .....	18
3.1 SITE SELECTION .....	18
3.1.1 Selection criteria.....	18
3.1.2 Motivation for sites selected.....	18
3.2 SITE DESCRIPTION AND BACKGROUND.....	19
3.2.1 Site 4L45.....	19
3.2.2 Site 4L24.....	19
3.2.3 Site 6L19.....	19
3.3 SAMPLING .....	20
3.3.1 Trench Positions, sampling and analysis .....	20
3.3.1.1 Site 4L45.....	20
3.3.1.2 Site 4L24.....	21
3.3.1.3 Site 6L19.....	22
3.3.2 Borehole Positions .....	22
3.3.2.1 Site 4L45.....	22
3.3.2.2 Site 4L24.....	22
3.3.2.3 Site 6L19.....	22
3.4 GEOCHEMICAL ANALYSES.....	23

	<u>Page No.</u>
<b>4 DATA EVALUATION .....</b>	<b>24</b>
<b>4.1 DATA ASSESSMENT .....</b>	<b>24</b>
4.1.1 Types of data and variables.....	24
4.1.2 Objectives.....	24
4.1.3 Quality assurance.....	24
4.1.4 Format.....	25
<b>4.2 SELECTED DATA .....</b>	<b>25</b>
4.2.1 Geochemistry .....	25
4.2.2 Geotechnical analysis.....	28
<b>5 CONCEPTUAL MODELS OF PROCESSES IN THE VADOSE ZONE .....</b>	<b>29</b>
<b>5.1 CONCEPTUAL GEOCHEMICAL MODEL .....</b>	<b>29</b>
5.1.1 Factors influencing mobility.....	30
5.1.2 Potential geochemical interactions/transformations.....	31
5.1.3 Generic conceptual model .....	32
<b>5.2 CONCEPTUAL HYDROGEOLOGICAL MODELS.....</b>	<b>35</b>
5.2.1 Site 4L45.....	38
5.2.2 Site 4L24.....	39
5.2.3 Site 6L19.....	39
<b>6 GEOCHEMICAL MODELLING: BASE CASE .....</b>	<b>41</b>
<b>6.1 MODEL CHOSEN AND MOTIVATION.....</b>	<b>41</b>
<b>6.2 DEFINITION OF THE BASE CASE FOR THE THREE SITES ....</b>	<b>42</b>
6.2.1 Site 1 .....	42
6.2.2 Site 2 .....	43
6.2.3 Site 3 .....	43
<b>6.3 MODEL DATA REQUIREMENTS .....</b>	<b>44</b>
<b>6.4 LIMITATIONS ASSOCIATED WITH MODELLING .....</b>	<b>44</b>
<b>6.5 ASSUMPTIONS.....</b>	<b>44</b>
<b>6.6 SENSITIVITY ANALYSES.....</b>	<b>47</b>
<b>6.7 METHODOLOGY.....</b>	<b>51</b>
<b>6.8 RESULTS OF THE BASE CASE MODELS .....</b>	<b>52</b>
6.8.1 Site 4L45.....	52
6.8.2 Site 4L29.....	55
6.8.3 Site 6L19.....	59
<b>6.9 DISCUSSION OF THE BASE CASE RESULTS.....</b>	<b>61</b>
6.9.1 Uncertainty in geochemical modelling results.....	61
6.9.2 Comparison of the effect of physical variation.....	62
<b>6.10 SUMMARY AND CONCLUSIONS .....</b>	<b>63</b>
<b>7 REHABILITATION SCENARIOS .....</b>	<b>64</b>
<b>7.1 INTRODUCTION.....</b>	<b>64</b>
<b>7.2 REMOVAL OF THE SOURCE TERM .....</b>	<b>64</b>
<b>7.3 MINIMIZATION OF INFILTRATION .....</b>	<b>66</b>
<b>7.4 PADDOCKING .....</b>	<b>68</b>
<b>7.5 <i>IN SITU</i> TREATMENT .....</b>	<b>70</b>

	<u>Page No.</u>
7.6 DISCUSSION .....	70
<b>8 RISK ASSESSMENT .....</b>	<b>72</b>
8.1 INTRODUCTION.....	72
8.1.1 Development of methodology .....	72
8.1.2 Source, pathway and receptor characteristics.....	73
8.2 RISK ASSESSMENT OF REHABILITATION OPTIONS .....	73
<b>9 CONCLUSIONS AND RECOMMENDATIONS .....</b>	<b>76</b>
9.1 GENERAL .....	76
9.2 TECHNICAL ASPECTS .....	77
9.3 RECOMMENDATIONS.....	78
<b>10 REFERENCES .....</b>	<b>79</b>

### LIST OF TABLES

Table 3.1 Samples obtained from the trenches on which geotechnical analyses Were performed at site 4L45 .....	21
Table 5.1 Simplified soil units used to describe the shallow unsaturated zone in the study area .....	34
Table 5.2 Unified soil classification classes and estimated saturated hydraulic Conductivity (cm/s), after Mathewson, (1980) .....	36
Table 8.1 Summary of risk assessment for the various rehabilitation options .....	75

### LIST OF FIGURES

Figure 2.1 Schematic outline of the essential procedures to be included as part of a guideline on rehabilitation of contaminated mine tailings footprints .....	13
Figure 3.1 Location of shallow test pits and identified soil zones at reclaimed tailings dam 4L45 .....	20
Figure 4.1 An example of change in elemental composition in soil profile with depth in the deep test pits .....	26
Figure 4.2 Change in Electrical Conductivity with depth in the deep test pits .....	27
Figure 4.3 Change in pH with depth in the different pits .....	27
Figure 4.4 Change in sulphur concentration with depth in the different pits .....	28

	<u>Page No.</u>
Figure 5.1	Depiction of the geochemical treatment of minerals in soils .....30
Figure 5.2	Conceptual geohydrological model of the shallow unsaturated zone of reclaimed tailings dam 4L45 .....33
Figure 5.3	Definition of nodes in conceptual geochemical model of the reclaimed 4L45 tailings dam .....35
Figure 6.1	Configuration of the continuum model for water – rock interaction in an open system, showing the position of reaction fronts as they migrate through the system .....46
Figure 6.2	Sensitivity analysis showing the effect of variation in pyrite content .....48
Figure 6.3	Sensitivity analysis showing the variation in flow rate .....48
Figure 6.4	Sensitivity analysis showing the variation in reactive surface area .....49
Figure 6.5	Sensitivity analysis depicting the difference between kinetic and equilibrium simulations in terms of pH .....49
Figure 6.6	Sensitivity analysis depicting the difference between kinetic and equilibrium simulations in terms of mineral solubilities .....50
Figure 6.7	Schematic outline of the methodology followed during the geochemical modelling exercise.....52
Figure 6.8	pH variation over time at site 4L45 .....53
Figure 6.9	Mineral solubility profile for selected minerals at site 4L45 .....53
Figure 6.10	Compositional diagram showing fluid species concentration over time at site 4L45.....54
Figure 6.11	pH profile at site 4L29 .....55
Figure 6.12	Mineral solubility profile for Na-rich minerals at site 4L29 .....55
Figure 6.13	Compositional diagram showing fluid species concentration over time at site 4L29.....56
Figure 6.14	pH profile at site 4L29 .....57
Figure 6.15	Mineral solubility profile for Na-rich minerals at site 4L29 .....57
Figure 6.16	Mineral solubility profile for Na-rich minerals at site 4L29 .....58
Figure 6.17	Compositional diagram showing fluid species concentration over time at site 4L29.....58
Figure 6.18	pH profile at site 6L19 .....59
Figure 6.19	Mineral solubility profile for Na-rich minerals at site 6L19 .....60
Figure 6.20	Compositional diagram showing fluid species concentration over time at site 6L19.....61
Figure 7.1	Compositional characteristics of the Source Removal rehabilitation option.....65
Figure 7.2	Compositional characteristics of the Minimize Infiltration rehabilitation option.....67
Figure 7.3	Compositional characteristics of Paddock as a rehabilitation option .....69

## LIST OF APPENDICES

- Appendix 1**      **Literature Survey on Risk Assessment Methodology**  
**Appendix 2**      **Literature Survey on Geotechnical Aspects Relating to the  
Vadose Zone**  
**Appendix 3**      **Literature Review of the Existing State of Knowledge with  
regard to Rehabilitation Methods on Reclaimed Mine Residue  
Deposits and their Water Quality Impacts**