PREDICTION OF HOW DIFFERENT MANAGEMENT OPTIONS WILL AFFECT DRAINAGE WATER QUALITY AND QUANTITY IN THE MPUMALANGA COAL MINES UP TO 2080

Report to the Water Research Commission

by

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EXECUTIVE SUMMARY

The Witbank and Middelburg Dam catchments are extensively mined. The water quality has deteriorated in the catchment. The water resources of the catchment are further threatened by the future decants that are expected from the mines post closure. The mines will be closing over the next 20 years. Thereafter the mine workings will fill and start decanting.

The objectives of the study were:-

- Evaluate the available management options that can be used to reduce mine drainage and / or improve its quality on the Mpumalanga coal field.
- Compile the currently available information and acquire additional information as required to model the long term water quality and quantity emanating from the mines in the Mpumalanga coal field.
- Establish an integrated modelling suite that simulates the change in the Mpumalanga coal field as affected by different management options.
- Compare the cost associated with different options with that of treatment to achieve target water qualities.

The approach adopted in the analysis is summarised as follows:-

- Identify a management option.
- Cost the management option.
- Set up the model for the identified management options.
- Run the model of the system and check the Middelburg and Witbank Dam's concentrations against the RWQO.
- Determine the net present value for the option for comparison with other options analysed.

The study involved a data collection phase where the mining data was collected and evaluated. The collection of data showed that the quality of the available data varied considerably from mine to mine. The mine data was collected by means of questionnaires followed by phone calls and site visits. The data collected included water quality, mining areas, types of mining, water balances, floor contours and water use. The data was collated and used as input to the models used to evaluate the management scenarios. The mining data for the Middelburg Dam catchment was better than for the Witbank Dam catchment. The mines were grouped together based on location and logical management of water.

Available management options that can be applied on the mines to reduce volumes and improve the water quality of the expected decants were identified in a literature survey. The options included diversions, covers, treatment (both conventional desalination and passive), underground management of water through seals and spoils handling. The options taken through for analysis were covers, conventional treatment, use of workings storage and intermine flow as these were considered to be the most practical and tested approaches.

A suite of models was selected for use in the study. The available models were collated and ranked. The ACRU-Salinity model was selected for the assessment of the local mining impacts while the Water Resource Planning Model (WRPM) was found to be best able to assess the regional impacts. The WRPM has a mine module that can be used to simulate mine water systems. The module allows for the different mining types, mining plans, use of water on the mines and mine storage. The data collected was used to set up the mine module for the mines and used in the analysis of the management scenarios.

The ACRU-Salinity model was applied to the Kleinkopje Colliery and the B11C quaternary catchment. The model was calibrated against measured volume and Total Dissolved Solids (TDS) data. The application of the model showed that it calibrated well and could be applied to assess local impacts of mining on volumes and water quality. The application of the model to the B11C quaternary highlighted the volumes that can be abstracted from mine voids. The increased recharge into a dummy mine void covering half the catchment increased the available water by 40%. This water will however have to be treated.

The 5 scenarios analysed for the Middelburg and Witbank Dam catchments were:-

- Scenarios 1, 2 and 3 involved using different covers. The three covers used were a poor cover, good cover and a 1200 mm thick cover. The recharge factors used for the covers were 20%, 15% and 10% for the poor, good and 1200 mm cover. The covers were applied to the different mine areas and the time to decant and decant volumes were determined. When the mines decanted, it was assumed that the decant was treated.
- Scenario 4 involved piping water from workings that were filling early to workings that still had capacity. This was applied to the Middelburg catchment where the water from the Kwagga Group was pumped to Schoonoord and the water from Optimum was pumped to Boschmanspoort. The idea being tested was to delay the need for treatment.
- Scenario 5 was the use of intermine flow as a post closure scenario. The use of intermine flow is best suited for mines located in the Witbank Dam catchment. The intermine flow can be directed to a low point at Douglas Colliery from where the water can be abstracted for treatment and supply as potable water to Witbank.

The following conclusions can be made as a result of this study:-

- The catchment situation is dire with deteriorating water quality in the Witbank and Middelburg Dams. There are still new mines to be developed in the catchments and the existing mines are still expanding.
- The water demands of the Steve Tshwete and Emalahleni Local Municipalities exceed the yields of the Witbank and Middelburg Dams. There is no further surface water resources that can be developed in the catchment to meet the growing water demands. The mine water is the only local source of water that can be used to meet the demands. The treatment of mine water and supply as potable water is already being undertaken by South African Coal Estates with a 20 ML/d plant and at Optimum with an 11 ML/d plant. Based on the available data, there is still a further 65 ML/d to 100 ML/d available for treatment and supply.
- The level of mine information varies from mine to mine. Some mines have a good understanding of the areas, storage volume available and the excess mine water generated over the life of the mine. The collection of information was halted early on in the study so that the analysis work could continue. A number of the mines have made significant progress in improving their water balances. Nonetheless the available data was used and was considered adequate to undertake the study and illustrate the management approaches that can be considered for the catchment.
- The modelling needs identified were to be able to assess the impact of mining on the local and regional water resource impacts. The ACRU-Salinity model was identified as the most appropriate model to apply to assess the local water quantity and quality impacts. The WRPM and the WQT models were identified as the most appropriate for assessing the regional impacts.
- The ACRU-Salinity model was applied to a quaternary catchment and was found to calibrate well against the measured flows and TDS concentrations. The model was used to determine the impact of a

dummy mine on the water resource of the quaternary catchment. The model was also applied to modelling the Kleinkopje mine complex with reasonable success.
- The application of the WRPM to the catchment was used to determine the impact of the mine scenarios on the dam water qualities and the excess mine water available. The results of these runs were input into the cost model.
- The shortcomings in the WRPM identified were that changes in water quality over time in the mine workings could not be modelled. The water qualities are entered in the model based on the measured data. The impact of the long term flushing of workings cannot be modelled.
- The application of the cost model to the scenarios that were formulated showed that the use of covers significantly reduced the water volume that needed treatment. The reduction in recharge also delayed the need for treatment. The total NPV for the scenarios showed that the use of a good cover significantly reduced the NPV of the scenarios. The 1200 mm cover is expensive and did not achieve the same magnitude of the reduction in the total NPV for the catchments.
- The use of storage to delay treatment showed that there was some merit but the cost of the piping to convey the water for storage in the workings was expensive and offset the changes in treatment costs.
- The intermine flow is a promising closure scenario. The water can relatively cheaply be transferred to a low point close to Witbank. A treatment plant can be constructed at the low point for supply to Witbank. The sale of water reduces the NPV significantly as a portion of the operating costs can be recovered. The intermine flow option however requires cooperation between the mines and planning to control the flows between the workings. Issues of liability would also have to be addressed if intermine flow is to be considered as an option.
- The closure of the mines is still some years off. The NPV show that although there are immediate management issues on some of the mines, relatively small sums of money can be provided now to cover the closure costs in 40 or 50 years time.
- The scenarios presented in the study were based on the available data and have not necessarily been optimised. However the scenario results provide useful guidance and direction on the way forward.

The following recommendations can be made as a result of this study:-

- The mines must keep their water balances current and all achieve a similar level of accuracy and confidence.
- Not all the mines were included in the study. There are a number of smaller mines and mining companies whose information should be collated and included in the modelling and long term planning.
- The mines must co-operate and continually update the life cycle costs and seek the most economic solution for the management of water in the long term. This includes incorporating intermine flow as a closure solution.
- The treatment and supply of mine water for potable use is the strategy to achieve reconciliation in the catchment. The long term changes in the recharge rates need to be assessed as the opencast mine workings consolidate and the perched aquifer previously destroyed by the mining starts to re-establish.
- The WRPM should be updated with a simple algorithm to model the water quality changes in the mine workings.
- One of the expenses in treatment is the disposal of brine. Consideration should be given to the storage of brine in the underground workings to reduce the costs of the treatment process.
- Impact of electricity costs on viability should be reviewed.

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The research in this report emanated from a solicited project funded by the Water Research Commission and entitled:

"Prediction of how different management options will affect drainage water quality and quantity in the Mpumalanga coal mines up to 2040"

The Reference Group responsible for this project consisted of the following persons:

Mr HM du Plessis (Chairman)	Water Research Commission
Dr J Burgess	Water Research Commission
Dr V Cogho	BHPBilliton Energy Coal South Africa
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Mr N Dooge	Xstrata Coal South Africa
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Mr W Kamish	Ninham Shand

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The assistance of Prof Frank Hodgson of the University of the Free State with the provision of mine data is also gratefully acknowledged. The patience and co-operation of the staff on the individual mines in finding time in their busy schedules to deal with the numerous and persistent requests from the project team for data is also gratefully acknowledged.

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LIST OF ABBREVIATIONS

ALD	Anoxic Limestone Drains
AMD	Acid Mine Drainage
CMS	Catchment Management Strategy
d/s	dust suppression
DWAF	Department of Water Affairs and Forestry
IGS	Institute of Groundwater Studies
LM	Local Municipality
MAP	Mean Annual Precipitation
MAR	Mean Annual Runoff
NWRS	National Water Resources Strategy
OLD	Oxic Limestone Drains
PCD	Pollution Control Dams
RO	Reverse Osmosis
RWQO	Resource Water Quality Objectives
SACE	South African Coal Estate
SLS	Sodium Lauryl Sulphate
SRP	Sulphate Reducing Prokaryote
STP	Sewage Treatment Plants
WMA	Water Management Area
WRPM	Water Resources Planning Model

1 INTRODUCTION

1.1 Background to the Study

The exploitation of the Mpumalanga coal fields started in the early 1900's in the Witbank area. The rate of exploitation accelerated in the 1970's with the construction of the coal fired power stations. The resulting large mining operations affect the water quality and quantity of the water in the water resource. The mining of the Mpumalanga coal fields will start winding down in 2040. This presents water resource planners, the regulators and the mining industry with a challenge as to how to manage the excess mine water after closure. Decisions taken now on the approach to mining and the management options put in place will influence the quantity and quality of mine water that has to be dealt with after closure.

The project was a solicited project with the Water Research Commission requesting proposals to assess the long term impacts of different management options applied by the coal mining industry on the water quantity and quality in the Mpumalanga coal fields up to 2040. During the inauguration meeting for the project, the study area was defined as the Loskop Dam catchment with the focus on Witbank and Middelburg Dam catchments. A number of studies have been carried out in the study area in the past. These include the intermine flow between different mine workings (Grobbelaar, 2004), the Department of Water Affairs and Forestry (DWAF) water resource studies (DWAF, 2001), Coaltech projects on passive water treatment and initiatives by the mining houses on water treatment.

The main study objective is to investigate the scenario of water management up until closure and beyond. However after the analysis of the mine data started, it became apparent that the closure scenario in terms of managing excess mine water would be some time after 2040. This is due to the time taken to fill some of the workings, particularly the underground bord and pillar workings. Current estimations are that it is likely that all the workings will only be filled and decanting by 2100. However in terms of the aim of the project which is to investigate the management of water up until closure and beyond the relevant date in the future is when the majority of the mines all start decanting.

1.2 Project Objectives

The project objectives were:

- Evaluate the available management options that can be used to reduce mine drainage and / or improve its quality on the Mpumalanga coal field.
- Compile the currently available information and acquire additional information as required to model the long term water quality and quantity emanating from the mines in the Mpumalanga coal field.
- Establish an integrated modelling suite that simulates the change in the Mpumalanga coal field as affected by different management options.
- Compare the cost associated with different options with that of treatment to achieve target water qualities.

1.3 Summary of Study Approach

The following steps were followed in the study:-

- The study area is described and the current water quality and water quantity situation is presented,
- A literature review was undertaken regarding available mine water management options and modelling systems.
- A document was compiled detailing the literature review and presented to the mining community in Witbank.

- A modelling system was chosen for use in the project.
- A data collection exercise was undertaken to collect mine water quality mining area and excess water volumes for use in the study.
- Management options were identified and costed. The efficacy of the management options were tested in the modelling system.
- The Net Present Values of the management options were compared and discussed.

1.4 Report Structure

The main Chapters of the report are briefly described below:

- **Chapter 1: Introduction**: This section introduces the study, the study area and the methodology to be used in the study.
- **Chapter 2: Descriptions of Study Area:** In this section the land use, geology and geohydrology characteristics of the study area are described. The available hydrological records and the water quality situation in the study area are discussed. The rapidly growing water requirements in the large urban centres of Witbank and Middelburg and the smaller towns are presented. The growing water requirements are contrasted with the water available from the current water sources.
- **Chapter 3: Description of Methodology:** The methodology used in the study is described in this section. The mining information collected is summarised and the costing model described and the inputs summarised.
- **Chapter 4: Management Options:** The management options that can be applied to mining are listed and discussed in this section. A management option report was produced during the study and circulated to the Reference Group for comment. A workshop was also held with the mines at Greenside Colliery on the 18 November 2005. At the workshop the objectives of the project were presented and the management options identified were explained and discussed.
- **Chapter 5: Selection of model suite:** In this section the way in which mining impacts on the surface and ground water resources are discussed. Based on these impacts and the management options, the requirements for the modelling suite are identified. The available models are listed and the selection of the model to be used in the study is discussed.
- **Chapter 6: Application of ACRU Salinity:** The application of ACRU Salinity was applied to the Kleinkopje Colliery and to the B11C quaternary catchment. The application to the colliery shows the ability of a model like ACRU Salinity to model the mine water system while the application to the quaternary catchment shows the impact at the local scale of a mine on the water balance.
- **Chapter 7: Description of scenarios analysed and application of model:** In this section the management scenarios for analysis are described. These included different types of cover, treatment and discharge, irrigation, intermine flow and combinations of management options.
- **Chapter 8: Discussion of Results:** The results of the application of the model are discussed in this section.
- **Chapter 9: Conclusions and Recommendations:** The conclusions and recommendations resulting from this study are presented in this section.

2 DESCRIPTION OF STUDY AREA

2.1 Location and land use in the study area

The study area is the Loskop Dam catchment located in the upper catchment of the Olifants River as shown in Figure 1. The catchment falls in the Olifants Water Management Area (WMA). The major tributaries of the Olifants River in the study area are the Wilge, Klein Olifants, Steenkoolspruit, Noupoortspruit, Tweefonteinspruit, Koringspruit, Klipspruit and Spookspruit. The catchment area of the study area is 12285 km^2.

The major towns in the study area are Witbank (Emalahleni Local Municipality), Middelburg (Steve Tshwete Local Municipality) and Bronkhorspruit (Kingwini Local Municipality). The smaller towns in the area are Kriel, Hendrina, Ogies, Clewer, Rietkuil and Delmas. The location of the major towns and the tributaries are shown in Figure 2.

There is extensive coal mining taking place in the study area. The coal mines are currently concentrated in the Witbank and Middelburg Dam catchments. The extent of the current mine workings in the study area is shown in Figure 3. The coal mining in the Wilge River Catchment is limited at this stage but more mines are opening up in the catchment. There are a number of defunct and abandoned mines located in the study area. There is a concentration of such mines in the Klipspruit catchment. The mining in this area started in the early 1900’s and the responsibility for the abandoned mines in the area has been taken over by the Department of Minerals and Energy.

There are 6 active coal fired power stations located in the study area. The “moth balled” Komati Power Station is due to be put back on line and Eskom is constructing a new power station in the Kendal area. The water for the power stations is transferred into the catchment from the Komati, Usutu and Vaal River Systems.

There is also extensive agriculture practised in the study area. The water for irrigation is supplied from farm dams and extensive irrigation water is supplied from the Loskop Dam to the irrigation boards located downstream of Loskop Dam. Water for domestic use in the Western Highveld Region (Elands River) and Groblersdal is also supplied from Loskop Dam. Water for the Western Highveld Region is also supplied from Bronkhorstspruit Dam.

The irrigation areas in the catchments of the major dams and the irrigation water requirements as given in DWAF (2001) are listed in Table 1. There are also limited areas of afforestation in the study area. The afforested areas in the major dam catchments are also listed in Table 1.

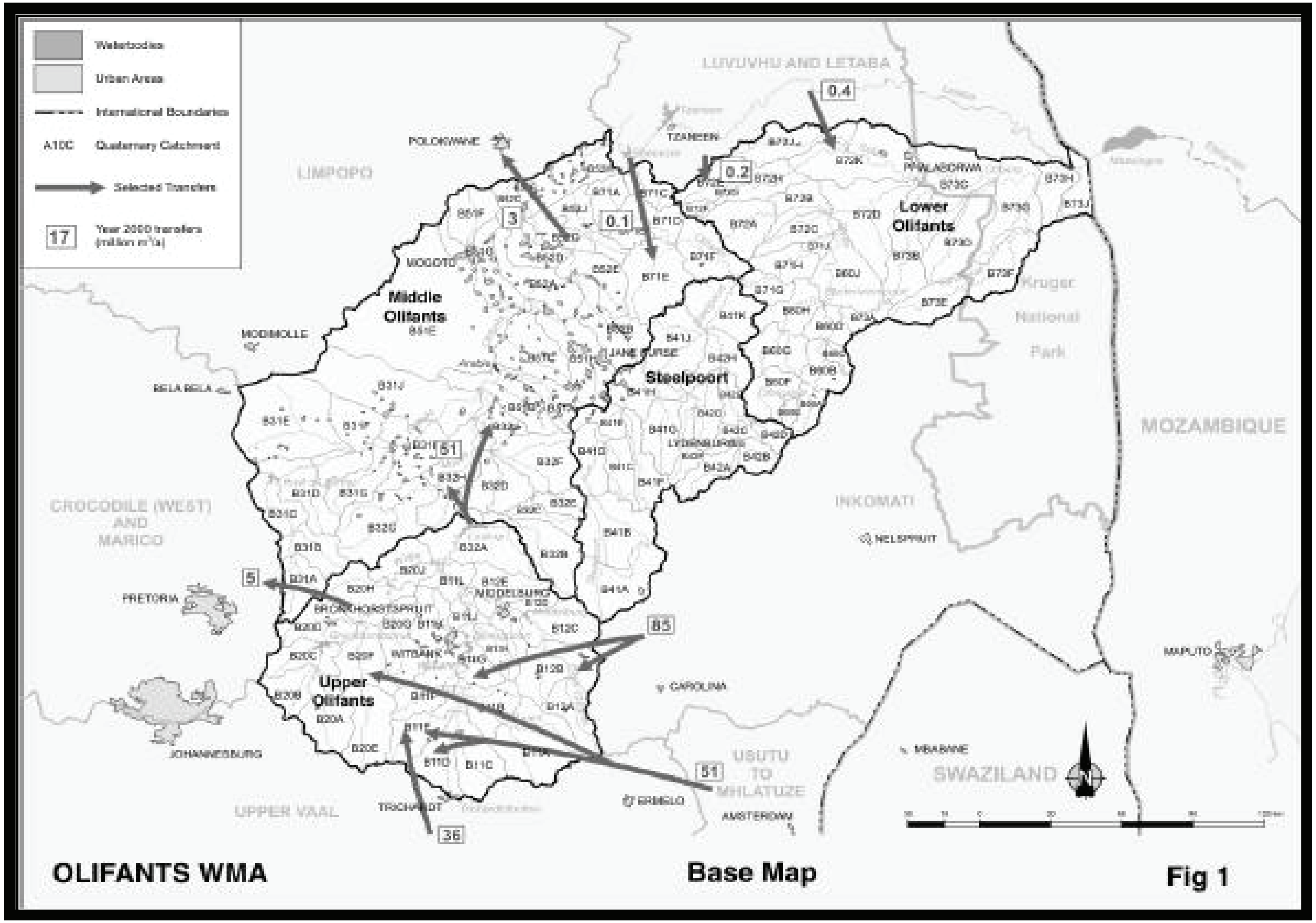

Figure 1: Location of study area in Olifants WMA (Source: NWRS, DWAF September 2004)

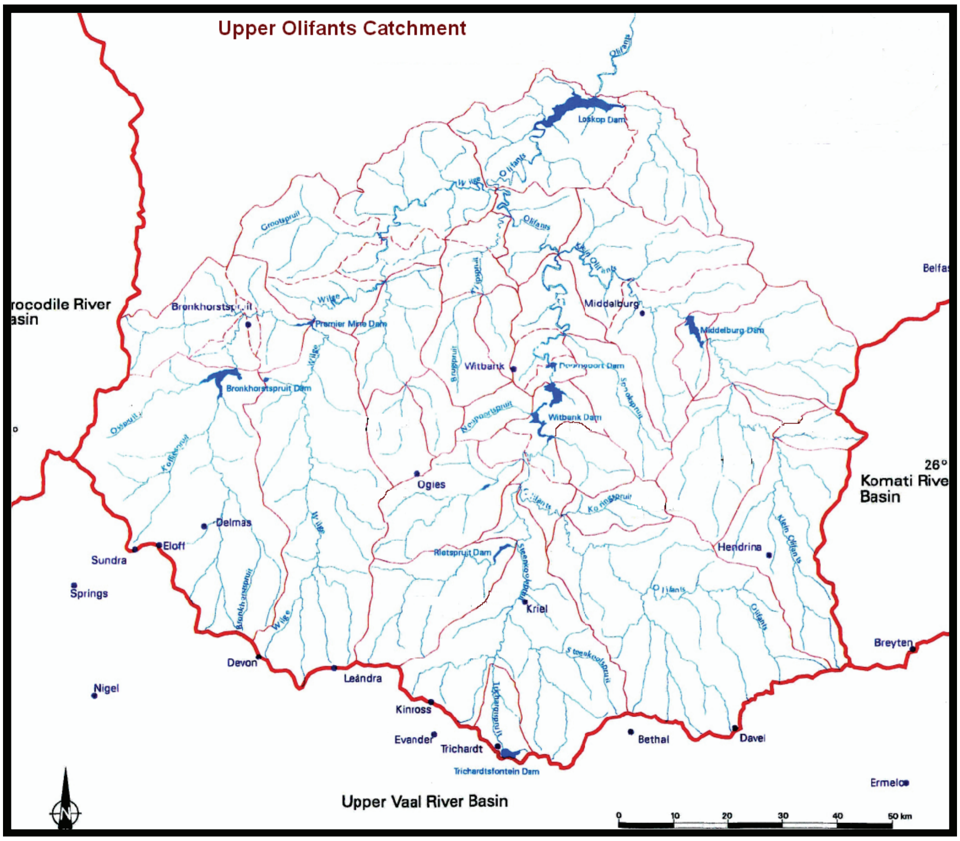

Figure 2: Location of major towns and tributaries in the Loskop Dam catchment

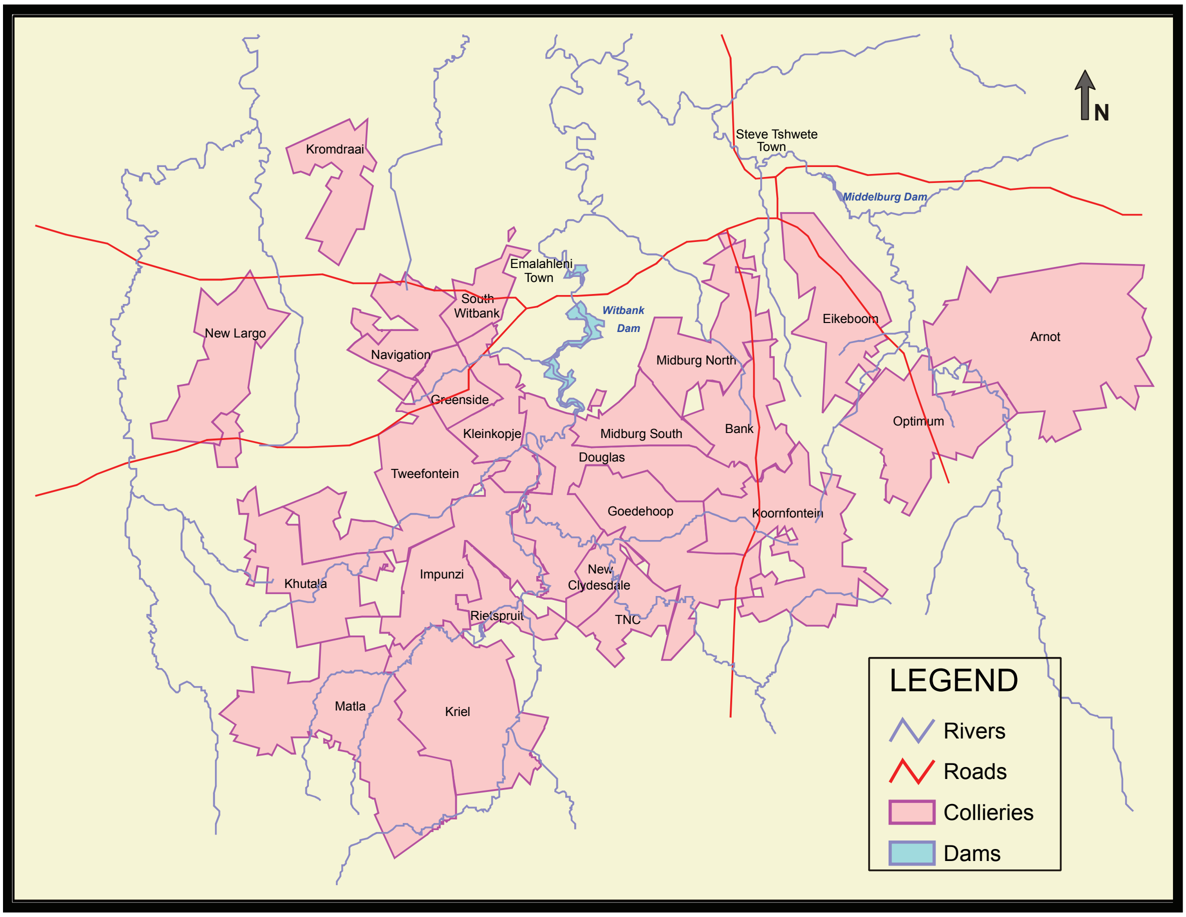

Figure 3 : Extent of current (2006) mining lease areas

Table 1: Summary of irrigation and afforestation areas

Dam catchment	Afforestation area (ha)	Irrigation area (ha)	Irrigation requirement (million m^3/a)
Witbank Dam catchment	27,97	1294	4,15
Middelburg Dam	40,91	1589	4,65
Bronkhorstspruit Dam	17,43	1350	6,92
Wilge Dam	27,41	2094	5,93
Loskop Dam incremental	164,63	4926	17,26
Total	278,35	11253	38,91
Irrigation supported from Loskop Dam	-	22837	175,85
Total	-	34090	214,76

2.2 Geology

Different types of sediments and rocks have different influences on the quality and quantity of water in the collieries. For this reason the geology of the area should be well known. The Karoo Supergroup in the Mpumalanga coal field comprises the Ecca Group and Dwyka Formation. The total thickness of these sediments ranges from 0-100 m.

The Ecca sediments consist predominantly of sandstone, siltstone, shale and coal. Combinations of these rock types are often found in the form of interbedded siltstone, mudstone and coarse-grained sandstone. Typically, coarse-grained sandstones are a characteristic of the sediments in the Witbank Area.

Five coal seams, numbered from bottom to top as No. 1-5, are present. Only two of the seams are mineable over most of the area. These are the No. 2 and 4 Seams, which are usually separated by sediments of a total thickness in the order of 20-30 m. Seams 1 and 5 are, however, mined locally (see Figure 4).

Dolerite intrusions in the form of dykes and sills are present within the Ecca Group.

The sills are highly undulating and some might conform to the ring structures described in the southern Orange Free State. The sills usually precede the dykes, with the latter being emplaced during a later period of tensional forces within the earth's crust.

The Ecca sediments overlie the Dwyka Group (loosely referred to as the Dwyka tillite). This formation consists of a proper tillite, siltstone and sometimes a thin shale development. The upper portion of the Dwyka sediments may have been reworked, in which case carbonaceous shale and even inclusions of coal may be found.

The Dwyka sediments are underlain by a variety of rock types, such as the Bushveld Complex in the north, Witwatersrand Supergroup in the south, Waterberg Supergroup in the north-west and Transvaal Supergroup to the west.

Tectonically, the Karoo sediments are practically undisturbed. Faults are rare. However, fractures are common in competent rocks such as sandstone and coal.

2.3 Geohydrology

Three distinct superimposed groundwater systems are present. They are the upper weathered Ecca aquifer, the fractured aquifers within the unweathered Ecca sediments and the aquifer below the Ecca sediments.

2.3.1 The Ecca weathered aquifer

The Ecca sediments are weathered to depths between 5-12 m below surface throughout the area. The upper aquifer is associated with this weathered zone and water is often found within a few meters below surface.

This aquifer is recharged by rainfall. The percentage recharge to this aquifer is estimated to be in the order of 1-3% of the annual rainfall, based on work in other parts of the country by Kirchner et al. (1991).

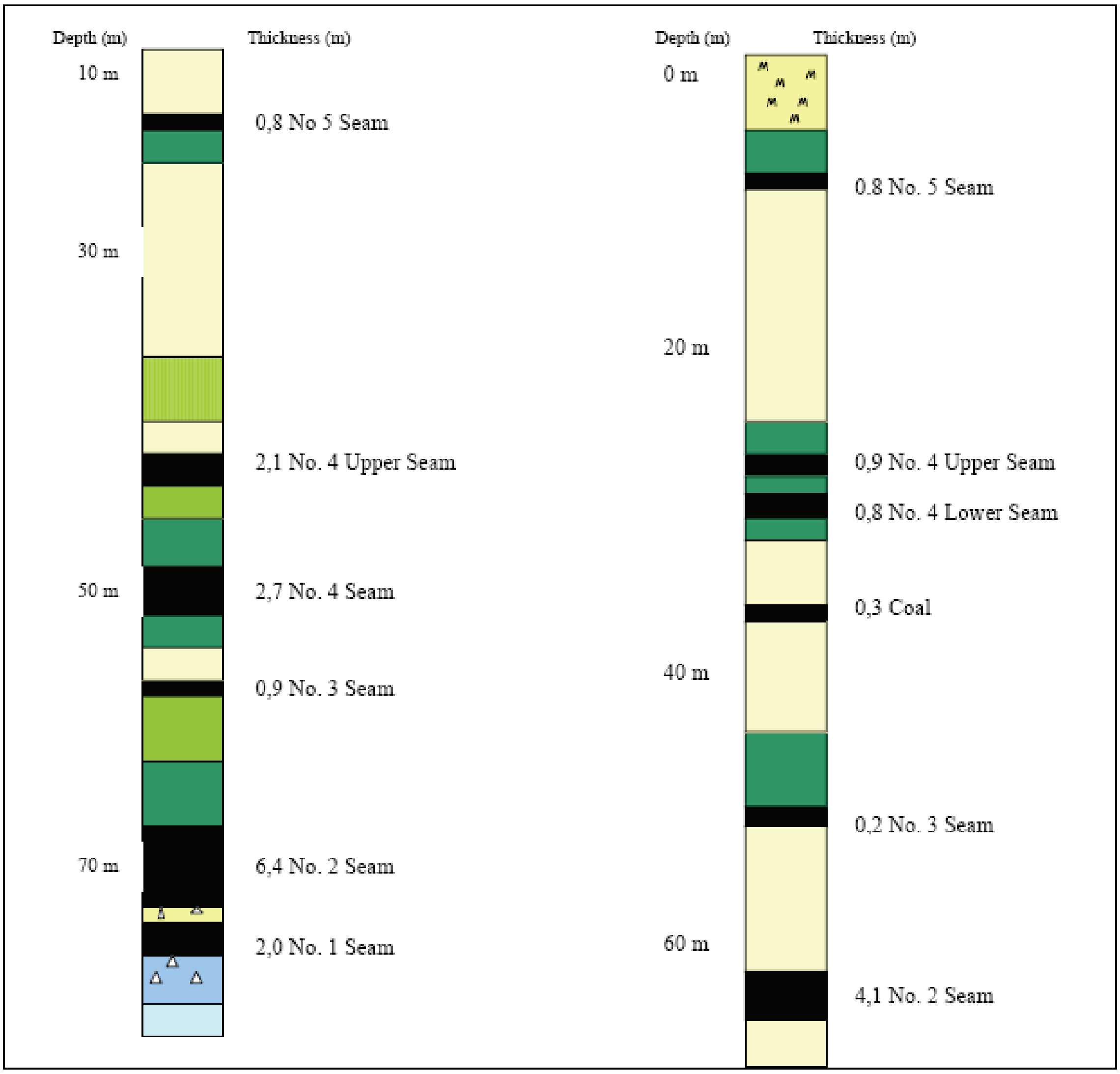

Figure 4: Two typical and generalised geological profiles for the Coalfields, showing the variability (modified from Hodgson et al., 1985).

Observed flow in the catchment confirmed isolated occurrences of recharge values as high as 15% of the annual rainfall (Hodgson et al., 1998). It should, however, be emphasised that in a weathered system, such as the Ecca sediments, highly variable recharge values can be found from one area to the next. This is attributed to the composition of the weathered sediments, which range from coarse-grained sand to fine clay.

The north-western portion of the coalfields is characterised by coarser grained sandstone and higher recharge values are expected here. It is concluded from the above information that a recharge value in the order of 3% of the annual rainfall is feasible.

The aquifer within the weathered zone is generally low-yielding (range 100-2000 ℓ /hour), because of its insignificant thickness. Few farmers therefore tap this aquifer by borehole. Wells or trenches, dug into this upper aquifer, are often sufficient to secure a constant water supply of excellent quality.

The excellent quality of this water can be attributed to the many years of dynamic groundwater flow through the weathered sediments. Leachable salts in this zone have been washed from the system long ago.

2.3.2 The fractured Ecca aquifers

Groundwater movement is along secondary structures, such as fractures, cracks and joints in the sediments due to the pores which are too well cemented to allow any significant permeation of water. These structures are better developed in competent rocks such as sandstone, hence the better water-yielding properties of the latter rock type.

Not all secondary structures are water-bearing. Many of these structures are constricted because of compressional forces that act within the earth's crust. At depths deeper than 30 m, water-bearing fractures with significant yield are found spaced 100 m apart or greater.

In terms of water quality, the fractured Karoo aquifer always contains higher salt loads than the upper weathered aquifer. This is demonstrated in the selection of water chemistries in Table 2 (Hodgson et al., 1998).

Table 2: Water qualities within the fractured Ecca aquifer in the Olifants Catchment.

Statistics	Sulphate mg/ℓ	Calcium mg/ℓ	Magnesium mg/ℓ	Chloride mg/ℓ	Sodium mg/ℓ	Elec. Cond. mS/m	pH
Mean	24	32	15	53	105	64	8.05
Median	20	27	10	22	65	58	8.04
Mode	10	22	8	8	30	59	7.70
Standard Deviation	18	18	13	78	89	34	0.45
Minimum	1	5	1	5	7	15	6.75
Maximum	80	76	69	463	330	145	8.95
Number of samples	76	76	76	76	76	76	76

Although the sulphate, magnesium and calcium concentrations in the Ecca fractured aquifer are high, they are well within expected limits. Their higher concentrations are attributed to the longer contact time between the water and the rock. The occasional high chloride and sodium levels are attributed to boreholes in the vicinity of areas where salts naturally accumulate on surface, such as at pans and some of the fountains (Hodgson et al., 1998).

2.3.3 Pre-Karoo aquifers

Drilling in only a few instances has intersected the basement to the Karoo Supergroup. Very few of the farmers, if any, tap water from the aquifer beneath the Dwyka Formation. The reasons for this are:

- The great depth.
- Low-yielding character of the fractures.
- Inferior water quality, with high levels of fluoride, associated with granitic rocks.
- Low recharge characteristics of this aquifer because of the overlying impermeable Dwyka tillite.

Instances where dewatering of this aquifer has, to some extent, occurred is where deep mining has occurred much as in the Evander Gold-fields in the Upper Vaal Catchment.

2.4 Water supply infrastructure

The major water supply infrastructure in the study area is the Witbank, Middelburg, Bronkhorstspruit, Wilge and Loskop Dams. The capacity and net catchment area (excludes endoreic areas) of the major dams as given in DWAF (2001) are listed in Table 3.

Table 3: Gross capacities and catchment areas of major dams

Dam	Gross capacity (million m^3)	Net catchment area (km^2)
Witbank Dam	104.0	3400
Middelburg Dam	48.0	1418
Bronkhorstspruit Dam	58.9	1203
Wilge Dam (formerly Premier Mine Dam)	1.6	1587
Loskop Dam	374.	4082 (incremental catchment area)

The estimate of the capacity of the farm dams and other small dams in the study area is 114 million m^3 with a surface area at full supply level of 44 km^2. These dams capacity is larger than the gross capacity of Witbank Dam.

The three pipeline transfer routes which supply water from other catchments into the study area are the Komati, Usutu and Grootdraai Dam pipelines. The transfer pipelines supply water to the power stations and provide water to some of the smaller towns such as Kriel and Hendrina. A few farmers and coal mines draw water from the pipelines.

2.5 Hydrology and water availability

The study area receives summer rain between October and May. The Mean Annual Precipitation (MAP) for the area is about 700 mm/a. The unit average runoff depth is about 5% to 8% of the MAP at between 35 mm/a to 60 mm/a. The potential mean annual Symons pan evaporation depth is 1650 mm/a.

The WR90 monthly time step hydrological model was calibrated for the Loskop Dam catchment in 1997. The historic naturalised monthly flow record produced using the model covered the period October 1920 to September 1996. The naturalised mean annual runoff (MAR) volumes produced using the model at the major dams, are listed in Table 4.

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Table 4: Summary of naturalised mean annual runoff volumes at major dams

Dam	Naturalised MAR (million m^3/a)
Witbank Dam	126,8
Middelburg Dam	41,2
Bronkhorstspruit Dam	55,3
Loskop Dam (Total Catchment)	490,0

The historic firm yields of the major dams are listed in Table 5. The yields for the Witbank, Middelburg and Loskop Dams are for the case with the water court order requiring the release of water from the Witbank and Middelburg Dams to compensate downstream farmer's water rights.

Table 5: Historic firm yield (million m3/a) from major dams in the study area

Dam	Historic firm yield (million m^3/a)
Middelburg Dam	15,3
Witbank Dam	23,9
Wilge Dam	6,4
Bronkhorstspruit Dam	16,4
Loskop Dam	155,0
Total Yield	217,0

Groundwater abstracted from the dolomites is used to supply water to meet the water requirements of Delmas. Otherwise groundwater is used in the study area on a small scale for agricultural purposes, largely for stockwatering and some irrigation.

2.6 Water Quality

The water quality in the study area has been deteriorating since 1970 when mining activities started to grow in the study area.

The sulphate and total dissolved solids (TDS) concentrations measured in the Witbank, Middelburg and Loskop Dams are shown in Figure 5,

Figure 6 and Figure 7 respectively. Also included in the plots are the water quality guidelines for the TDS and the sulphate water quality objectives set for the dams.

The plots show the increase in the TDS and sulphate concentrations in the dams over time. There was a significant increase in the concentrations after the floods of 1995. This was due to the mines holding onto the water stored in the workings after the heavy rains. When the high flow conditions and associated assimilative capacity had abated the mines discharged the excess water on the mine complexes pushing the concentrations up in the dams which had stopped spilling. This gave rise to the establishment of the controlled release scheme by the mining industry, power stations and the Department of Water Affairs and Forestry (DWAF). The scheme allows for the discharge of neutral saline water into the river system when assimilative capacity is available. The scheme has been in place since 1996 in the Witbank Dam catchment and 1997 in the Middelburg Dam catchment.

The plot of the water quality in the Loskop Dam shows the increase in the concentrations over time. The deterioration in water quality is due to the deterioration in water quality in the Witbank and Middelburg Dam catchments as well as the Klipspruit and Spookspruit.

The increase in the concentration in Loskop Dam would have been more rapid and the levels reached higher if the good quality water from the Wilge River had not arrested the increase in the concentration. The water quality in the Wilge River is under threat with the expansion of mining activities in the catchment. The water quality of the Loskop Dam is still suitable for the domestic and irrigation users using the water from the dam. The water quality however cannot be allowed to deteriorate anymore.

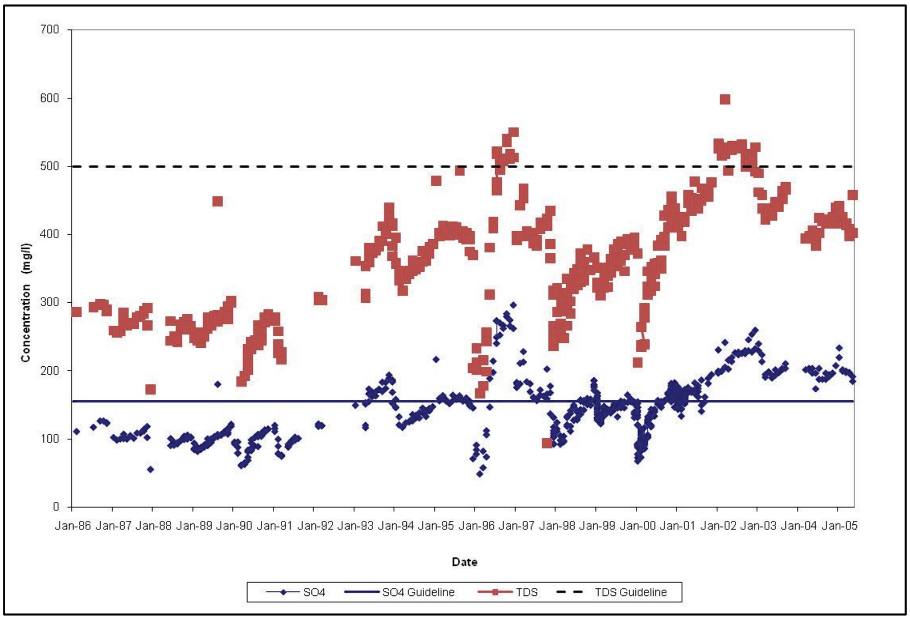

Figure 5: Plot of sulphate and TDS concentrations in Witbank Dam

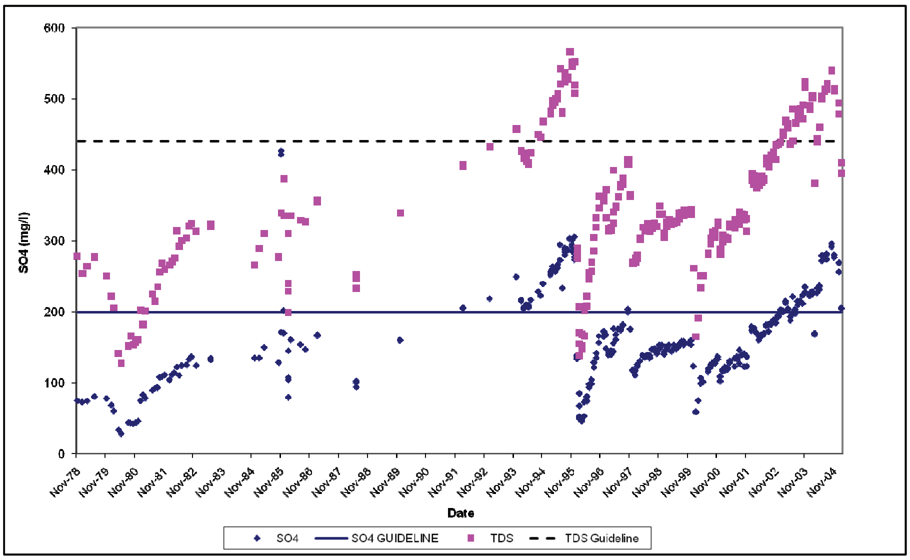

Figure 6: Plot of sulphate and TDS concentrations in Middelburg Dam

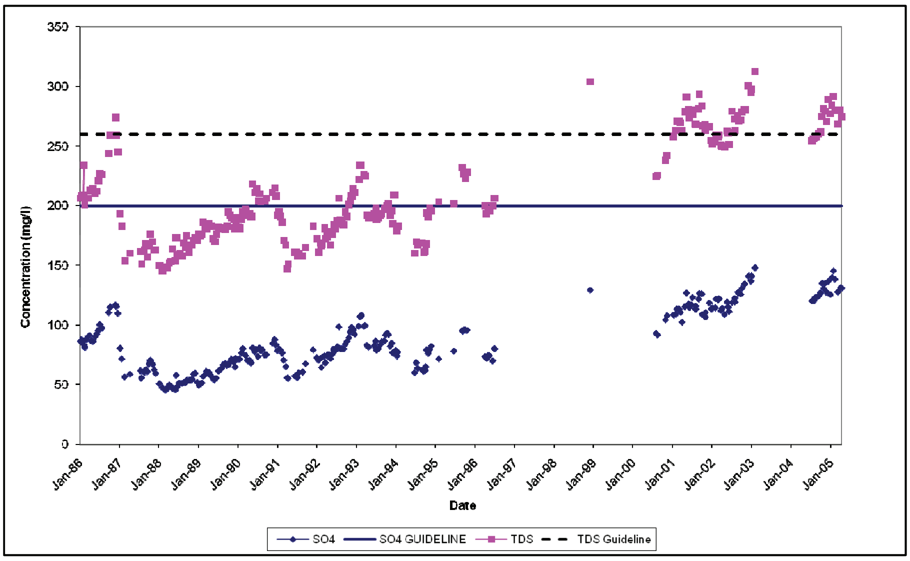

Figure 7: Plot of sulphate and TDS concentrations in Loskop Dam

2.7 Water requirements in the study area

The Steve Tshwete and Emalahleni Local Municipalities are the major water users in the study area. These local municipalities represent a possible customer for treated mine water. The water requirements of the two local municipalities are discussed below.

2.7.1 Steve Tshwete Local Municipality (LM)

The main towns in the Steve Tshwete LM are:

- Middelburg/ Mhluzi, and
- Hendrina/ KwaZamakuhle.

Middelburg is the main urbanised area in the Steve Tshwete LM with almost 84% of the population resident in this town. There are several smaller villages also situated within this municipal area. The population growth of Steve Tshwete LM was estimated to be 1.07% based on Stats SA population estimates between 2004 and 2005. However, this growth rate was based on 18 rural communities and may therefore not reflect the urban communities in the area. The water requirements for this municipality are more likely to approximate the national average population growth rate of 2%.

Current Water Use

The town of Middelburg abstracts raw water from the Middelburg Dam situated on the Klein Olifants River, with support from the smaller Pienaars Dam on the Vaalbankspruit. The current DWAF permit allows for the abstraction of 36.4 ML/day from the Middelburg Dam. The historic firm yield after allowance for the water court order (excluding the Ecological Reserve requirements) is 41.9 ML/day (15.3 million m^3/a). In the past, a large volume of raw water was supplied to industrial and commercial users such as Columbus Steel and Kanhym. However, since 1994, the industrial raw water demand decreased as both Columbus Steel and Kanhym are now partly supplied with purified sewage effluent. This has resulted in a reduction of the industrial and commercial raw water consumption of approximately 50% compared to the pre -1994 situation.

The town of Hendrina/KwaZamakuhle is supplied with water from the Komati Government Water Scheme. This line feeds raw water to a water treatment plant in Hendrina. The water allocation in 1997 was 1.8 ML/day and the projections for 2027 estimate a requirement of 4.3 ML/day.

In March 2006 the Department of Water Affairs and Forestry alerted the municipality to the fact that the yield from the Komati scheme would be reduced and that the authorised volume for Hendrina would be reduced by 20% to 1.4 ML/day, effective from January 2006.

Projected Water Requirements

Based on the historical water use recorded by the Steve Tshwete Municipality and the projected population figures for 2006, the current average daily intake per person is estimated at 242 litres.

In projecting the water requirements, the population of Middelburg/Mhluze is assumed to grow at 3% until 2030 and thereafter at 1% until 2050. After 2050 the population is assumed to be constant and the water requirements will therefore not change. The water requirements were projected on this basis assuming a use of 242 L/ca/d.

The water requirements for the smaller towns are assumed to grow at 1% until 2030 and remain steady thereafter. The water requirements projected on this basis are given in Table 6.

Table 6: Projected water requirements for the Steve Tshwete Local Municipality

Town Community	Water requirements (ML/day)			
	2007	**2030**	**2050**	**Water Source**
Middelburg/Mhluzi	32.7	64.5	78.7	Middelburg Dam
Hendrina/KwaZamakuhle	2.9	3.6	3.6	Komati pipeline
Rietkuil	1.2	1.5	1.5	Arnot Power Station
Pullenshope	1.2	1.5	1.5	Hendrina Power Station
Komati	0.7	0.9	0.9	Komati Power Station
Blinkpan	0.3	0.4	0.4	Koornfontein Mine
Presidentsrus	0.1	0.1	0.1	
TOTAL	**38.3**	**72.5**	**86.7**	

2.7.2 Emalahleni Local Municipality (LM)

The Emalahleni LM consists of the following main towns:

- Witbank town
- Ogies and Phola
- Kriel and Thubelihle
- Rietspruit.

The bulk of economic activity within the Local Municipality takes place in the town of Witbank which represents the core area/gravity point in the Emalahleni LM with approximately 79% of the total population. The projected water requirements were calculated using the population growth of Emalahleni LM which was estimated to be 3.13% based on Stats SA population estimates between 2004 and 2005.

Current Water Use

Witbank, Ogies and Phola currently obtain all their water from Witbank Dam which was constructed in 1971 and has a capacity of 104 million m^3 and a historic firm yield of 65.5 ML/day (23.9 million m^3/a). The current abstraction permit allows for an abstraction of 75 ML/day. However, this is already exceeded by *de facto* water abstractions of up to 105.8 ML/day.

The Highveld Steel Corporation is one of the largest industries in Emalahleni LM and is also the largest single consumer of water. Their current water demand is approximately 22 ML/day which still varies, with a higher demand during dry periods when little storm water is available to augment the supply of water to the industry. The company has self-imposed water demand management targets of 1% reduction per year and does not expect any significant increase in demand due to expansion.

The current demands on the dam are therefore:

- Witbank Water Treatment Works ± 88 ML/day
- Highveld Steel Corporation ± 22 ML/day

These water requirements clearly exceed the historic firm yield of Witbank Dam by a large margin.

Kriel obtains raw water from Eskom via Kriel Power Station. There is a potable water purification works with a nominal capacity of 7 ML/day. The current water use is estimated to be approximately 3.8 ML/day. This is still well within the capacity of the existing supply.

The Rietspruit Township obtains raw water from Rietspruit Dam. The treatment plant has a capacity to provide more than 4 ML/day. The consumption of water in this township is however excessively high and according to available records is on average more than 3.2 ML/day. Based on the projected 2006 population figures, this implies an average utilisation of 400 litres per person per day.

Emalahleni LM, as most other local municipalities in South Africa, has an ever growing challenge with the development of scattered informal communities within its area of jurisdiction, in some cases illegally. In terms of the Water Services Act, 1997, the municipality is responsible for providing these communities with basic services and these communities are currently served by means of water tankers.

Table 7 indicates the projected water requirements for the Emalahleni LM. The water requirements are projected to grow at 3% until 2030 at 1% until 2050 and to remain constant thereafter.

Table 7: Projected water requirements for Emalahleni local Municipality (Ml/day)

Town/Community	Water Requirements (ML/day)			
	2007	2030	2050	Water Source
Witbank (Potable)*	81.4	160.6	195.9	Witbank Dam
Phola/Ogies (Potable)*	6.2	12.2	14.9	Witbank Dam
Highveld Steel (Raw)	22.0	22.0	22.0	Witbank Dam
Total from Witbank Dam	109.6	194.8	232.8	
Rietspruit**	3.0	3.8	4.6	Rietspruit Dam
Kriel/Thubelihle***	3.9	6.1	9.1	Usutu GWS
TOTAL	116.5	204.7	246.5	

*Note: *based on 3% population growth rate; ** 1% growth rate; ***2% (national average)*

In terms of the housing backlog, there are still approximately 36 157 houses that need to be built. If these houses are supplied with full services, assuming low income standards, the water demand could grow by approximately 25 ML/day.

2.8 Reconciliation of water availability and water requirements

2.8.1 Steve Tshwete Local Municipality

Middelburg/Mhluzi

It is clear that based on the development that is planned for the next 20 to 25 years, the Steve Tshwete LM has a huge challenge to ensure sufficient raw water that can be purified to satisfy its projected water requirements. The Middelburg Dam which has a historic firm yield of 41.9 ML/day is the major source of water, supplying almost 84 % of the Steve Tshwete LM population.

Based on the projected water requirements, the supply from Middelburg Dam will have to be augmented by 2015.

Hendrina/ KwaZamakuhle

Based on the historical water use reported in Table 6 , it is clear that the current water supply of 1.4 ML/day from the Komati pipeline is already only 50% of the Hendrina/KwaZamakuhle requirement and by 2027 will contribute only 33% of the towns' requirements. Hendrina/KwaZamakuhle urgently requires a supplemental water resource. The Local Municipality has placed a moratorium on further developments in the town.

Informal and Rural areas

Informal and rural areas are supplied either by tanker in certain cases or else abstract water from boreholes.

Small mining towns

The small mining and power station towns such as Pullenshope, Rietkuil, Komati, and Blinkpan are currently supplied with potable water supplies via the mines or power stations. It is not expected that this will change in the near future.

Table 8 indicates that there is already a need to supplement water supplies in the Hendrina/KwaZamakuhle area, and by 2015 the Middelburg/Mhluzi area will also require a supplemental source of water.

Table 8: Excess/shortfall for water requirement in the Steve Tshwete LM

Town	Available (Ml/day)	Current requirements (Ml/day)	Current Excess/ shortfall (Ml/day)	Requirement in 2027(Ml/day)	Excess/ shortfall in 2027 (Ml/day)
Middelburg/Mhluzi	41.9	32.7	8.3	48.6	- 6.7
Hendrina/KwaZamakuhle	1.4	2.9	- 1.5	4.3	- 2.9

The water requirement projections of Middelburg/Mhluzi are being revised and are expected to increase. This will move the date forward for the next source of water for the local municipality.

2.8.2 Emalahleni Local Municipality

From the above, it is clear that based on the development that is planned for the next 20 to 25 years, the Emalahleni LM has a huge challenge to ensure sufficient raw water that can be purified to satisfy its projected water requirements. The Witbank Dam, which has a historic firm yield of 65.5 ML/day, is the major source of water, supplying almost 90% of the Emalahleni LM population.

Based on a 3 % population growth rate, the projected demand for potable water by 2030 is around 180.1 ML/day (this assumes that the water used by Highveld Steel and SA Coal Estates will not increase). This figure is considerably higher than the historic firm yield of the dam.

The Witbank town is currently growing rapidly with residential developments covering the range from low-income to high-income markets. The future growth of the town will be severely constrained without an additional source of water.

The Emalahleni Water Reclamation Project involving Greenside, Kleinkopje and South Witbank Collieries will reclaim mine water for municipal use from mid-2007. The project will ramp up the supply of water to the town from 10 ML/day in 2007 to 20 ML/day in 2009.

Kriel

The town of Kriel has a reliable source of water from Eskom. The concern in this area is the high cost of water. The next source of water for Kriel would be a supply of water transferred from the Vaal River System. The cost of this transfer water is expected to be about R6/m^3 for raw water.

Rietspruit

The community of Rietspruit is not expected to grow over the next few years, however, the current water supply is adequate for a population of 20 000 people each using 200L/day, almost three times the number of people currently resident in Rietspruit. Water conservation measures could decrease the amount of water used in this town.

Informal Areas

The informal areas that cannot be supplied by the Witbank potable source are supplied by water tankers. This type of supply is expensive and other water supply options for these outlying areas are being investigated. Table 9 summarises the current and projected future water requirements with associated excess or shortfalls.

Table 9: Excess/shortfall for water requirements in the Emalahleni LM

Town	**Available (Ml/day)**	**Current requirements (Ml/day)**	**Current excess/ shortfall (Ml/day)**	**Requirement in 2030 (Ml/day)**	**Excess/ shortfall in 2030 (Ml/day)**
Witbank (Potable) and Phola/Ogies (Potable)*	87.7	112.6	- 24.9	171.0	- 83.3
Rietspruit	4,0	1.6**	+ 2.4	3.7	+ 0.03
Kriel/Thubelihle	7.0**	3.8	+3.2	5.8	+1.2

*Note: *These figures include a constant volume used by Highveld Steel; ** adjusted based on 200litres/person/day and not based on current excessive usage; **based on water treatment plant capacity; [#]Emalahleni Water Reclamation Project included*

In the Witbank area, the shortfall of potable water is expected to grow from the current 24.9 ML/day to more than 80 ML/day. Emalahleni LM will therefore have to take immediate steps to secure a further water resource, without which growth will be stunted.

3 DESCRIPTION OF METHODOLOGY

3.1 Introduction

One of the main objectives of the study is to identify a suite of models that can be used to evaluate the long term impacts and management of coal mining on the water quantity and quality of a catchment. The model suite was applied to the Middelburg and Witbank Dam catchments to investigate long term strategies to manage the mining impacts in the catchments.

As most of the mining is located in the Middelburg Dam and Witbank Dam catchments, this project focused on these two catchments. Resource Water Quality Objectives (RWQO) have been set for the Middelburg and Witbank Dams. The RWQO are instream concentrations for a range of water quality variables. The RWQO ensure that the water users and the ecology are protected if the RWQO are met. Mine water can contribute acidity, salinity and heavy metals to the receiving water environment. Acid water should be treated before release to the receiving water environment and the neutralising process should include the removal of heavy metals. Sulphate as a product of pyrite oxidation processes is a good indicator of mining impacts. If the sulphate is managed to meet the RWQO and the discharge water is neutral then the balance of the water quality variables will most likely meet the RWQO. Sulphate has therefore been used in the assessment of the performance of the different management options investigated in this project. The RWQO for sulphate for the Middelburg and Witbank Dams are 180 mg/ℓ and 155 mg/ℓ respectively. If a management strategy results in the RWQO at the dams being met then the strategy is successful. The baseline case is the “do nothing” scenario. The other management options can be compared to this option.

The approach adopted in the analysis is summarised as follows:-

- Identify a management option
- Cost the management option
- Set up the model for the identified management options.
- Run the model of the system and check the Middelburg and Witbank Dam’s concentrations against the RWQO
- Determine the net present value for the option for comparison with other options analysed.

To be able to carry out the process described above, the following activities were undertaken:-

- Data Collection
- Workshops
- Identification of management options
- Model identification, selection and model framework development
- Formulation of management scenarios for analysis
- Modelling impact of scenarios on water quality at key points in the study area for the different scenarios
- Cost-analysis of the management options applied at the mines for each scenario
- Reporting

The approach adopted in each of the activities listed above is given in more detail in the sections below.

3.2 Collection of mine data

The mine data was collected from the mines by sending a letter requesting the data to the individual mines and the head offices of the major mining groups. The mines agreed in principle to provide the data for the project. The approval was followed up with a list of requirements sent to the mines. Where necessary site visits were undertaken to collect the data. The following data was requested:

- Mine plans including mining methods (opencast, high extraction underground, Bord and pillar underground).
- Percentage extraction of coal.
- Discard dump areas and seepage rates.
- Floor contours – x,y,z in electronic format.
- Topographical plan of the mine area showing infrastructure. This map should be provided electronically if possible.
- Water quality in workings.
- Water balance diagram showing circuits and volumes.
- Current water levels in workings.
- Pollution control dam capacities and water quality of water in dams.
- Location of current and future decant positions and levels.

The level of data received from the different operations varied. The BHP Billiton mines had recently embarked on a series of studies undertaken by Prof F Hodgson of the IGS. This series of reports provided useful information on the floor contours, mine plans, water volumes in the workings and locations of decant positions. Similar information was available for the South African Coal Estates (SACE) complex, Mafube and Arnot opencast. A recent survey was undertaken by the mining industry on the available water on the mines that can be used to supply water users external to the mine. This survey gave the excess water available on the mines in 2006, 2017 and 2027 and at closure. These volumes have been used for the mines for which the more detailed information is not available. The pertinent data collected for the Middelburg and Witbank Dam catchments are presented in the sections below.

The water quality of the water in the different workings was not readily available from the mines. The water quality database of the controlled release scheme was used as a source of the latest sulphate concentrations of the mine waters that will be released to the river system or that have to be managed.

3.2.1 Information for mines in the Middelburg Dam catchment

The mines for which information is available in the Middelburg Dam catchment are Woestalleen, Optimum, Arnot opencast (Anglo Coal), Arnot underground (Exxaro), Eikeboom and Mafube. Mafube is a new mine and is in the construction phase of its development. Optimum includes the Eikeboom section and the recently opened Kwagga Sections. The Klipbank section which falls in the Vaalbankspruit catchment is being mined by Optimum with the coal processed at Eikeboom. The old Arnot U2 underground workings fall under Optimum as well. Optimum supplies coal to Hendrina Power Station and coal for export and Arnot underground supplies Arnot Power Station. The Arnot opencast is a defunct mine and is managed by Anglo Coal on a care and maintenance basis. Mafube Colliery is to be supplied with water abstracted from the Arnot opencast workings. The locations of the mines in the Middelburg Dam catchment are shown in Figure 8.

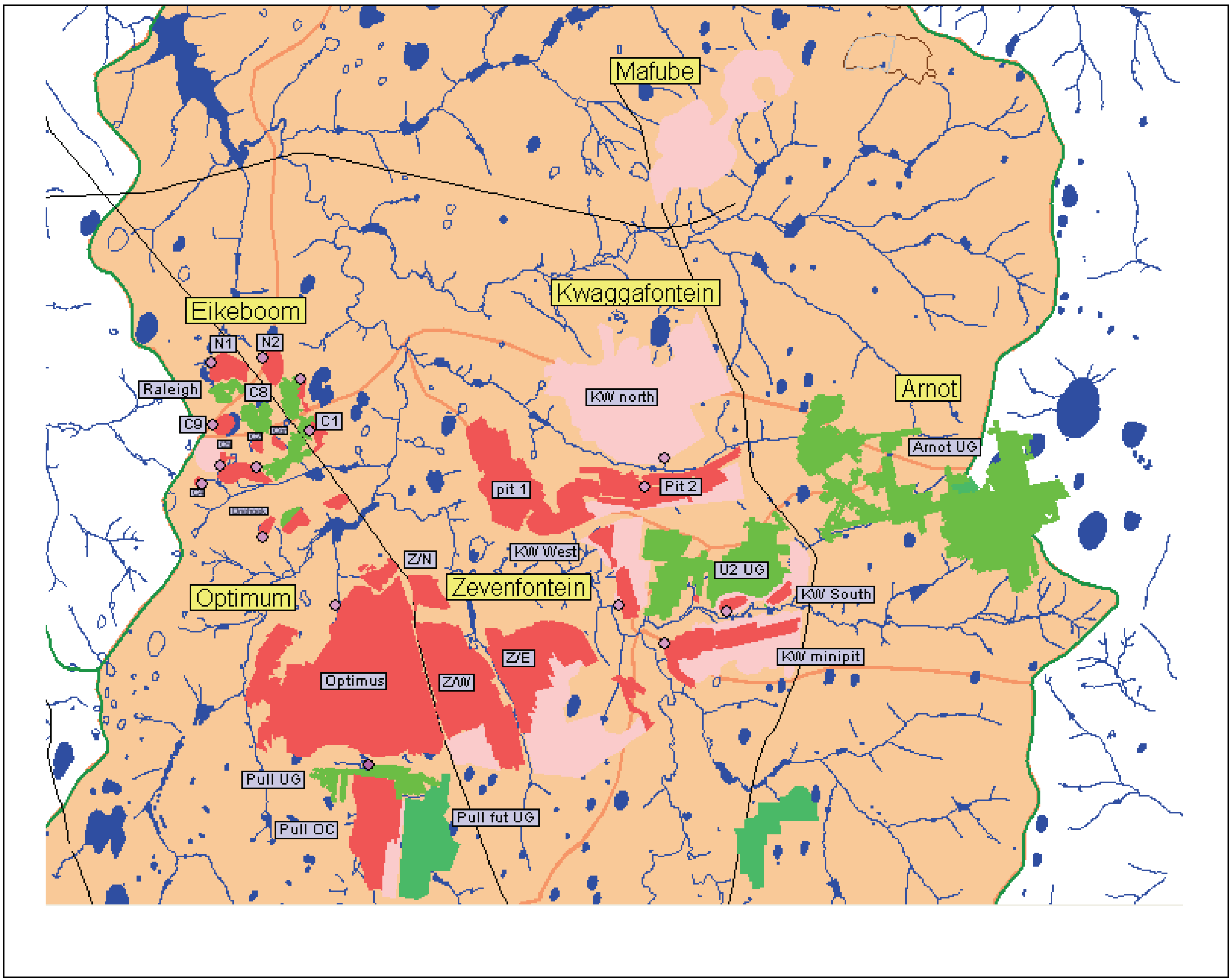

Figure 8: Location of mines in the Middelburg Dam catchment

Optimum Colliery has excess mine water which has over the years been managed by controlled releases. However the excess mine water volumes now exceed the assimilative capacity that can be made available through controlled releases. A feasibility study has been undertaken by the colliery to investigate the future water management on the mine. The result of the study is the construction of a 33 ML/d desalination plant in modules of 11 ML/d. The first 11 ML/d module will manage the water from the Optimus, Pullenshope and Zevenfontein sections. The tenders for the first 11 ML/d unit are being evaluated with construction envisaged in 2008. The plant will supply potable water to Hendrina/KwaZamakuhle with the balance of the treated water released to the Zevenfonteinspruit. The water make from the recently started Kwagga sections is presently managed separately as will the water for the future Schoonoord and Boschmanspoort sections.

For the assessment of management options, the mines were grouped into the following three groups:

- Optimum grouping which includes the Optimus, Pullenshope and Zevenfontein sections.
- Kwagga grouping which includes Arnot U2 underground and the Kwagga opencast sections.
- Schoonoord
- Boschmanspoort
- Eikeboom and Klipbank.
- Mafube
- Arnot/Eskom Collieries

The groupings are based on the location of the mines to each other which dictates the feasibility of managing the water as a grouping. By managing water together as a group use can be made of the storage available in the mine workings on the different mines and the water supply infrastructure can be better managed. The opencast and underground mining areas as well as the available storage volume in the workings for the 7 groupings are shown in Figure 9, Figure 10, Figure 11, Figure 12, Figure 13 and Figure 14.

The water requirements of each water use grouping include water for use in the coal beneficiation plant and for dust suppression. The estimated water requirements in each grouping are listed in Table 10.

Table 10: Water requirements for mines in groupings

Grouping	Water requirements (m^3/d)
Optimum	6000 (Optimum plant) + 500* (d/s) = 6500
Kwagga	1000 (d/s)
Eikeboom/Klipbank	3200 (Eikeboom plant) + 500 (d/s) = 3700
Schoonoord	500 (d/s)
Boschmanspoort	1000 (d/s)
Mafube	2200 (plant + d/s)
Arnot opencast and underground	3000 (Arnot plant)

* d/s dust suppression

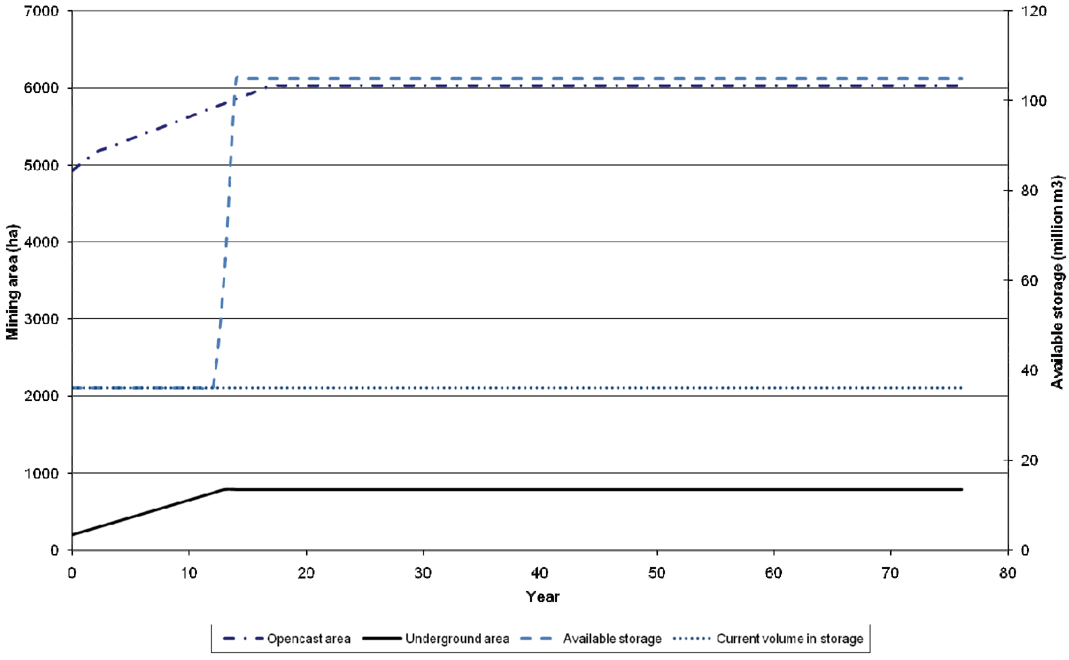

Figure 9: Plot of mining areas and available storage in the Optimum grouping for the 74 year period from 2006 to 2080

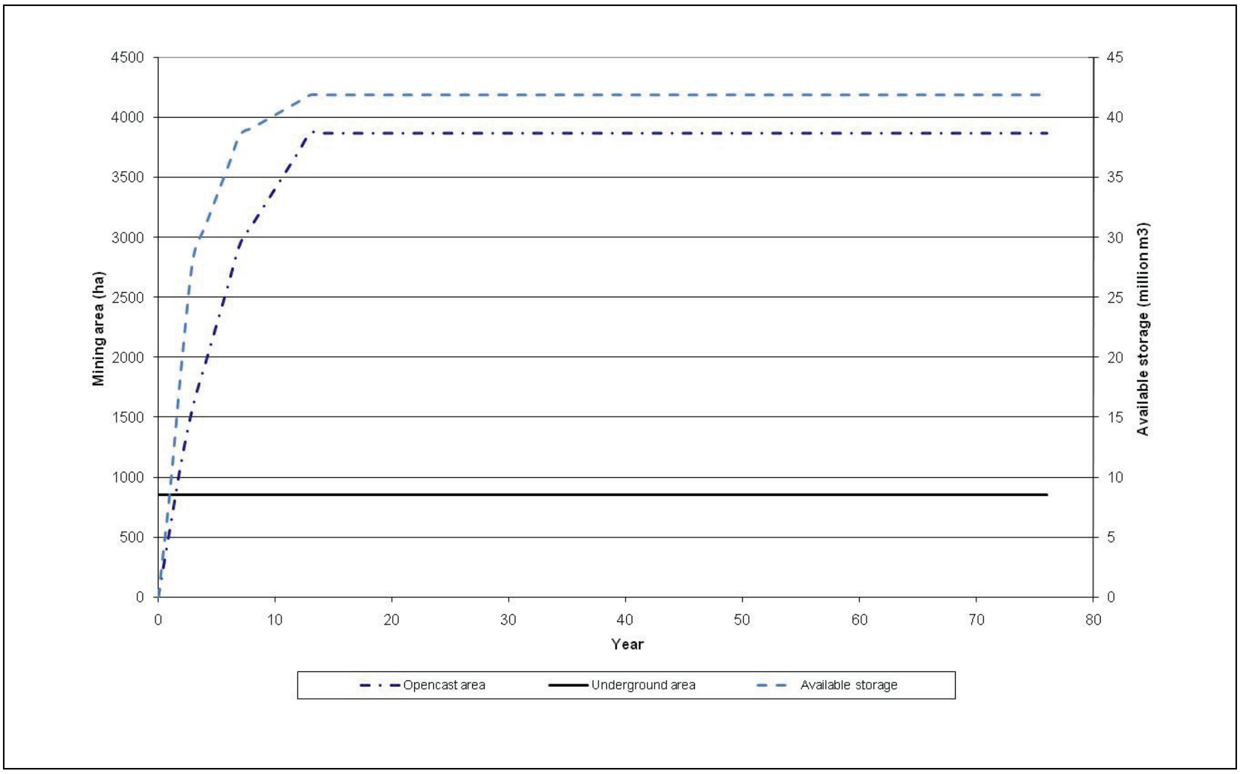

Figure 10: Plot of mining areas and available storage in the Kwagga grouping for the 74 year period from 2006 to 2080

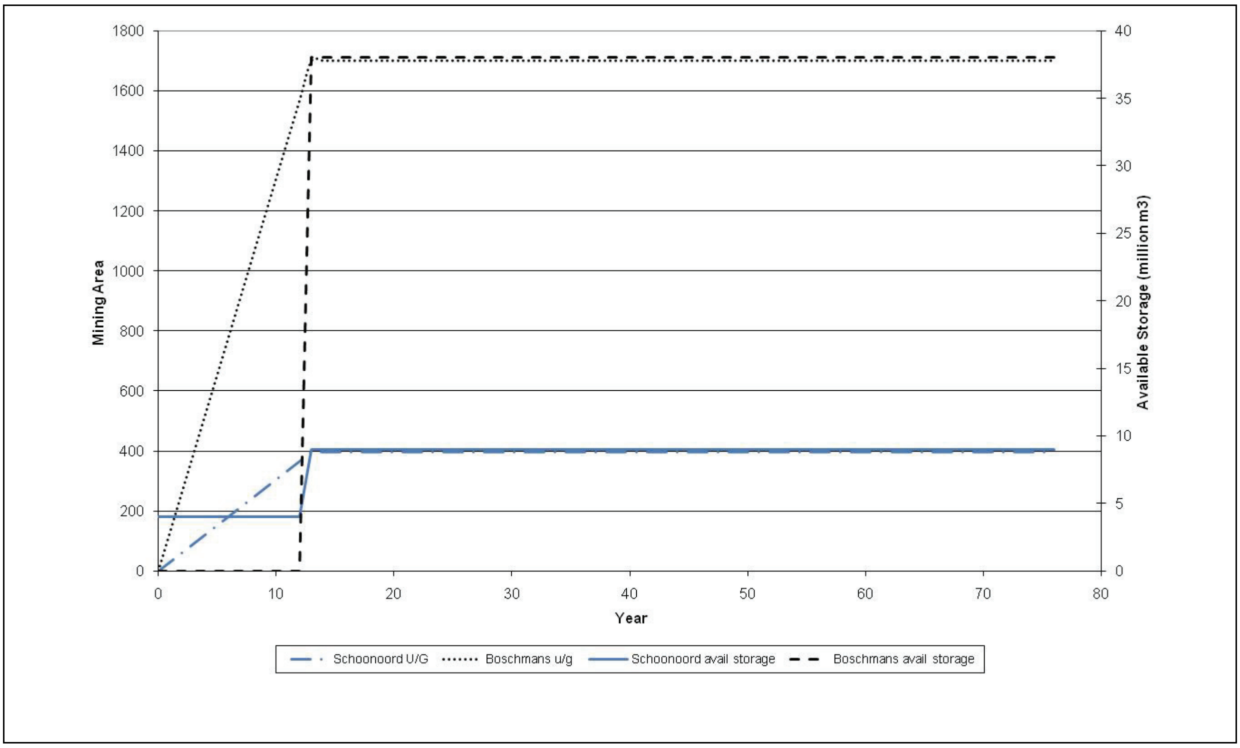

Figure 11: Plot of mining areas and available storage in the Schoonoord and Boschmanspoort underground workings for the 74 year period from 2006 to 2080

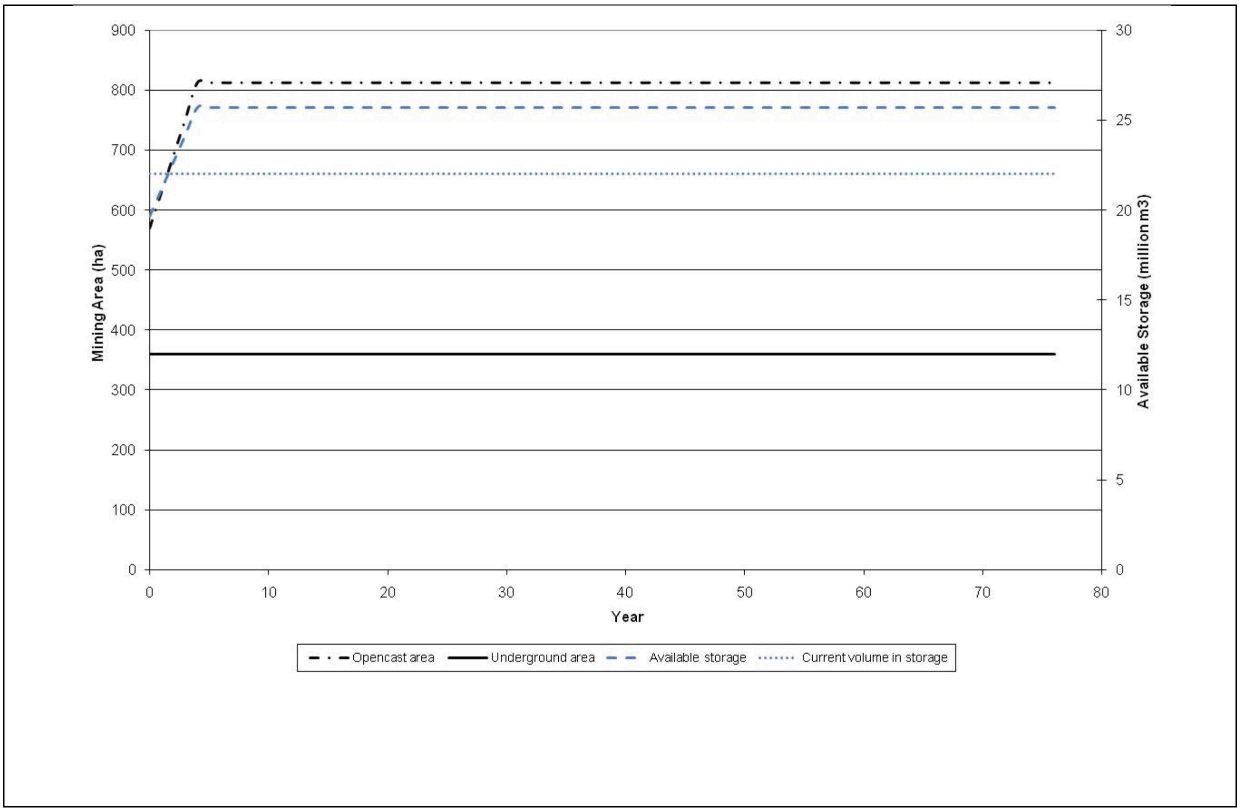

Figure 12: Plot of mining areas and available storage in the Eikeboom/Klipbank grouping for the 74 year period from 2006 to 2080

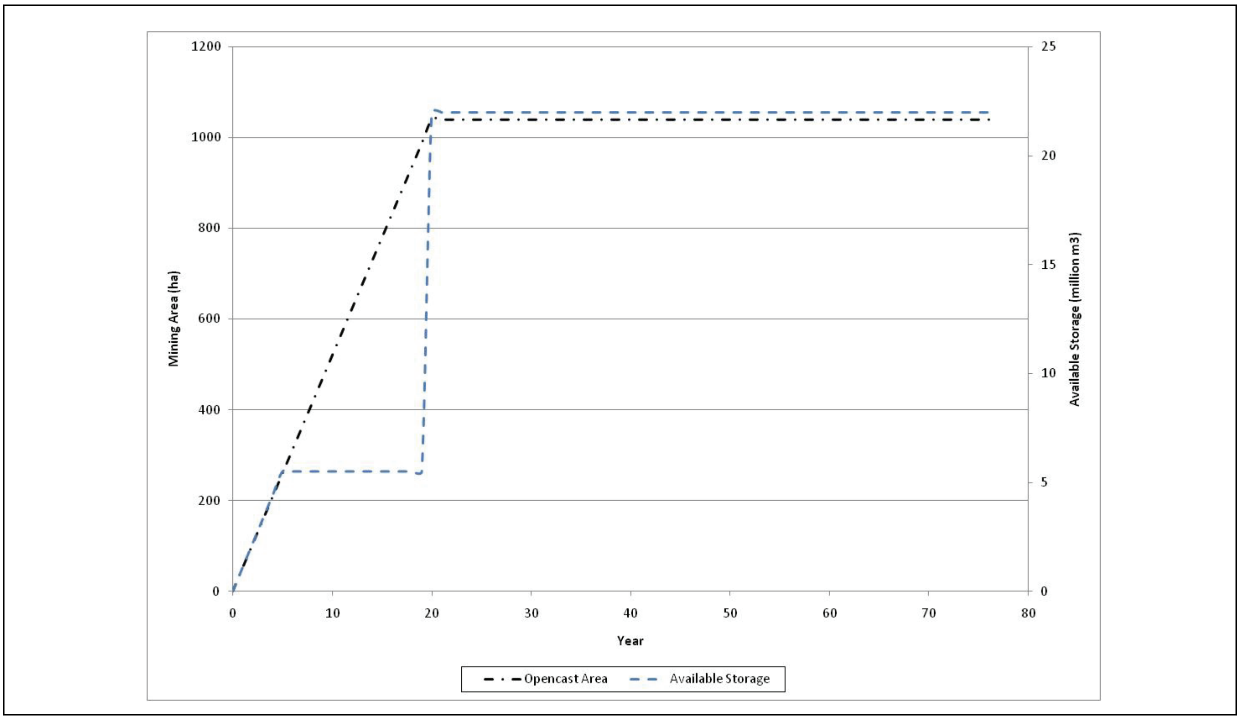

Figure 13 : Plot of mining areas and available storage at Mafube Colliery for the 74 year period from 2006 to 2080

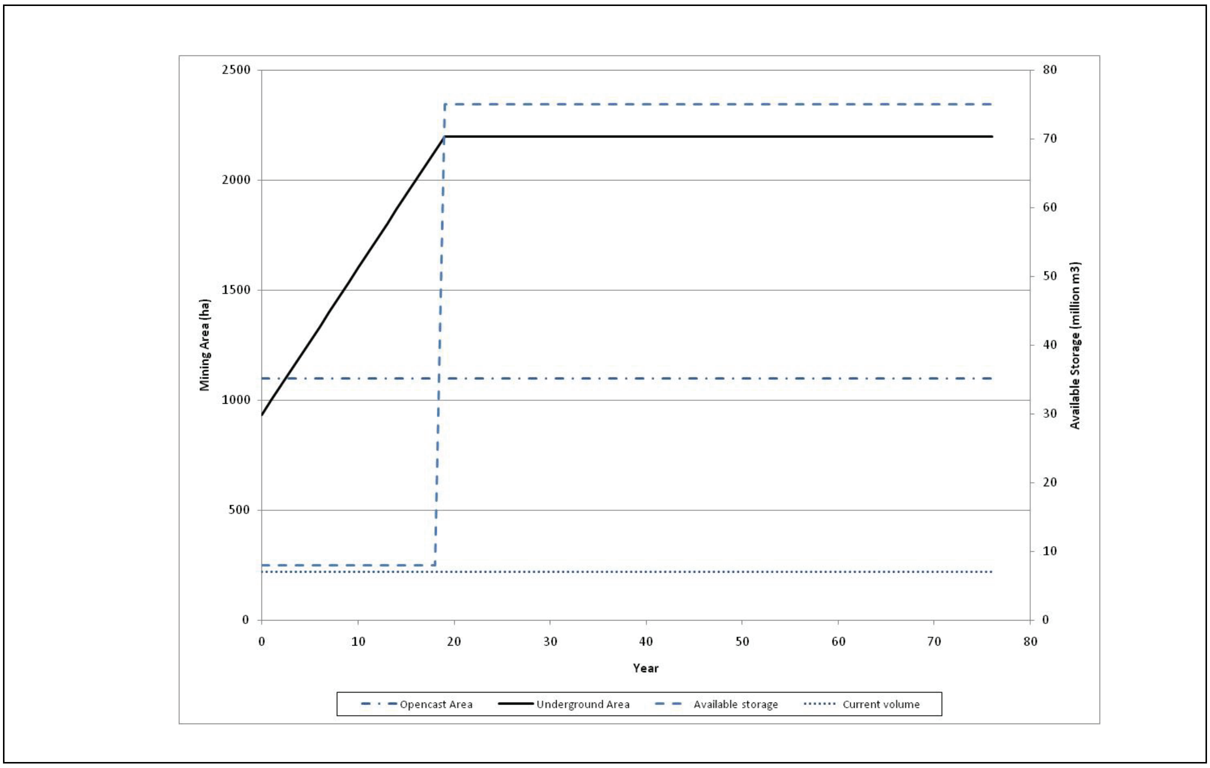

Figure 14: Plot of mining areas and available storage at Arnot/Eskom Collieries for the 74 year period from 2006 to 2080

3.2.2 Mine information for Witbank Dam Catchment

The mines in the Witbank Dam catchment are Kendal/Khutala (except Block I opencast), Kriel, iMpunzi, Tweefontein, Goedehoop South, Middelburg Mine Services South, Douglas, Matla, Rietspruit, SACE (Kleinkopje, Greenside, Landau), New Clydesdale, Transvaal Navigation Colliery, Syferfontein, Koornfontein and Isibonelo. The locations of the collieries for which information was made available are shown in Figure 15.

The level of information obtained from the mines in the Witbank Dam catchment was variable. For some of the mines the areas of the different types of mining, stage storage curves for the workings and the volumes of water in the workings was obtained. For others an indication of the available water and the time at which the excess water would be available was provided.

The more detailed level of information was available for the SACE complex, Kendal/Khutala, Rietspruit, Koornfontein, Middelburg Mine Services and Douglas. The excess water information was available for the balance of the mines. The excess water is the water available after filling of the available storage and the use on the mine. Another use has to be found for this water.

The data for the mines for which a more detailed level of data is available are shown plotted in Figure 16, Gigure 17 and Figure 18..

The total water make, water use and storage for the Xstrata Coal South Africa (XCSA) iMpunzi, Tweefontein, Goedegevonden and Southstock mines were taken from Jones and Wagener (2006). The change in the total water make and the available storage over time is shown in Figure 19. The mining at the Koornfontein and Douglas Collieries has largely been completed and Rietspruit Colliery has closed. The rehabilitation of the Rietspruit Colliery is underway. The feasibility of mining the pillars at the Douglas

Colliery is being investigated by BHP Billiton Energy Coal South Africa (Becsa). If this happens, a dewatering program will have to be developed to empty the workings to allow mining to take place. This will involve treatment of the mine water. At this stage the future mining of the Douglas pillars has not been considered for this study.

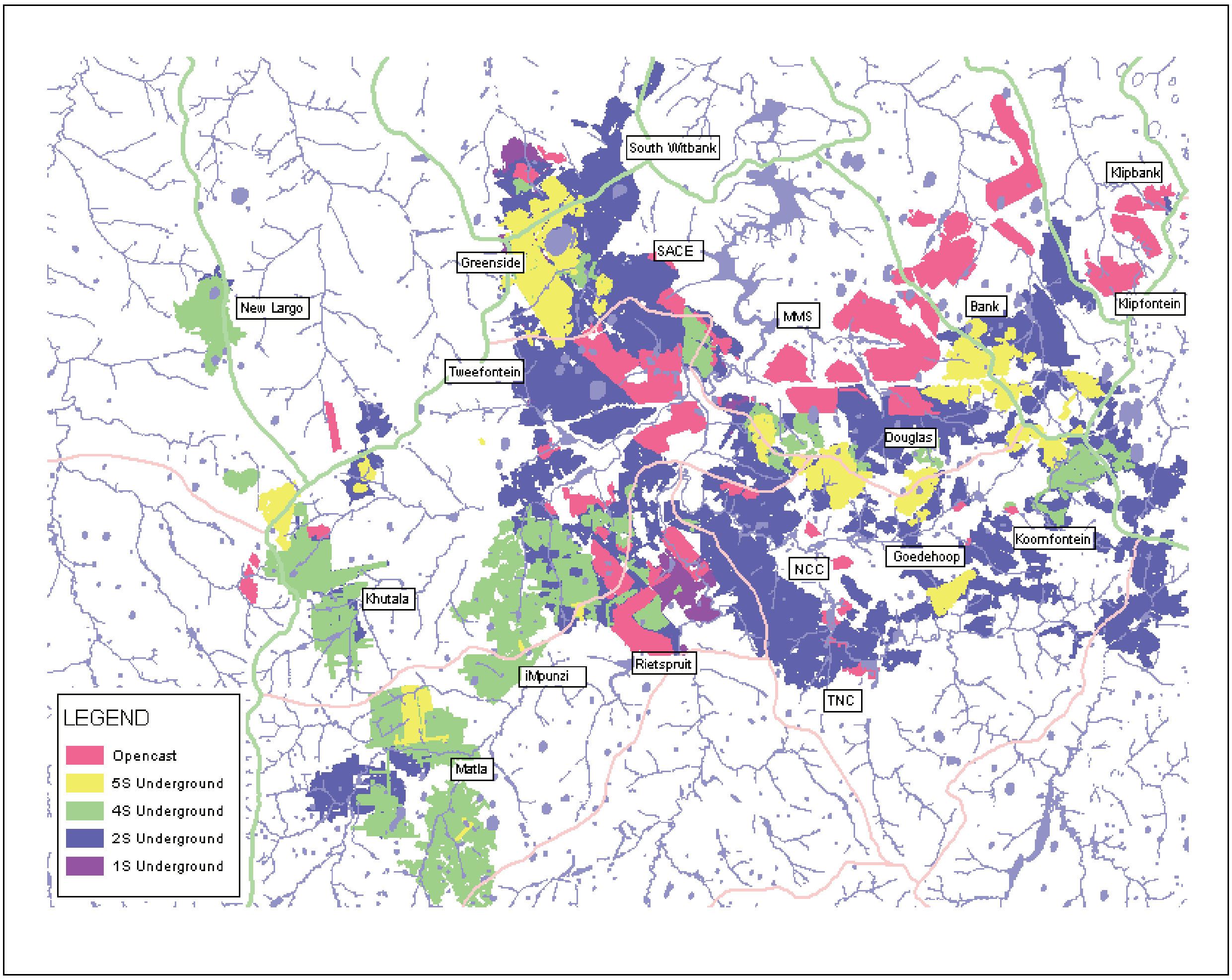

Figure 15 : Location of mines in the Witbank and Loskop Dam incremental catchments

The areas, current volumes and storage volumes at decant are listed in Table 11 for Douglas, Koornfontein and Rietspruit Collieries. The chances of Rietspruit Colliery decanting are unlikely. The colliery is adjacent to the iMpunzi and at some stage the head developed in the workings will be such that the volume in the workings will seep into the adjacent collieries at a rate that equals the average recharge to the workings.

The excess water from the balance of the mines for which a lower level of detail was available are listed in Table 12.

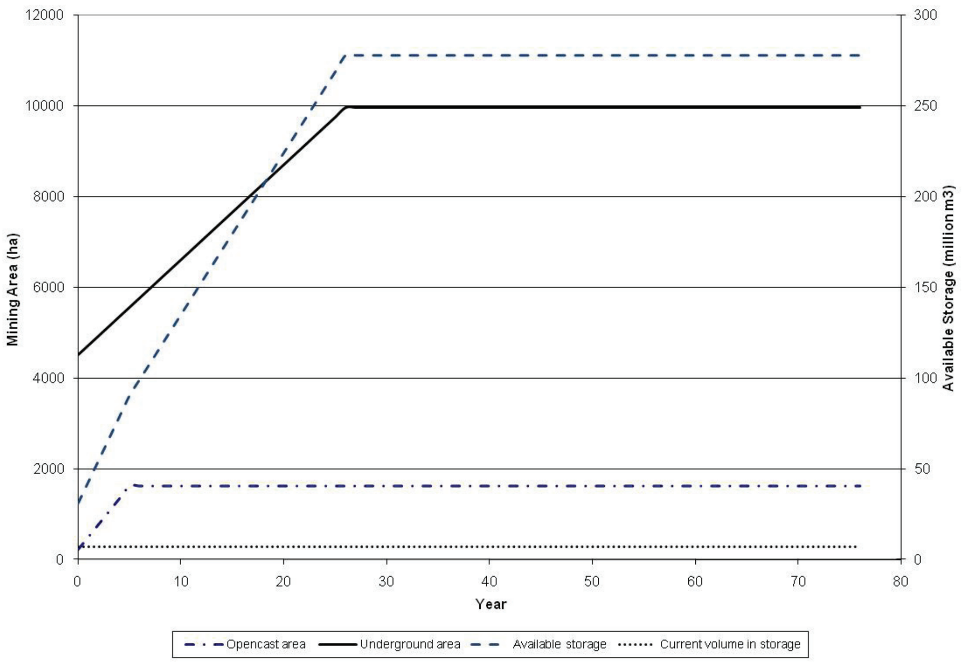

Figure 16 : Plot of mining areas and available storage at Khutala/Kendal Colliery for the 74 year period from 2006 to 2080

Table 11: Mining areas, current volume and available storage in Rietspruit, Koornfontein and Douglas mines

Mine	Mining Area (ha)	Current volume in storage (million m^3)	Storage Volume at decant (million m^3)
Rietspruit	Underground – 678 opencast – 1097	14.3	104.3
Koornfontein	Underground – 5938 opencast – 57	15.0	72.0
Douglas	Underground – 5201	45	90

Table 12 : Summary of mine excess water volumes (m3/d) for mines with lower level of information detail

Colliery	Year			
	2006	2017	2027	2040
New Clydesdale	1.5	1.8	2.0	2.0
TNC	3.0	3.0	3.0	3.0
Goedehoop	2.3	4.4	5.5	5.5
Matla	4.0	6.3	7.7	7.7
Isibonelo	0.0	0.6	1.0	1.0

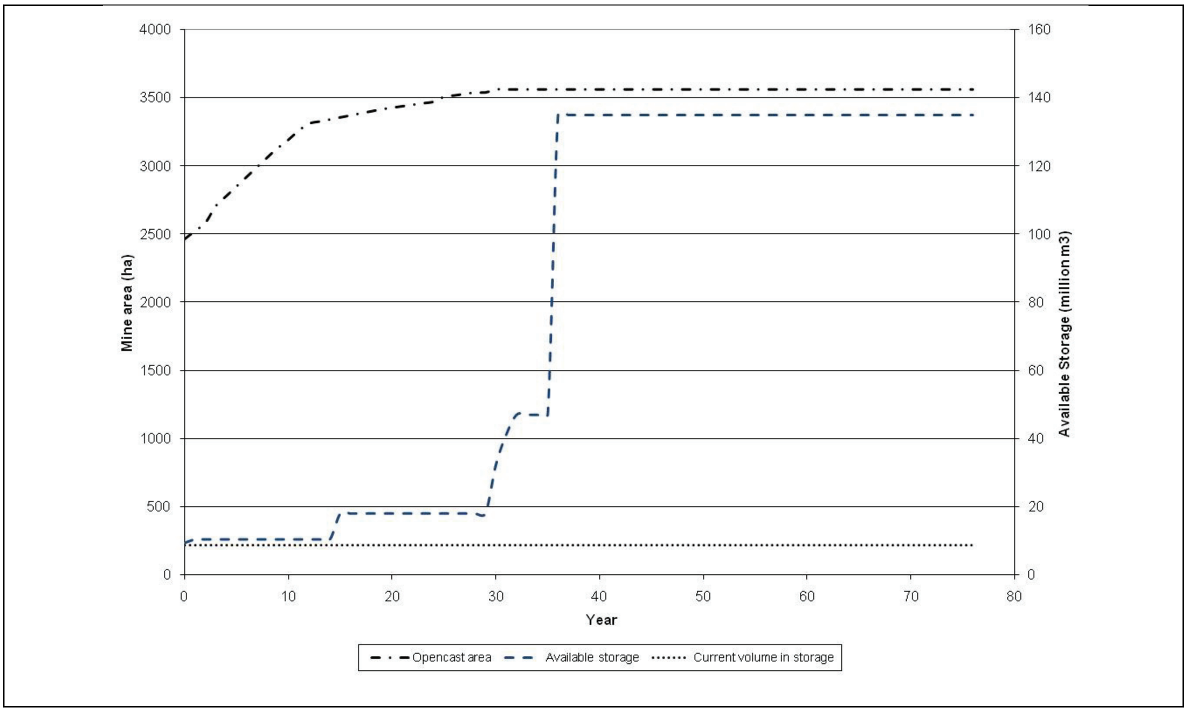

Figure 17 : Plot of mining areas and available storage at Middelburg Mine Services – South Section for the 74 year period from 2006 to 2080

The water requirements of the mines for which detailed information was made available are listed in Table 13. The water requirements include the water needed to operate the plant and dust suppression. In the case of the SACE complex the water used in the mine water irrigation trials are also listed as a water use. For Middelburg Mine Services allowance has been made for the planned provision of water to Duhva Power Station at about 6000 m^3/d.

Table 13: Water requirements for mines in Witbank Dam catchment

Grouping	Water requirements (m^3/d)
Khutala\Kendal	1000
Xstrata – iMpunzi, Tweefontein, Goedgevonden, Southstock	15000
Douglas	6000 (Vandyksdrift plant)
Middelburg Mine Services – South Section	2000 (Plant) + 1500 (D/s) = 3500 Supply to Duhva Power Station
SACE	5700 (Kleinkopje+Greenside plant) + 930 (irrigation) + 1000 (D/s) = 7630

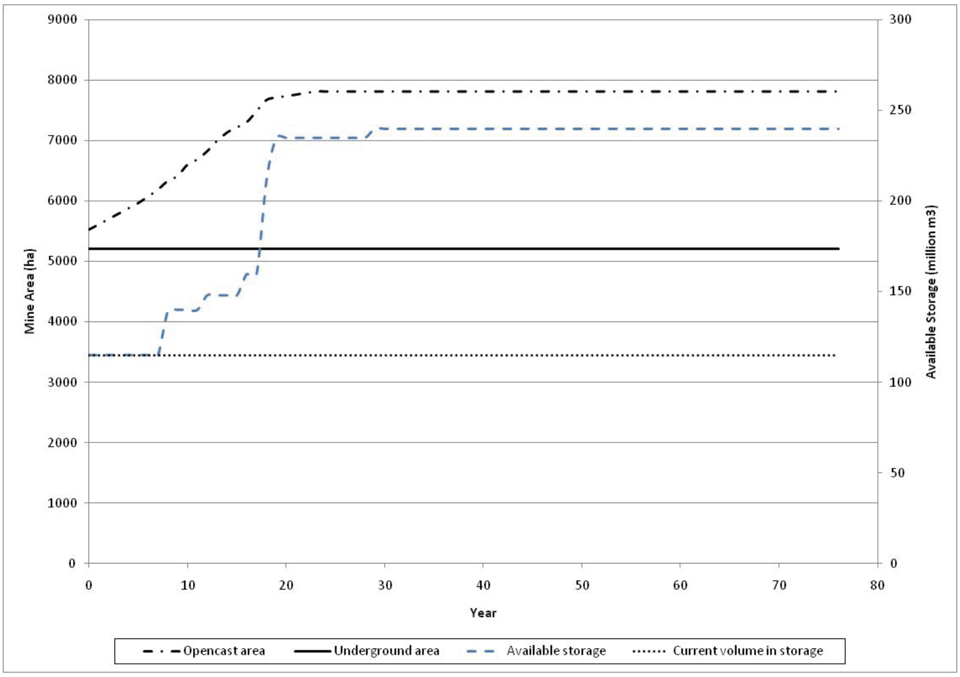

Figure 18 : Plot of mining areas and available storage at SACE for the 74 year period from 2006 to 2080

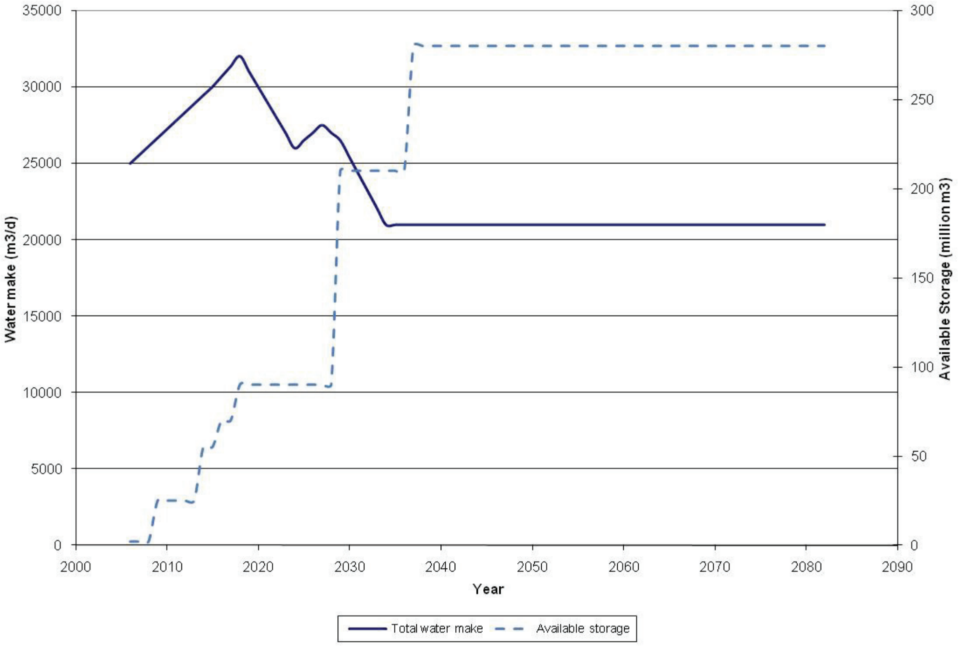

Figure 19 : Plot of total water make and available storage at iMpunzi, Southstock, Tweefontein and Goedgevonden Colliery for the 74 year period from 2006 to 2080

The sulphate concentrations in the workings are presented in Table 14.

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Table 14: Sulphate concentration of mine water

Mine	Sulphate concentration (mg/ℓ)
Khutala/Kendal	2119
Koornfontein	Gloria shaft – 152 Block B opencast – 1585
Douglas	Pit 4a – 720-1020
MMS- South	Driefontein Dam – 2650-2860
Kleinkopje	Dam 2A – 1305-2020 Pit 5W – 1225-2580
IMpunzi	Kromfontein Dam – 748 Tweefontein Dam – 1200
Rietspruit	Third Pit – 2181 North – 3271 South – 2768
Matla	Mine 1 – 332 Mine 2 – 797 Mine 3 – 390
Isibonelo	98-120 – current essentially groundwater
Goedehoop	1000 – 2000
TNC	824-1617

3.3 Workshops

A workshop was held with the mines at Greenside Colliery on the 18 November 2005. At the workshop the objectives of the project were presented and the management options identified were explained and discussed. The project was well received by the mines and the value of the project was recognised by the workshop. Further feedback was given to the mines through the controlled release management committee meeting held monthly.

3.4 Identification of management options

A review of the literature dealing with management options was undertaken by the project team. An interim report was produced detailing the findings of the literature review. The report was circulated to the mines and to the project Reference Group for input. The management options identified are presented and discussed in Chapter 4 of this report.

3.5 Model selection and model framework development

There are a number of models available that can be used to assess the impacts of mining on the groundwater and surface water. There are two levels of impact assessment needed *viz*. the local or management unit level and the regional or catchment level.

The local level would be at a level of a quaternary catchment or smaller while the regional level would be at the Witbank Dam or Middelburg Dam catchment level. Generally the Environmental Management Programme (EMP) that has to be developed before a mine gets a mining licence addresses the local impacts over the life of mine and at closure. The regional level impacts will have to be quantified using a catchment level model. Ideally the catchment level models should be set up by DWAF for the catchment. The new mine can then be included in the model and the impacts assessed.

The models can be divided into groundwater, geochemical and surface water models.

The issues that have to be addressed at the local level by groundwater and geochemical models are:

- Extent of the cone of depression that will develop around the mine during the operation.
- The contribution that groundwater will make to the mine water workings during operation.
- Develop a dewatering program for the mine if required.
- The water quality of the groundwater that will report to the workings and will be pumped from the workings. The evolution of the water quality profile from the mine over time.
- The re-watering of the workings and the prediction of the water quality in the workings after re-watering
- The extent and nature of the pollution plume emanating from the mine workings and waste disposal facilities.

The groundwater flow regimes and the groundwater and geochemical models related to mining are discussed in the following sections in more detail.

In general groundwater models are used to assess local impacts. A groundwater model could be set up for the region. This type of model would be used to assess the impact of a number of mines on the groundwater regime and the interaction between groundwater and surface water.

In other words, a regional groundwater model can be used to assess the reduction in the groundwater contribution to surface flow due to the changes in groundwater caused by mining. Ideally surface and groundwater should be in a combined modelling system.

At the regional scale, the surface water models need to assess the impact of mining on flow and water quality. Individual mines are part of a bigger catchment perspective and have to be viewed in this light. Local impacts affect the regional scale. The regional scale is managed by a Catchment Management Strategy (CMS) and mines have to fit into this plan. The CMS will typically address RWQO, land use management, water availability and water requirements. The CMS will dictate where the mines will have to get water from for their operations as well as the instream water quality that will have to be achieved locally and regionally.

The regional scale models therefore have to integrate the mine with the catchment. The impacts that this mine as an entity has on the catchment have to be identified and included in the model at a level of detail which capture the impact mechanisms appropriately. Regional scale models are typically run at a monthly time step for long periods of time typically in excess of 50 years. The longer time periods are needed to capture the hydrological variations that are experienced at regional level

A number of models were identified that could be used in the study. The identified models were evaluated against a set of criteria and the model chosen for use on the project.

3.6 Formulation of management scenarios for analysis

The formulation of management scenarios requires crystal ball gazing especially 80 to 100 years into the future. Assumptions have to be made regarding climate change, population growth, water requirements and the local and regional economy. The assumptions made for this study were:

- The power stations will still be present in the catchment. The power stations will continue to supply the local towns with water.
- The population of the main towns of Witbank and Middelburg will continue to grow until 2050, thereafter the population and water requirements will stabilise.
- The water supply for the smaller towns such as Kriel, Rietspruit and Rietkuil will continue as they are at present.
- There are no further water resources available for development in the study area. Treated mine water is the only water available to meet the projected water requirements of Steve Tshwete and Emalahleni Local Municipalities.

- Further irrigation with groundwater and surface water will not be allowed in the catchment. Further irrigation will only be considered if excess mine water is used on rehabilitated mine areas.
- The current mine plans and mine water management systems are assumed to be followed over the analysis period.
- In developing the management options cooperation between mines is assumed. The legal aspects of transferring polluted water between mines is not considered in the management options.

A management scenario consisted of a series of interventions spaced in time that can be used to manage the excess mine water. A management scenario could include at source management such as improved covers and rehabilitation standards, irrigation with mine water for a period of time or the construction of mine water treatment plants. The series of management interventions are input into the catchment model and the impact of the management scenario on the water quality and quantity is determined.

3.7 Impact modelling

This project has focused on the impact of mining on the water resources at both the local and regional levels. The local impacts were assessed by applying the daily time step ACRU-salinity model to the B11C quaternary catchment. The model was applied to assess the impact of a dummy mine on the flow and water quality in the quaternary. The water resource planning model (WRPM) was applied to assess the impacts of the current and future mining and management options at the regional scale.

The assumptions used in the impact modelling were:

- The analysis was done from 2006 to 2080 using the available historic hydrological record.
- The historic rainfall and flow records covering the period October 1920 to September 1996 were used in the analysis. The records were assumed to start in 2006 i.e. 1920 year was used at 2006 and 1996 became 2083. This historic record contains all the recorded combinations of wet and dry years as well as seasonality that can be used for determining the impacts.
- The mining data collected during the study were input into the model. The start year for the mining data was 2006. The mining areas were assumed to change over time.
- The current management options planned by the mines were assumed to go ahead. These are the 20 ML/d Emalahleni water reclamation plant at Greenside Colliery, the 11 ML/d plant at Optimum Colliery and the supply of water from the Arnot opencast to Mafube Colliery.
- The impact of each of the management scenarios on the water quality and quantity was assessed using the model. The water quality impact was measured by comparing the modelled time series of sulphate concentrations to the RWQO for sulphate in the Middelburg and Witbank Dams.
- The water requirements of towns must be supplied without failure over the historic record.

3.8 Cost analysis

A cost model was developed. The model included both capital and operating costs for each management scenario. The model was applied to determine the net present value (NPV) for each management scenario. The level of costing applied was at the desktop level. The costs generated at this level will allow for a realistic comparison of the strategies.

The assumptions made in the cost model are:

- The discount rate used for the calculation of the NPV was 8%. This is the typical interest rate used by DWAF to assess water resource information projects such as Lesotho Highlands. Therefore this interest rate was adopted for this project.
- Inflation was ignored in the cost calculations. The costs were determined in 2006 costs.

- The management strategies were developed for the 74 year simulation period and the NPVs were determined over this period.
- The treatment costs are based on the recently received tenders for the Emalahleni and Optimum treatment plants. The technology used was reverse osmosis (RO) and the plants specifications are a 98% recovery. The waste after filter pressing is a sludge cake and a brine. The brine is disposed of in solar ponds that meet the minimum requirements and the sludge cake in a waste disposal facility.
- It is assumed that the brine ponds and the sludge disposal facility are located adjacent to the plant.
- The waste disposal facilities at desalination plants are based on current technology with no recovery of by products for sale.
- Many of the costs will be site specific. A default value based on experience was used for the rehabilitation costs.
- If treated mine water is supplied to the local municipalities then potable water is provided by pipeline into the municipalities potable water network. A revenue stream is generated for the sale of the water.

The capital and operating costs for the management options considered are summarised in Table 15. The 2006 electricity costs were used in the analysis. However the potential for significant increases in the electricity tariff exists. The growth in electricity cost has not been considered in the analysis.

3.9 Capacity Building

The capacity building that was included in the proposal was achieved with two students undertaking post graduate studies on the project. Mr. Idowu Olefemi achieved a PHD at the University of KwaZulu-Natal. He applied the ACRU Salinity model to the Kleinkopje Colliery and to the B11C quaternary catchment to determine the impact of mining on runoff.

Mr Neil Scholtz of the Institute of Groundwater Studies (IGS) completed his MSc on the project. Mr. Scholtz was involved in the collection of mine data, the management option progress report and applied the WQT model to look at the management options at closure in the Middelburg Dam catchment.

Table 15: Capital and operating costs for the management options considered

Management option	Capex (Rand)	Opex (R/m^3)	Comment
Desalination plant	R10 million per ML/d Replacement of membranes every 5 years at 5% of capital cost	6.50	The operating cost includes R2/m^3 for replacement of plant every 20 years.
Brine pond	R1.4 million per ML/d	Included in plant operating costs	This cost is variable and depends on the location of the brine ponds in relation to the plant, topographical and the geotechnical conditions. The life of the brine ponds.
Sludge disposal facility	R1.0 million per ML/d	Included in plant operating cost	This cost is variable and depends on the distance that the sludge has to be transported, topography and the geotechnical conditions.
Cost of standard 600 mm cover poorly constructed	R150000/ha	Annual maintenance cost of R4000/ha for a period of 5 years after construction of cover	This cover is not well constructed without consideration given to free draining surfaces, material selection and erosion in terms of rehabilitation slopes and protection.
Revenue stream from sale of water	R2.80/m^3		This is the income that can be generated from the sale of water from the potable water treatment plants to water users for domestic use
Cost of standard 600 mm cover well constructed	R250000/ha	Annual maintenance of R2000/ha for a period of 5 years after construction of cover	
Cost of well constructed 1200 mm cover	R400000/ha	Annual maintenance of R2000/ha for a period of 5 years after construction of cover	In constructing this cover consideration is given to erosion protection, slopes and free draining surfaces. Particular attention is given to making the rehabilitated surfaces free draining so as to minimise recharge to the workings.
Electricity cost	R0.17/kwh		
Irrigation – centre pivot	R40000/ha	1.1 kwh/ha and an average duty cycle of 4 hour/d	Life of centre pivot 5 years
Pipeline costs	R3000/m installed	Power consumption calculated for each pipeline depending on pumping height and pipe diameter	

4 MANAGEMENT OPTIONS

4.1 Introduction

The management options discussed in this section relates to the management of water quality during and post mining. Many of the options are geared not so much to improve the water quality during operations, but to ensure that measures are implemented at the appropriate times during the operation which results in a decrease in the water quantity and an improvement in the water quality that will be produced from the mine post closure. The implementation of many of the management options will result in the expenditure of money earlier in the mine life but will result in savings post closure.

The efficiencies of the management options or groups of management options, with regard to decreasing pollution loadings, are based on limiting one or more of the following factors:

- Amount of pyritic material
- Availability of oxygen to the pyritic material
- Contact of water with the pyritic material

4.2 Pollution Prevention and Control Planning

Early planning and careful design of operations is the key to minimizing pollution associated with mining activities. Specific responsibilities should be assigned for the implementation and monitoring of environmental measures. Before mining begins, a mining plan and a mine *closure* and rehabilitation plan must be prepared and approved. This forms part of the EIA and EMP processes followed to get mining approval. These plans define the sequence and nature of extraction operations and detail the methods to be used in closure and rehabilitation. These plans should be updated regularly (every three to five years) as mining progresses.

4.3 Mining and Water Management Plan

This plan defines the sequence and nature of extraction operations and details the methods to be used in closure and restoration. At a minimum, the plan must address the following:

Opencast

- Removal and proper storage of topsoil.
- Early rehabilitation of worked-out areas and of spoil heaps to minimize the extent of open areas.
- Diversion and management of surface and groundwater to minimize water pollution problems. Simple treatment to reduce the discharge of suspended solids may also be necessary.
- Identification and management of areas with high potential for acid mine drainage (AMD) generation.
- Minimize the generation of AMD by reducing disturbed areas and isolating drainage streams by avoiding contacts with sulphur bearing materials.
- A water management plan for operations and post-closure including minimization of liquid wastes by methods such as recycling water from tailings wash plant.
- Minimization of spillage losses by proper design and operation of coal transportation and transfer facilities.
- Reduction of dust by early revegetation and by good maintenance of roads and work areas. Specific dust suppression measures may be required for coal handling and loading facilities such as minimizing drop distances, covering equipment, and wetting storage piles. Release of dust from crushing and other coal processing and beneficiation operations should be controlled.

- Controlling the release of chemicals (including floatation chemicals) used in beneficiation processes.
- Development of suitable rehabilitation and revegetation methods, appropriate to the specific site conditions.
- Proper storage and handling of fuel and chemicals used on-site to avoid spillages.

Underground methods

- Mine from deep to shallow
- Diversion and management of surface and groundwater to minimize water pollution problems.
- Identification and management of areas with high potential for AMD generation.
- Minimize the generation of AMD by reducing disturbed areas and isolating drainage streams by avoiding contacts with sulphur bearing materials.
- Controlling the release of chemicals (including floatation chemicals) used in beneficiation processes.
- Development of suitable rehabilitation and re-vegetation methods, appropriate to the specific site conditions.
- Minimization of the effects of subsidence by careful extraction methods in relation to surface uses.

4.4 Mine Closure and Rehabilitation Plan

The plan should include reclamation of open pits, waste piles, beneficiation tailings, sedimentation basins, and abandoned mine, mill, and camp sites. Mine reclamation plans should incorporate the following:

- Return of the land to conditions capable of supporting prior land use, equivalent uses, or other environmentally acceptable uses.
- Use of overburden for backfill and topsoil (or other plant growth medium) for reclamation.
- Contour slopes to minimize erosion and runoff.
- Plant native vegetation to prevent erosion and encourage self-sustaining development of a productive ecosystem on the reclaimed land.
- Management of post-closure AMD from workings and seepage from tailings facilities.
- Budget and schedule for pre- and post-abandonment reclamation activities.

Upon mine closure, all shaft openings and mine adits should be sealed or secured.

There is a need to reserve money over the life of the mine to cover the costs associated with mine closure. The amount of money and the type of financing required will depend on a number of factors such as the projected life of the mine, the nature of the operations, the complexity of environmental issues, the financial and environmental management capacity of the borrower/project sponsor, and the jurisdiction in which the mine is located. The mine reclamation and closure plan, the timing of its submission, and its financing should be discussed and agreed with the borrower/sponsor as early as possible.

4.5 Diversions

Diversions are engineering controls that are used to divert ground water or surface water so as to prevent the water entering mining areas (opencast and underground workings), thereby reducing the volume of water that could potentially become polluted and have to be managed on the mine. Two types of diversions are run-on controls and capping:

Run-on controls prevent surface water from entering mining areas or areas of contamination and becoming contaminated. For example, surface waters may be diverted to avoid contact with stockpiled waste rock or the inflow of water into a mine. Examples of run-on controls would include retaining walls, gabion dams, check dams (both permanent and temporary), and diversion ditches. The costs of run-on controls are low to medium depending on the method used for the diversion. The use of run-on controls to divert surface water away from areas of contamination is effective in reducing the quantity of water that requires treatment and returning clean water back to the water resource.

An example of a run-on-control is shown in Figure 20 where Map A shows that uncontaminated surface water originating uphill of a tailings pile will become contaminated after flowing across or through the contaminated pile. Map B shows that a properly placed diversion ditch will channel the water originating uphill of the pile away from the pile to avoid becoming contaminated.

The maintenance of diversion ditches is required for their continued effectiveness. Water should flow unencumbered along the base of the ditches and should not overflow the ditch walls for the design recurrence interval flood peak. In South Africa, the ditches are required to be sized for a 50 year recurrence interval flood peak. Ditch maintenance should include cleaning debris out of the ditches, checking that there is a constant drop in slope of the ditch bottom, and repairing erosion along ditch walls.

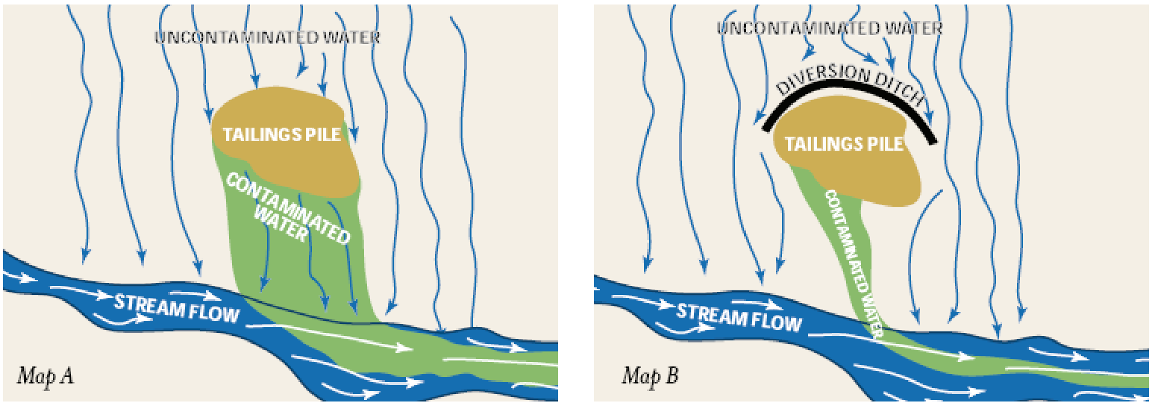


Figure 20: Schematic showing an example of a run-on-diversion control

4.6 Capping/covers of rehabilitated spoil and waste heaps

4.6.1 Capping/covers

Capping of waste rock tailings or rehabilitated spoils is a protective layer or cover of soil, graded to promote runoff rather than infiltration into the reactive materials (mostly opencast, but also underground workings). Any minor water or wind erosion that occurs will remove soil from the cap and should not disturb the contaminated waste rock or tailings. This will ultimately improve the water quality downstream of the waste rock or tailings pile, by eliminating the source of contamination.

The cap will also provide an uncontaminated soil layer in which vegetation can grow. Vegetation of the cap will further protect the soil and decrease erosion of the cap by cushioning the impact of the raindrops on the capping material. The vegetation further binds the soil and reduces the velocity of overland flow and the potential for erosion of the cover.

Caps range from simple to complex in design and vary widely in cost. The different types of caps depend on the toxicity of the material to be capped and what materials are available at or near the site. In the majority of cases, simple covers are adequate. Composite covers are used when the material is highly reactive if mixed with surface water. Complex caps are used in situations of highly toxic materials and are often combined with liners under the toxic material.

Covers are often referred to as evaporative covers in that the infiltrating water is held in the cover material and is evaporated. In this way the infiltration water into the mine workings or the waste heaps is reduced. The covers also reduce the ingress of oxygen and hence the pyrite oxidation reactions are slowed. The climate in the Mpumalanga coal fields is ideally suited to evaporative covers as the potential for evaporation exceeds the rainfall. The selection of the material for the cover is important as it has to hold onto the water so that it can be evaporated during dry periods between rainfall events.

1) Simple cover: The simplest, least expensive type of cap consists of soil obtained at the site.

A minimum of 150 mm is desirable, because some erosion may occur before vegetation is established. A cover in excess of 300 mm is optimum. The material for the cover is often sourced from the overburden and top soil stockpiles, the excavation material from diversion ditches and from borrow pits.

2) Composite cover: These caps have at least two layers of different soil types. The lower layer lying next to the waste rock or tailings is fine-grained, high density and low permeability. The purpose of this layer is to inhibit water from the surface from seeping into the contaminated pile and forming acid drainage. The upper layer consists of coarser material and is lower in density. The purpose of this layer is to encourage plant growth. This cap should be vegetated once it is in place.

3) Complex cover: A complex cover consists of inter layered synthetic filter fabrics and fine and coarse material. The principles of this cap are the same as the simple and composite caps, which is to inhibit water infiltration into the reactive material below and encourage plant growth on the top. The actual design and installation of these caps is site-specific and generally costly. Capping should be performed immediately after grading of the pile in order to minimize the opportunity for erosion.

The costs will vary depending on site topography and location of the capping material relative to the location of the pile. The primary cost is based on equipment usage and may include dump trucks, excavators, bulldozers, backhoes or loaders. The covers require maintenance after construction and re-vegetation. This can go on for a period of 10 years after completion depending on the standard of the initial cover. Maintenance involves fertilizing, cutting back vegetation, re-vegetation and repair to erosion gullies and subsidence areas.

A set of experiments were carried out at the Kilbarchan Colliery in KwaZulu-Natal where a set of cells were constructed at the site. A weather station was established at the site, the cells were filled with coal spoils and different covers were placed on the cells. The capping ranged from no cover, single layers, compacted layers and multiple cover layers.

The volume and quality of the water reporting to the bottom of the cells was measured. The water volumes reporting to the base of the cells was expressed as a fraction of the annual rainfall over the monitoring period from 1994 to 2001 at the cells. The results for the various covers as reported in Vermaak et al. (2000) is shown in Figure 21.

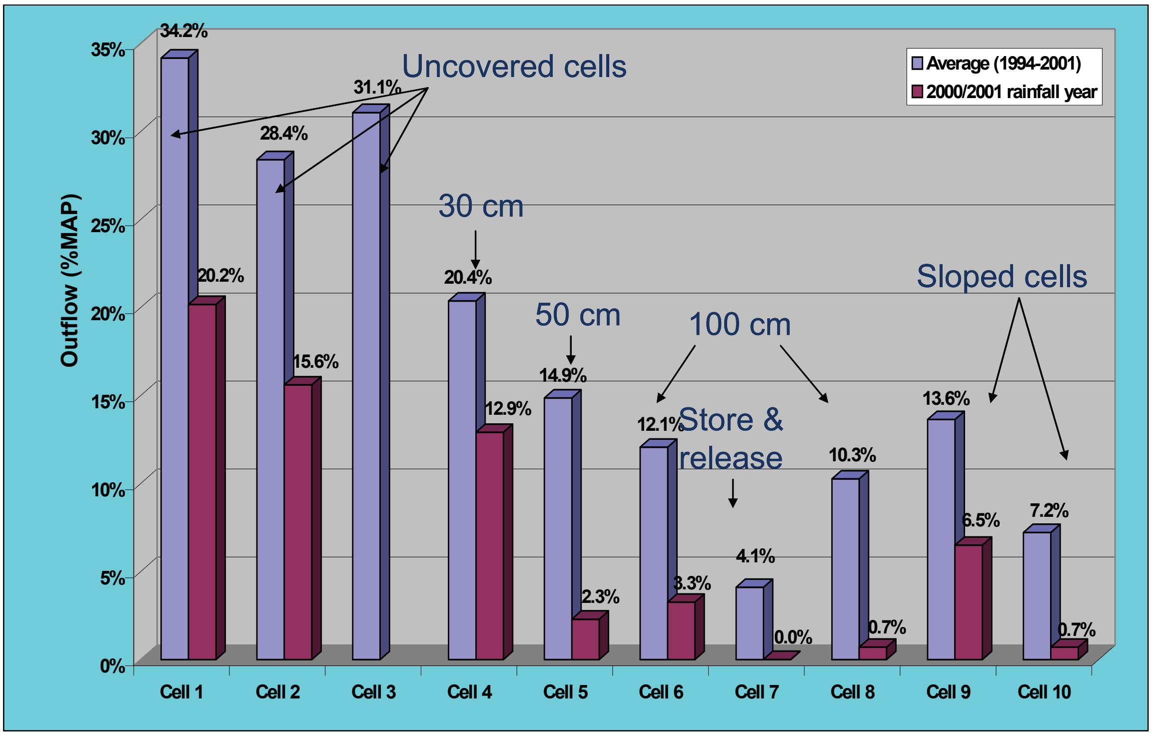


Figure 21: Recharge rates through different covers after Vermaak et al. (2000)

The results in Figure 21 show that the recharge rates range from 30% of rainfall for uncovered cells to 20% for a 300 mm cover, 15% for the 500 mm cover and down to 12% for a 1 m cover thickness. The multiple store and release covers were able to reduce the recharge percentage to about 4%.

4.6.2 Selective Spoil Handling

This method entails the selective placement of spoils to limit AMD. An example is mixing the potential acid material with the potentially alkaline material to prevent acidification in the spoils. Another approach is to place the potentially high risk acid forming material below the water table at the lowest possible elevation in the workings to inundate the material as soon as possible (Skousen, 2000). The practicality of this method will depend on the distribution of the potential acidic material and the mining methods employed. A truck and shovel operation allows for the sorting and selective placement of material. This is more difficult in a dragline operation. If the potentially acidic material is distributed through the whole overburden, selective spoil layering is not easy to apply.

A number of collieries are located adjacent to power stations. There is ash available from the power station which can be used to add alkalinity to the workings. The ash can be placed in the mine workings in layers to add alkalinity and to seal off infiltration into the workings.

4.6.3 Revegetation

Revegetation on a waste rock or tailings pile helps to contain the reactive material by protecting the pile from erosion and reducing the amount of water that can infiltrate into the pile. In addition, vegetation growth provides nutrients to the soil cover and improves the wildlife habitat. Vegetation is often used in combination with other management options, protecting the soil from erosion along diversion ditches and on areas that have been regraded and/or capped.

4.7 Artificial recharge as a tool for flooding

High recharge areas for underground workings can be constructed by drilling boreholes from the surface into the underground workings (Figure 22). The reason for this option is to flood the mine as quickly as possible to reduce the time that pyrite can be exposed to oxygen. The effect on the water quality in the workings should be similar to the effects on water quality if the workings are flooded from a river. The effect on water quality by using the development of high recharge areas would not be as effective as direct flooding due to the slower rate of filling. The slower rate of filling exposes the more reactive surfaces over a longer period of time.

Figure 22: Dam with surface run-off and recharge borehole from the dam into the mine

High recharge areas for opencast pits can be constructed by leaving small sections of the spoils bare and channelling the runoff into these bare spoils. Due to the high hydraulic conductivity of these spoils the water will infiltrate freely into the spoils. The effect would be similar to flooding by cutting off oxygen from the reactive surfaces by inundating the spoils in water.

4.8 Control of Infiltrating Groundwater

4.8.1 Underground Mine Sealing

There are a number of defunct and abandoned mines in the study area. The AMD problems associated with these older underground mines can be aggravated by inadequate barrier pillars between mines, inadequate outcrop barriers and hydraulic interconnection of adjacent mine complexes.

While AMD problems associated with some of these older mines can be addressed by re-mining the abandoned mine complex, this option is not always economical for most abandoned mine complexes. Mine sealing can minimize the AMD pollution associated with abandoned underground mines (Figure 23). The primary factor affecting the selection, design and construction of underground mine seals is the anticipated hydraulic pressure that the seal will have to withstand when sealing is completed.

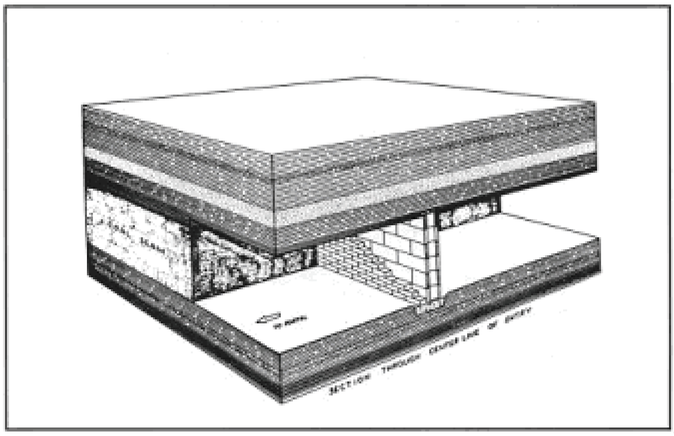


Figure 23: A typical masonry block dry seal used to seal underground mine entrance when no water is draining from the portal

4.8.2 Grout Curtains and Walls

Grout curtains are vertical or nearly vertical, tabular-shaped, low-permeability layers that are emplaced to prevent or divert ground-water movement.

Grouts can be used to separate acid-producing rock and groundwater. Injection of grout curtains may significantly reduce the volume of groundwater moving through spoil and thereby greatly reduce the amount of AMD coming from a site.

In one sense, grouting to form curtains or walls is analogous to underground water diversion. Gabr et al. (1994) characterized the groundwater flow of an acid-producing reclaimed site where a 1.5-m thick wall was installed by pumping a mixture of Class F fly ash and portland cement grout into vertical boreholes near the highwall.

After two years, the grout wall reduced groundwater inflow from the highwall to the spoil by 80%, resulting in one of two seeps completely drying up and substantially reducing the flow of the other seep.

4.9 Active Treatment

The management options that use geochemical approaches to reduce pollution load are discussed in this section. Active treatment can be defined as the improvement of water quality by methods which require ongoing inputs of artificial energy and/or (bio)chemical reagents. The active treatment methods discussed in this section are addition of alkaline material, bactericides and direct treatment of the mine water.

4.9.1 Alkaline Addition

Mine sites with an abundance of naturally occurring limestone or alkaline strata produce alkaline water, even in the presence of high concentration of sulphide minerals. However, many sites contain little or no alkaline material and, as a consequence, often produce acidic drainage even when sulphide contents are relatively low. One approach to improving alkaline deficient sites is to import alkaline material to amend the spoil in order to obtain alkaline drainage.

Neutralisers such as NaOH or $CaCO_3$ (fly ash is also a source of alkalinity but must be handled with care due to the high heavy metal content of the material) can be used for the alkalinity component. Neutralisers such as sodium hydroxide have a high solubility and can be easily moved with percolating water deep in the strata to sites where acid drainage is produced (Evangelou, 1995), but its use is discouraged because of indescribable effect of sodium on irrigation water quality .

A critical step in successful alkaline addition is to ensure that the alkali addition plan is properly implemented. Both the amount of material to be applied and its distribution throughout the site should be appropriate. Because of the large quantities of materials involved, careful record keeping of each shipment of alkaline material and calculation of the quantities of material distributed is required. Depending on the method of mining, quantities of alkaline material to be applied or distributed should be tabulated for each individual cut or phase of the operation.

It is necessary also to periodically retest the neutralization potential of the alkaline material being used, with a frequency determined by the variability of the material.

4.9.2 Application of bactericides

Research has been conducted on micro-organism control within coal environments. A combination of sodium lauryl sulphate (SLS) and sodium benzoate is an effective inhibitor of *Thiobacillus ferrooxidans* (Dugan, 1985) on laboratory scale. This is confirmed by the work of Loos *et al.* (1990) for South African coal dumps (see Figure 24).

These bactericides are relatively non-toxic and should not pose an environmental threat in the short term. The health effects of long-term exposure to bactericides do not appear to have been investigated to date.

Although the impact of the chemicals is immediate, the presence of bacteria may be noted two to five weeks after treatment (Dugan, 1985). In the case of opencast mining, leaching of the inhibitors from the spoil will reduce the effectiveness of these chemicals. Further work by Dugan (1987) indicates that low concentrations of the bactericides (25 mg/ℓ) actually stimulate the acidification process.

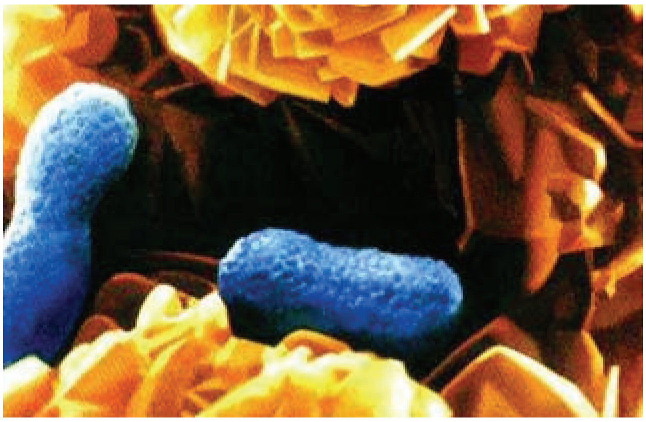


Figure 24: Thiobacillus ferrooxidans cell suspension viewed by an electron microscope magnified

The amount of oxygen present within the pore gas of mine spoil or coal refuse is an important factor when considering the use of bactericides. Figure 25 shows pyrite oxidation rates under biotic and abiotic conditions. At oxygen levels of approximately 14 percent, biotic and abiotic rates are about equal. Below oxygen levels of 14 percent, pyrite oxidation rates are considerably slower when bacteria are absent. In the presence of bacteria, pyrite oxidation can be significant even at oxygen concentrations as low as one percent. Thus bactericides are most advantageous where oxygen concentrations are low.

Pellets containing bactericides were successfully applied to spoil waters in the United States (Sobek *et al.*, 1985). The water quality improved between 82-95% with respect to acidity, iron, aluminium and sulphate concentrations. The duration of release of the bactericides from such pellets is three to five years (Sobek *et al.*, 1985).

Attaining such saturation for the top 0,5 m of the spoil would cost R29 000/ha for SLS at 1990 prices (Loos *et al.*, 1990). The application of sodium benzoate would cost approximately R13 000/ha at 1990 prices. This translates to approximately R100 000 000 for a mine of 2 000 ha for a once off application. This is clearly not economically viable for opencast mines.

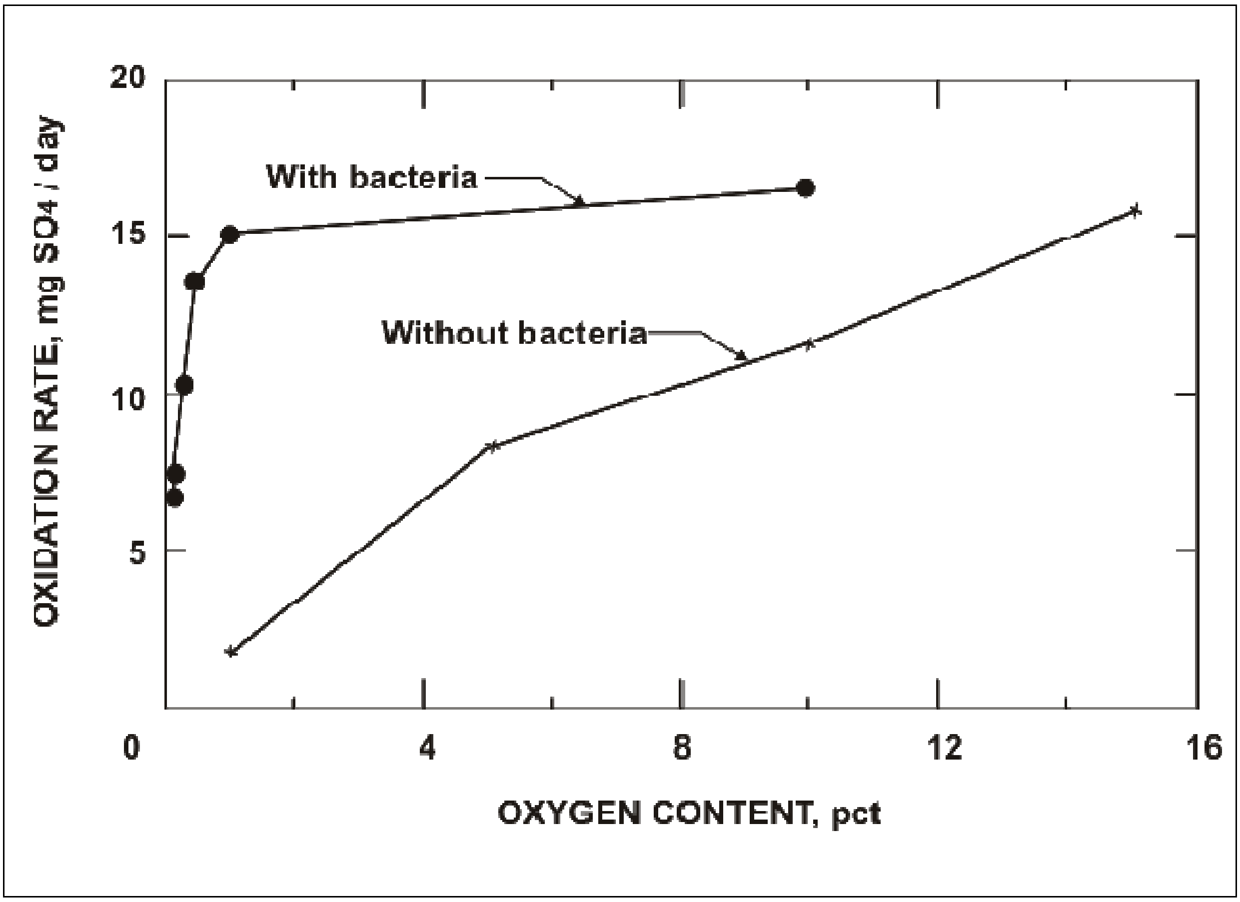


Figure 25: Rates of Pyrite Oxidation with and without Iron-oxidizing Bacteria (Hammack and Watzlaf, 1990).

4.9.3 Application of Barium sulphide

This process is based on the insolubility of barium sulphate. The process consists of two parts:

- Water treatment, where barium sulphide, oxide or carbonate is dosed to sulphate containing water which results in a barium sulphate precipitate.
- Thermal reduction, where the barium sulphate sludge from water treatment is reduced at 1200OC to BaS or BaO.

The benefits of this technology are that it can reduce/remove sulphate to low levels as it is based on a chemical precipitation. The capital cost of the treatment plant is low, as the main equipment consists of an agitated reactor tank with 15 minutes residence time and a turbimetric dosage control (www.csir.co.za).

4.9.4 Reverse Osmosis

Reverse Osmosis (RO) is a proven technology for the treatment of water and the removal of TDS and other constituents. RO involves the removal of water from a solution containing dissolved solids by passing the water through a semi-permeable membrane.

As pressure is applied, the semi-permeable membrane allows water to pass while the membrane retains the dissolved solids. The membranes are often cleaned by a cross flow which removes the molecules retained on the surface, these molecules are then collected and concentrated to be disposed. Once treated the water could be used for a variety of beneficial uses.

4.10 Passive Treatment as a Management Option

Passive treatment encompasses a series of engineered treatment facilities that require very little to no maintenance once constructed and operational. Passive water treatment generally involves natural physical, biochemical, and geochemical actions and reactions, such as calcium carbonate dissolution, sulphate/iron reduction, bicarbonate alkalinity generation, metals oxidation and hydrolysis, and metals precipitation. The systems are commonly powered by existing water pressure created by differences in elevation between the discharge point and the treatment facilities.

4.10.1 Anoxic and oxic limestone drains

Anoxic limestone drains (ALD)

ALDs are ditches filled with limestone gravel. As minewater flows through them, the limestone dissolves, adding alkalinity and increasing the pH. The water needs to have very little oxygen dissolved in it or else iron hydroxides can form, clogging the drain and causing it to fail (Figure 26).

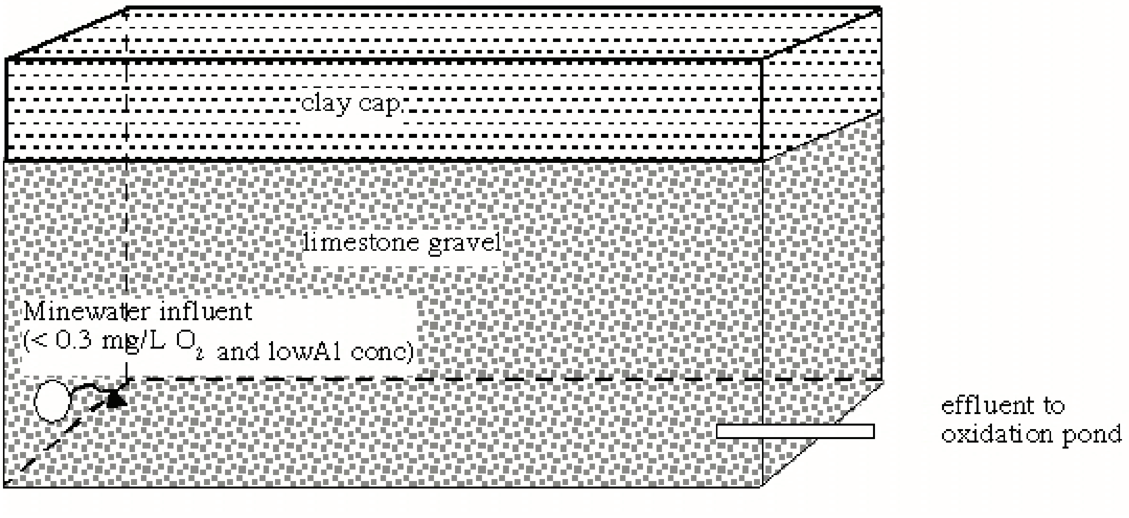


Figure 26: Schematic representation of an anoxic limestone drain

Regardless of the oxygen content, aluminum can also cause ALDs to fail by forming aluminum hydroxides.

Oxic limestone drains

OLDs are similar to ALDs, but they are more experimental. Iron or aluminum hydroxides form within them, and hopefully these solids are periodically flushed out by temporarily increasing the pressure or head, then releasing water from the drain rapidly (Figure 27).

Limestone channels are sized based on a projected 90 percent acidity neutralization with one hour of contact time or 100 percent acidity neutralization with three hours of contact time. Construction criteria are determined from the flow rate, channel slope, and acidity concentration. This information will determine the mass of limestone, the cross-sectional area and length of the drain, and ultimately, the in-channel detention time.

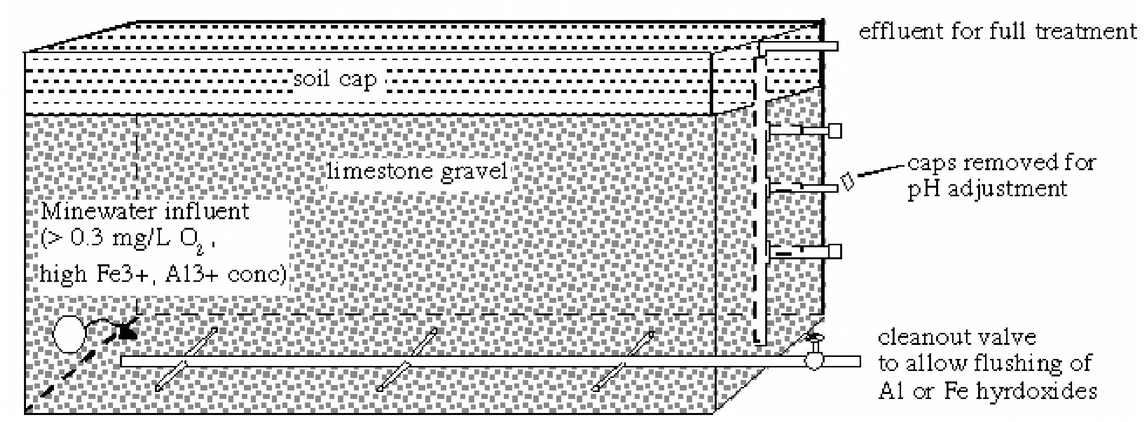


Figure 27: Schematic representation of an oxic limestone drain

4.10.2 Open limestone channels

More recent research has been conducted on the treatment with limestone in an environment open to the atmosphere (oxic). As previously stated, when dissolved iron is oxidized, it will precipitate, armouring limestone and creating iron hydroxide sludge. In theory, limestone, even if completely armoured with iron, will continue to yield some alkalinity. (Figure 28).

Channels are constructed with an initial dam-like structure at the upstream end to trap sediment and other debris and keep it from clogging the pore spaces between the limestone material throughout the remainder of the channel.

Open limestone channels are relatively simple and inexpensive systems to construct. However, there are some limitations to their use. Neutralization ability of these channels is greatly limited by the dissolution rate of armoured limestone, atmospheric CO_2 concentrations, and contact time.

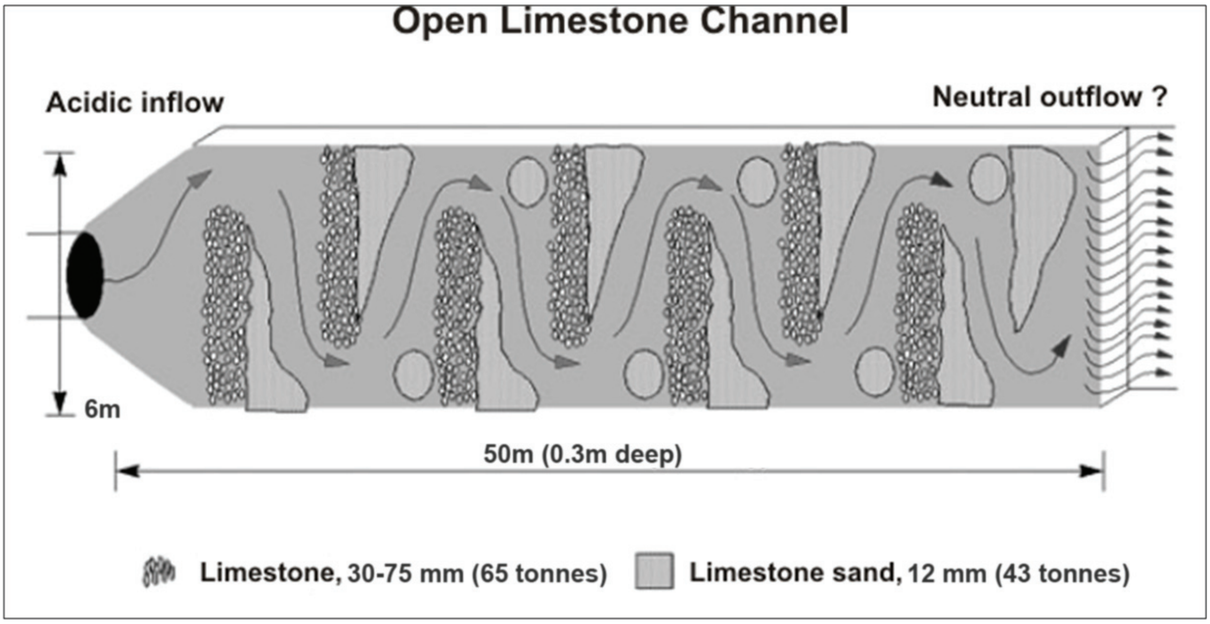


Figure 28: Schematic representation of an open limestone channel

4.11 Interconnection of mines and mixing of water

Water volumes in mined out areas can be management through the interconnection of mines where possible. This will reduce the rate of water rise to the level of decanting and the mixing of water of different qualities to improve the overall water quality.

Very few of the mines are informed on mining activities in neighbouring mines. This is a serious shortcoming in the overall planning of intermine flow management. Much more emphasis should be placed on information exchange with adjacent mines. Joint water management committees should be established. This should be extended to the regional level, where corporate houses should contemplate management strategies for catchments (Grobbelaar, 2004). BHP Billiton and Anglo Coal have agreed to co-operate as far as water management is concerned. This level of co-operation should be extended to include the other mining houses.

The following can be obtained through the interconnection of neighbouring mines:

- The reduction of the number of decanting points through the interconnection of mines.
- The control of decanting positions through interconnection of mine workings.
- Mixing of water of different qualities

The opportunity exists for most of the larger mines to mix their mine waters of different qualities, thus improving the overall water quality (as mentioned above). Typical benefits of doing this would lie in pH adjustment and iron precipitation.

For the latter, retention of the mine water in a surface-holding facility where aeration is possible, is necessary. Such a facility could also be used for quick release of the water during flood discharge. Very few other chemical benefits would be forthcoming from mine water mixing, because most of the constituents are under saturated in this water (Grobbelaar, 2004).

The effectiveness of this method will vary for different geological and geohydrological environments.

4.12 Power station use of mine water

Most power plants in the study area use large volumes of water to condense steam and transport ash. In many locations around the country, the existing surface water supplies are not large enough to accommodate additional withdrawals for new power plants.

If mine water can be used in power plants, it will offer a dual benefit. First of all, the power plants will have more flexibility in siting, and secondly, use of the water will help to avoid or postpone undesirable contamination of surface water bodies by mine pool water (Figure 29).

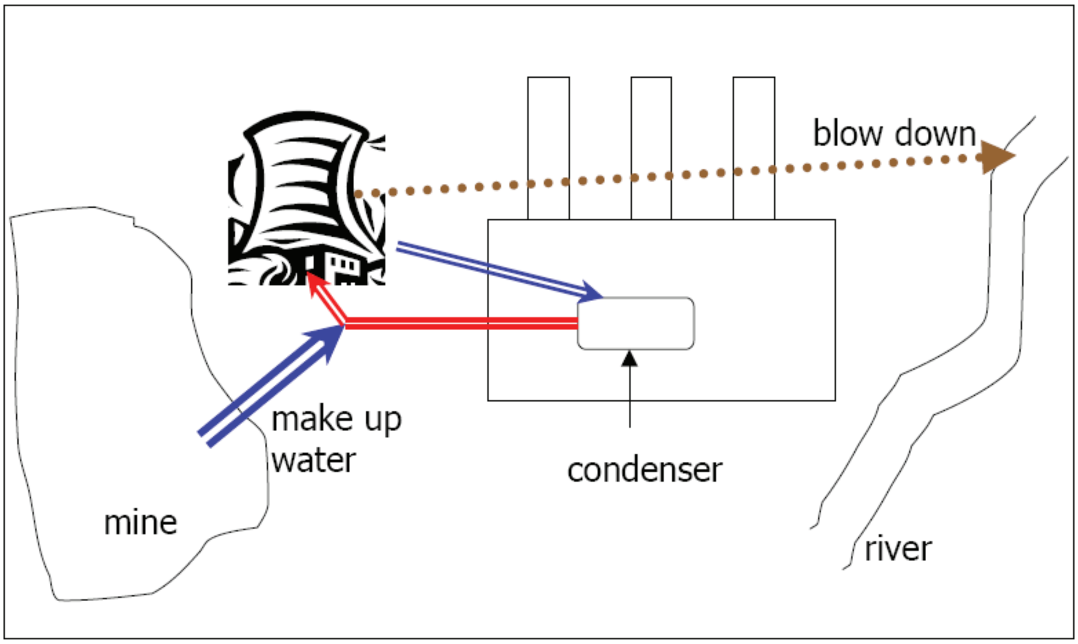


Figure 29: Schematic representation of a closed-cycle cooling modes

4.13 Irrigation with gypsiferous mine water

Irrigation of agricultural crops with gypsiferous mine water is a promising technology that could utilise mine effluent and add value through agricultural production. Crop response to irrigation with gypsiferous mine water, as well as the impact on soil and groundwater resources were investigated for 3 years at Kleinkopje Colliery.

Salinity in the soil increased over the duration of the trial due to high concentrations of Ca, SO_42 and Mg2+ in the irrigation water, but this never reached levels critical to yields of most crops. Exchangeable Ca and Mg in the soil increased with time, whilst K decreased.

The groundwater impact was limited based on borehole measurements, indicating the presence of a buffer zone between the cropped soil profile and groundwater. Commercial production of crops under irrigation with gypsiferous mine water is feasible and the resulting environmental impact is limited, but further research is required to confirm these findings over a longer period (*Water SA*, 2002).

4.14 Aeration and settling ponds

Aeration and settling ponds promote the precipitation of heavy metals such as iron, zinc and manganese through oxidation processes. This management option is particularly effective for treating mine drainage water that is high in total dissolved solids (TDS) but has a pH close to neutral (7.0). Aeration is accomplished by channelling the mine drainage over a series of small waterfalls or drops, which will increase the oxygen content of the water into a quiet settling pond, where the metals will drop out.

Aeration is accomplished by making the water turbulent. Turbulence can be initiated by channelling the drainage down a steep slope, over rough slopes (such as ditches lined with riprap or large rocks) or over a series of drops or small waterfalls.

A settling pond should be located at the base of the aeration channel. Ideally, it is in a naturally low area, but not along or in flowing water. An embankment at the lower end of the pond holds the water in the pond. This allows clean water to flow over the top of the embankment back into the main stream without eroding the dam. The embankment is generally composed of a mix of rock and soil with larger rocks lining the upstream side and smaller rocks on the top to discourage erosion as the water flows over the top.

Settling ponds should be designed so that the water entering the pond will remain in the pond for a minimum of 24 hours before being discharged. A 24-hour retention period will allow the oxidized metals to precipitate. In order to design the pond for 24-hour retention, the expected flow into the pond must first be measured. This can generally be done with a bucket and stopwatch. Using that flow rate (probably measured in gallons per minute), the amount of water that will flow into the pond in a 24-hour period can be calculated. The pond should be large enough to hold at least that amount.

4.15 Evaporation pans

Evaporation pans are pans on the surface, filled with mine water for evaporation to take place, without contamination of ground or surface. Successful use of evaporation pans for mine water requires that evaporation equal or exceeds the total water input to the system, including rainfall. The net evaporation may be defined as the difference between the evaporation and rainfall during any time period.

Evaporation rates are to a great extent dependent upon the characteristics of the water body. Evaporation from small shallow ponds is usually considered to be quite different than that of large lakes mainly due to differences in the rates of heating and cooling of the water bodies because of size and depth differences.

Additionally, in semi-arid regions, hot dry air moving from a land surface over a water body will result in higher evaporation rates for smaller water bodies. The evaporation rate of a solution will decrease as the solids and salt increase.

4.16 Wetland treatment of mine water

Wetlands will improve the quality of acid mine drainage using common bacteria found in decomposing organics to remove the heavy metals. Sulphate-reducing prokaryotes (SRPs) utilize the oxygen in sulphates for respiration, producing sulphides. The sulphides combine with heavy metals in the drainage to form relatively insoluble metal sulphides, which precipitate or drop out. The bacteria derive their energy from a carbon source, most commonly cow manure or mushroom compost.

Depending on the grain size of the soil, the wetland cell may need to be lined with either compacted clay or a PVC or HDPE geomembrane liner. If the soil is fine grained with very little rock, no liner is necessary. The system may leak temporarily, but should seal off in a period of weeks.

A thin layer of gravel (about 7 to 15 cm) is placed on the bottom of the cell (or on the liner) and perforated collection pipes are buried within this layer. A highly permeable geotextile fabric, such as a loose weave erosion fabric, is placed on top of the gravel layer. This fabric must allow drainage into the gravel, while keeping the finer material above the fabric from piping into the gravel.

The substrate or treatment layer is placed on the geotextile to a depth of about one to two meter. The substrate can consist of cow manure, mushroom compost, sawdust or in some cases soils from the site depending on their permeability.

Drainage enters at the top of the system but must exit at the base of the system to ensure that the drainage flows through the substrate material and is exposed to the SRBs.

Mine drainage enters the system through a pipe buried just beneath the top of the substrate or can simply be pooled on the surface of the substrate. A riser pipe, through which treated water will exit, is installed starting in the gravel layer at the low end of the wetland and angling up through the berm where it discharges (Figure 30).

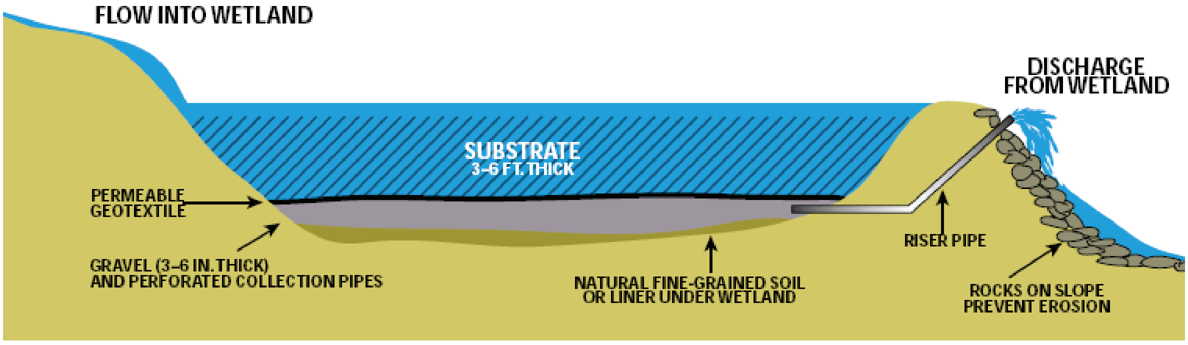


Figure 30: A schematic cross section of a sulphate reducing wetland

The size of the wetland depends on the amount of metals and pH of the drainage, the volume of the drainage and the area available to install the wetland. A general rule of thumb is that five cubic meters of properly designed and installed wetland will treat 3.5 L per minute of mine drainage. Therefore, if the depth of your wetland is 1 m, and you are treating 35 L per minute of drainage, the total area of the wetland should be about 50 m^2. The wetland can consist of one large cell or be broken into several smaller cells in order to achieve the necessary area to treat the drainage.

Considerations

Sulphate-reducing bacteria prefer an environment with a pH above 4.5. In situations where the pH of the drainage is below 4.5, design modifications are necessary, such as channelling the drainage through a lined buried trench filled with two- to six-inch chunks of limestone prior to entering the wetland, or adding limestone to the substrate in the wetland.

Some pooling on the cells is desirable, because it discourages plant growth. Plants will introduce an additional source of oxygen and the system works best in an oxygen-deficient environment. However, pooling should not approach the top of the berm.

Sulphate-reducing wetlands should generally be constructed away from population centres, because these systems commonly produce excess hydrogen sulphide, which can cause undesirable odours up to 2-3 km away from the system. Note that when the system is first installed, the treated water will be discoloured and may look worse than the untreated water entering the system. This is normal and should change after a few months.

Maintenance

Metals will precipitate as the drainage is treated in the wetland. Wetlands, properly designed for the metals content of the drainage being treated, generally have a life of 20 to 30 years, after which time the accumulated metals will begin to slow the flow and the treatment will not be as effective. This metal sludge must be removed and properly disposed of in either a landfill or an on-site lined and capped trench, or it can be sold for re-mining if the metals content is sufficient.

In South African conditions the use of wetland for the treatment of mine water has been a failure to date. Nowhere in the Mpumalanga coalfields do wetlands of any significance exist in terms of mine-water treatment. This is, after more than 25 years of research into the matter (Grobbelaar, 2004).

4.17 Phytoremediation

It is the use of plants and trees to extract, stabilize or detoxify contaminants in soil and water. The phytoremediation process generally describes several ways in which plants are used to remediate or stabilize contaminants at a site. Plants can break down organic pollutants or stabilize metal contaminants by acting as filters or traps. The two ways that phytoremediation works are: phytoextraction and rhizofiltration.

Phytoextraction, also termed phytoaccumulation, refers to the uptake of metal contaminants by plant roots into stems and leaves. Plants that absorb large amounts of metals are selected and planted at a site based on the type of metals present and other site conditions that will impact the growth. The plants are harvested and either incinerated or composted to recycle the metals. The cost of phytoextraction is in the low to medium range depending on site conditions and the costs of disposal of the harvested plant material.

The O&M costs may be significant if the plants need to be harvested for many years. The effectiveness of phytoextraction has been good for some metals where there are shallow, low levels of contamination; the technology is, however, considered innovative for most metals.

Rhizofiltration is used to remove metal contamination in water. The roots of certain plants take up the contaminated water along with the contaminants. After the roots have become saturated with metals, they are harvested and disposed. The cost of rhizofiltration is in the low to medium range depending on site conditions and the cost of disposal of the harvested plant material. The O&M costs may be significant if the plants need to be harvested for many years. The effectiveness of rhizofiltration is not yet determined as the technology is considered innovative.

4.18 Mine water for flooding and neutralisation purposes in underground mines

Several options for minimising the salt loads from mines need to be exploited in the future. These typically are: (1) Flooding of mines as soon as possible after closure; (2) Active flushing of flooded mines and (3) Greater utilisation of the natural base potential in the coal and rock for acid water neutralisation. These are all concepts with great potential, but will necessitate a change in the direction of thinking by the controlling authorities.

Investigation on the feasibility of flooding in an underground coal mine as an amelioration option, was first introduced by Miorin *et al.* (1977), so as to restore or partially restore the groundwater table and thus reduce acid formation.

Flooding could have two important implications in abandoned sections of mines. Firstly the quality of surface water is far superior to that of groundwater and flooding could considerably improve the quality of the underground water. Secondly, provided that recharge can be affected within a reasonably short period of time, exclusion of oxygen will restrict acid formation. The investigation by Miorin *et al.* was eventually abandoned, because of the high cost of installing seals to isolate an area in which experiments could be conducted. Conditions in South Africa are far more favourable for such experiments and several studies of this nature are presently in progress (Hodgson et al., 1998).

Historically mine water has been pumped from active workings to allow unhindered coal production. The best management strategy for water while mining is to mine from deep to shallow areas and leave water behind in the mined-out workings. This strategy has, for the past few years, been applied in several of the larger collieries with significant success.

The advantage of this mining sequence does not only lie in managing water volumes, but also in water quality (minimising the salt loads). Mined-out areas are flooded, thus excluding oxygen. Furthermore, the natural alkalinity of the water is not flushed from the rock. This counteracts acidification.

Active flushing would imply the controlled release of salt into a catchment, with the specific purpose of improving the mine water quality to the extent that it would become a useable resource.

Cut-off Walls.

Cut-off walls are structures used to prevent the flow of ground water from either leaving an area, in the case of contaminated ground water, or entering a contaminated area, in the case of clean ground water. Types of cut-off walls include: slurry walls, cement walls, and sheet piling.

Slurry walls are basically trenches refilled with a material (e.g., bentonite slurry) that combines low permeability and high adsorption characteristics to impede the passage of ground water and associated contaminants. The cost of slurry walls is in the medium range, with depth being a factor on the cost due to equipment limitations. The effectiveness of slurry walls is dependent on the ability of the wall to get a seal on the bottom (i.e., by contact with an impermeable soil or rock layer) to keep the ground water from flowing under the slurry wall. Similarly, effectiveness is affected by construction of the slurry wall with no gaps or other points for by-pass.

Cement walls are similar to the slurry walls, except that instead of a low permeability clay-type slurry, a cement-based slurry is used. Construction may be by trench and fill as with the slurry wall construction. Alternately, construction may utilize a larger excavation in which forms are constructed to pour a concrete wall after which the excavated area around the wall is backfilled. The backfill may be with a high permeability material used to capture and channel the ground water flow (e.g., for recovery if contaminated, or to prevent its contamination). The cost of the cement walls is greater than the slurry walls especially if the wall is formed in place, with a cost range of medium to high. This increased cost however may buy an increase in effectiveness.

Sheet piling is a technology that is often used to install a cut-off wall. Sheet piling has been used in the past to funnel ground water to a treatment cell for treatment and is regularly used as a temporary cut-off wall during the remediation period. The cost of the sheet piling is in the medium to high range, with the high range utilizing a better mechanism to seal the joints between the sheets. The effectiveness of sheet piling is similar to the slurry wall, however there is a greater potential of the wall to have leaks at the joints

4.19 Conclusions

Environmental best practice is about achieving more than compliance with legislation. It is about cost-effectively and proactively developing and implementing systems to prevent or minimise environmental impacts. Best practice also requires attention to continuous improvement, and must constantly adapt to changing conditions and technology.

The workforce most committed to environmental protection will be the one driven by a strongly committed management prepared to provide resources for its employees, train them and lead by example. Technology and risk management systems can be installed to reduce environmental impacts, but their continued success relies on a trained workforce where every member has ownership in the goal of environmental best practice.

Managing water used on, and leaving, a mine site is a key aspect of minimising environmental impacts.

The water environment is the mechanism which can most easily and quickly carry and disperse pollutants from the site. To be most effective, the water management system needs to be incorporated in the initial planning stages and adapted as conditions and mine layout develop during operations, right through to decommissioning and beyond. We must always remember, prevention is better than cure.

Many of the management options discussed in this chapter are in the development stages. The passive treatment option for instance are still being developed and tested. Other options such as cut off walls and anoxic drains would be suitable on specific sites and for the management of small volumes of water. Other options such as the use of pans to evaporate water are not accepted by the Regulators and are therefore not recommended. The options considered for the management of mine water in the study area are therefore treatment using proven technology, the use of covers to limit recharge, diversion structure and storage in workings.

5 SELECTION OF MODEL SUITE

5.1 Impact of mining on the water resource

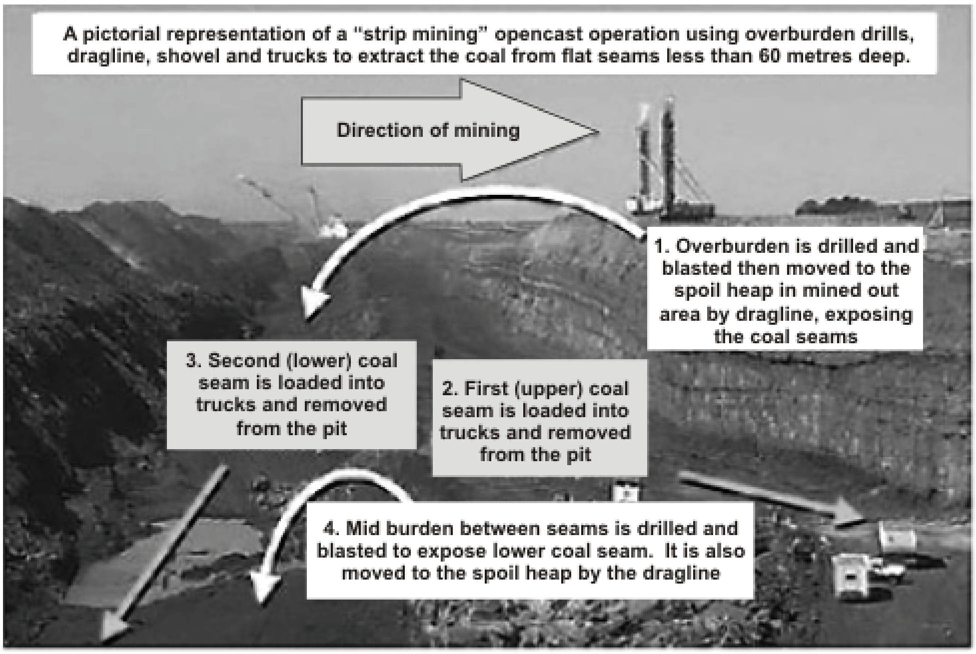
The extent of the different types of mining in the Mpumalanga coalfields is given in Grobbelaar *et al.* (2002) and Usher *et al*. (2002). Most of the mining is through underground methods with almost a third currently through opencast methods. In the Witbank area, bord-and-pillar mining predominates, while in the Highveld coalfield more extensive use is made of high extraction methods such as stooping and longwall mining. The mining in many of the mines in the Mpumalanga coalfields is starting to wind down. The mines are starting to look at ways of prolonging the life of their operations. One of the remaining coal reserves is the pillars left in the bord and pillar underground mines. Re-mining of the pillars using opencast mining methods where the coal is shallow enough is being considered. In the deeper mines stooping of the pillars is being considered.

Mine drainage is a common problem associated with coal mines. It begins during active mining operations, when water enters the mines from groundwater and/or surface water. In some cases this water is pumped from the mines while in other cases it drains freely from the mines to adjacent areas. In the case of mines for which pumping is used during active operations, water fills these mines upon closure and eventually discharges at the surface.

5.1.1 Impact of Opencast Mining on Water Quantity

Opencast mining has the greatest impact on the groundwater and surface water flow regimes. A typical opencast mining operation is shown in

Figure 31. The mining disturbs the perched water table in the weathered aquifer. The pits intercept the groundwater flow and disrupt the surface topography. Areas of the catchment are removed or become isolated due to the mine workings.



A pictorial representation of a "strip mining" opencast operation using overburden drills, dragline, shovel and trucks to extract the coal from flat seams less than 60 metres deep.

1. Overburden is drilled and blasted then moved to the spoil heap in mined out area by dragline, exposing the coal seams

2. First (upper) coal seam is loaded into trucks and removed from the pit

3. Second (lower) coal seam is loaded into trucks and removed from the pit

4. Mid burden between seams is drilled and blasted to expose lower coal seam. It is also moved to the spoil heap by the dragline

Figure 31 : Typical opencast mining operation

The following factors can influence the normal groundwater hydraulic conditions of an opencast area:

- the exposure of unweathered strata to atmospheric conditions,

- increased gradients of groundwater flow, and
- higher hydraulic conductivities of disturbed strata.

Figure 32 illustrates the generalised hydrological conditions associated with an opencast environment after closure of the pit. Normal groundwater movement still takes place in aquifers. Groundwater flow directions will necessarily be directed toward the pits, due to an artificial change in gradients on a local scale.

This normal groundwater flow, together with direct recharge into the spoils, will create a groundwater level in the heaped spoil until a decant level is reached. Water that decants out of the spoils as well as run-off from the surface of the spoils follows the natural gradient and flows to the nearest river or stream.

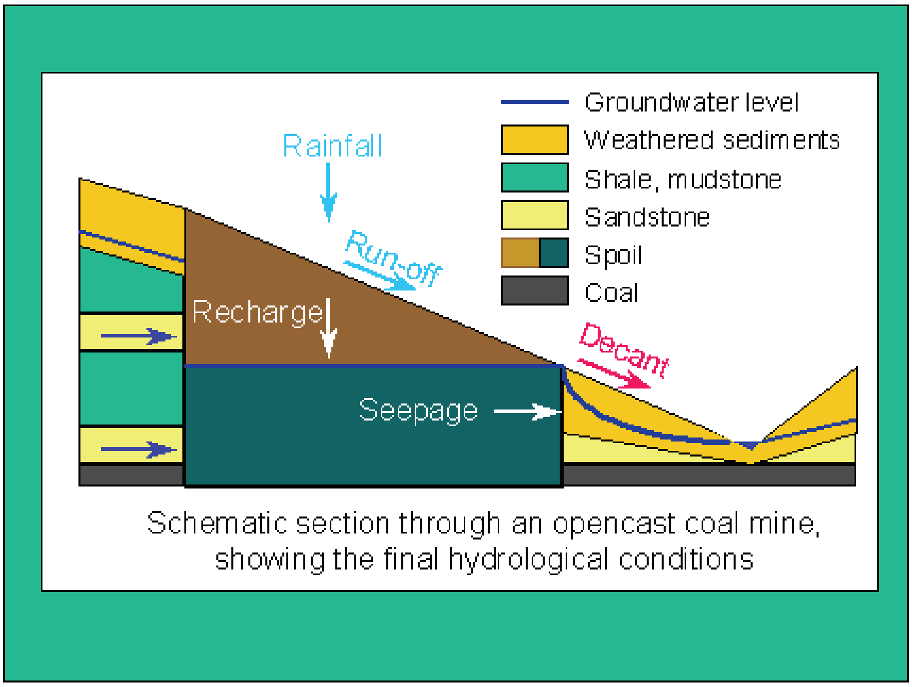


Figure 32: General geohydrological conditions of an opencast pit (Grobbelaar et al., 2001).

The impacts of opencast mining on the water resource can be summarized as follows:

- Groundwater is intercepted and creates a cone of depression around the workings. The cone of depression could impact on water levels in boreholes located close to the pit. The groundwater and recharge in the cone of depression no longer reports to the river system. This will reduce the base flows in the rivers of heavily mined areas. Local streams and springs may dry up due to the mining.
- Portions of the mining area will be isolated from the catchment. These are typically the mine workings areas, unrehabilitated spoils heaps, pre-strip area and possibly portions of the rehabilitated area. The rehabilitated areas are generally made free draining with the runoff from the areas directed as far as possible back to the streams. The runoff from these isolated areas is taken up in the mine water management system and no longer reports to the river systems.
- At closure however the recharge into the rehabilitated opencast pits is higher than the natural system. The perched aquifer is destroyed during mining and no longer holds water in the upper weathered zone aquifer. The percolation of water from the cover escapes the evaporation zone and passes rapidly into the spoils store. The recharge factor can be range from 5% to 20% depending on the type of rehabilitation cover compared to the 1% to 3% groundwater recharge of the natural catchment. If the opencast pit is

rendered free draining then the runoff from the surface can be added to the additional water available from the higher recharge rates associated with the opencast mining.

5.1.2 Impact of Underground Mining on Water Quantity

Two classes of underground mining can be differentiated in the South African Coalfields: *viz.*

Bord-and-pillar and high extraction.

Bord and pillar mining methods are used in flat tabular deposits (seams) from 1.5 to 7 metres in thickness where it is required to prevent subsidence (collapse) of mined-out areas from affecting the surface. Generally between 55% and 65% of the mineable coal is extracted. The seam is mined in a 'streets' and 'avenues' fashion ('bords') advancing in one direction. 'Pillars' of coal are left behind to support the roof and prevent collapse. Additional support is provided through the use of roofbolts. Coal is cut by continuous miners and loaded onto haulers which tip the coal onto a conveyor system. From there, it is transported out of the mine (See Figure 33).

Bord-and-pillar mining has less subsidence of the roof than for high extraction methods due to less collapse, although several areas of subsidence have been noted in shallower mines. Bord and pillar mining results in lower influxes of water than those found in high extraction areas. In the deeper bord and pillar mines the recharge rates are between 1% and 3% which is similar to the recharge of the natural aquifers.

When mining occurs, underground workings form a separate aquifer, thus a two-aquifer system is formed. The one aquifer in the system is the natural aquifer (top aquifer) and the other aquifer is the manmade void (underground workings – bottom aquifer) into which the groundwater seeps. While the void fills up through seepage from the top and sides, piezometric pressures are created (depending on the slope of floor contours of the seam), which enables the underground workings to mix their water with the rest of the aquifer below the piezometric pressure.

Therefore mixing of unpolluted and polluted mine water can take place due to piezometric pressures developed as a function of the slope of the floor contours (see Figure 34).

This piezometric pressure can also enable underground workings to decant on the surface. When the underground working is completely filled with groundwater the original aquifer system is restored, since a fluid continuum is re-established between the two entities.

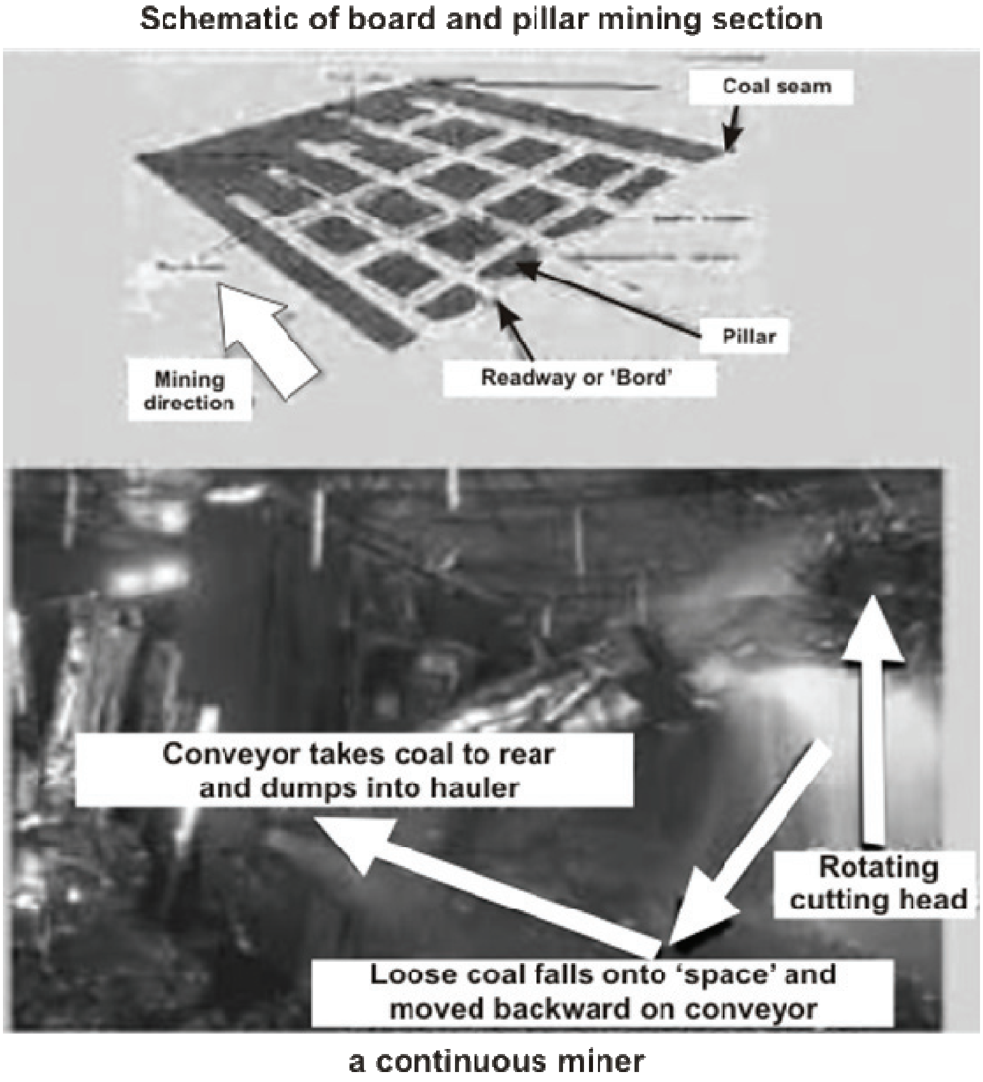


Figure 33: Bord and Pillar mining operation (www.ingwe.co.za/)

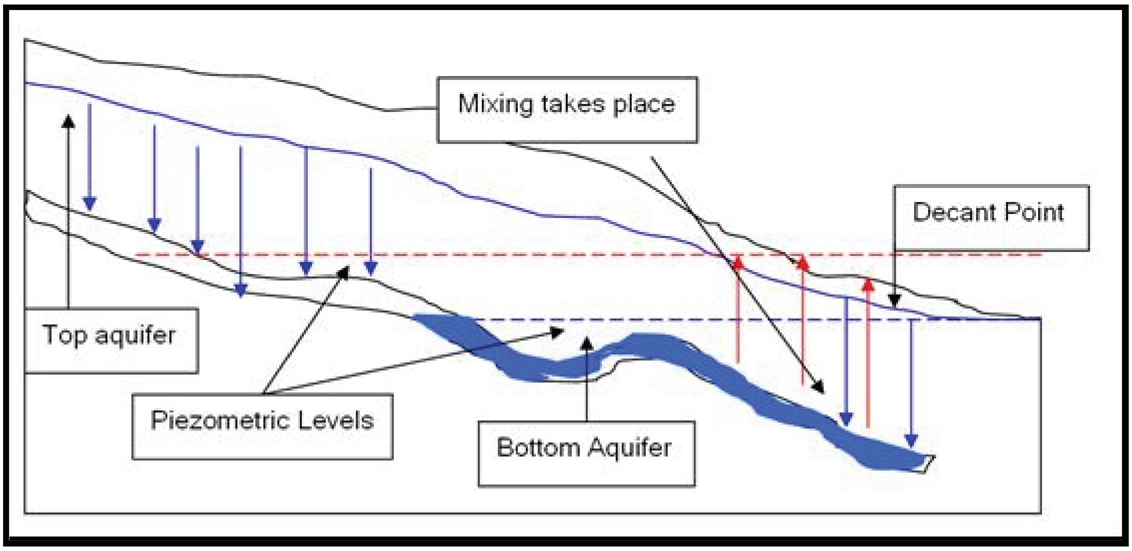


Figure 34: Conceptual model showing that the top aquifer will leak towards the bottom mine aquifer until the water level of the bottom mine aquifer is equal to the water level of the top aquifer (Hough, 2002).

The impacts of Bord and Pillar underground mining on the water resources can be summarized as follows:-

- **Deep bord and pillar** mining does not disturb the perched aquifer. The deeper aquifer is however disturbed and the groundwater enters the underground compartments. The water is removed from the workings as part of the mine water dewatering program and used on surface for dust suppression or in the plant.
- Subsidence of the **shallower bord and pillar** mines does occur. An example of a typical subsidence in shown in Figure 35. If not repaired the ingress of water can be high into the workings. The ingress of oxygen can also exacerbate the water quality problems and lead to spontaneous combustion.

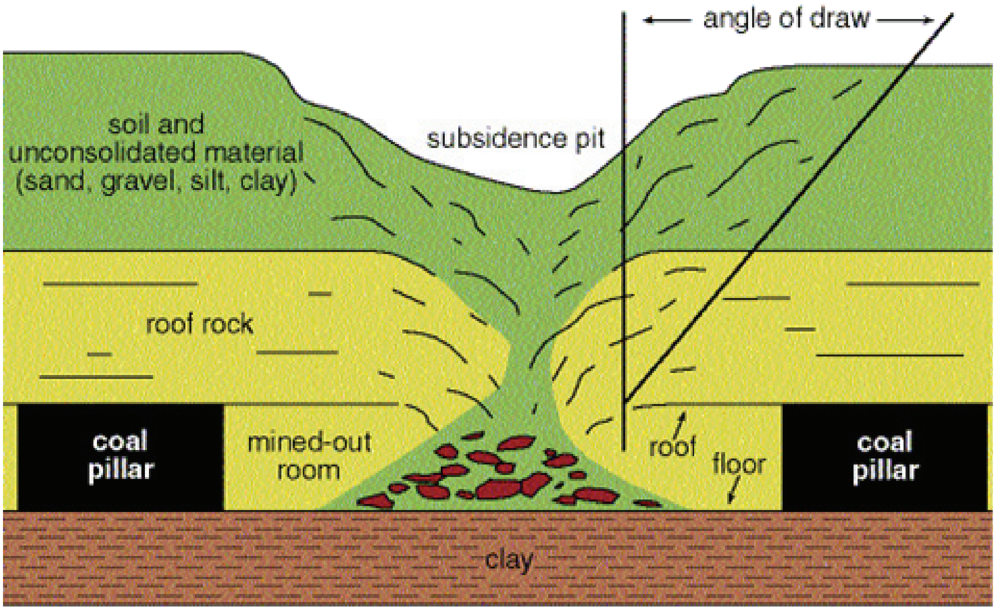


Figure 35: Diagrammatic cross section of typical subsidence resulting from mine-roof collapse

- The ingress of water into the bord and pillar mines is a lot lower than those mined using the opencast or high extraction mining methods. During operations there is significantly less water that has to be managed when compared to the other mining methods. The mine does also not significantly impact on the surface topography. Post closure, the mine voids can take over 50 years to fill in many cases. The disadvantage of the mine voids taking so long to fill is that the pyrite remains exposed to oxygen for a long period of time which result in the build-up of oxidation products over time.

High extraction is done principally through two methods *viz.* stooping and longwall mining

Stooping is a further stage of the bord-and-pillar method, with increased pillar extraction. Continuous miners are generally used for this extraction process, removing pillars or parts of pillars in a particular section. The degree of extraction varies, based on the geology, coal quality and usually safety factors. (Grobbelaar, 2001). Depending on the competence of the overlying lithology and the degree of extraction, goafing or collapse can occur.

Longwall mining (Figure 36) has been done in the Mpumalanga Coalfields since 1979. Longwall mining is classified as a total extraction methodology and can recover over 75% of the mineable coal. The mining process takes place over a face length of between 100 m (shortwall) and 250 m (longwall). The coal is cut from the face by a coal shearer which traverses backwards and forwards across the exposed coal face. The coal produced by the shearer is transported along the face by an armored face conveyor. At the end of the face, the coal is loaded by a stage loader onto conventional troughed conveyor belts and transported out of the mine. The roof over the shearer and armored face conveyors is supported by hydraulically operated shields. As the coal face is cut and removed, the shields advance in the direction of mining, allowing the unsupported roof to collapse behind the mining operation.

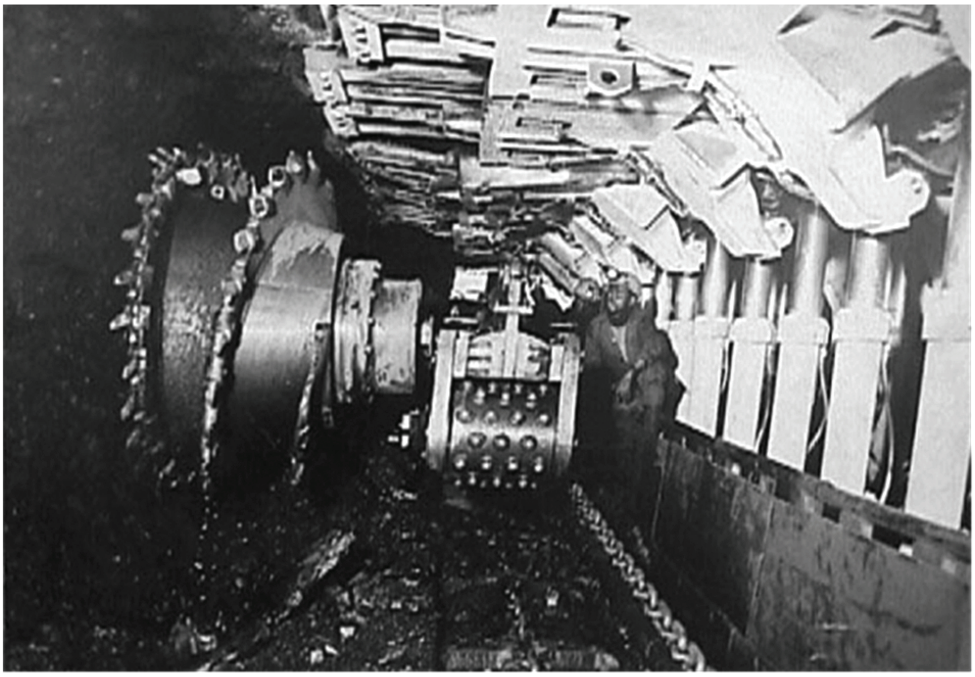


Figure 36: One of the first longwall operations in South Africa (1979).

Mining height in longwall panels will dependent on the seam thickness, but 3 m is usually the maximum height catered for. In some of the mines, the average seam thickness is only 2 m.

The amount of surface subsidence above the longwall panels has been documented extensively. This usually amounts to about 50% of the mining height. As a result of this collapse, a greater proportion of water is expected in high extraction areas.

Three processes occur in subsidence in high extraction area as recognised by Ropski and Lama (1973):

- As the coal seam that supports the overlying rock mass is removed, the immediate roof of the seam fails and collapses, forming rubble fill (goaf). The caved rock breaks up into blocks varying in size from a few centimetres to several metres. These blocks rotate and pile up, partially filling the mined void. A stage will be reached when the mine workings are filled due to bulking of the rubble (Wagner *et al.*, 1989).

- As the coal mining face advances, higher-lying beds fail, settle and compress the caved layer. The stress in this “secondary caving zone” depends on the degree of compression of the goafed material. Typically, an extensive network of horizontal and vertical cracks develops, although the degree of displacement is not such that the beds lose their relative positions.

- Strata overlying the secondary caving zone bend and sag under their own weight, and compress the goaf. As a result, the strata part along bedding planes. Continuity of the beds is maintained although some fractures develop from the stress of bending and sagging. Sagging results in zones of tension and compression in the rock strata, and the development of cracks (See Figure 37).

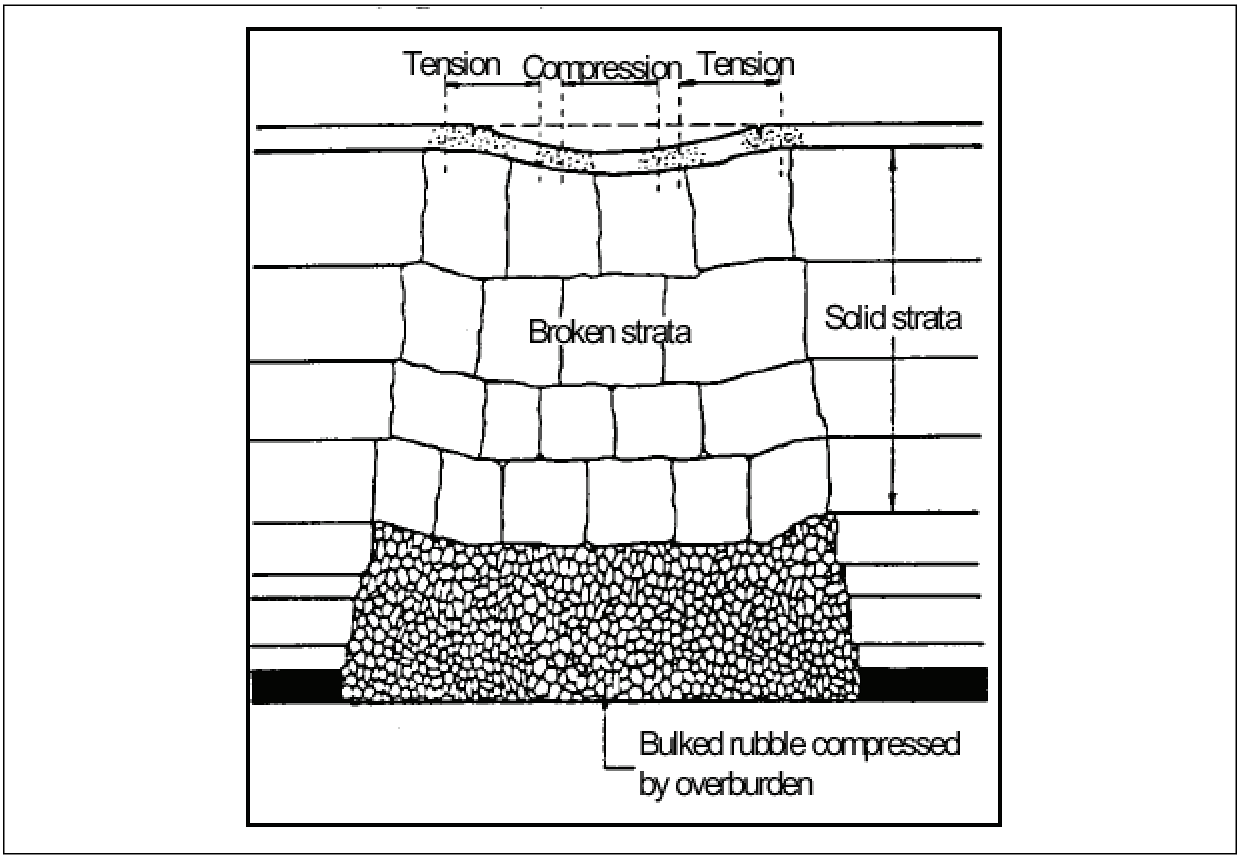


Figure 37: Schematic cross section of a subsided high extracted panel (Ropski, 1973).

The degree of subsidence is dependent on the strength of the overlying strata. Palchik (2002) indicates that in the weak rock, a ratio of 4.1-11.25 exists between the height of the caved zone and the height of the underground coal workings, whereas in strong rocks this ratio is 1.63-4.

The impacts of high extraction underground mining on the water resources can be summarized as follows:-

- The collapse of the overlying strata causes cracks and subsidence on surface. The perched aquifer in the weathered zone is broken due to the collapse of the overlying strata. The ingress of water into these areas is higher than bord and pillar methods but generally lower that the opencast areas.

- The topography at surface is disturbed and surface runoff can be intercepted by the cracks and subsidence on surface. River diversion and cut off berms sometimes have to be constructed to divert the runoff around the disturbed area.

- Regular maintenance of the surface is also required. The filling in of subsidence areas and the repair of surface cracks has to be undertaken.

5.1.3 Impact on water quality

The following needs to be known about the water quality in the mining environment:-

- Characterise and interpret current contaminant load.
- Environmental assessment (source and receiving environment).
- Predict future contaminant concentrations and loads.
- Assess future treatment needs.
- Compare management and decommissioning options.

Computer models are often used to provide the answers to the above questions. To support this, Lichtner (1996) states: "Computer models can provide, if not a direct quantitative description, at least a far better qualitative understanding of the geochemical and physical processes under investigation than might otherwise be possible."

Therefore typical objectives of modelling AMD drainage include:

- Prediction of soluble and mobile metal species.
- Prediction of maximum metal concentrations.
- Prediction of maximum metal loadings.
- Prediction of the duration of dissolved metal production.
- Prediction of concentrations and loadings versus time.
- Evaluation of decommissioning options using all of the above information (Perkins *et al*., 1997).

According to the level of detail required, AMD prediction can entail a range of tasks (Li, 2000), listed below in increasing degree of complexity:

- Predicting whether a mine workings will ever become acid-generating (yes/no).
- Predicting how soon a potentially acid-generating rock will become acidic (lag time).
- Predicting the long term trend in acidity loading from the mine workings, and
- Predicting temporal variations in contaminant loading and drainage water quality over time.

The first two can usually be accomplished by laboratory tests, supplemented when necessary by weathering tests.

Task 3 involves collection of input data for the model of choice, including full characterisation of the mine workings with respect to its chemical and physical properties, meteorological information, etc. The second part is running the model, which can consist of kinetic/equilibrium geochemical and a transport part. Where the reaction products are completely washed out by annual rainfall, this can be accomplished. Where net accumulation within the mine workings cannot be neglected, information on heterogeneity is necessary to predict loading from the spoils. At the present time and with currently available models, prediction of long-term loadings is possible, but *uncertainty* associated with prediction results is generally *high* (Li, 2000).

Task 4 is generally impossible to accomplish at this time.

The major geochemical processes in mine workings and waste rock piles are:

- Oxidation of sulphides, releasing acid, major and trace metals and sulphate,
- Precipitation of oxyhydroxides, releasing acid and consuming the more insoluble major and trace metals;
- Dissolution/precipitation of sulphate minerals mediating the dissolved metal concentrations as well as TDS; and
- Dissolution of oxyhydroxides, carbonates and silicates, thereby consuming acid. Co-precipitation may also provide a major control on trace element concentrations.

All these processes need accurate data and detailed simulation for a model to begin to approximate the field situation.

Mass transfer models, which address geochemistry in more detail, require more geochemical data and have the best potential for predictable capability in the long term.

The most important however, is the validity of the conceptual model, i.e. does the system behave as suggested by the model and are the simplifying assumptions valid and realistic?

Geochemical modelling can thus be a very useful tool in predicting the water quality from mining operations. The type and intensity of modelling should be determined by the objectives and the field situation. Above all, the appropriate model must be used for the objectives and where long-term predictions of loadings are made, these models should have some field verification to show validity.

5.1.4 Conclusions

A modeling suite has to address the mining impacts at the local or mine level and at the regional level. The application of models at the local level needs to provide insight into:

- The quantity and quality of water that will be produced from the mine workings. The modeling suite needs to assess management options that can be used to reduce the quantity and improve the quality of the water that can be expected from the workings.
- The prediction of the extent of the cone of depression and the development of any pollution plumes from the mine complex. The plumes could be from waste deposit areas or from the polluted water stored in the workings.
- Behaviour of water in the mine voids. This is understanding the movement of water through the mine voids and the water quality of the water that will have to be managed on the mine during operation.
- Develop a rewatering program for the workings after closure.
- Determine the impacts of the mine on the surface flows in the local streams.

At the regional level, a modeling suite would have to address the following:

- The impact of the mine on the regional water resources. The reduction of flow in the river and yield of the dams.
- The impacts change over time as the mining areas change.
- The model must be able to model water quality and be able to predict the impact of decants on the water quality at the regional scale.
- The affect of different management options on the impact must be able to be assessed. For instance, the affect of cover type on the reduction in decant volumes must be able to be modelled.
- The level of complexity must not be excessive so that model run times are reasonable.

5.2 Screening of available models

The models that have been identified for possible use in the study are discussed in the sections below. The models are screened against the following set of criteria:

- The model must be able to be integrated with the catchment so that the water quality and quantity impacts of the mines can be assessed. The model must be able to synchronise the mine behaviour with the catchment for wet and dry cycles.
- The model must be able to assess the management unit or local impacts (<100 km^2) as well as the regional scale impacts such as Loskop Dam.
- Be able to model the management options applicable to the mines and catchments.
- Readily available and modifiable

The models identified for possible use in the project were:

- Modflow/Feflow
- Acru Salinity
- HSPF

- Isis
- WRPM/WQT
- Mike 11
- WRSM2000

5.2.1 Modflow and Feflow

The modeling of the movement of water through the mine voids, the estimation of the cone of depression and the migration of pollution plumes can best be modeled using the well established Modflow or Feflow groundwater models. The Modflow model is a finite difference model while the Feflow uses finite element techniques. These two models are typical of the type of model that will be applied to the individual mines. The models can be set up to give an indication of the reduction in base flow in the rivers due to the mining activities. The models do not have a surface runoff component that can be used together with the mine plan to predict the impact of isolated areas on the river flows. The groundwater models are normally applied to the mine workings to quantify the volumes of water that reports to the workings. The time series of modeled inflows is input into a model which models the surface flow and mine infrastructure in more detail than the groundwater models.

5.2.2 ACRU Salinity

Acru Salinity is essentially a daily time step model. The model has been expanded recently to include an underground reservoir for the modeling of underground storages. A salinity component has also been included in the model which can be used to model TDS concentrations. The input parameters to the model have been related to the soil properties as a starting point to establishing a set of parameters for the model. The model has been applied to the Kleinkopje Colliery and is ideally suited to the assessment of the impact of mining on the local water resources.

The model was applied as part of this study to the B11C quaternary catchment. The application of the model is discussed in .Chapter 6 of this report.

5.2.3 HSPF

HSPF is a comprehensive hydrological daily time step model. The model was developed by the United States Geological Survey of the USA. HSPF has a number of modules which can be used to address a particular problem. The main modules are the Perlnd, Implnd and RChres which are typically used to model catchments. The model can model erosion/sedimentation and quality parameters such as pesticides, nutrients and conservative elements such as TDS. The model does not specifically address mine systems although some of the elements can be adapted to represent mine workings. The model though is not suited to the assessment of the impact of mining on the rivers and streams or the assessment of mine related management options.

5.2.4 Isis/Mike 11

Isis and Mike 11 are used for modeling steady and unsteady flows in networks of open channels and flood plains. The models are sold under licence and an annual licence fee has to be paid. The flow routing algorithms offered in the models are a solution of the full St Venant equations, Muskingum and Muskingum-Cunge routing. The models include the routing of conservative and non-conservative pollutants through the river system. The models are however not suited for the project as the model routes flow through the channel network and does not address the catchment water balance adequately. The impact of mine on catchment water balance cannot be assessed using Isis or Mike 11.

5.2.5 WRSM2000

The WRSM2000 model has been updated with a mine module which accounts for the impact of extensive mining on the flow in the rivers. The WRSM2000 model does not have a water quality component and therefore cannot be used for the project as one of the impacts that have to be assessed for the different management options is the compliance with the RWQO.

The Water Resource Planning Model (WRPM) and the WQT water quality model have been applied to catchments to develop reconciliation strategies, assess annual operating rules and water quality management strategies. The WQT model models TDS or sulphate concentrations. The models operate at a monthly time step. The models are flexible and can be adapted to represent a variety of management options. A mine module has been added to the WRPM and the WQT and can be used to model the impacts of mining on the water resources. The approach adopted in the model is shown in Figure 38.

In the WRPM/WQT models the mining, impervious areas and the irrigation areas are removed from the total catchment area. The balance of the area is referred to as the pervious area. A module has been developed for each of the areas that have been removed from the catchment. The modelling of the water quality and water balance of these areas is undertaken in the module. The outputs from the module being put back into the catchment. The mining module is discussed below.

A typical mining operation can consist of underground mining (high extraction and/or bord-and-pillar), opencast mining, a coal washing plant, discard and slurry dumps, pollution control dams and isolated polluted areas. A generic layout was formulated into which the coal mining operations assessed during the situation assessment can be represented. The generic layout is shown in Figure 39.

A coal mine water circuit generally consists of two circuits or systems. A system that supplies the domestic or potable demands of the mine complex and deals with the sewage effluent produced on the mine. Potable water is used on the mine complex for the villages, offices and workshops. Many of the mines have their own water treatment plants to produce the required potable water.

5.2.6 WRPM/WQT

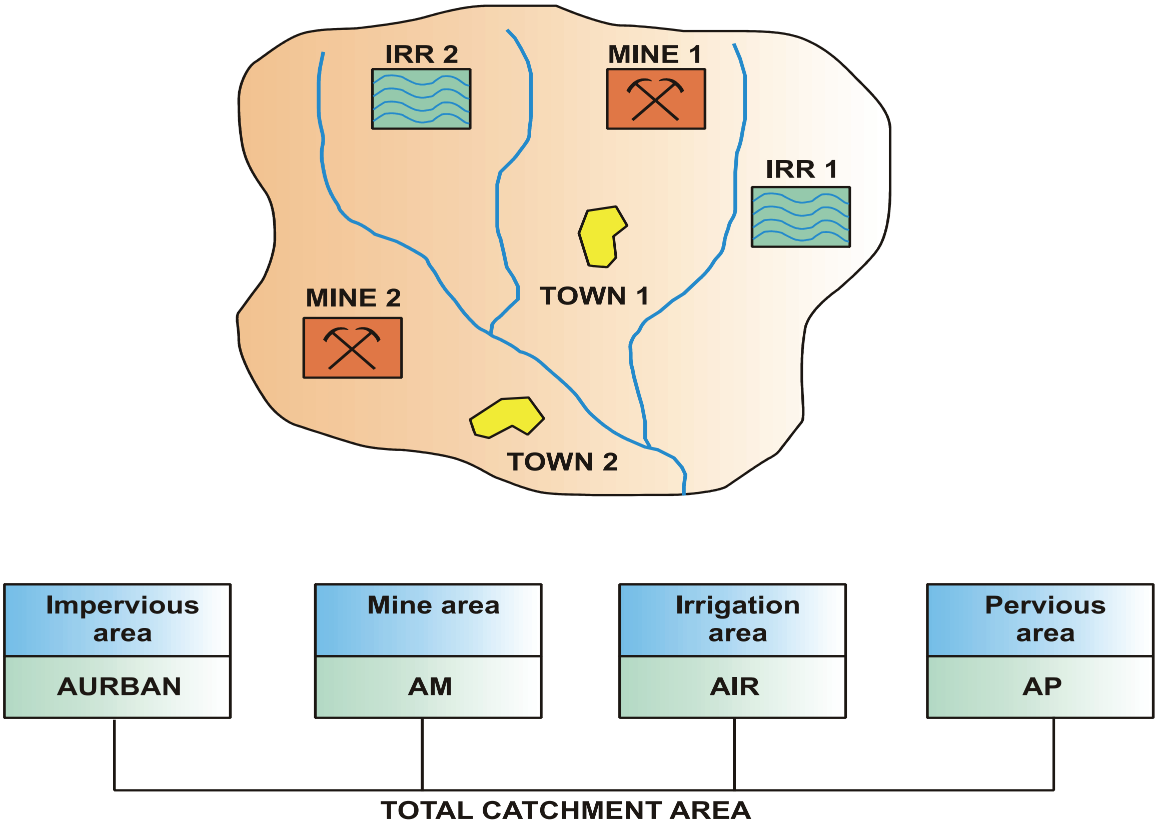


Figure 38: Schematic of representation of areas used in the WRPM

The raw water for this circuit can be abstracted from a borehole, a river or dam, supplied from Eskom, or supplied by a municipality. The mines generally have sewage treatment plants (STP) on the complex to deal with the sewerage.

The effluent from the STP can be used for irrigation, dust suppression, or released to the river system as a point source. This circuit is treated in the water quality model as an abstraction and a point source return flow via the STP.

The other circuit on a mine complex is the polluted water circuit. The water in the dirty water circuit could include runoff from dirty catchment areas collected in pollution control dams, the return water from a slurry disposal facility, decant or water make from an opencast pit and water pumped from underground. A sub-module has been developed for an opencast pit, an underground mining section, a dirty catchment area and dumps. These outputs from these modules are connected as per Figure 39 to represent a particular coal mine.

Figure 39 shows, for illustrative purposes only, a single opencast pit and underground mining section. However provision has been made in the model for up to 10 pits, 10 underground section and 10 dumps for a particular mine complex.

The coal beneficiation plant is the main water demand centre on a coal complex. The plant is often supplied with recycled polluted water from the mines polluted water circuit with make-up water perhaps being supplied from the potable water circuit. The quantity of water used at the plant is a function of the coal throughput and the type of beneficiation process employed at the plant. A time series of water demands are input to the model over the simulation period. These demands being met with water from the central pollution control dam.

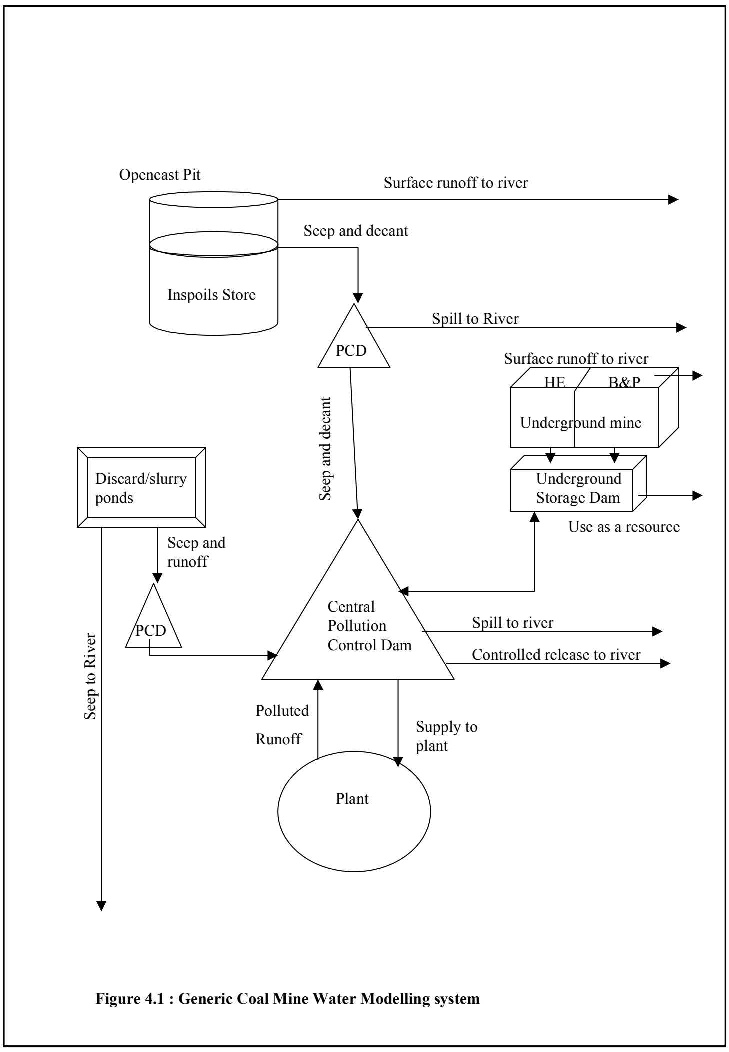


Figure 39 : Generic coal mine water modelling system

Practically on a mine complex, there are a number of pollution control dams (PCD). In the generic representation of the complex these have been lumped into a single pollution control dam called the central pollution control dam. This PCD receives water from the underground mine section, the opencast section, the discard dump/slurry pond PCD and polluted runoff from the dirty areas on the complex. Allowance has been made for the water stored in the central PCD to be pumped underground. This management option is practised on some mines.

The opencast component of the mine module allows for the variation over time of the different mining areas. The mine areas included in the model include the mine workings, spoil heaps, levelled spoils and rehabilitated spoil. The volume of the inspoils store also varies over time and allows for the decant when the volume stored in the inspoils store exceeds the available capacity. The recharge is calculated as a fraction of the rainfall. A monthly recharge fraction is entered into the model. This allows for the reduction in recharge for the different covers to be modeled.

Both bord and pillar and high extraction underground mining is catered for. The bord and pillar section of the model allows for the ingress of a fraction of the runoff from the upstream catchment into the mine workings. The mine workings are represented in the model as a reservoir. The volume of the reservoir can change over time to represent the growth in the workings as the mining progresses. The spill from the reservoir is the decant. As for the opencast, monthly recharge factors are entered into the model for the bord and pillar and high extraction underground workings.

A simplistic approach to the modeling of water quality is used in the WRPM/WQT model. The sulphate concentration of the water pumped from the inspoils store is represented by a log-normal distribution. The standard deviation and the mean of the distribution are entered into the model. The same approach is used for the water flowing into the underground workings.

The modeling of the central pollution control dams and the underground storage reservoirs are treated as completely mixed tanks. The load associated with the inflows into the reservoir are assumed to mix completely and instantaneously with the contents of the reservoirs. The sulphate concentration is assumed to be conservative and the precipitation of mass once concentration limits are reached is not catered for in the model.

6 APPLICATION OF ACRU SALINITY

6.1 Introduction

After extraction of coal through opencast mining and subsequent rehabilitation, increased groundwater storage in the rehab void may occur though groundwater rebound in the spoil and coal discard in the void, as well as through increased infiltration. The purpose of applying ACRU-Salinity is to determine the volume of groundwater that recharges to storage (and hence the groundwater availability for pumping) before and after opencast mining with subsequent rehabilitation in a part of the B11C quaternary catchment. The model was also used to assess the impact of a dummy mine on the flow from the study area.

6.2 Study Area

The study area for the application of ACRU-Salinity is located in the Mpumalanga Province, South Africa. It constitutes one of the DWAF quaternary catchments located in the Upper Olifants basin, upstream of Witbank Dam (Figure 40). The quaternary catchment is B11C and it lies between longitudes 29^0 15’ and 29^0 30’ E and latitudes 26^0 15’ and 26^0 30’ S. The catchment has a total area of 349 km^2. The main river draining the catchment is the Steenkoolspruit while DWAF gauge B1H017 records the outflow from the catchment.

6.3 Soils and Land Use

The catchment comprises clayey and clayey loam soils (Midgley, 1994). The following land use types can be found in the study area (Johnson, 1996): commercial dryland and irrigated areas, forest plantations, unimproved grassland and water bodies. The land types are listed in Table 16 and their distribution is shown in Figure 41.

Table 16: Areas of land use types in catchment B11C

Description	Area (km^2)
Cultivated: temporary – commercial dryland	143.3
Cultivated: temporary – commercial irrigated	0.4
Forest plantations	0.2
Unimproved grassland	185.4
Water bodies (with 60 m stream width)	9.3
Urban / built up land – residential	0.007
Total	348.607

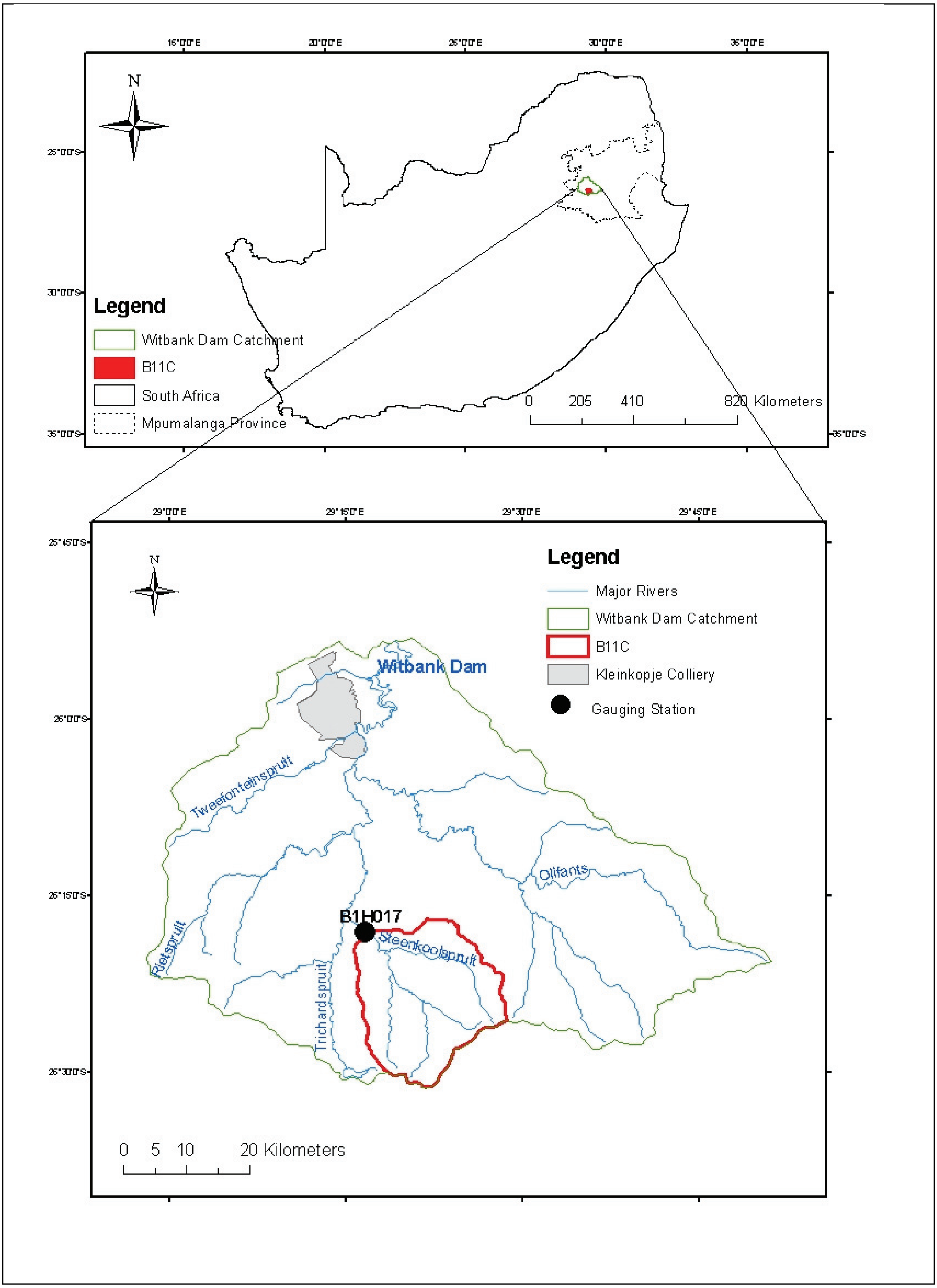


Figure 40: The study area on the Steenkoolspruit

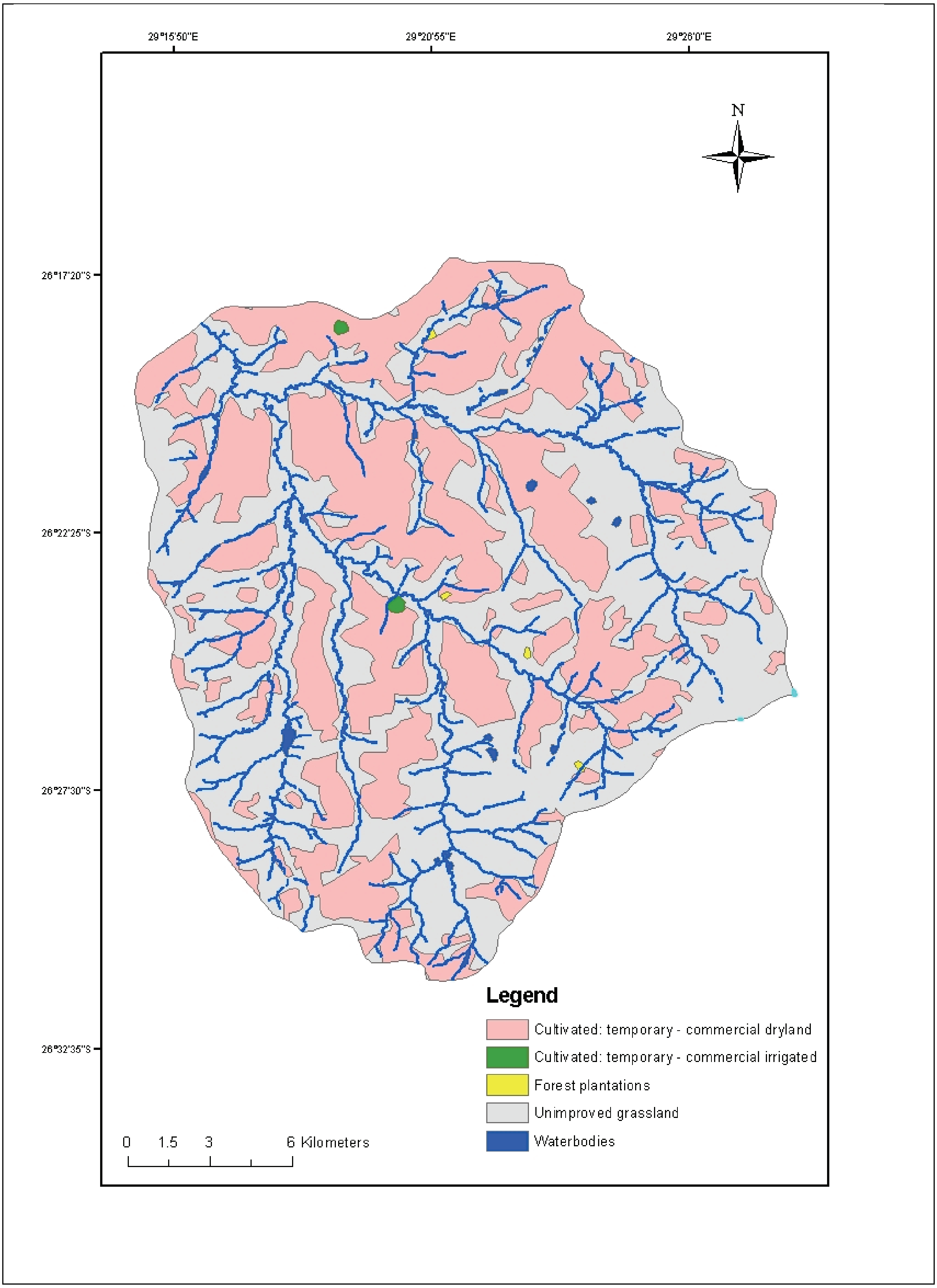


Figure 41: Land use types in the study area with the stream width assumed to include a 30 m strip on each side

6.4 Hydrology

B11C forms part of the headwaters of the Witbank Dam catchment (Figure 40). It is a summer rainfall area with a mean annual rainfall of between 600 mm and 700 mm and a mean annual evaporation of between 1500 and 1600 mm (Midgley, 1994). The mean annual runoff of the catchment is 37 mm (DWAF, 1993). The salt concentration of the runoff from the catchment varies indirectly with the volume of runoff as a result of a dilution effect. From the observed weekly water chemistry data covering a period of 13 years (1990-2003), the weekly total dissolved solids (derived from the weekly electrical conductivity measurements) of the observed runoff from the catchment varies between an extreme low 89 mg/ℓ during summer and high of 722 mg/ℓ during the winter. However, the TDS concentrations generally vary between 100-300 mg/ℓ in summer and between 400-500 mg/ℓ in winter. The TDS variation with the runoff volume is shown in the Figure 42.

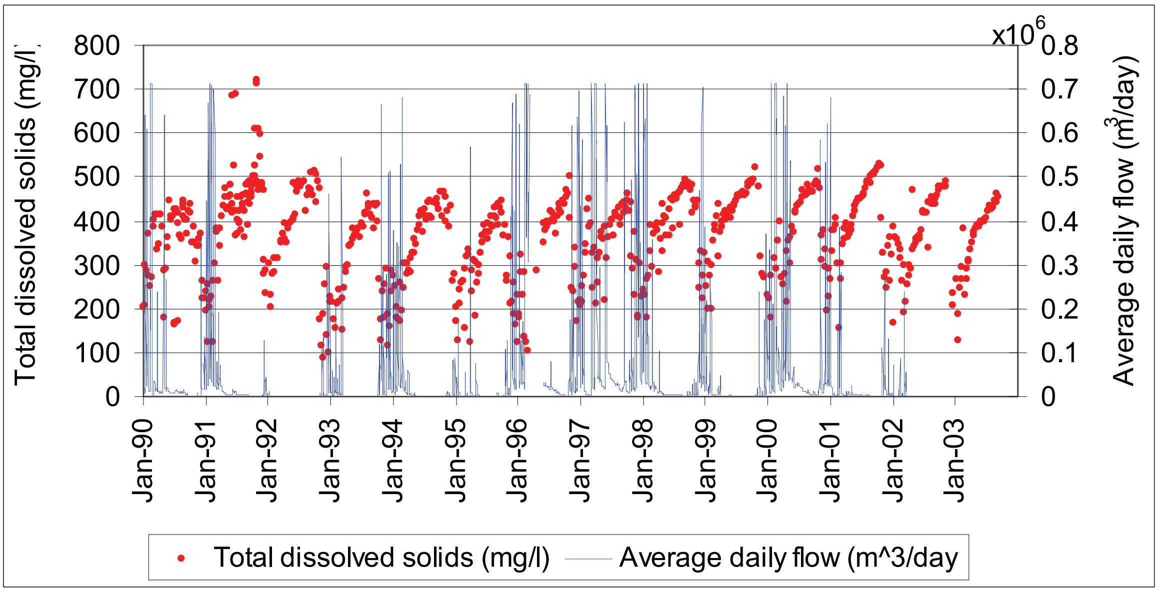


Figure 42: Observed average daily flow and weekly total dissolved solids in Steenkoolspruit

6.5 Objectives of Task

The objective of this task was to carry out a desktop assessment of

- The runoff volume and salt load output from B11C under a condition representative of the current land use types in the catchment, and of
- The impact that the exploitation of coal in the catchment through opencast mining and the subsequent rehabilitation of the disturbed land (a rehab) will have on the runoff and groundwater in the catchment.

6.6 Methodology

6.6.1 General

Two scenarios were simulated in order to achieve the objectives. The first was the current land use (baseline) in the catchment as described by Johnson (1996). The second scenario comprised the current main land use, with a rehabilitated coal mine land (rehab) covering 50% of the entire catchment. The daily rainfall and temperature data used in the scenarios were for Bethal, on the southeastern edge of the catchment. The daily rainfall and temperature data were obtained from the South African Weather Service. The rainfall quality for the catchment was assumed to have a TDS of 26 mg/ℓ as determined by the chemical analyses of rain water in the Johannesburg city and environ by the Johannesburg City Council (Blight, 1992). Considering that air pollutants disperse quickly on the Transvaal Highveld (Blight, 1992), this value may not be significantly different from that of the study area. A 16-year record was employed for the simulation using the *ACRU2000* model and its salinity module, *ACRUSalinity*. The *ACRU2000* model and *ACRUSalinity* module have been modified to enable their application in a coal-mining environment. The relevant modifications and calibrations are summarised in the section that follows.

6.6.2 Scenario Description

Scenario 1

The simulated runoff from the catchment and its salt load were calibrated using the observed average daily flow and the derived total dissolved solids (TDS) of Steenkoolspruit at gauge B1H017 (Figure 40). The derived TDS concentration for a particular day was multiplied by the average daily flow for that day to obtain the average salt load. The observed average daily flow and the derived TDS data (reported on a weekly basis), between 1990 and 2003 was used. The initial soil water and groundwater salinity used for the catchment was 83 mg/ℓ, this being the average groundwater salinity in boreholes located in the Upper Olifants basin as reported by Hodgson and Krantz (1998). Within the catchment is an irrigated area of 42 ha, which was assumed to be planted to maize, just as the dryland agricultural areas of the region. Irrigation water was assumed to be supplied directly from a stream within the catchment, with the streamflow reduced by the amount of the daily irrigation water application. Irrigation water was applied to refill the soil profile to the drained upper limit.

Scenario 2

In the second scenario, half of the catchment area, i.e. 175 km^2, was assumed to be rehabilitated coal mine land. In order to simulate the catchment with rehab as one of the land use types, the area covered by the unimproved grassland was reduced by the area of mine rehab area. The rehab was assumed to have “veld in fair condition”. The *ACRU2000* model, modified to simulate mine land hydrological processes, was validated against measured discharges and salinities in the Kleinkopje Colliery catchment by Idowu, (2007). In order to justify using the model in the B11C rehab scenario, parameter sets and validations of the Kleinkopje Colliery simulations are summarized below.

The soil water retention characteristics of the rehab area are assumed typical of the rehab areas in Kleinkopje Colliery, derived from a monitored centre pivot on rehabilitated mined land (Idowu, 2007). The location of Kleinkopje colliery in relation to the study area is shown in Figure 40. In the monitored centre pivot (Tweefontein pivot), the soil water content and salinity, runoff quantity and quality, as well as the rainfall and irrigation water supply were observed in order to assess the water and salt balances. A summary of the verification studies in Tweefontein pivot are provided in Section 6.6.5. Water quality deterioration occurs in spoils because of prolonged oxidation of sulphide-bearing minerals (Hodgson and Krantz, 1998). The salt uptake rate constant in *ACRUSalinity* is used to account for the increased salt concentration in the soil water and groundwater due to salt generation from chemical weathering processes and subsequent release of solutes into solution. The calibrated salt uptake rate constant obtained for the coal discard dump in Kleinkopje Colliery (1.2 x 10^{-3}) is applied to the groundwater in the rehab, while in the unmined condition, the value obtained for the unmined parts of Kleinkopje Colliery (1.0 x 10^{-5}) is applied.

Groundwater Availability

Baseflow generation in the catchment is based on the “coefficient of baseflow response” (Smithers *et al.*, 1995). The coefficient represents the fraction of the water from the groundwater store released as baseflow.

The typical value of the coefficient would range from 0.01 to 0.03 (Smithers *et al*., 1995). A value of 0.02 is assumed for the baseline condition in the catchment i.e. prior to opencast mining. In the rehab, the calibrated coefficient of baseflow response (0.0002), obtained for the monitored rehab area in a centre pivot in the Kleinkopje Colliery, is used. The lower value of the coefficient in the rehab is a result of the higher permeability in the spoil (than the unmined sediments) underlying the rehabilitated area causing percolating water to move more quickly through the spoil and accumulate at the bottom of the spoil, in comparison to the pre-mining condition. Opencast mining leads to dewatering of aquifers and the lowering of the water table, which may form a depression cone not usually extending laterally more than 40 m in the Upper Olifants (Hodgson and Krantz, 1998). In the rehab void, water level recovery may occur, with the water level rising to the lowest rehabilitated surface elevation and then decanting, thereby establishing a new equilibrium. Prior to the re-establishment of the new equilibrium however, percolating water will gradually accumulate in depressions at the bottom of the rehab area, with the water table gradually rising until the decanting level is reached. Consequently, contribution of baseflow to runoff would be insignificant during the period of groundwater rebound, but may well continue to contribute to runoff after the establishment of the new equilibrium when groundwater will flow in the direction of the hydraulic gradient. However, this will not detract from the water available for pumping from the groundwater store, as this is dependent on the average recharge rate.

6.6.3 Summary of Relevant Modifications to and Application of *ACRU2000* and *ACRU Salinity*

6.6.4 Modifications to *ACRU*

ACRU2000 and *ACRUSalinity* have been modified to enable their application to a coal-mining environment. A summary of the modifications is presented below, followed by demonstration of calibrations relevant to this study.

- The addition of a soil surface layer to model the process of overland flow taking into solution, salts accumulated near the surface due to evaporation;
- The addition of a new hydrologic component, an underground reservoir, to represent the occurrence of water in underground mined-out areas. Leakages into and seepages from the reservoir are taken into consideration. Parameters driving fluxes from these sources are based on knowledge of these processes;
- The possibility of multiple transfer of water of different salinities from at least six different sources into a surface reservoir;
- The addition of a special kind of surface reservoir, a mine-pit reservoir, to represent water that accumulates in opencast pits. Relevant fluxes of rainfall and seepage are taken into consideration;
- Inclusion of controlled releases from reservoirs in coal mines, which can be permitted during periods of high flow (Coleman *et al.*, 2003) in the reservoir water and salt budgeting; and
- In the surface reservoir yield analysis, seepage has been modified to be dependent on the volume of water in storage and reflect the dynamics with which the surface reservoir interacts with groundwater.

6.6.5 Verification of Routines and Parameter Sets at Kleinkopje Colliery

The modified *ACRU2000* model and *ACRUSalinity* module have been applied to a centre pivot on rehabilitated land and to a catchment to demonstrate their applicability in a coal mining environment (Idowu, 2007).

Tweefontein Pivot

The Tweefontein pivot is on rehabilitated mine land. The results of the verification study, using the volume and salinity of the runoff from the centre pivot, are presented in Figure 43 and Figure 44. The results show that the runoff volume and salinity are adequately simulated.

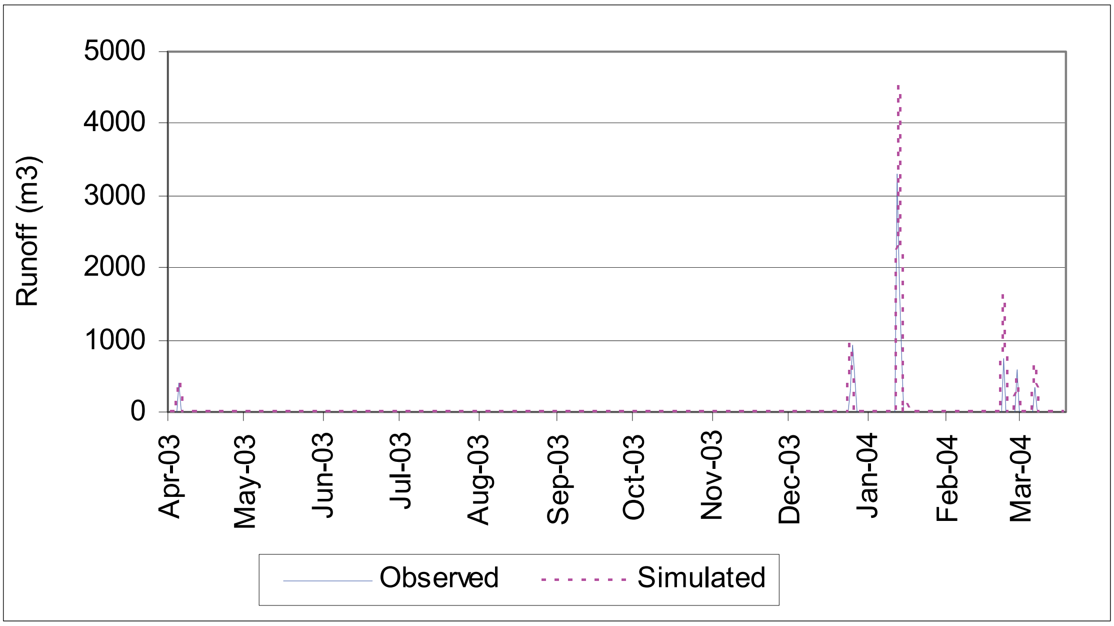


Figure 43: Observed and simulated daily runoff from pivot Tweefontein

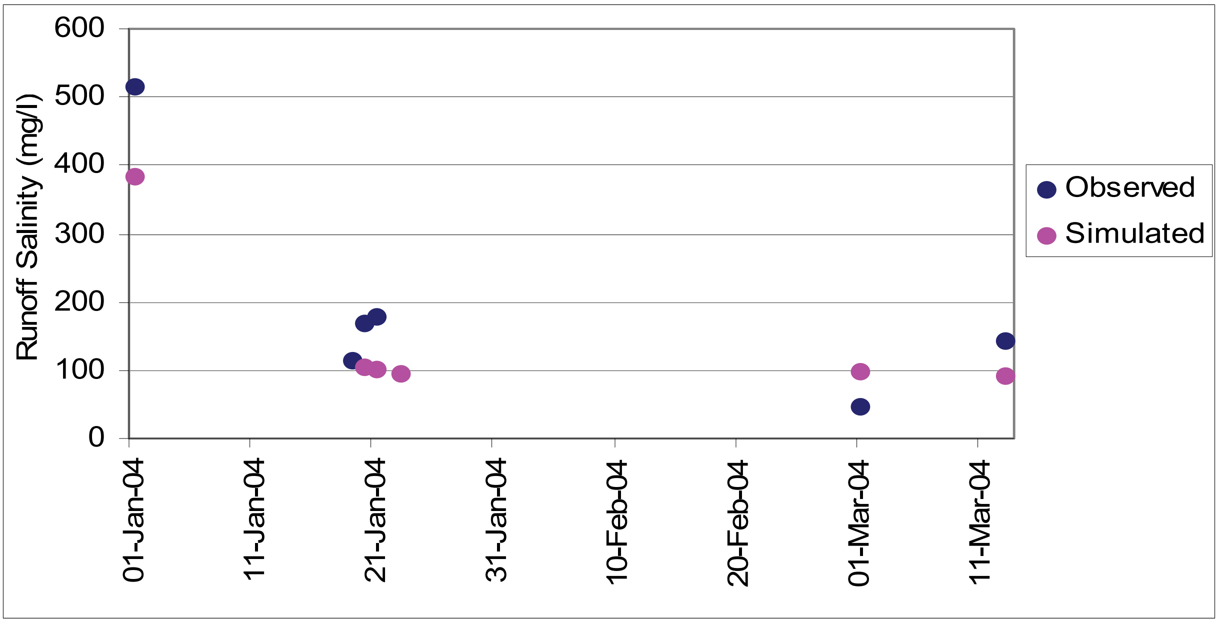


Figure 44: Daily salinities of sampled and simulated runoff from pivot Tweefontein

Tweefontein Catchment

The Tweefontein Pan catchment is unmined but lies almost entirely within the Kleinkopje Colliery. Successful simulations of the catchment proved that the revised model yields realistic results in this environment. The Tweefontein Pan catchment has the following characteristics:

- An area of 4.7 km^2
- An internally draining surface reservoir (Tweefontein Pan) containing mine wastewater and with a capacity and surface area (at full capacity) of 4 000 Ml and 1. 5 km^2 respectively,
- A centre pivot of 30 ha (pivot Four) irrigating agricultural crops with water from the Tweefontein Pan,
- The non-irrigated area in the catchment has grasses and the vegetation is assumed to "Veld in poor conditions" and
- An underground reservoir with estimated capacity of 2 x 10^9 Ml.

Three illustrative scenarios are presented in the following section, *viz*.

Scenario 1: Baseline simulation against recorded data representing the current condition in the catchment,
Scenario 2: Assumed widespread irrigation on unmined soils in the catchment and
Scenario 3: Assumed widespread irrigation on rehabilitated mine land in the catchment .

The following were taken into consideration in simulating the catchment:

- volume of water pumped in and out of the Tweefontein Pan,
- return flow from the irrigated area, as well as the
- leakages into the underground reservoir

Scenario 1

The volume and salinity of water in storage in the Tweefontein Pan over a period of 5 years (1999-2004), as well as the salinity of the soil water in the irrigated pivot are used for verification. The results of the verification are presented in Figure 45 and Figure 46. With correlation coefficients of 0.96 and 0.76 respectively, the volume and salinity of water in the Tweefontein Pan are simulated satisfactorily. Limited observed data was available on the soil water quality in pivot Four due to difficulties encountered in extracting soil water with the ceramic soil water samplers, particularly under dry conditions (Figure 47). The observed and simulated salinity in the underground reservoir is shown in Figure 48.

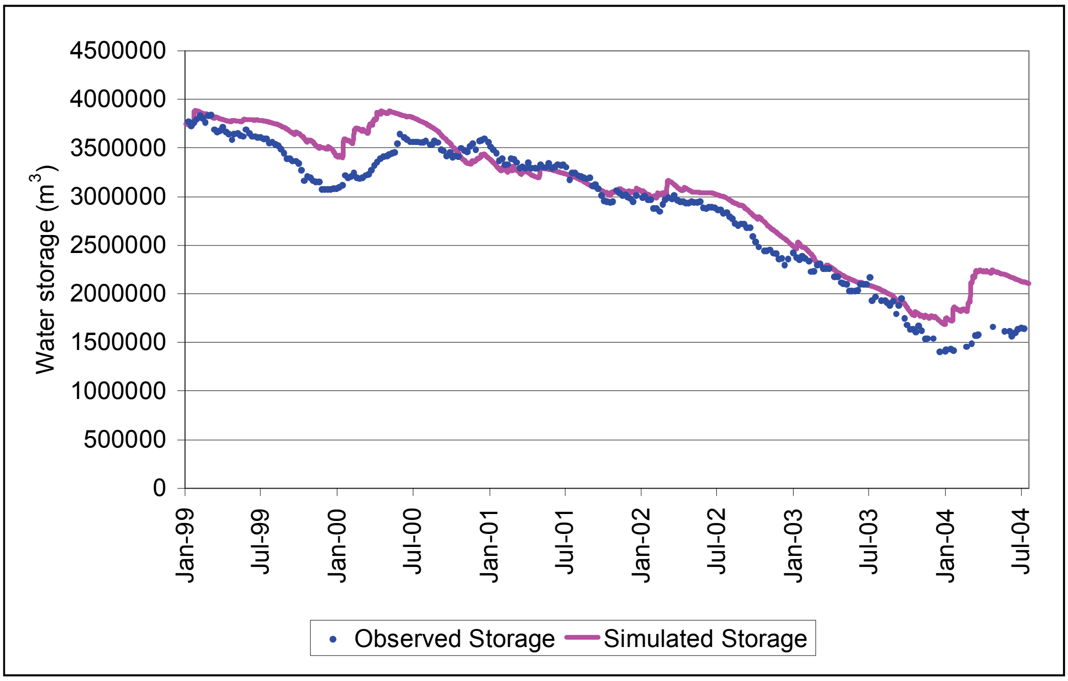


Figure 45: Simulated and observed daily water storage in the Tweefontein Pan

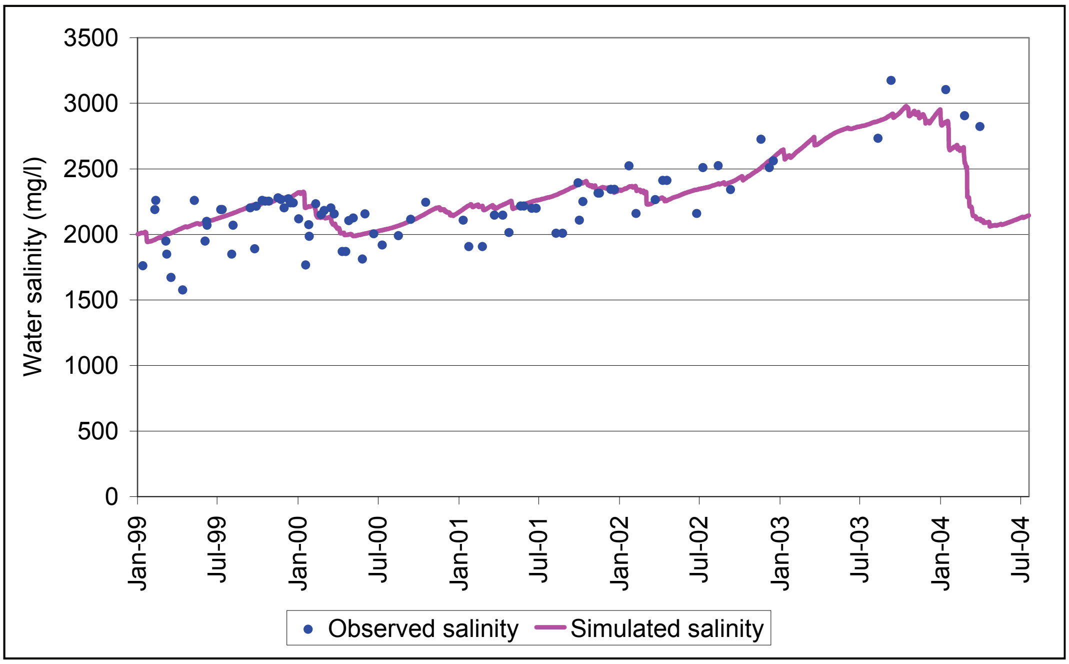


Figure 46: Observed and simulated quality of water in storage in the Tweefontein Pan

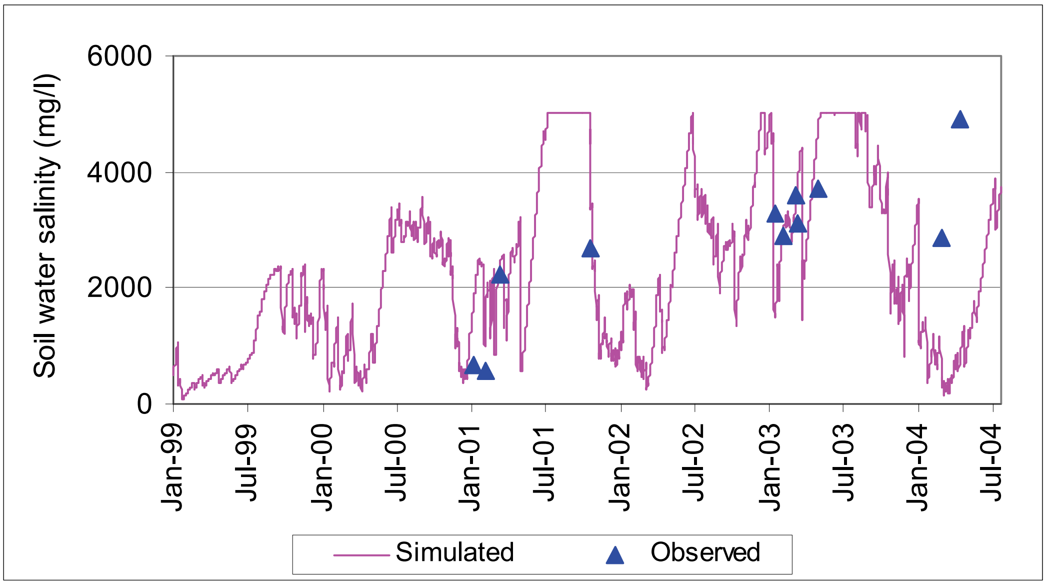


Figure 47: Observed and simulated daily salinities of soil water at 100 cm in the irrigated area of pivot Four

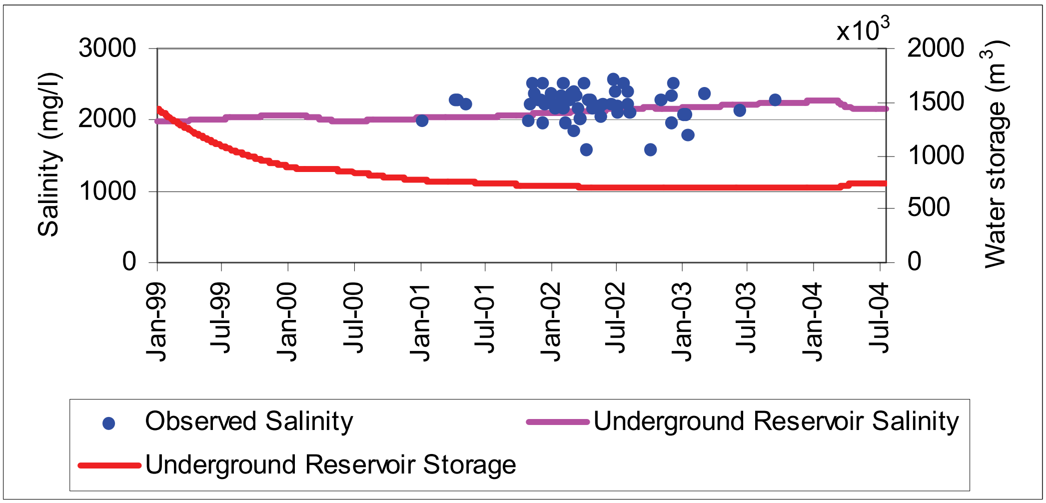


Figure 48: Observed salinity and simulated daily water storage and salinity in the underground reservoir

Scenario 2

The impact of widespread irrigation, using the mine water in the Tweefontein Pan, was assessed by increasing the irrigated area in the catchment. The irrigated area was assumed to be similar to that of the pivot named “Pivot Four” located in the catchment. The assessment shows that in addition to the irrigation of a rehabilitated area of 20 ha at pivot Tweefontein (located outside the catchment) with the water from Tweefontein Pan, a virgin area of 160 ha, representing an additional 8 centre pivots of 20 ha each, could still be sustained with irrigation water from Tweefontein Pan over the simulation period but that the stored water in Tweefontein Pan will be depleted by the end of the simulation period. The impact of widespread irrigation in the catchment was compared with the baseline scenario in Figure 49 and Figure 50. What is demonstrated with the results is that, in making decisions on widespread irrigation with mine water, it is very important that sustainability, in terms of the availability of adequate mine water for widespread application, be assessed.

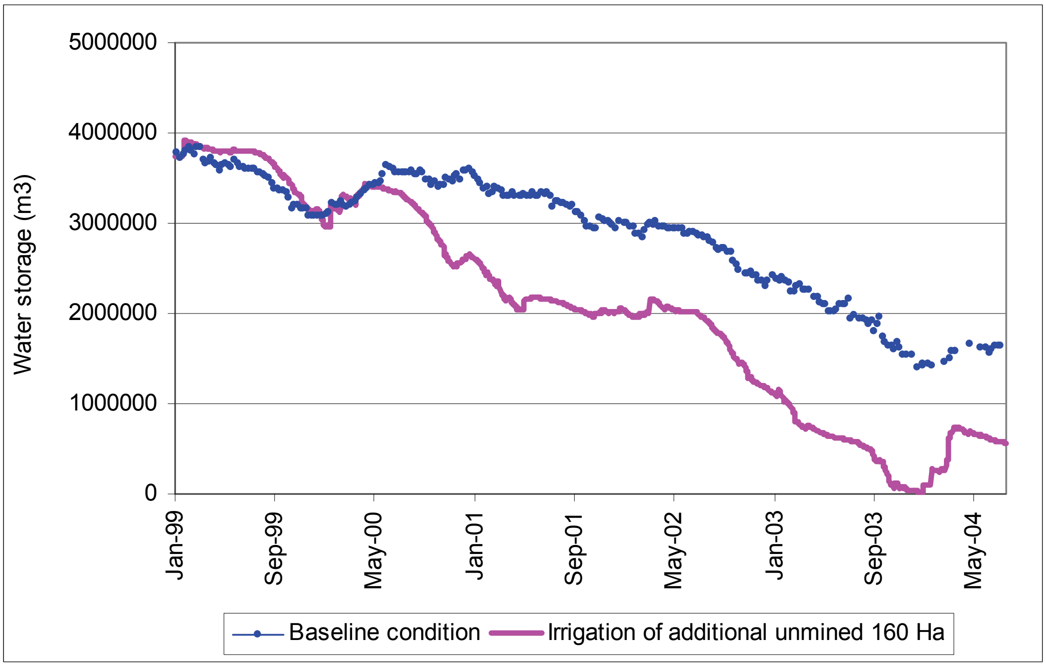


Figure 49: Effect of widespread irrigation of 160 ha in the Tweefontein Pan catchment on the water storage in the Tweefontein Pan

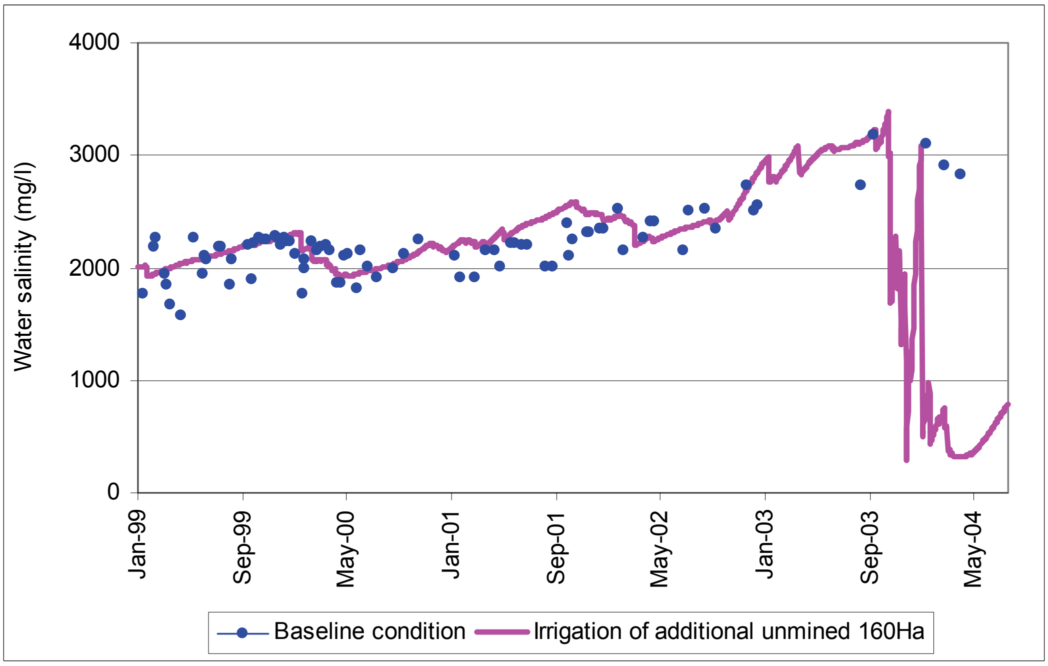


Figure 50: Effect of widespread irrigation of 160 ha in the Tweefontein Pan catchment on the water quality in the Tweefontein Pan

The drop in TDS concentration at the end of the simulation period is due to the volume in the pan recovering in 2003/2004 due to higher than average rainfall. The addition of the low TDS concentration rainfall and runoff associated with the rains resulted in the concentration in the pan dropping and the volume stored in the pan recovering.

Scenario 3

In a mine pit void, prior to the re-establishment of the new ground water equilibrium as explained in Section 6.6.2, percolating water will gradually accumulate in depressions in the pit floor, with the water table gradually rising until the decanting level is reached. Consequently, contribution of baseflow to runoff may be insignificant, unlike after the establishment of the new equilibrium when groundwater will flow in the direction of the hydraulic gradient and increase the contribution to the runoff. Taking these into consideration, during the simulation of rehabilitated areas representing post-water table re-establishment, the default value of the baseflow response fraction is taken as 0.02. Prior to the re-establishment of the water table however, the baseflow response parameter is set at 0.0002, which is the calibrated value used for the centre pivot located on an irrigated rehabilitated mine land at Kleinkopje Colliery. If Tweefontein Pan catchment is mined-out, rehabilitated and the water table has not been re-established, only a maximum of 120 ha can be adequately irrigated with mine water from the pan, indicating that the area that can be sustained by irrigation with water from the Tweefontein Pan will be less than if the catchment were unmined.

A comparison of the impact of this scenario on the volume and salinity of water in Tweefontein Pan with the two other scenarios of irrigating an unmined area and a rehabilitated area, post water table re-establishment, are presented in Figure 51 and Figure 52. Irrigating a rehabilitated area of 120 ha in Tweefontein Pan catchment (either pre- or post- water table re-establishment) will deplete the water in the pan more rapidly than irrigating a virgin area of 120 ha (Figure 52).

This would be because, the runoff (and runoff salt load) from the rehabilitated area would be lower and the volume of water and salt that would go into groundwater storage would be more when the irrigated area is rehabilitated than when it is unmined. Hence, less water reaches the Tweefontein Pan in the rehab scenario than in the baseline case. The pre-water table re-establishment has the lowest flow due to the removal of the baseflow into the mine pit void. The post water-table re-established case, the water in the mine void has reached equilibrium and some baseflow is re-established.

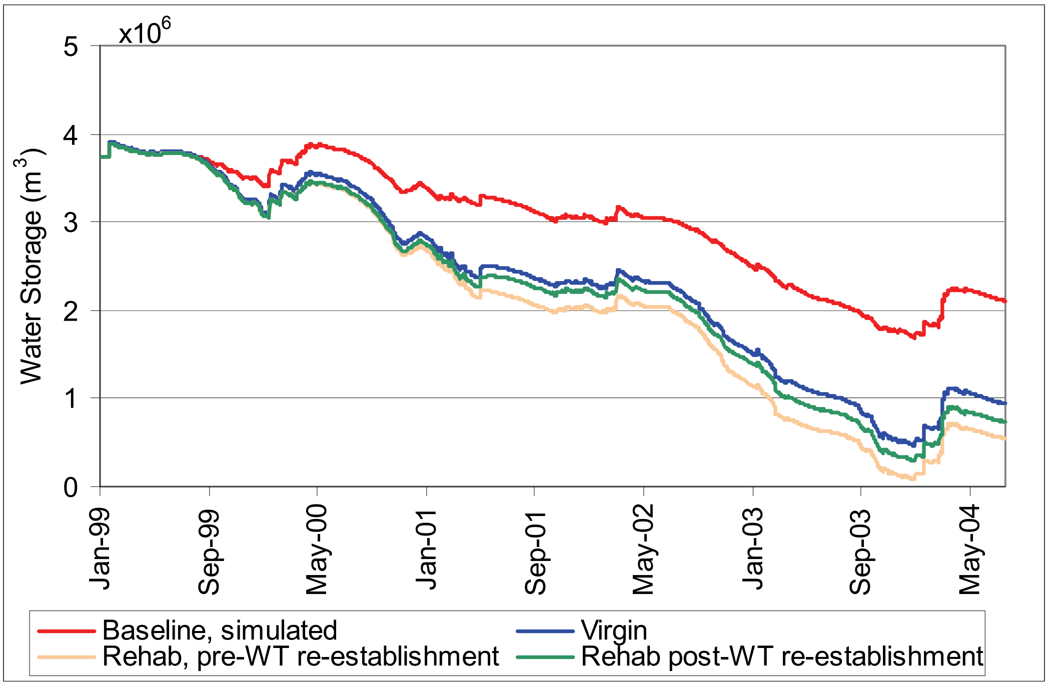


Figure 51: Comparison of the effect of widespread irrigation on the Tweefontein Pan water storage for irrigation on unmined and rehabilitated land.

6.7 Results of Scenario Simulations for B11C Quaternary

A comparison of the observed average daily runoff and the simulated total daily runoff at gauge B1H017 is presented in Figure 53. The over topping of the rating limit during high flows (as recorded by DWAF) meant that such flows could not be accurately recorded. The calculated daily salt loads are compared with the simulated daily salt load in Figure 54. The simulations are realistic, despite the extreme values exceeding the gauge capacity. The mean annual runoff and salt load for the catchment are 40.8 x 10^6 m^3 and 5758 metric tons respectively (Table 17).

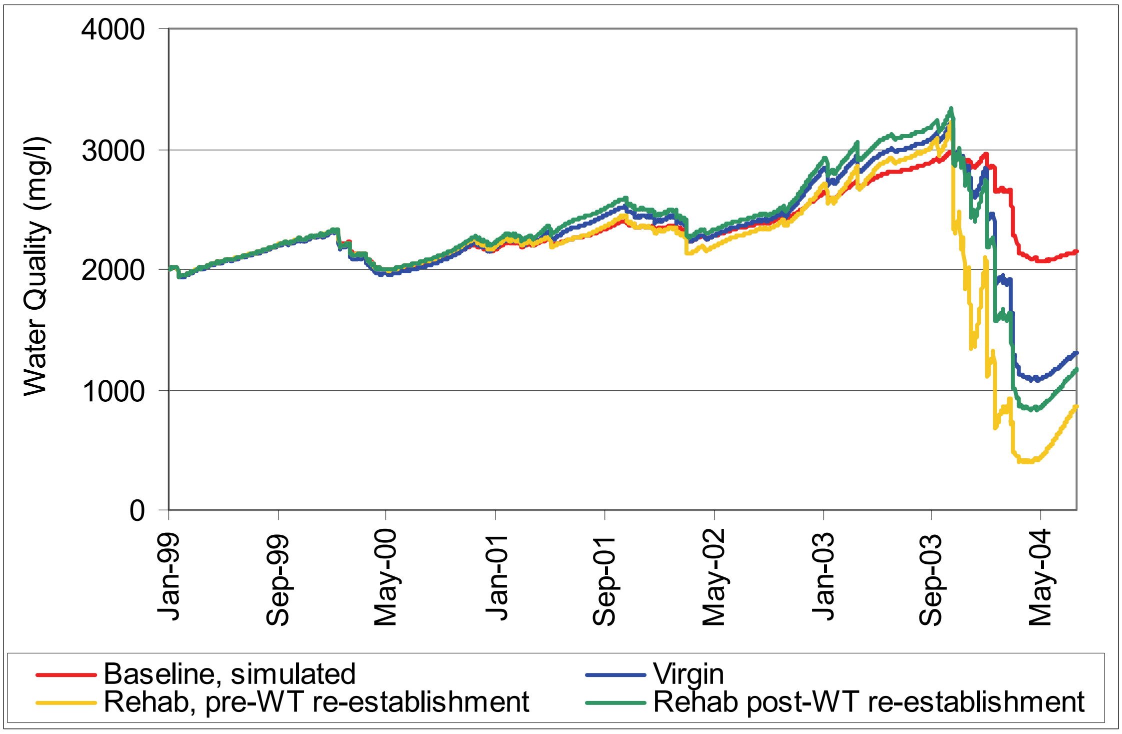


Figure 52: Comparison of the effect of widespread irrigation on the Tweefontein Pan water quality for irrigation on unmined or rehabilitated land.

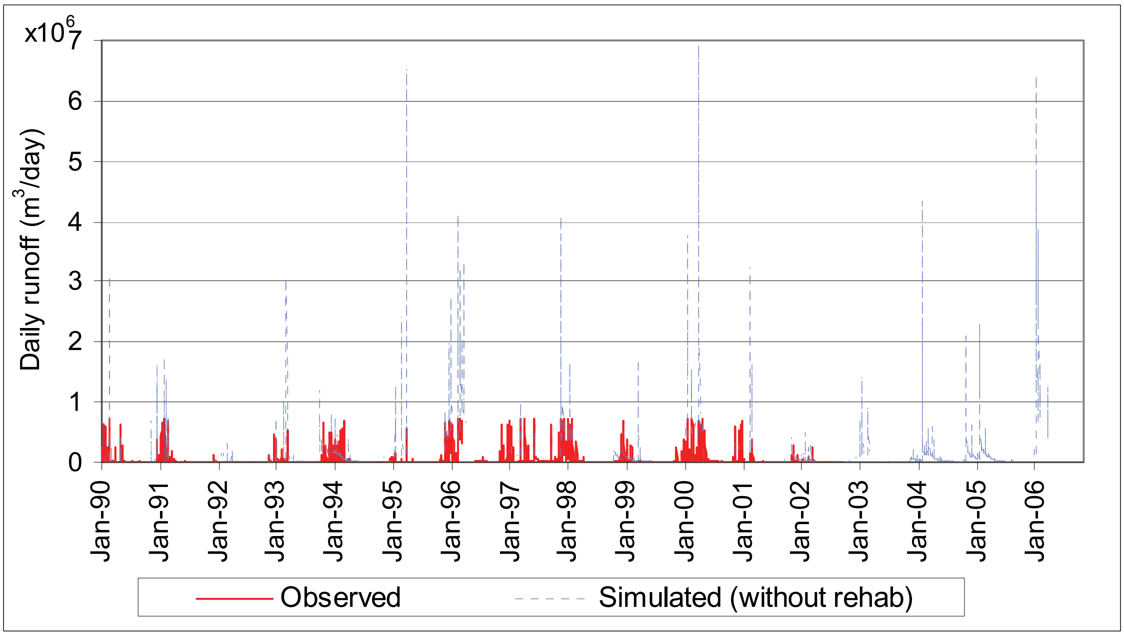


Figure 53: The observed and simulated daily runoff of B11C

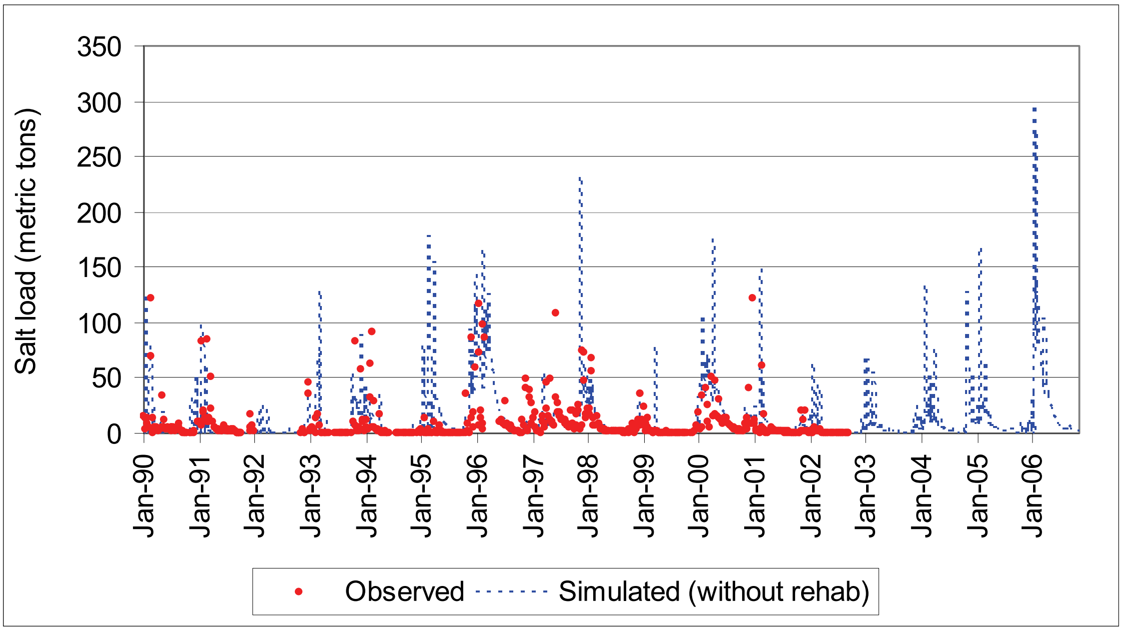


Figure 54: The observed and simulated daily salt load from B11C. In the baseline condition, the simulated mean annual runoff volume and salt load

Table 17: Results of simulations in catchment B11C

Runoff	**Catchment under baseline condition**	**Catchment with 175 km^2 rehab**	**Difference %**
Mean Annual Runoff (m^3)	40.8 x 10^6	33.5 x 10^6	-18
Mean annual salt load (metric tons)	5758	32612	466
Average daily runoff salinity (mg/ℓ)	177	1739	882
Groundwater and Runoff	**Unimproved grassland**	**Rehab**	**Difference %**
Average annual percolation (mm)	31	98	216
Percolation as % of rainfall	4	13.3	232
Average groundwater salinity (mg/ℓ)	145	2918	1912
Mean annual runoff (mm)	114	72	-37
Average runoff salinity (mg/ℓ)	152	2794	1738
TOTAL	346	5895.3	4061

A decrease in the mean annual runoff volume of 18% from the catchment was obtained with the existence of a rehab of 175 km^2, which is half the area of the catchment (Figure 55, Table 17), whereas a significant increase of 466% was obtained in the mean annual runoff salt load. The daily average runoff salinity increased from 177 mg/ℓ to 1 739 mg/ℓ. A comparison of the daily runoff and its salinity, with the catchment simulated under baseline conditions and with a rehab of 175 km^2, are presented in Figure 55 and Figure 56 respectively.

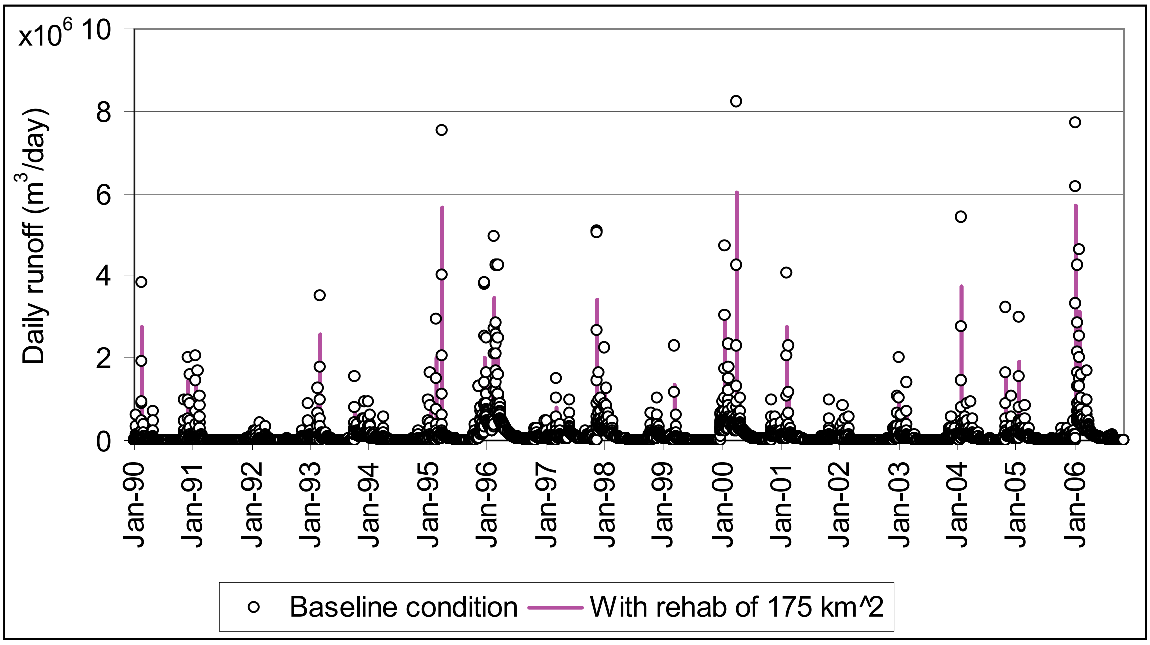


Figure 55: Comparison of the simulated daily runoff volume under baseline condition and with a rehab of 175 km^2

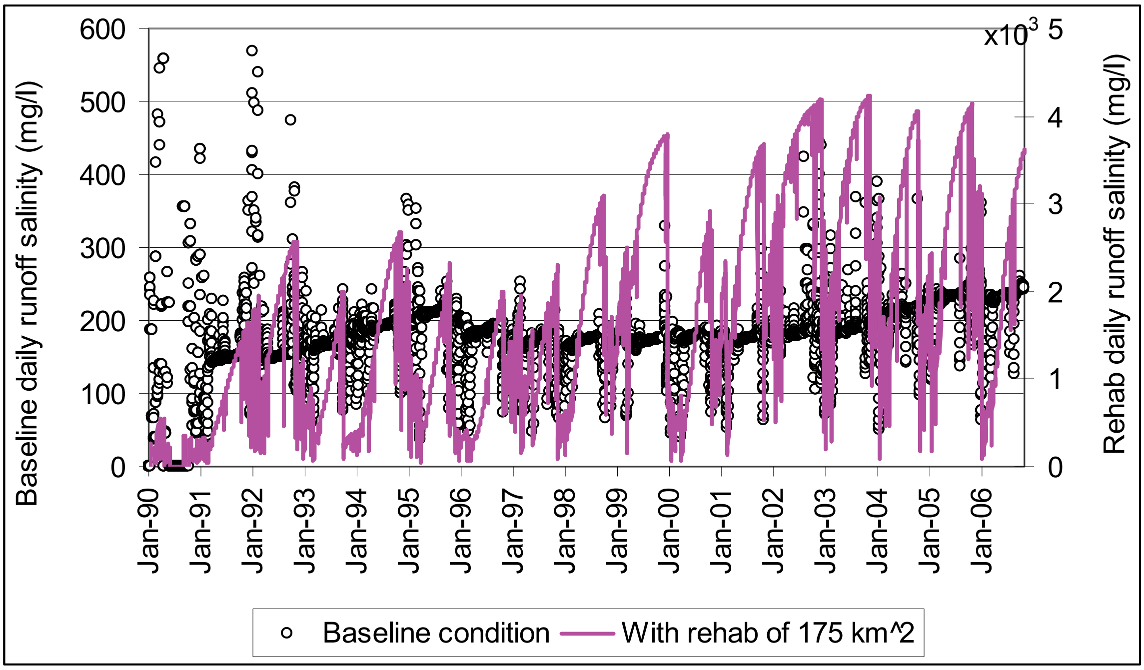


Figure 56: Comparison of the simulated daily runoff salt load under baseline condition and with a rehab of 175 km^2

Significant differences were obtained in the characteristics of the groundwater in the baseline condition and in the corresponding rehab area covered by the unimproved grassland. An increase from 31 mm to 98 mm in the average annual amount of percolation to groundwater will occur in the rehab over that in the original unimproved grassland (Table 17). The average annual amount of water that can be utilised for pumping in a sustainable manner in the rehab is therefore 98 mm, amounting to 17.2x10^6 m^3 per annum from the 175 km^2 rehab. However, the average annual volume of groundwater in storage resulting from recharge through the spoil is 512 mm. It should be noted that this amount represents the accumulated volume of water that goes into storage from percolation and contributes to the water level recovery in the rehab. If a new equilibrium has been re-established as a result of the water level rising to a decanting level, the amount of groundwater in storage may be less. However recharge will not change and pumping capacities would be sustainable.

Therefore, careful monitoring of groundwater is necessary to ascertain the nature of water level recovery in a rehabilitated mine land.

In the simulated pre-mining condition, the average annual volume of groundwater store is much less (4.6 mm) than in the rehab scenario. The average groundwater salinity will increase to 2 918 mg/ℓ in the rehab from 145 mg/ℓ in the pre-mining condition in the unimproved grassland, while the runoff from the rehab will be less by 37% from the runoff from the unimproved grassland (Table 17, Figure 57). The mean annual runoff from the rehab and baseline are 68 mm and 100 mm respectively (Table 17). An increase in runoff salinity manifests in the rehab compared to the pre-mining condition.

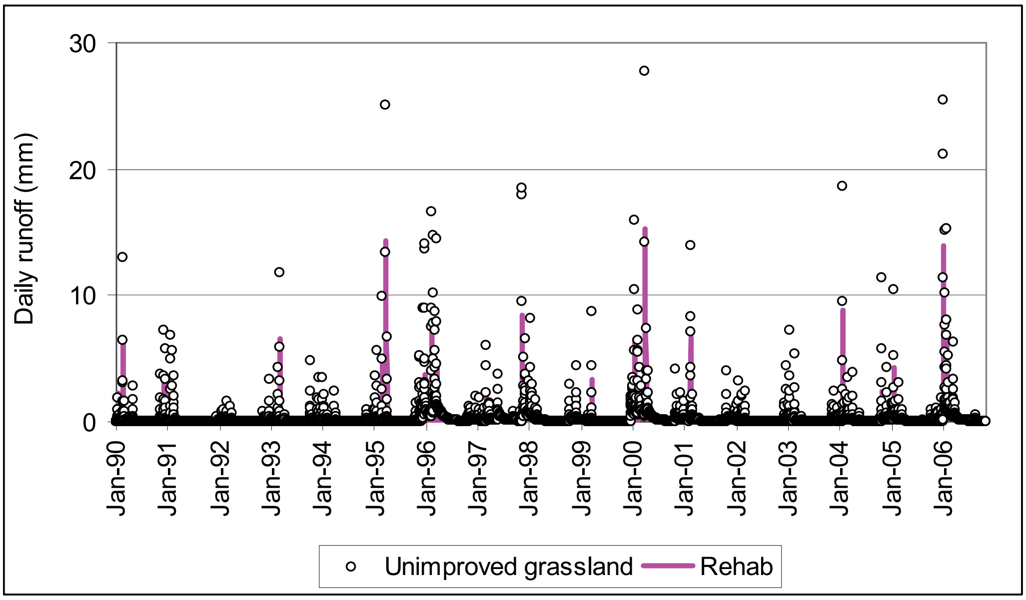


Figure 57: Comparison of runoff from the unimproved grassland and rehab B11C catchment scenarios

The decrease in the total runoff from the whole catchment when it contains a rehab area of 175 km^2 compared to the baseline condition can be attributed to the decrease in the runoff from the rehabilitated area, caused by the increase in infiltration and percolation into the spoil.

6.8 Conclusions

With the mining-out and rehabilitation of half of B11C, a temporary decrease in the total runoff volume from the catchment can be expected prior to decant. However, a significant increase in the salt load and the salinity of the runoff will occur. The runoff volume from the rehab area can be expected to decrease compared to that from the same area under pre-mining condition, while the quality of groundwater can be expected to deteriorate in the rehab compared to the pre-mining condition. In the rehab, an average annual percolation of 98 mm/yr can be expected, with the same amount of water (17.2 x 10^6 m^3) available for pumping in a sustainable manner, thereby making the mean annual catchment yield for water supply a total of 50.6 x 10^6 m^3.

The average total storage in the rehab over the simulation period is 512 mm, which would be adequate for continuous groundwater extraction. However, because of the varied nature of spoils and methods of their rehabilitation, a careful monitoring of the groundwater in the rehab is recommended to determine the nature of water level recovery and the effects of possible high permeability in the spoil affecting yield.

7 DESCRIPTION OF MODELLING SCENARIOS AND APPLICATION OF IMPACT MODEL

7.1 Introduction

The scenarios investigated were divided into:-

- The use of rehabilitation covers to reduce the recharge and hence the volumes of water needed to be treated. The impact on the sulphate concentrations in the Middelburg and Witbank Dams was investigated with the decants being treated and discharged and without treatment. The purpose of this was to determine if by using good covers the assimilative capacity of the receiving streams would be sufficient to take up the decant volumes without exceeding the RWQO.
- Optimal use of storage. This involves the transfer of water between groups of mines to workings where storage is available. This will involve the construction of pipelines between the workings but will delay the need for a treatment plant.
- Intermine flow. This is where the mine workings can be linked through the barrier pillars so that the water can drain under gravity to a low point in the coal floor. The water can be abstracted at this point and treated for supply to a local municipality. This option only applies to the Witbank Dam Catchment.

7.2 Reduction of volume for treatment by using covers

7.2.1 Description of Scenario 1 – poor standard cover

This scenario includes the following:-

- The planned Emalahleni (20 ML/d) and Optimum (11 ML/d) plants are in place and operational. The Optimum plant is supplying the water requirements of Hendrina and KwaZamakuhle with the balance of the treated water being discharged to the Zevenfonteinspruit.
- The Kwagga/Arnot group supplies the Mafube Colliery with its water requirements until the end of Mafube's life of mine.
- The standard 600 mm poorly constructed cover is assumed to be used to rehabilitate the opencast workings. A recharge factor of 0.2 was used for this cover.
- A recharge factor of 0.02 and 0.06 was used for the underground bord and pillar and high extraction areas respectively.
- The mines install the pipe infrastructure to utilise the underground storage as it becomes available in a group.
- Once the storage is full the decant reports to the river and flows to the Witbank and Middelburg Dams for use by the local municipalities.
- Alternatively, decant water is treated and discharged to river. The impact on the water quality of the water resources of no treatment and discharge was also investigated.

7.2.2 Description of Scenario 2 – good standard cover

This scenario is the same as scenario 1 except for the cover which is replaced with a good standard cover on the opencast workings. A recharge factor of 0.15 was used for this cover.

7.2.3 Description of Scenario 3 – good 1200 mm thick cover

This scenario is the same as scenario 1 except for the cover which is replaced with a good 1200 mm cover on the opencast workings. A recharge factor of 0.10 was used for this cover.

7.3 Optimal use of storage in the mine workings – Scenario 4

This scenario includes:-

- The planned Emalahleni (20 ML/d) and Optimum (11 ML/d) plants are in place and operational. The Optimum plant is supplying the water requirements of Hendrina and KwaZamakuhle with the balance of the treated water being discharged to the Zevenfonteinspruit.
- The Kwagga/Arnot group supplies the Mafube Colliery with its water requirements until the end of Mafube's life of mine.
- Treatment plants are installed at each of the groups to treat the water and discharge to the rivers upstream of the dams. No revenue stream is received for the water. Storage in the workings will be used first before treatment is applied. Pipelines will be constructed to link workings. The Optimum Colliery is linked to Boschmanspoort workings and the Kwagga Group to Schoonoord. A 32 km pipeline is needed to transfer the water from the Kwagga Group to Schoonoord and a 18 km pipeline to transfer water from Optimum to Boschmanspoort.
- The standard 600 mm well constructed cover is assumed to be used to rehabilitate the opencast workings. A recharge factor of 0.15 was used for this cover.

7.4 Intermine Flow – Scenario 5

The use of intermine flow by connecting the mine workings so that water will flow to a desired point will obviate the need for expensive pipe systems to convey the water to the desired point. The Witbank Dam mining areas present an opportunity to use intermine flow to direct the mine water to a low point in the floor contours near Douglas Colliery. The possible flow routes are shown in Figure 58. The application of this approach is only feasible at closure and the connections between the different mine workings will have to be planned and installed while the mines are still operational. The direction of the mine water to the low point at Douglas Colliery allows for the piping of treated water to supply Witbank. For this scenario, the links between the workings are assumed to be installed by the mines during the mine operations. The scenario will be the abstraction of water at Douglas Colliery with a pipeline to supply potable water to Witbank. The water is sold to Witbank at R2.80/m^3. The problem with the assessment of this option is that the links between the workings will only be achieved at closure. In the meantime, mines need to treat water at different times going forward to closure. The approach used was to look at the scheme at closure in 60 years time. The NPV has been calculated for a 30 year period after closure in 60 years time.

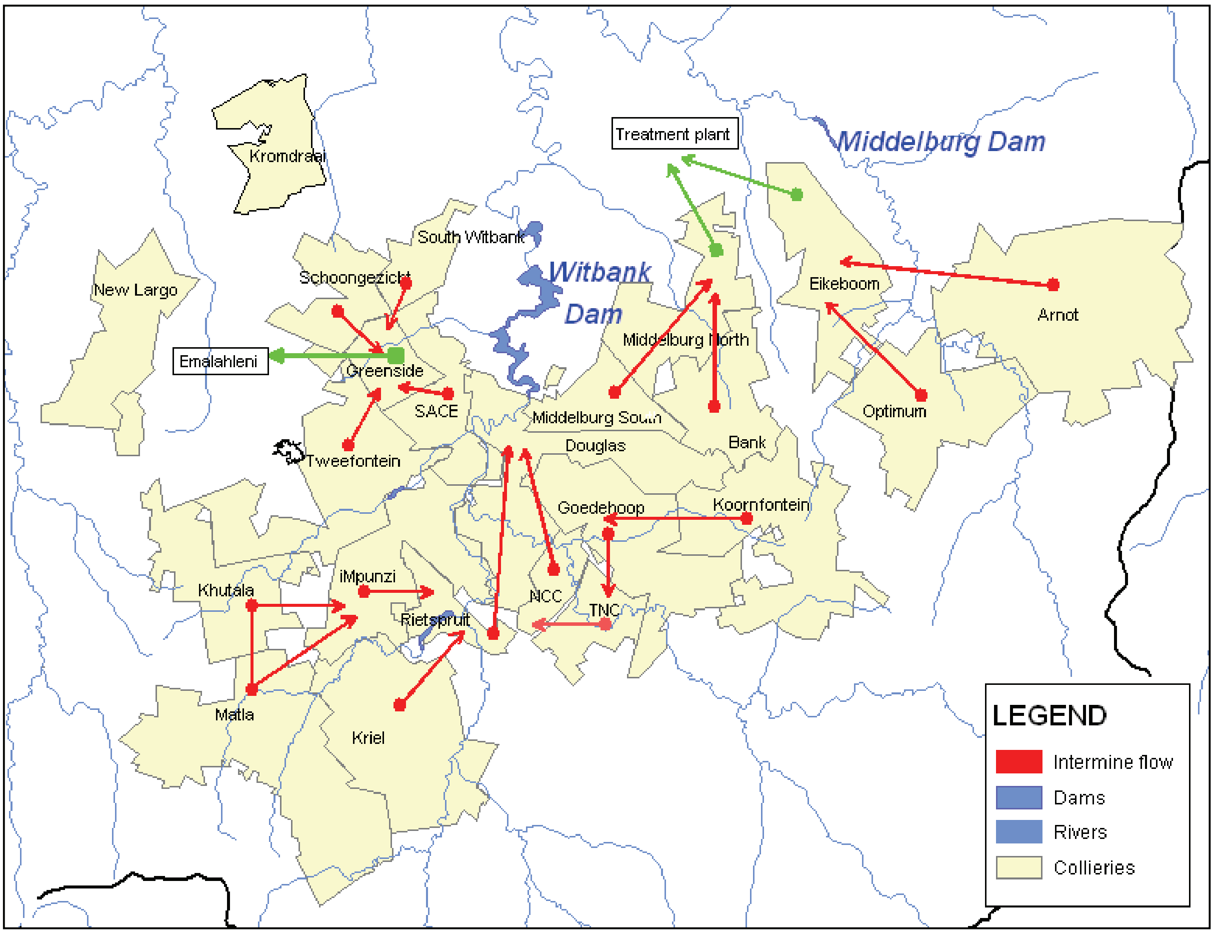


Figure 58: Potential intermine flow routes between mine workings

7.5 Analysis Results – Cover scenarios 1, 2 and 3

7.5.1 Middelburg Dam Catchment

Optimum group

The plot of the water make from the Optimum grouping is shown in Figure 59. The data collected shows that there is no storage currently available in the workings and there will be some decant. However once the storage in the Pullenshope underground and opencast workings becomes available, the decant will stop until the workings are filled. The graphs clearly show the effect of the different covers on the time to fill the workings and the final decant volumes that can be expected. The time to fill, the final decant volumes, the NPV of the treatment costs and the NPV of the rehabilitation costs required to achieve the poor standard, good standard and good 1200 mm cover are given in Table 18. The analysis showed that the good 1200 mm cover reduces the recharge to the workings so that the current water treatment plant of 11 ML/d can manage the recharge.

Kwagga group

The analysis shows that a treatment plant will be required within the next 10 to 20 years to handle the excess water. The treatment plant implementation date and the plant capacity varies depending on the cover type.

Eikeboom group

There is limited storage capacity available at Eikeboom and Klipbank. The available storage will be filled in 10 to 20 years time thereafter a treatment plant will be required. The capacity and implementation date is affected by the type of cover that is used on the opencast workings.

Schoonoord and Boschmanspoort group

Schoonoord is an underground bord and pillar mine which has about 9 million m^3 of storage capacity available in about 12 years time. The workings do not fill up over the 76 year simulation period due to the low recharge rates associated with bord and pillar underground workings. Similarly the Boschmanspoort underground mine has about 40 million m^3 of storage capacity available in 12 years which does not fill over the simulation period. The available storage represents an opportunity to pump excess water into the workings as storage capacity becomes available. The Kwagga and Optimum groups are located sufficiently close for the excess water to be stored in these two sections.

Mafube Group

The simulation showed that Mafube Colliery will need a treatment plant early on in its life as there is insufficient storage capacity on site to store the excess water between years 10 and 20. A further treatment plant will be required after 30 years depending on the cover used. The time period and the volume that needs to be treated initially depend on the cover used. There is an opportunity to perhaps manage this excess water using a temporary irrigation scheme before treatment is required from year 30.

Arnot/Eskom Group

The Arnot opencast pit is already full and close to decant. The water in the pit will be used to supply Mafube Colliery until the colliery generates its own excess water. This alleviates the immediate threat of decant from the pit. Thereafter the storage in the Arnot Colliery underground workings can be used to store the excess water until year 60. Thereafter there will be a decant which will need treatment.

The costing model was applied to each group of collieries in the Middelburg Dam catchment. The times to decant, treatment volume as well as the NPV of treatment costs and rehabilitation costs are given in Table 18. The impact of the decant volume and sulphate concentrations on the water quality of Middelburg Dam is shown plotted in Figure 66. The plots show that even with a 1200 m cover the decant volumes and qualities are such that the concentrations will exceed the 180 mg/ℓ RWQO for the dam. The plot of the simulated sulphate concentration in the dam with treatment and discharge in place is shown in Figure 66. The plot shows that treatment and discharge will meet the RWQO for the dam.

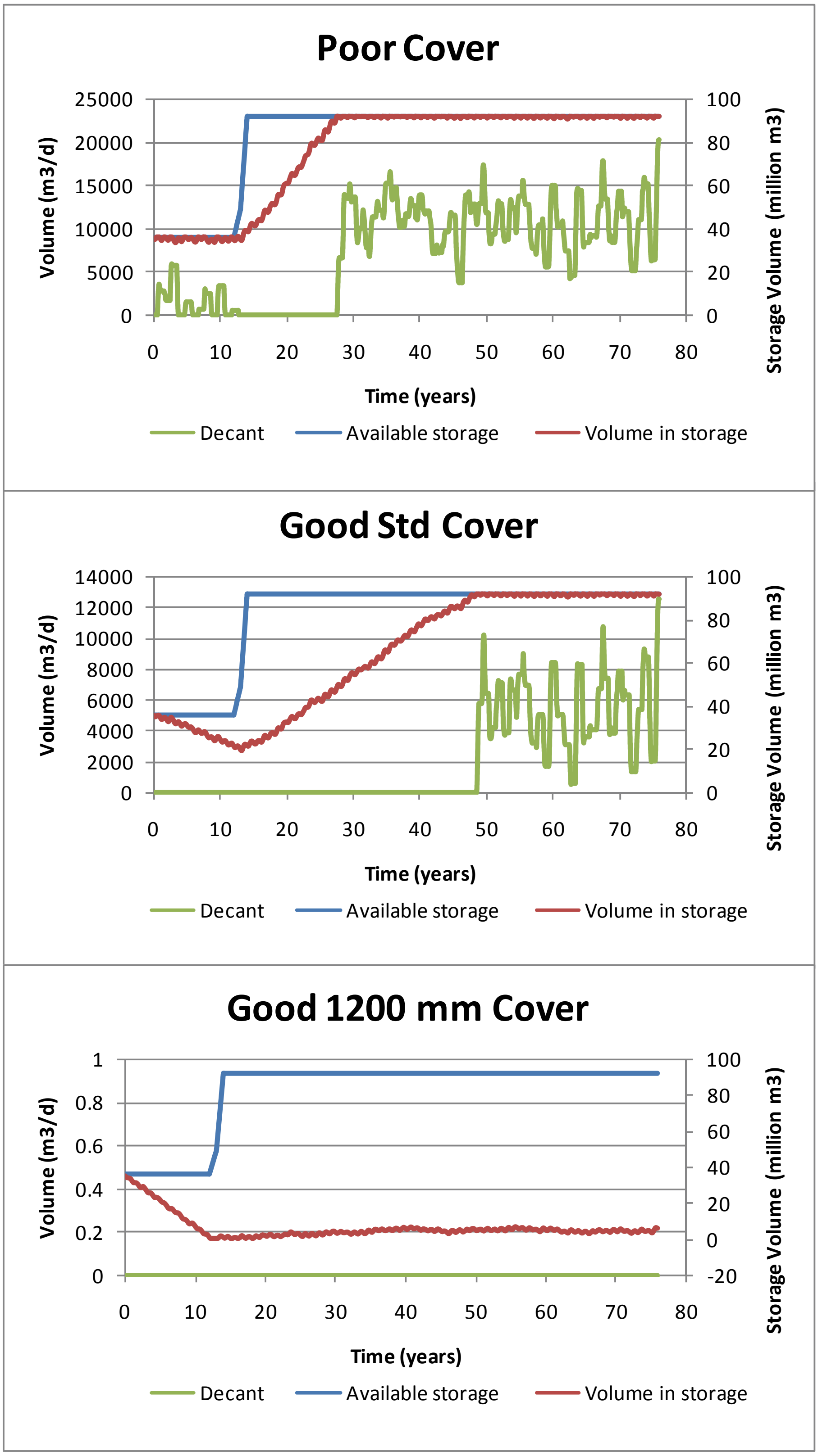


Figure 59: Plot of available workings storage, water in workings and average decant volumes from Optimum group for different covers

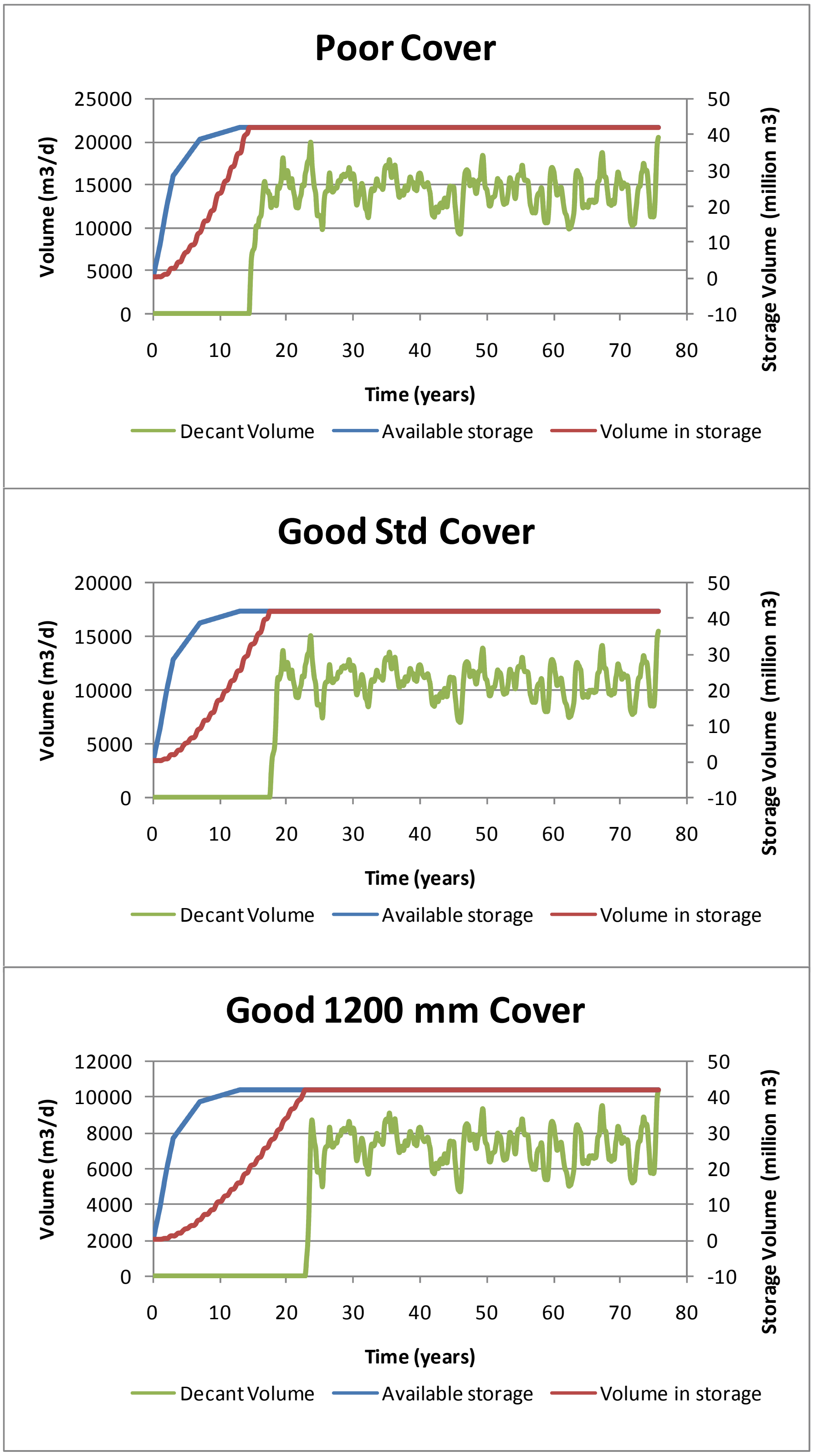


Figure 60: Plot of available workings storage, water in workings and average decant volumes from Kwagga group for different covers

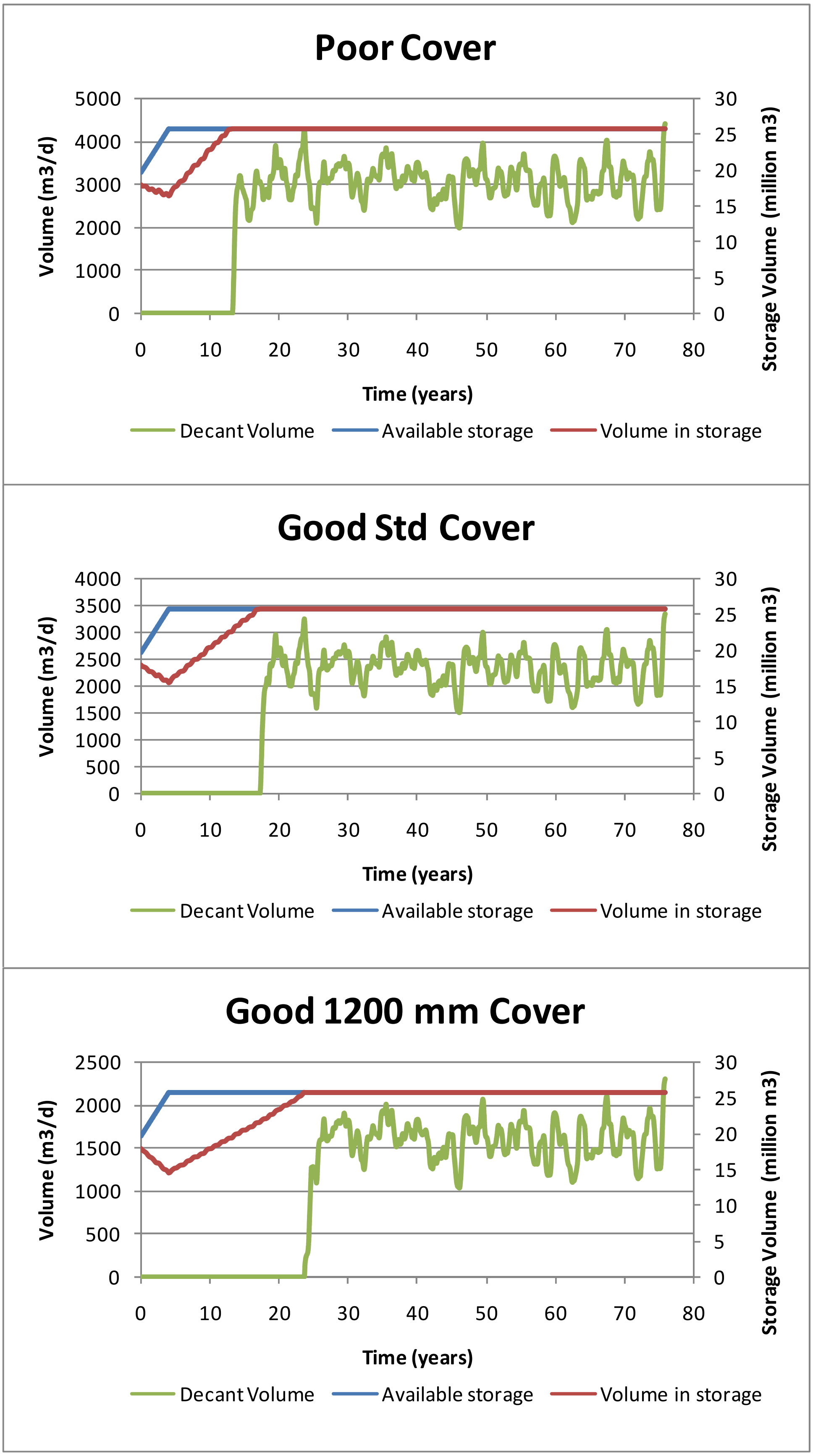


Figure 61: Plot of available workings storage, water in workings and average decant volumes from Eikeboom group for different covers

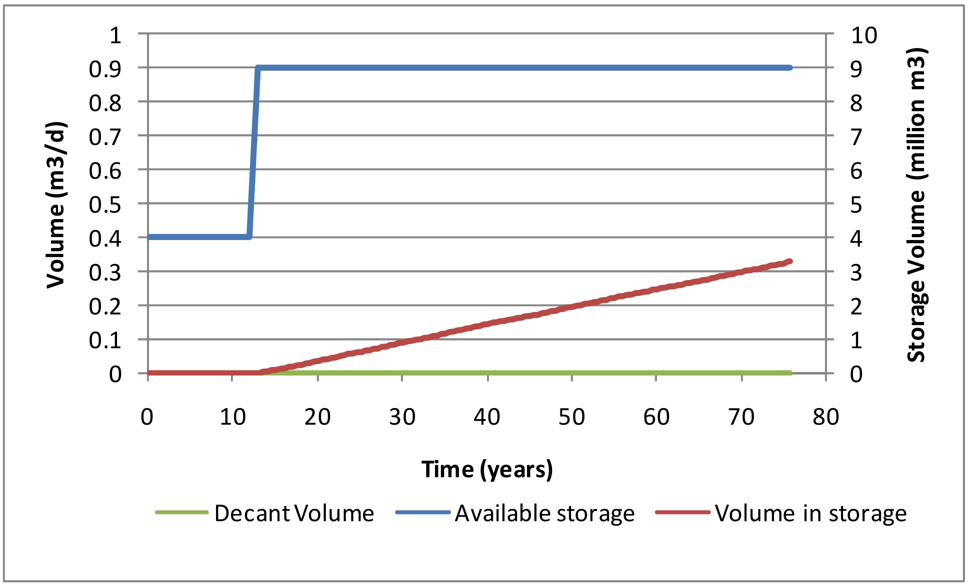


Figure 62: Plot of available workings storage, water in workings and average decant volumes from Schoonoord group

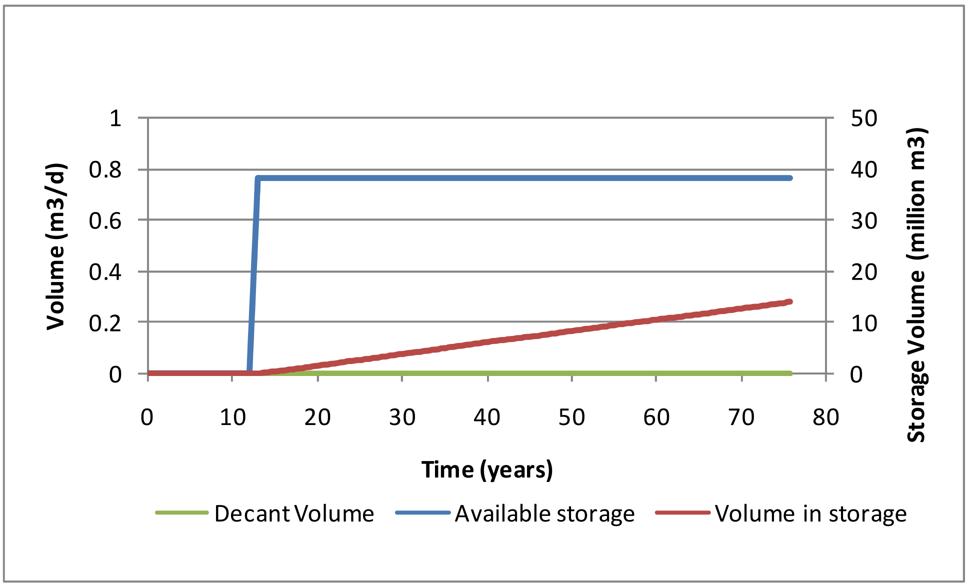


Figure 63: Plot of available workings storage, water in workings and average decant volumes from Boschmanspoort group

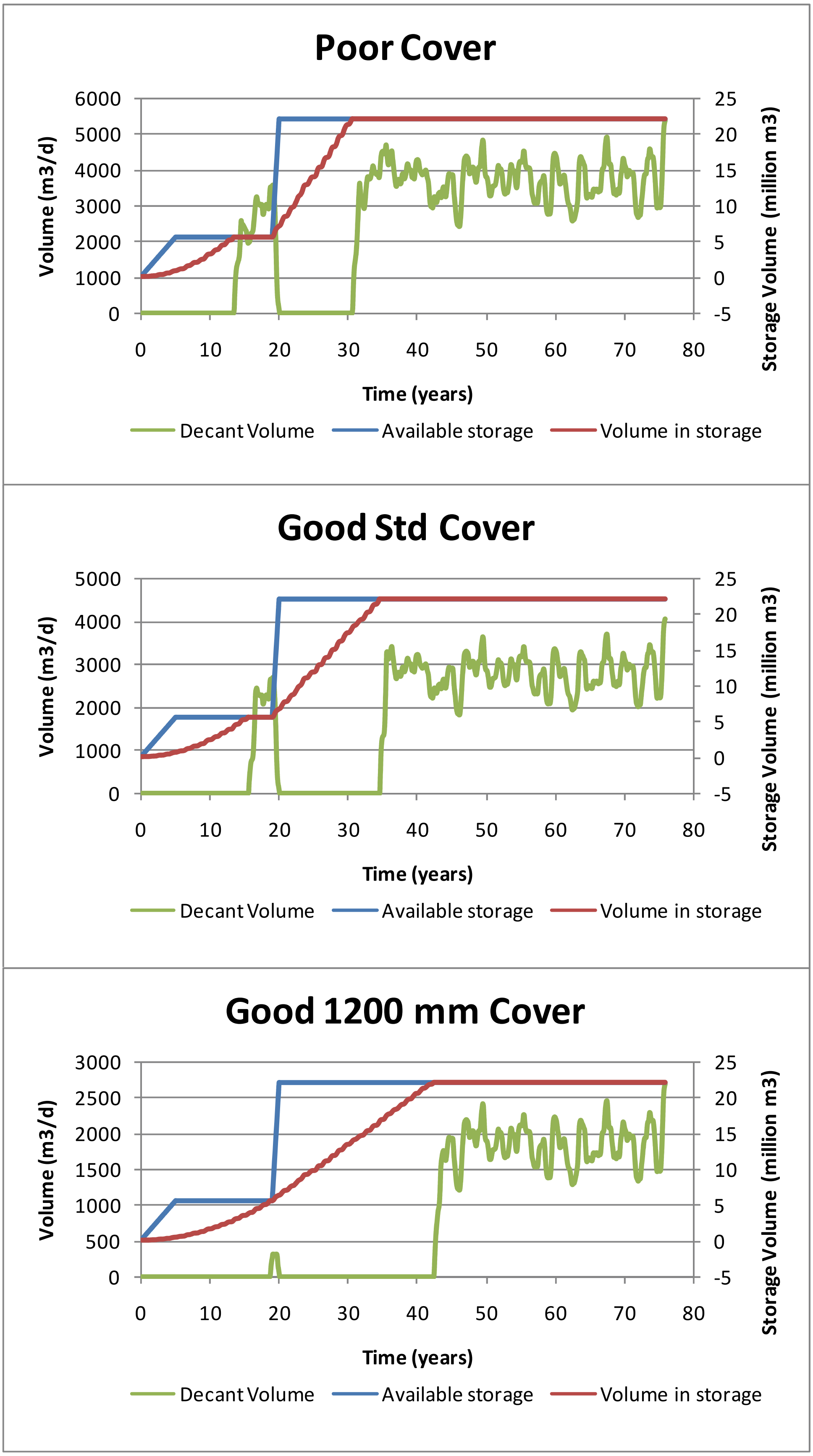


Figure 64: Plot of available workings storage, water in workings and average decant volumes from Mafube group for different covers

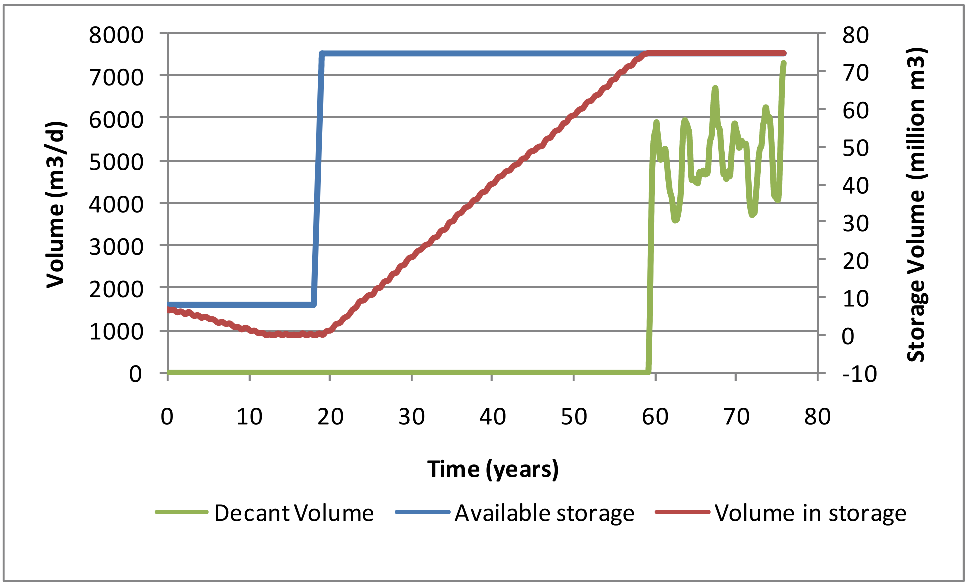


Figure 65: Plot of available workings storage, water in workings and average decant volumes from Arnot/Eskom group

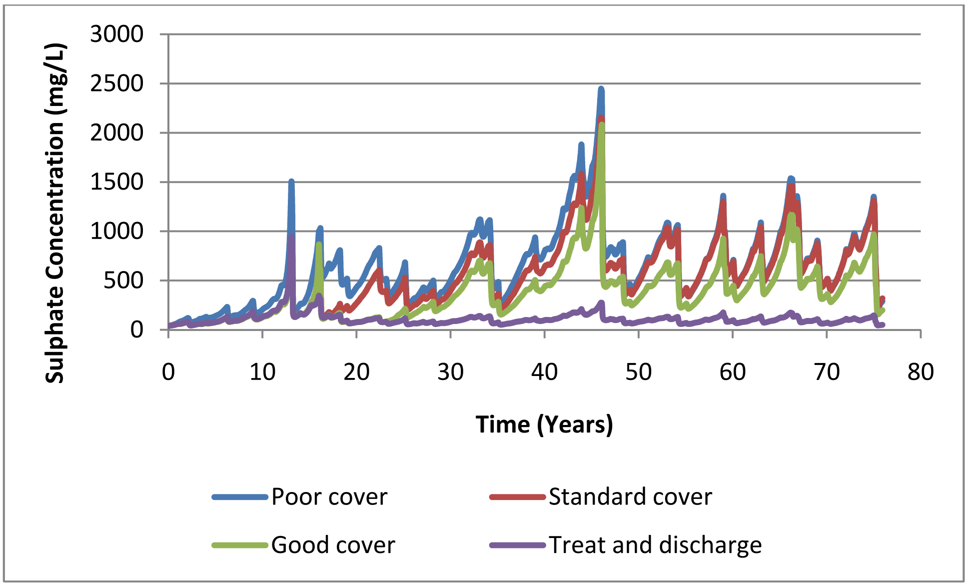


Figure 66 : Plot of simulated sulphate concentrations in Middelburg Dam for poor, standard and good covers as well as treat and discharge

Table 18: Summary of time to decant, decant rate, NPV treatment costs and NPV of additional rehabilitation costs for the different covers for Middelburg Dam Catchment

Mine Group	Cover	Time to Decant (years)	Decant Volume (m^3/d)	NPV treatment costs (million Rand)	NPV rehabilitation costs (million Rand)	Total NPV (million Rand)
Optimum	Poor Standard	27	14000	74	16 cover 22 maintenance	112
	Good Standard	49	6000	5.9	26 cover 11 maintenance	43
	Good 1200 mm Cover	never	0	0	42 for cover 11 maintenance	53
Kwagga	Poor Standard	15	15000	202	79 cover 77 maintenance	358
	Good Standard	18	12000	128	131 cover 39 maintenance	298
	Good 1200 mm Cover	22	7000	55	210 cover 39 maintenance	304
Eikeboom	Poor Standard	12	3000	51	9 cover 5 maintenance	65
	Good Standard	18	2200	26	14 cover 2 maintenance	42
	Good 1200 mm Cover	22	1600	12	23 cover 2 maintenance	37
Mafube	Poor Standard	12 30	2500 4000	52	28	80
	Good Standard	12 35	2000 2800	38	23	61
	Good 1200 mm Cover	42	1700	3	30	33
Arnot/Eskom	Not applicable	59	5000	5	0	5

7.5.2 Witbank Dam Catchment

Kendal/Khutala Group

There is sufficient storage capacity available in this group to store the recharge water over the simulation period. There is storage capacity available within this group to store excess water from other mines. However the adjacent mines are not suitably located. Long pipelines and high pumping heads prevent the feasible use of the available storage at Kendal/Khutala.

Koornfontein

The Koornfontein mine is assumed to be closed currently with about 70 million m^3 of storage available in the underground workings. There are opencast workings present on the complex and it is assumed that the infrastructure has been put in place to collect the water from the opencast workings for delivery to the underground workings. The simulations show that the workings will fill in about 60 years and the decant will be about 2000 m^3/d. The storage in these workings could be used by adjacent mines which will result in the workings filling up faster and treatment required sooner.

Douglas

The mining of the available reserves at Douglas Colliery will finish in 2010. In this analysis the mining of the pillars and the development of new opencast workings has not been considered as the feasibility is still being investigated. There is a substantial volume of storage available on this complex with the workings taking 68 years to fill. There is storage available in the Douglas workings which can be used to store excess water from adjacent mines to delay the need for treatment.

iMpunzi

The iMpunzi Colliery complex has excess water until storage becomes available in 5 years time. There is a further need to treat excess water in 20 years time for a period of 3 years. In the assessment, the treatment of 8 ML/d from 2006 was assumed in the assessment. Thereafter there is excess storage capacity in the workings until the end of life of mine. In about 50 years time the mine will fill and excess water of 22 ML/d will be generated on the complex.

Rietspruit

Rietspruit Colliery is closed and the rehabilitation completed. The mine is expected to take about 60 years to fill after which there will be about 4000 m^3/d excess water. It is unlikely that this excess will be realised on surface as the excess water is likely to seep into the adjacent mine workings.

Middelburg Mine Services (MMS) South

The MMS South section has an immediate need for treatment if a poor cover is applied to rehabilitate the opencast areas. The affect of the improvement in the cover design is reducing the need for treatment is clearly shown in Figure 72. Treatment is no longer needed if a good or 1200 mm thick cover is applied. The mine in fact has storage available if good covers are applied. The water balance for MMS South includes the ongoing supply to Duhva Power Station.

SACE Complex

The SACE complex shows similar trends to MMS South. The better the cover the lower the decant volume. If a 1200 mm cover is applied then the current 20 ML/d treatment plant will be able to manage the excess mine water on the complex.

Mines with lower level information

The excess water emanating from the mines with lower level (less confident) information is summarised in Table 12 . In this assessment it is assumed that the decant form these mines are treated and discharged. The volume grows from 10800 m^3/d to 19200 m^3/d. No management is assessed with these volumes.

The costing model was applied to each group of collieries in the Witbank Dam catchment. The times to decant, treatment volume as well as the NPV of treatment costs and rehabilitation costs are given in Table 19.

As for Middelburg Dam, the simulations show that the use of good covers does not reduce the excess mine water volumes sufficiently so that the decants can be assimilated in the Olifants River and the Witbank Dam will still meet the RWQO of 155 mg/ℓ sulphate.

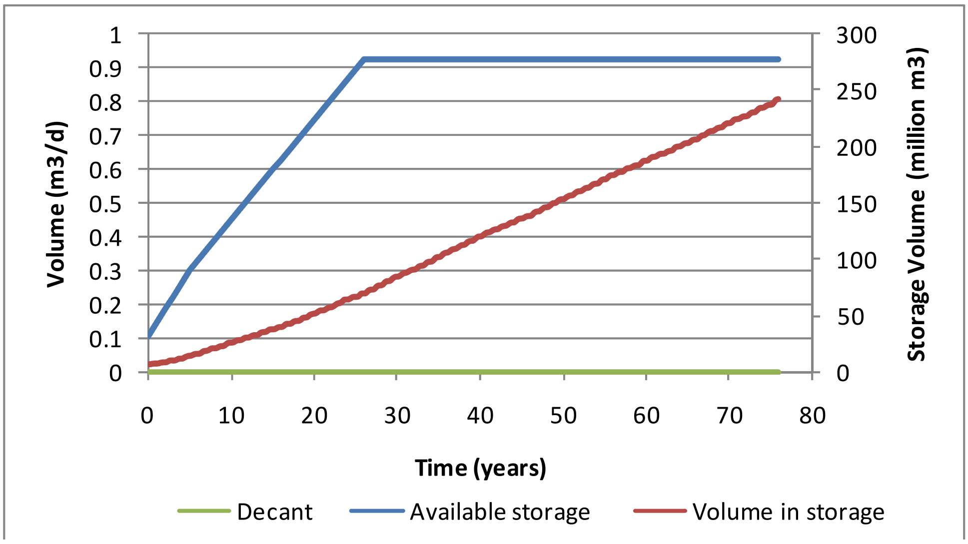


Figure 67: Plot of available workings storage, water in workings and average decant volumes from Kendal/Khutala

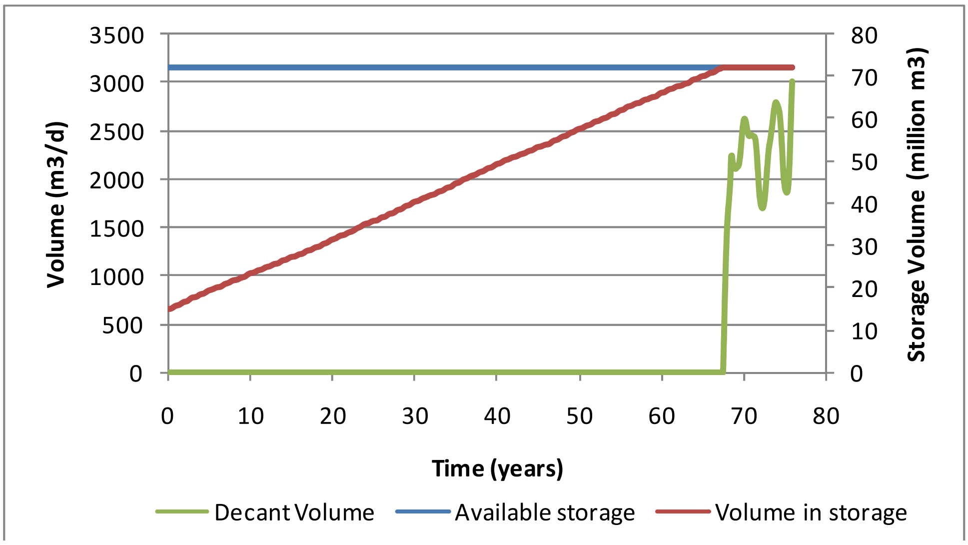


Figure 68: Plot of available workings storage, water in workings and average decant volumes from Koornfontein

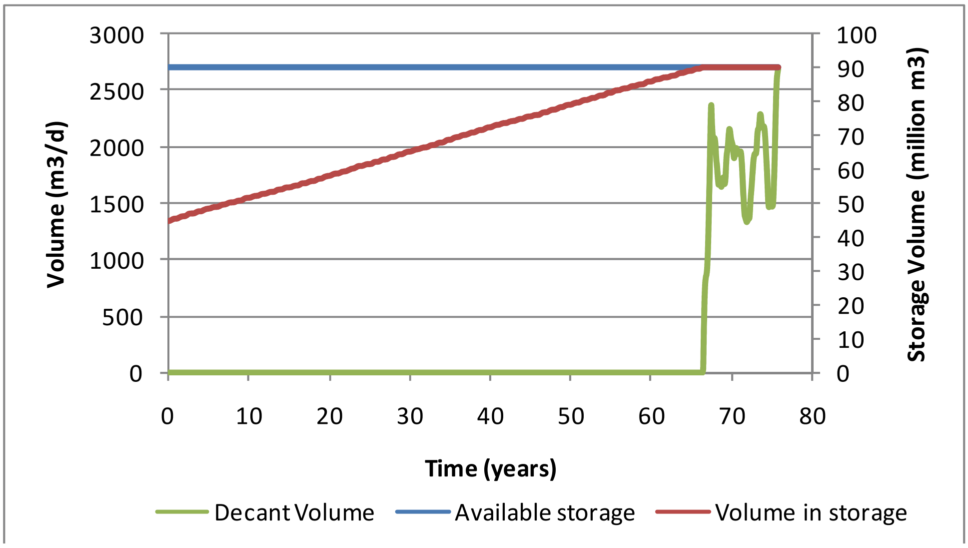


Figure 69: Plot of available workings storage, water in workings and average decant volumes from Douglas

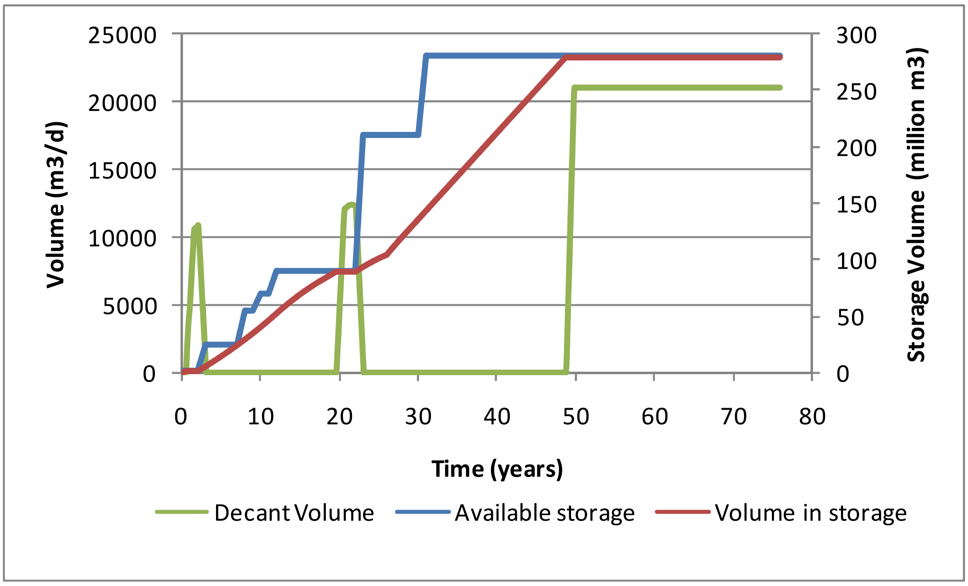


Figure 70: Plot of available workings storage, water in workings and average decant volumes from iMpunzi

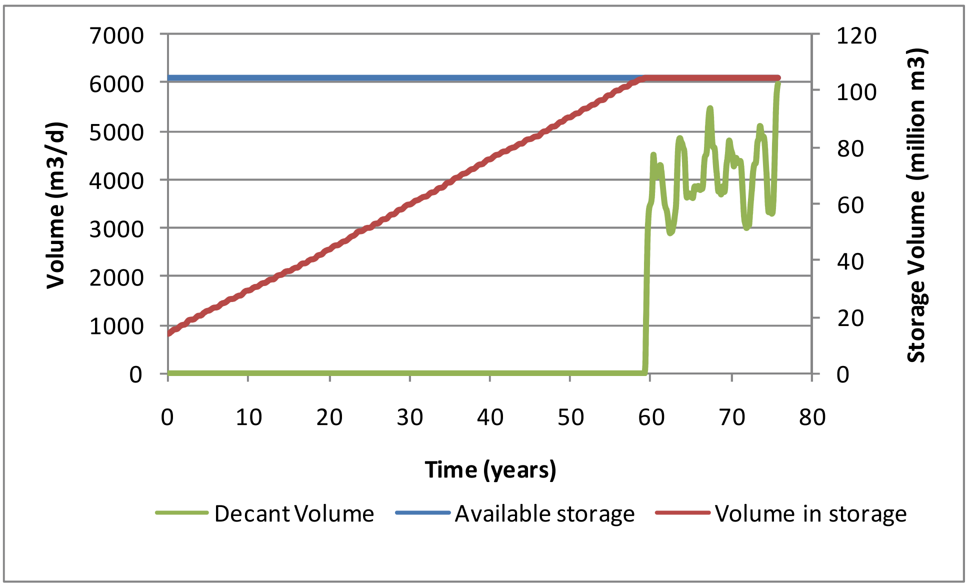


Figure 71: Plot of available workings storage, water in workings and average decant volumes from Rietspruit

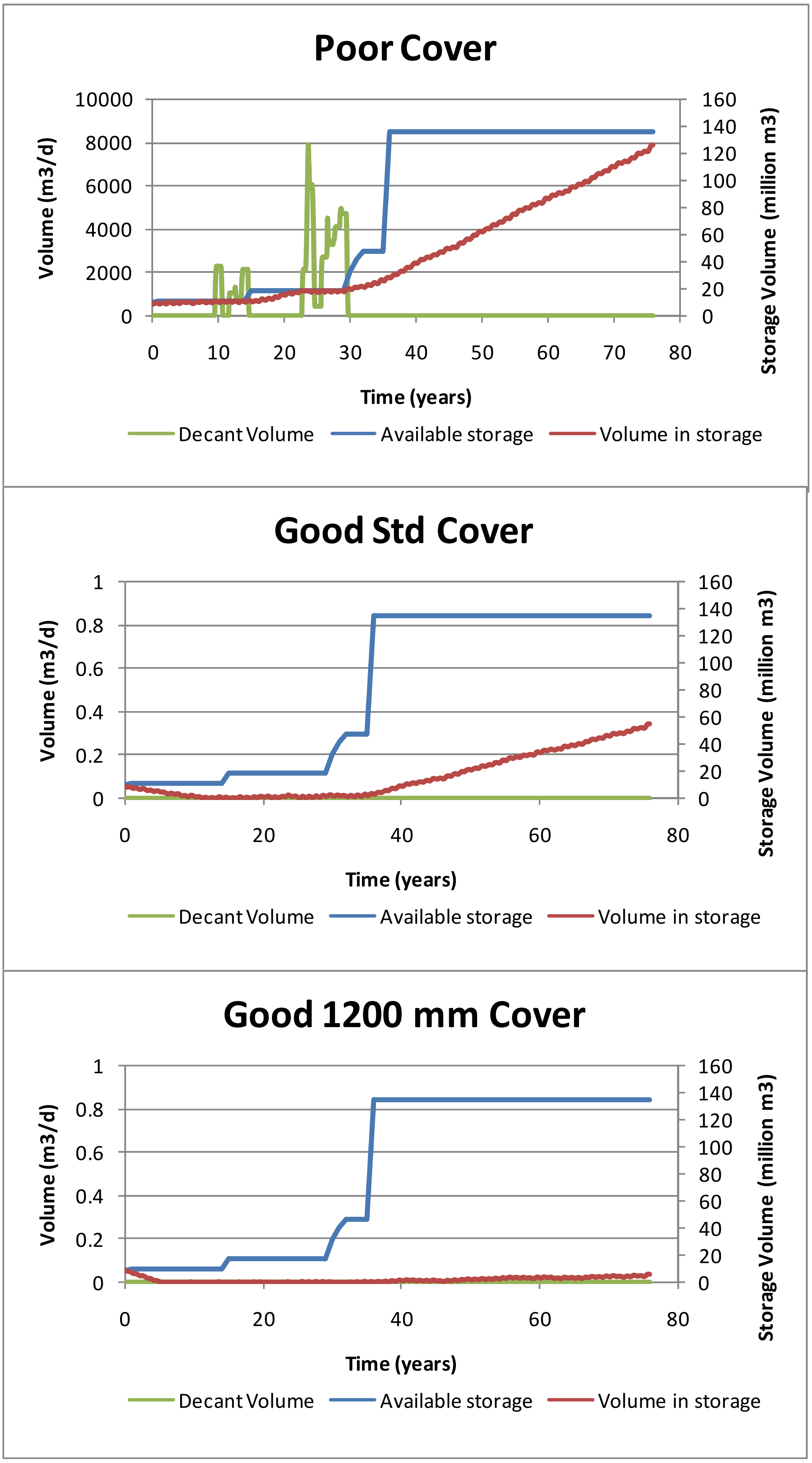


Figure 72: Plot of available workings storage, water in workings and average decant volumes from MMS South

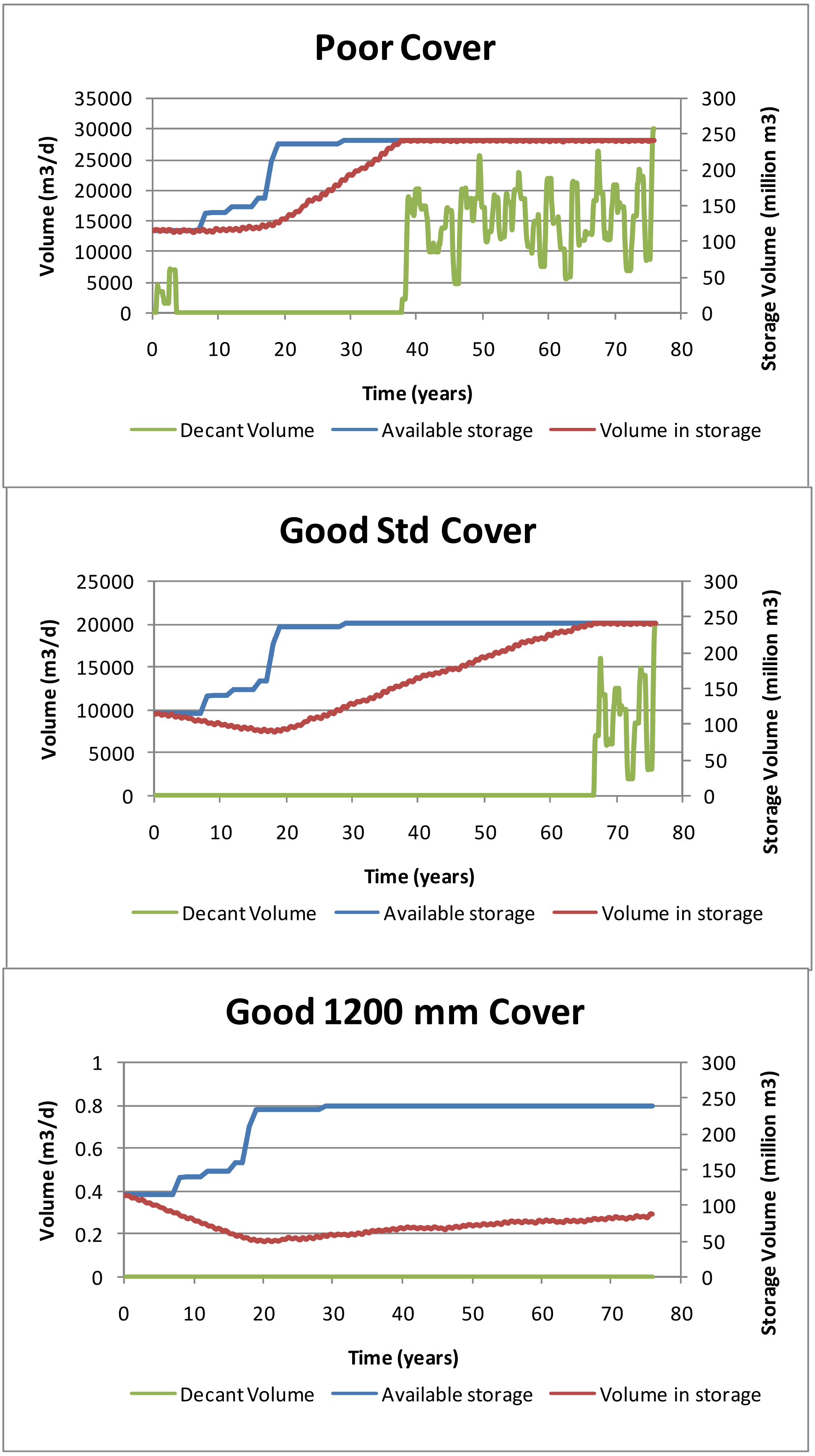


Figure 73: Plot of available workings storage, water in workings and average decant volumes from SACE

Table 19: Summary of time to decant, decant rate, NPV treatment costs and NPV of additional rehabilitation costs for the different covers for Witbank Dam Catchment

Mine Group	Cover	Time to Decant (years)	Decant Volume (m^3/d)	NPV treatment costs (million Rand)	NPV rehabilitation costs (million Rand)	Total NPV (million Rand)
Khutala/Kendal	Not Applicable	No decant over simulation period	0	0.0	68	68
Koornfontein	Not Applicable	69	2200	0.3	-	0.3
Douglas	Not Applicable	68	1700	0.2	-	0.2
Rietspruit	Not Applicable	59	4200	1.6	-	1.6
MMS South	Poor Standard	10 22	1000 3000	38	32	70
	Good Standard	No decant over simulation period	0	0	27	27
	Good 1200 mm Cover	No decant over simulation period	0	0	37	37
SACE	Poor Standard	38	15000	33	36	69
	Good Standard	66	7500	1.0	44	45
	Good 1200 mm Cover	No decant over simulation period	0	0.0	57	57
iMpunzi	-	0 48	8000 21000	358	-	358
Others	-	0	10800 m^3/d to 19200 m^3/d	594	-	594

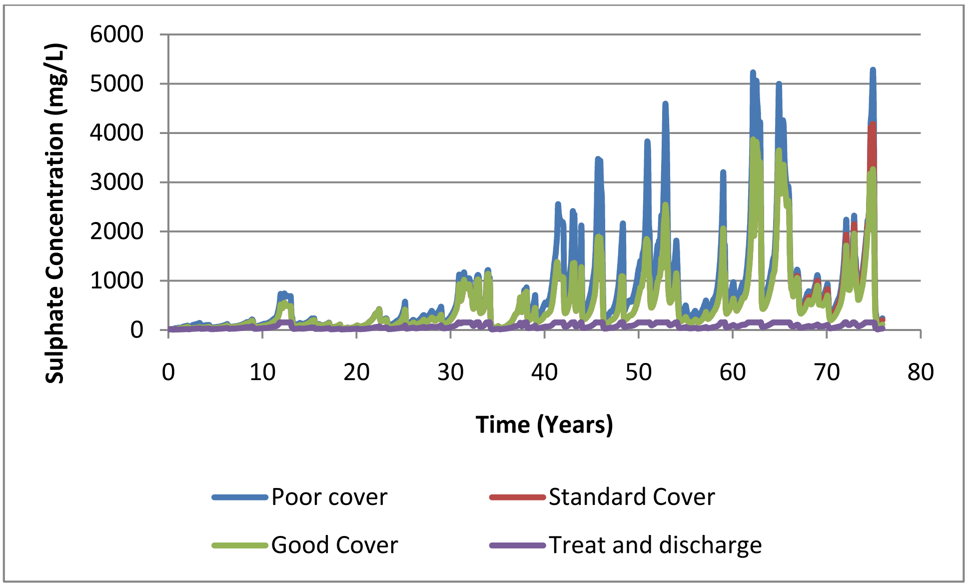


Figure 74 : Plot of simulated sulphate concentrations in Witbank Dam for poor, standard and good covers as well as treat and discharge

7.6 Analysis Results – Storage Scenario 4

The NPV calculated for each of the mining groups for this scenario are given in Table 20. The analysis shows that the use of the Schoonoord storage by Kwagga Group only puts off the need for treatment by 2 years while the use of the Boschmanspoort storage by Optimum group puts off the need for additional treatment at Optimum by 11 years.

Table 20 : Summary of NPV (million Rand) for Scenario 4

Mine Group	Cover Type	Time to Decant (Years)	Decant Volume (m^3/d)	NPV Treatment Costs (million Rand)	NPV Rehabilitation Costs (million Rand)	NPV Pipeline Costs (million Rand)	Total NPV (million Rand)
Optimum	Good Standard	0	0	0	37	2 (pipeline needed year 49)	39
Kwagga	Good Standard	0	0	0	170	38 (pipeline needed year 18)	208
Eikeboom	Good Standard	18	2200	26	16	-	42
Mafube	Good Standard	12 35	2000 2800	38	23	-	61
Arnot Eskom	Good Standard	59	5000	5	0	0	5
Schoonoord	-	20	12200	102	-	-	102
Boschmanspoort	-	60	6500	2.2	-	-	2.2
Total	**-**	**-**	**26900** **27700**	**173.2**	**246**	**40**	**459.2**

7.7 Analysis Results – Intermine flow Scenario 5

The mines included in the intermine flow scheme and the volumes to be treated assuming a good cover on the opencast mining areas are listed in Table 21. The capital and operating costs as well as the NPV with and without the sale of water are given in Table 22. The results show that the NPV is low for the intermine scheme due to the long time frames before closure and filling when the treatment plants are required. This implies that a relatively small sum of money can be invested by the mines and over a 60 year period, if 8% growth is realised, sufficient money should be available to fund the schemes. The analysis also shows that although the sale of water does not cover the full costs of the treatment scheme but does reduce the cost of the scheme significantly.

Table 21: Mines and volumes included in intermine flow Scenario 5

Mine	Volume of water at closure (ML/d)
Koornfontein	2.2
Douglas	1.7
Rietspruit	4.2
MMS South	10.2
iMpunzi	21.0
NCC	2.0
TNC	3.0
Goedehoop	5.5
Matla	7.7
Isibonelo	1.0
Khutala	8.5
Total	**67.0**

Table 22: Capital, operating and NPV for Scenario 5

Cost	Value (Million Rand)
Capital cost	871
Annual operating cost (No Water Sales)	159
Annual operating cost (With water sales)	90
NPV (No water sales)	27
NPV (With water sales)	19

8 DISCUSSION OF RESULTS

8.1 Mine Information

At the time of data collection, more detailed information on mining areas was available for the Middelburg Dam catchment than the Witbank Dam catchment. The growth in the mine areas in the Middelburg Dam catchment is shown plotted in Figure 75. The mining will be complete in about 20 years time with the total mined area of 20000 ha. The predominant mining type is opencast.

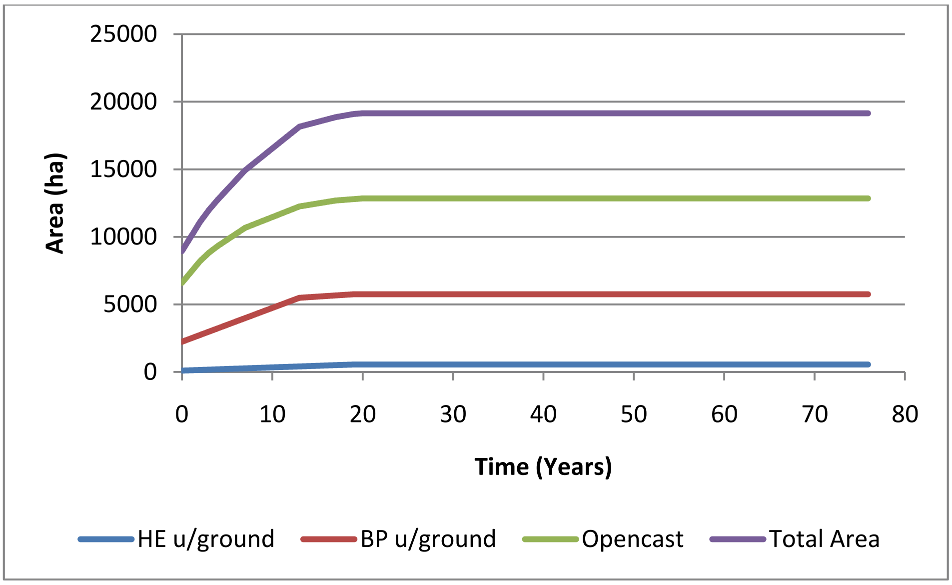


Figure 75: Plot of mining areas in the Middelburg Dam Catchment

The expected total water makes from the mines in the Middelburg Dam and Witbank Dam catchments are shown plotted in Figure 76 and Figure 77 for the three cover types.

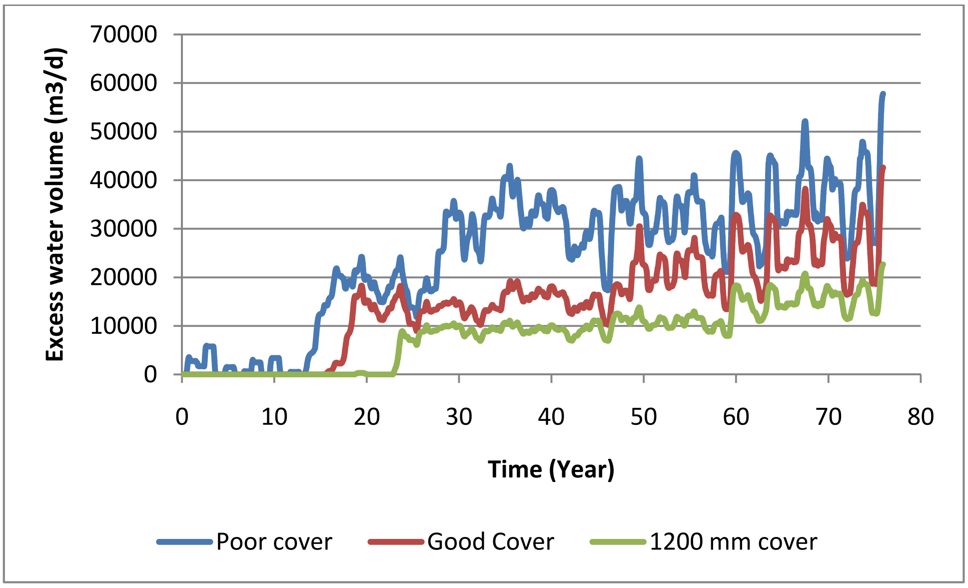


Figure 76: Plot of excess water make over time from mines in the Middelburg Dam Catchment

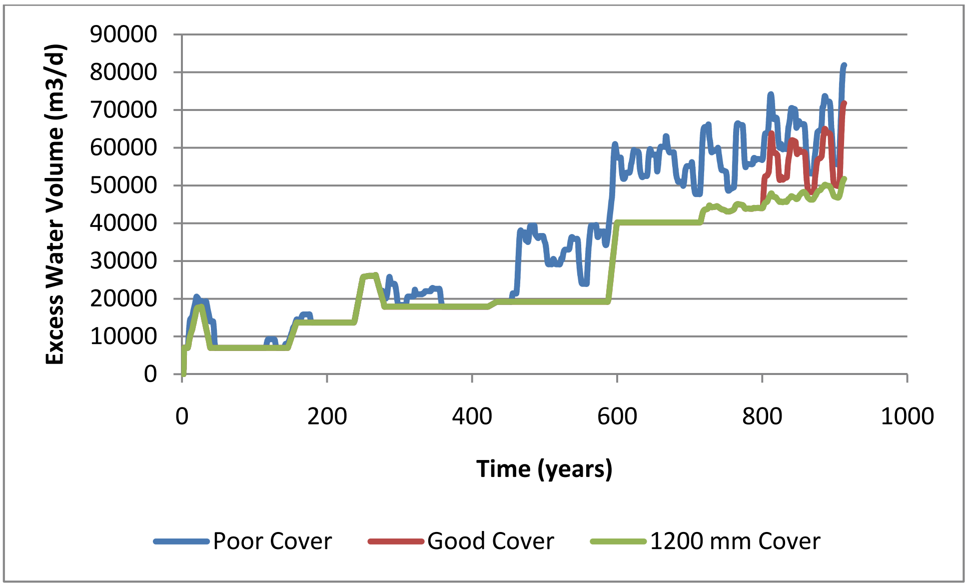


Figure 77: Plot of excess water make over time from mines in the Witbank Dam Catchment

The excess water graphs exclude the current installed treatment capacity of 11 ML/d at Optimum and 20 ML/d at SACE. The plots clearly show the reduction in the excess water volumes due to the use of good covers. In the case of the Middelburg Dam catchment, the progressive improvement in the standard of the cover results in a drop in the excess water volume from 35 ML/d to 15 ML/d. This has a significant impact on the expected future treatment costs. However the cost of the covers increases and the use of covers is a balance between the cover cost and the treatment cost. The information for the Witbank Dam catchment consists mostly of decant volumes and insufficient detail on the mining areas was obtained to undertake a useful analysis of the impact of covers on the excess water volumes.

An analysis was undertaken to determine the incremental cost of saving 1 ML/d of improved covers. The base case used was the poor cover. The NPV was determined over a 30 year period at 8% and the incremental NPV for the good and 1200 mm cover were determined per ML/d of recharge saved. The recharge volumes were determined using a 20%, 15% and 10% recharge factor for the poor, good and 1200 mm cover respectively with a 0.7 m annual rainfall. The NPV of treating 1 ML/d was also determined for the 30 year period at 8% interest rate. The results of the analysis are presented in Table 23. The results indicate that the use of good covers is more expensive than the cost to treat the 1 ML/d saved. However this analysis does not take into account the saving related to putting off the need for treatment further into the future using the more expensive good covers.

Table 23: Incremental NPV per ML/d or recharge saved compared to treatment costs

Cover	NPV to save 1 ML/d (million Rand per ML/d)	NPV treatment cost per ML/d (million Rand per ML/d)
Good	65	40
1200 mm Cover	67	40

8.2 Comparison of total NPV for scenarios

The total NPVs to manage the excess water in the Witbank and Middelburg Dam catchments for the different scenarios analysed are summarised in Table 24. The discussion of the results is limited to the Middelburg Dam catchment as the data available allowed for a more complete assessment.

The results show that the use of a good cover reduces the costs significantly when compared to the poor cover. This is due to the need for treatment being delayed significantly. The use of a 1200 mm cover does further reduce the total NPV but the change is not as significant as the use of the good cover. The use of storage with a good cover is comparable to the good cover. The cost of the pipelines offset the savings in NPV due to the delay of the treatment plants.

Table 24: Summary of total NPV to manage excess water in the Middelburg and Witbank Dam catchments

Middelburg Dam		
Scenario	**Description**	**Total NPV (million Rand)**
1	Poor cover	620
2	Good cover	449
3	1200 mm cover	432
4	Storage with good cover	459
Witbank Dam		
Scenario	**Description**	**Total NPV (million Rand)**
1	Poor cover	1161
2	Good cover	1094
3	1200 mm cover	1116

9 CONCLUSIONS AND RECOMMENDATIONS

The following conclusions can be made as a result of this study:-

- The catchment situation is dire with deteriorating water quality in the Witbank and Middelburg Dams. There are still new mines to be developed in the catchments and the existing mines are still expanding.
- The water demands of the Steve Tshwete and Emalahleni Local Municipalities exceed the yields of the Witbank and Middelburg Dams. There are no further local surface water resources that can be developed in the catchment to meet the growing water demands. The mine water is the only source of water that can be used to meet the demands. The treatment of mine water and supply as potable water is already being undertaken by SACE with a 20 ML/d plant and at Optimum with an 11 ML/d plant. Based on the available data, there is still a further 65 ML/d to 100 ML/d available for treatment and supply.
- The level of mine information varies from mine to mine. Some mines have a good understanding of the areas, storage volume available and the excess mine water generated over the life of the mine. The collection of information was halted early on in the study so that the analysis work could continue. A number of the mines have made significant progress in improving their water balances. Nonetheless the available data was used and was considered adequate to undertake the study and illustrate the management approaches that can be considered for the catchment.
- The modelling needs identified were to be able to assess the impact of mining on the local and regional water resource impacts. The ACRU-Salinity model was identified as the most appropriate model to apply to assess the local water quantity and quality impacts. The WRPM and the WQT models were identified as the most appropriate for assessing the regional impacts.
- The ACRU-Salinity model was applied to a quaternary catchment and was found to calibrate well against the measured flows and TDS concentrations. The model was used to determine the impact of a dummy mine on the water resource of the quaternary catchment. The model was also applied to modelling the Kleinkopje mine complex with reasonable success.
- The application of the WRPM to the catchment was used to determine the impact of the mine scenarios on the dam water qualities and the excess mine water available. The results of these runs were input into the cost model.
- The shortcomings in the WRPM identified were that changes in water quality over time in the mine workings could not be modelled. The water qualities are entered in the model based on the measured data. The impact of the long term flushing of workings cannot therefore be modelled.
- The application of the cost model to the scenarios that were formulated showed that the use of covers reduced the water volume that needed treated significantly. The reduction in recharge also delayed the need for treatment. The total NPV for the scenarios showed that the use of a good cover significantly reduced the NPV of the scenarios. The 1200 mm cover is expensive and did not achieve the same magnitude of the reduction in the total NPV for the catchments.
- The use of storage to delay treatment showed that there was some merit but the cost of the piping to convey the water for storage in the workings was expensive and offset the changes in treatment costs.
- The intermine flow is a promising closure scenario. The water can relatively cheaply be transferred to a low point close to Witbank. A treatment plant can be constructed at the low point for supply to Witbank. The sale of water reduces the NPV significantly as a portion of the operating costs can be recovered. The intermine flow option however requires cooperation between the mines and planning to control the flows between the workings. Issues of liability would also have to be addressed if intermine flow is to be considered as an option.
- The closure of the mines is still some years off. The NPV show that although there are immediate management issues on some of the mines, relatively small sums of money can be provided now to cover the closure costs in 40 or 50 years time.

- The scenarios presented in the study were based on the available data and have not necessarily been optimised. However the scenario results provide useful guidance and direction on the way forward.

The following recommendations can be made as a result of this study:-

- The mines must keep their water balances current and all achieve a similar level of accuracy and confidence.
- Not all the mines were included in the study. There are a number of smaller mines and mining companies whose information should be collated and included in the modelling and long term planning.
- The mines must co-operate and continually update the life cycle costs and seek the most economic solution for the management of water in the long term. This includes incorporating intermine flow as a closure solution.
- The treatment and supply of mine water for potable use is the strategy to achieve reconciliation in the catchment. The long term changes in the recharge rates need to be assessed as the opencast mine workings consolidate and the perched aquifer previously destroyed by the mining starts to re-establish.
- The WRPM should be updated with a simple algorithm to model the water quality changes in the mine workings.
- One of the expenses in treatment is the disposal of brine. Consideration should be given to the storage of brine in the underground workings to reduce the costs of the treatment process.
- Impact of electricity costs on viability should be reviewed.

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