
Table of Contents

ACKNOWLEDGEMENTS.....	ii
EXECUTIVE SUMMARY	iii
1 INTRODUCTION	1
1.1 SCOPE OF THE INVESTIGATION	2
1.2 APPROACH TO THE RESEARCH	3
2 BACKGROUND INFORMATION	3
2.1 EXTENT OF MINING.....	4
2.2 TOPOGRAPHY AND SURFACE DRAINAGE	4
2.3 SURFACE WATER QUALITY	5
2.4 GEOLOGY AND GEOHYDROLOGY	11
2.4.1 <i>Geology</i>	11
2.4.2 <i>Geohydrology</i>	13
2.4.2.1 The Ecca weathered aquifer	13
2.4.2.2 The fractured Ecca aquifers	14
2.4.2.3 Pre-Karoo aquifers.....	15
3 MINING METHODS IN THE MPUMALANGA AREA.....	15
3.1 INTRODUCTION.....	15
3.2 BORD-AND-PILLAR EXTRACTION	16
3.3 STOOPING	19
3.4 LONGWALL MINING.....	21
3.5 OPENCAST MINING.....	24
4 DATA ACQUISITION	28
5 THE GEOGRAPHIC INFORMATION SYSTEM	30
5.1 INTRODUCTION.....	30
5.2 DATA HANDLING	30
5.2.1 <i>Data in Microsoft Excel</i>	30
5.2.2 <i>Data in *.dat files</i>	32
5.2.3 <i>Information on maps</i>	33
6 REGIONAL MINE PLANS	34
7 COAL FLOOR CONTOURS AND MINE-WATER FLOW.....	41
8 SALT BALANCE	64
9 MANAGEMENT OPTIONS	79
9.1 REGIONAL MANAGEMENT OPTIONS.....	79
9.2 LOCALISED WATER MANAGEMENT OPTIONS AND NON-OPTIONS.....	80
9.2.1 <i>Neighbouring mining activities</i>	80
9.2.2 <i>Containment of mine water for flooding and neutralisation purposes</i> ... 80	
9.2.3 <i>Design of barrier pillars</i>	80
9.2.4 <i>Minimising water volumes</i>	81
9.2.5 <i>Mixing of mine water</i>	81

9.2.6	<i>Minimising salt loads</i>	81
9.2.7	<i>Isolation of mine water - not an option</i>	82
9.2.8	<i>Wetland treatment of mine water - not an option</i>	83
9.2.9	<i>Future technology - not an option</i>	83
10	CONCLUSIONS.....	83
11	RECOMMENDATION FOR FURTHER WORK.....	84
12	REFERENCES.....	86

APPENDIX A - GROUNDWATER FLOW MODELLING..... 90

1	PRINCIPLES OF GROUNDWATER FLOW MODELLING.....	90
1.1	INTRODUCTION.....	90
1.2	HYDRODYNAMIC EQUATIONS.....	93
1.2.1	<i>GROUNDWATER FLOW - FLOW EQUATION</i>	93
1.2.1.1	THE CONTINUITY EQUATION.....	94
1.2.1.2	MASS TRANSFER EQUATION.....	94
1.3	SOLUTION OF THE HYDRODYNAMIC EQUATIONS.....	95
1.3.1	<i>INITIAL AND BOUNDARY CONDITIONS</i>	95
1.3.2	<i>FLOW EQUATION</i>	95
1.3.3	<i>MASS TRANSPORT EQUATION</i>	96
1.3.4	<i>SOLUTION METHODOLOGY</i>	96
2	THE FINITE ELEMENT METHOD.....	97
2.1	DISCRETISATION.....	99
2.1.1	<i>TIME DISCRETISATION</i>	99
2.1.2	<i>DOMAIN DISCRETISATION</i>	99
3	THE FEFLOW MODEL.....	101

APPENDIX B - CHEMISTRY OF COLLIERIES..... 103

1	INTRODUCTION.....	103
2	STAGES IN THE DEVELOPMENT OF MINE SITE DRAINAGE.....	105
2.1	STAGES IN DEVELOPMENT OF AMD.....	106
3	BASIC CHEMISTRY OF AMD GENERATION.....	107
3.1	REACTIONS.....	107
3.2	REACTION MECHANISMS.....	112
4	BASIC CHEMISTRY OF AMD NEUTRALISATION.....	112
5	CONCLUSIONS.....	116

List of Figures

Figure 1.	Locality plan of the area under investigation.	1
Figure 2.	Plan showing mines included in the study.....	2
Figure 3.	Surface topography, drainage systems and catchments of the Mpumalanga Coalfields.....	4
Figure 4.	Regional surface water monitoring points of the DWA&F in the study area. Scale from left to right is 150 km (Names in black at streams indicate stream names).....	5
Figure 5.	DWA&F water quality and quantity monitoring positions leading away from mining areas. Scale from left to right is 150 km.	6
Figure 6.	Water qualities in the Klip and Olifants Rivers and the Spook Spruit.	7
Figure 7.	Water qualities in the Klein Olifants and Komati Rivers.	7
Figure 8.	Water qualities in the Waterval and Vaal Rivers and Leeu Spruit.	8
Figure 9.	Piper diagram of the major elements at the sampling positions indicated in Figure 5.	8
Figure 10.	Stiff diagrams for the eight streams (Figure 5) leading water from the collieries.	9
Figure 11.	Average sulphate concentrations (range 0 - 1140 mg/L) left and average sodium concentrations (range 0 - 120 mg/L) right, demonstration the relative surface water contamination. (Red = very high; Yellow = moderately high; Green = Acceptable).....	10
Figure 12.	Two typical and generalised geological profiles for the Coalfields, showing the variability (modified from Hodgson <i>et al.</i> , 1985).	11
Figure 13.	Photographs of typical sedimentary rocks from the Mpumalanga Coalfields.	12
Figure 14.	Example of bord-and-pillar mining in a modern underground colliery. Apart from the coal pillars, certain surface infrastructure such as streams, roads and survey markers are also shown.	16
Figure 15.	Floor contours and water flow vectors for bord-and-pillar mining.	17
Figure 16.	Extent of subsidence areas above bord-and-pillar mining west of Witbank. Scale from left to right is 6 km.	18
Figure 17.	Empirical relationship between the area mined by bord-and-pillar methods and water influx.	19
Figure 18.	Example of stooped areas at Usutu Colliery with access to the central area only from the south.....	19
Figure 19.	Detailed examples of bord-and-pillar with partial stooping.	20
Figure 20.	Example of a mine where stooping has partially been done and the classification of areas according to the likelihood of roof failure (goafing) to surface.....	20
Figure 21.	One of the first longwall operations in South Africa (1979).	21
Figure 22.	Example of longwall panel lay-out with a structural discontinuity transecting it, also showing bord-and-pillar mining to allow access.	22
Figure 23.	Circular fracture above a longwall panel, in a ploughed field, with a diameter of 160 m.	23
Figure 24.	Schematic representation of dewatering cones and the vertical interaction between aquifers which are intersected by fractures from underground high extraction.....	24

Figure 25.	Dragline mining in an opencast pit	25
Figure 26.	Typical map without co-ordinates, available at the DME in Witbank.	29
Figure 27.	Example of information required in the Basic Information sheet.	31
Figure 28.	Example of the information in the Chemistry datasheet.	31
Figure 29.	Example of the information in the Geology datasheet.....	31
Figure 30.	Example of the information in the Water-level datasheet.	32
Figure 31.	Example of the information in a Hydrochemical Log datasheet.	32
Figure 32.	Example of the information in a *.dat file for contouring.	32
Figure 33.	Example of underground mine workings superimposed on 1:50 000 topographic information.....	33
Figure 34.	Locality plan of the mine lease areas in the Mpumalanga Coalfields.	34
Figure 35.	Underground mining on the No. 1 Coal Seam.....	35
Figure 36.	Underground mining on the No. 2 Coal Seam.....	36
Figure 37.	Underground mining on the No. 4 Coal Seam.....	37
Figure 38.	Underground mining on the No. 5 Coal Seam.....	38
Figure 39.	Opencast mining on all coal seams.....	39
Figure 40.	All opencast and underground mining in the Mpumalanga Coalfields...40	
Figure 41.	Example of a zoomed area (Vandyksdrift) with the 1:50 000 topographic map in the background.....	41
Figure 42.	Example of water occurrences in underground bord-and-pillar areas, also showing floor contours. Scale from left to right is 2 700 m.....	42
Figure 43.	Floor contours elevations for the No. 2 Coal Seam in the Mpumalanga Coalfields.	43
Figure 44.	Regional lows (blue lines) and highs (red lines) on the No. 2 Coal Seam floor elevations.	44
Figure 45.	No. 2 Coal Seam floor contours for the collieries in the Witbank area. Scale from left to right is 67 km.	45
Figure 46.	No. 2 Coal Seam floor elevations below the possible decant level of 1 505 mamsl in the Olifants River.....	46
Figure 47.	Paleo-highs and -lows on the No. 2 Coal Seam horizon in the Witbank area.	47
Figure 48.	Major areas of possible intermine flow between collieries after full recovery of the water levels in all the mines.....	48
Figure 49.	Example of a complex arrangement of underground an opencast mining in close proximity of each other.....	49
Figure 50.	Complex arrangement of mining, underground water bodies and surface water.....	50
Figure 51.	Finite element network (left) and simulated water pressures across the mine boundary (right).	50
Figure 52.	Complex arrangement of mining on an intermine level.	51
Figure 53.	No. 2 Coal Seam floor contours, also showing decanting positions and elevations.	52
Figure 54.	No. 4 Coal Seam floor contours, also showing decanting positions and elevations.	52
Figure 55.	Stage curves for No.'s 2 and 4 Coal Seams.....	53
Figure 56.	Area for combined water treatment management.	55

Figure 57.	Example of redirecting underground decant from one surface catchment to the next to decant at 1581 mamsl. Also shown are the numerous decanting points that will result, if left to decant uncontrolled.....	56
Figure 58.	Coal-floor contours and monitoring borehole positions	57
Figure 59.	Stage curve for the underground water-holding capacity of the mine. ...	58
Figure 60.	Projected water-levels and fill time for the mine.	58
Figure 61.	Flushing rates of mine water (mg/L) based on different recharge rates.	59
Figure 62.	Flushing rates of mine water (t/d) based on different recharge rates. ...	59
Figure 63.	Mine extent and coal-floor contours.	61
Figure 64.	Dam with surface run-off and recharge borehole from the dam into the mine	61
Figure 65.	Stage curve showing the current water level in the mine (1 561 mamsl) and the decanting level (1 562 mamsl).....	62
Figure 66.	Simulated constituent concentration in the mine water against time, using Geochemist Workbench software.	62
Figure 67.	Projected flux from existing collieries during future decanting.	63
Figure 68.	Natural and oxidised pH-levels of coal and rock samples versus their NNP's.	65
Figure 69.	Example of cumulative acid and base potentials down a borehole.	66
Figure 70.	Water qualities in a stream receiving periodic discharge of mine water.	68
Figure 71.	Typical reaction path pH-conditions for rocks and coal mined in the Mpumalanga Collieries.	69
Figure 72.	Availability of elements from rock and coal at various pH-levels.	70
Figure 73.	Availability of elements from rock and coal at various pH-levels (continued)	70
Figure 74.	Availability of elements from rock and coal at various pH-levels (continued).	71
Figure 75.	Vertical profiles showing physical and chemical characteristics of the various layers.	72
Figure 76.	Multiple chemical logs of acid water in an opencast mine.	73
Figure 77.	Multiple chemical logs of neutral water in an opencast mine.	73
Figure 78.	Multiple chemical logs of water above and in an underground mine.	74
Figure 79.	Typical concentration curves from mine water in a closed system.	82
Figure 80.	Representation of averaging volumes (REV) in the hydrological system (modified from Diersch, 1980 and Kolditz and Zielke, 1994).....	92
Figure 81.	Darcy's experiment (after Bear, 1979).	93
Figure 82.	Properties of the program are outlined as follows by the WASY Home Page (http://www.wasy.de).....	101
Figure 83.	The three stages in the evolution of drainage chemistry (Morin and Hutt, 1997).	106
Figure 84.	Schematic evolution of pH plateaux (after Morin, 1983 and Morin, 1988).	107
Figure 85.	Model for the oxidation of pyrite (from Stumm and Morgan, 1981).	110
Figure 86.	Equilibrium concentration of HCO ₃ ⁻ (alkalinity) from dissolution of calcite (CaCO ₃) by pure water at various partial pressures of carbon dioxide (P _{CO2}) at 25°C. (calculated after Garrels and Christ, 1965).	115