

Executive Summary

INTRODUCTION AND SCOPE OF INVESTIGATION

Coal mining in South Africa has a history of more than 100 years. Strict legislation for licensing and environmental control has been introduced during the past 15 years. It has become increasingly difficult for mines to comply with this legislation, often because of historic shortcomings in mine planning and lack of provision for environmental control. To obtain mine closure after mining operations cease is difficult because of the many unknowns that could contribute to future water quantities and qualities. Applications that succeeded in obtaining mine closure during the past ten years are a very small percentage of the mines that have applied or are about to apply for this. In many of these applications, essential questions cannot be addressed because of the lack of data, incomplete time series information or inadequate interpretation.

During the past ten years, several studies have been completed that address some of the issues for mine closure application, through sponsorship from the Water Research Commission. Many private investigations have also been completed through mining companies. However, much of this information is of a technical nature and only available to the original client.

The scope of this report is to extract available and relevant information from all previous investigations, generate new information, and consolidate this into a report that could assist mining companies, individuals and governmental departments to improve their understanding of processes and consequences relating to groundwater management in collieries. This document could also serve as a guide towards procedures and typical results for mine water management.

This investigation was intended to:

1. Investigate and describe the *status quo* in terms of mining methods, scheduling, geology, geohydrology, hydrochemistry, water and salt balances at six underground collieries that are in the process of decanting or where decanting is imminent.
2. Investigate management options whereby the quality of the mine water can be influenced in operating underground collieries, thus minimising the long-term salt load that will be released into the environment.
3. Document the six case histories to be used for future reference, demonstrating the time-dependency of these systems.
4. Extract and discuss management options that should be applied in operating collieries to achieve the long-term goal of minimising the salt load to the environment.

APPROACH TO THE RESEARCH

The following is a summary of the approach to the research:

Technical:

- With the assistance of two of the larger coal mining houses, Anglo Coal and Ingwe, six mines in the process of decanting, or where decanting was imminent, were selected.

- All available data were obtained from the mining houses and other relevant sources. This proved to be a formidable task, since the mines have closed many years before the current study and most of the mining plans were not readily available.
- Field programmes were initiated at each of the mines to generate additional information on water levels and quality. Observation holes were available at some of the mines, but had to be drilled at others. Chemical profiling of water columns above and into the mines provided insight of the *in-situ* chemical conditions. These were supplemented, where necessary, by chemical analyses of the water and static acid-base accounting.

Scientific:

The Institute for Groundwater Studies has a substantial data and knowledge base in coal mine hydrogeology and hydrochemistry that has been acquired during the past 27 years. This ensured well informed and up to date interpretation of data generated during this investigation. The philosophy throughout this study has been “to measure is better than to simulate”. Simulation (modelling) is used in this investigation only for scenario analysis and not to make up for a shortfall of data.

All data were entered and processed in the WISH (Windows Interpretation System for Hydrologists), which was developed by the Institute for Groundwater Studies for the Water Research Commission in 1995. This data format is compatible with that which most mining companies are currently using for their data storage and processing.

Management:

Management options for water in the coal mining industry usually revolve around the execution of a series of well-planned mining strategies; the end result usually leads to minimisation of water volumes and salinities. Such strategies should be implemented during and after mining. In the case of this investigation, only the “after mining phase” could be addressed because the mines have already ceased operations. Much is, however, to be learned from the six case histories addressed in this document. The strength of this document lies in the fact that all collieries should find some similarity to their current situation(s).

DATA ACQUISITION

Data were requested digitally as far as possible. However, all the mines have closed down years before this investigation and most of the information, including maps, had to be digitised. This constituted about 20% of the workload.

The generation of new information, field sampling, laboratory analysis, data interpretation and investigation of water management options comprised 60% of the work. All this work was done in-house at the Institute for Groundwater Studies, using students and the analytical and computing facilities of the IGS. Five students on B.Sc. (Hons) level and one on Master’s level partook in this programme.

The rest of the time was spent during feedback presentations to the mine houses, the writing of the reports and the restructuring thereof.

GEOGRAPHIC INFORMATION SYSTEM

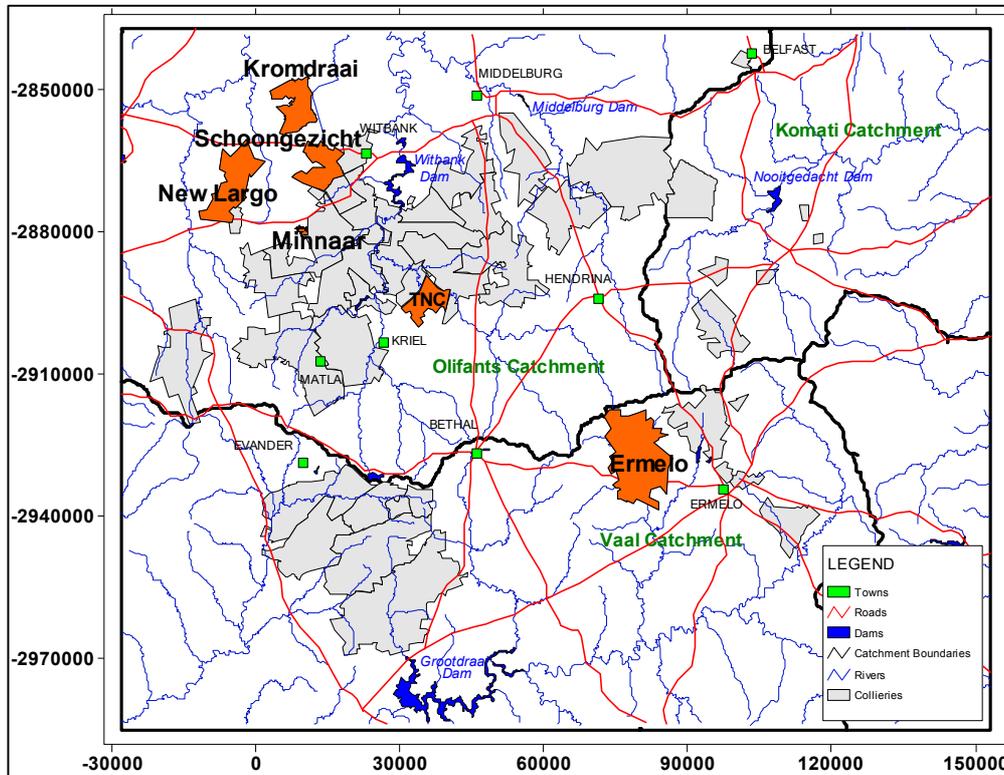
The geographic information system that was used for this project is the Windows Interpretation System for Hydrogeologists (WISH). This software is already in use by the coal mining industry and the Department of Water Affairs and Forestry (DWAf). WISH is a graphics user interface that allows the extraction of maps, contours, sections, borehole logs, hydrochemical profiling, a variety of specialised hydrochemical diagrams and time series analysis. The final data sets for each of the mines have been submitted to the two mining houses that partook in this investigation.

SIX CASE STUDIES

In consultation with Anglo Coal and Ingwe Coal, six collieries were selected for this investigation. These are:

Colliery	Characteristics and possible studies	Mining Method
Minnaar	<ul style="list-style-type: none">• Small underground mine• Compartments are filled with water• Artificial recharge of mine is done• Irrigation is done using mine water• Mine water balance to be studied	Bord-and-pillar
Ermelo	<ul style="list-style-type: none">• Large underground mine• Partial pillar extraction and subsidence• Mine in the process of filling up with water• Flushing of mine water to be considered	Bord-and-pillar Stooping
TNC	<ul style="list-style-type: none">• Complex arrangement of underground and opencast mining• Partially filled with water• Water quality management is possible through mixing	Bord-and-pillar Stooping Opencast
New Largo	<ul style="list-style-type: none">• Underground mine with a few subsidence structures• Partially filled with water• History of acid and neutral water• Water balance calculations and seepage losses to be done	Bord-and-pillar Limited Stooping
Schoongezicht	<ul style="list-style-type: none">• Underground mine• Currently decanting water onto the surface• Water and salt balance studies to be done	Bord-and-pillar Opencast
Kromdraai	<ul style="list-style-type: none">• Underground mine currently being reworked by opencast methods• Impact of change in mining method to be studied	Bord-and-pillar Secondary opencast

The localities of the selected collieries with respect to the rest of coal mining in Mpumalanga are shown below.



Mine lease areas for collieries in Mpumalanga. (The investigated mines are highlighted in orange).

Many aspects, apart from that mentioned in the above table, could be studied at each of the collieries. The following is a list of topics that are addressed in this document.

Topic	Colliery
Acid-base accounting	Kromdraai
Capacities to store water	All collieries
Complex water management	TNC
Flushing	Minnaar, Ermelo, Schoongezicht
High sodium water	Ermelo
Irrigation with mine water	Minnaar
Opencast	TNC, Kromdraai
Opencast flushing	TNC
Opencast mining	Kromdraai
River opencast	TNC
Seepage	New Largo, TNC
Stooping	Ermelo
Water balance	All collieries

The six collieries in this investigation have been selected for specific reasons, as each of them has specific merit for inclusion in this investigation. They have been dealt with separately in this document. For detailed information, the reader is referred to the relevant chapters. This chapter summarises lessons from the investigation. In short, the following are the main conclusions:

- Mining methods and mining geometry play a decisive role in the amount of water to be managed during and after mining.
- Mine scheduling is one of the most important water management tools to be considered from the outset of mining, throughout the life of the mine.
- The filling up of mines with water is inevitable after closure. Seepage of water away from the mines will occur once they approach the full mark.
- A large proportion of the collieries will eventually decant water onto the surface. Plans to manage this must be in place.
- No significant variation exists in the geology, mineralogy and geohydrology of the Mpumalanga Collieries. Mine water chemistries are controlled by mining methods, and an increase in the base potential of the groundwater to the south. This explains the acid character of the mine water in the north and the alkaline nature of the water in the south.
- Sophisticated computer software has been developed for the calculation of water balances for the mines. This is explained in the relevant chapters.
- Salt generation rates determined during this investigation confirm previous information for opencast mines, but suggest lower rates for underground mining.
- Flooding of collieries as soon as possible after mining is one of the best management tools. This activates the base potential of the remainder coal and excludes oxygen from the coal seam horizon.
- Flushing of mines once they are flooded is inevitable. This could improve the water quality in the mine, but reduces the available base potential of the mine as a whole.

These conclusions are discussed in more detail below and in the individual chapters that deal with the different collieries.

MINING METHOD AND GEOMETRY

This investigation has shown that the mining method and mining geometry are two of the main considerations that control water influx and water qualities in collieries. Bord-and-pillar, stooping, longwall and opencast are the four mining methods currently used in Mpumalanga. Numerical values (risk values) are proposed in terms of the amount of water associated with each of the mining methods. These numerical values arise from the percentage recharge from rainfall that enters into mines whilst employing the different mining methods. The values derived from this study are:

<i>Type of mining</i>	<i>Score</i>
Deep bord-and-pillar mining	1
Shallow bord-and-pillar mining	3
Stooping	6
Longwalling	12
Opencast	20

These suggest that opencast mining generates on average 20 times the amount of water that would be expected in deep bord-and-pillar mining. These values should not be taken as fixed. Of significant additional risk is the undermining of streams and surface water bodies using high extraction methods. The sequence of mining and interlinking of underground workings are also important when considering the eventual flooding of mine workings. These are but two examples to indicate that other aspects should also be considered when calculating risk.

MINING SCHEDULE

From this study, it is concluded that water enters into collieries and water management problems often result because of a lack of storage space after about 20 - 30 years of mining. In areas of high underground extraction, problems may arise earlier. The scheduling of mining, commencing with mining in low-lying areas and retreating to higher coal seam elevations, can solve this problem. This is an important water control strategy. New mines or new development in a mine should be planned so that natural compartments are created in which excess water can be stored while mining continues in other areas.

SEEPAGE OF MINE WATER

All six mines investigated in this study will eventually fill with water. Thereafter, seepage of mine water into the weathered strata will commence. The rate of seepage is controlled by the hydraulic conductivity of the strata. If the hydraulic conductivities of these strata are too low to transmit significant volumes of mine water, recharge rates to the mines will exceed seepage rates, and excess water will eventually decant onto the surface.

DECANTING OF MINE WATER

This investigation stresses the importance of making provision for the eventual decanting of water from collieries. Pathways along which decanting would take place are numerous. These typically are: Shafts, subsidence areas, opencast mining and boreholes. At large collieries, more than 1 000 prospect boreholes are typically drilled during the life of the mine. These should be sealed by grouting. In many instances, particularly at the older boreholes, this has not been done.

Collapsed surface areas must be rehabilitated to channel the run-off away from these areas. Cracks should be destroyed by ploughing across them.

Many of the larger collieries extend over several catchments. Through proper planning, catchments could be selected into which water can be allowed to decant. The interconnection of collieries may be considered to channel mine water to specific points for treatment or utilisation, rather than having numerous small uncontrolled decants into streams. It has been demonstrated in previous research by the IGS for the WRC that

excess mine water can be channeled over vast distances through underground workings, to emanate in areas where better control of the excess water is possible. In short, all collieries need not decant.

GEOLOGY, MINERALOGY, GEOHYDROLOGY AND HYDROCHEMISTRY

- It is concluded that, on a regional basis and in terms of water management, there is no significant change in the geology, mineralogy and geohydrology of the collieries in Mpumalanga. Coal seams deepen to the south, eventually to reach a depth of some 250 m in the far south. Dolerite intrusions are more prolific in the south-eastern portion of the coalfield.
- In terms hydrochemical control of the mine's waters, the coalfield could be subdivided into northern and southern sections:
 - The northern section of the coalfield has a greater potential for acidification because of a low natural base potential in the coal.
 - In the southern section, the coalfield has a higher natural base potential because of the high bicarbonate content in the connate water of the sediments. High sodium concentrations are also present.
- These differences should be utilised when developing water management strategies for the coalfield. The northern mine water, being low in sodium content, has the potential to be used for crop irrigation and could be desalinated using sulphur-reducing technologies. The advantage of the latter process is that it leaves no brine to be disposed of. The southern mine water, being high in sodium, cannot be used for most normal purposes, and desalination is one of the few options to improve the mine water quality. Such desalination will lead to a concentration of salts. Disposal of the brine without further treatment may be impossible because of environmental considerations. Crystallisation of salt from the brine and disposal of the salt on properly constructed waste sites would add considerable cost. These are all aspects to consider when managing mine water with high sodium concentrations.

WATER BALANCE

Water balances are important in determining areas of recharge, water loss and reaction rates. These are mine dependent. Controlling factors are the method of mining, depth of mining and the surface hydrology. A summary of the percentage influx to be expected for the various mining methods, as determined during this investigation, is as follows:

•Deep bord-and-pillar with no subsidence	1% of the rainfall.
•Shallow bord-and-pillar	3 -10% of the rainfall.
•Stooping	4 - 12% of the rainfall.
•Longwall	6 - 15% of the rainfall.
•Opencast	14 - 20% of the rainfall.

The actual percentages of recharge depend on specific circumstances.

Through the use of the WISH software package, water balance calculations for the mines have been refined and automated. Stage curves have been calculated, potential water bodies in the mines identified and volumes of water calculated. The results are included for each of the mines described in this document.

SALT GENERATION RATE

In this investigation, salt generation rates are determined by measuring outflows and chemistries from which tonnages of salt are calculated. This is the only accurate way to obtain answers. Static and kinetic modelling has also been used in this investigation to improve the understanding of processes, but these techniques have been found to be limited in their predictive capabilities. Salt generation rates have been calculated for five of the six collieries. The following are the main conclusions:

- The daily rate of sulphate generation in opencast mining is 5 - 10 kg/ha/d. An average daily value of 7 kg/ha/d has been used in salt balance calculations for individual collieries.
- The daily sulphate generation rate for underground mining is in the range of 0,4 - 2,7 kg/ha/d. These rates, which are lower than those for opencast mining, are mainly due to less available reactive surfaces in underground mines.
- In the Witbank Coalfield, sodium has been almost totally leached from the coal and overlying rock, due to circulating groundwater. In the Highveld Coalfield, high sodium and bicarbonate concentrations are present. Solution reactions play almost no role in the north, but in the south soluble salts form an important buffer against the initial acidification of mine water.
- Heavy metals in the coal are present throughout the Mpumalanga Coalfields. Even though they temporarily mobilise during oxidation, most precipitate under alkaline conditions. Of the mines investigated, four have alkaline water. It is a common phenomenon that collieries enter into an alkaline phase while being flooded. The base potential in the coal left behind in the mine is usually sufficient to neutralise the acid mine water generated during the mining phase. This is an important conclusion.

With 24 years of data available on the geohydrology and hydrochemistry, the principles that matter as far as acid mine drainage is concerned are well-understood.

MANAGEMENT OPTIONS

Management options for mine water, during the after mining, can be reduced to a few simple concepts. Following this, endless branching into more sophisticated, sometimes more complex procedures is possible. The following is a list of simple management options, that in the opinion of the author, includes all the important issues:

- Select the mining method based on environmental considerations.
- Mine from deep to shallow.
- Flood the mine workings.
- Flush the mines after being flooded.

FLOODING

Collieries should, after closure, flood as much of the mined areas as possible, thus exposing any acid water to the alkalinity in the remaining coal. This investigation has indicated that much more can be done in terms of mine planning to flood redundant mine workings. Flooding also reduces oxygen in the mine workings. Mines with a potential acid character can often be converted to alkaline systems by flooding the mine workings. This has been observed at four of the six collieries investigated. At the other two collieries, only partial flooding has been achieved with the result that the remaining base potential in the coal could not fully be utilised for neutralisation of the acid mine water.

FLUSHING

Flushing of collieries, once they are flooded, is inevitable, as water will continue to enter into them. Models have been run as part of this study to calculate the impact of flushing on mine water quality. It was demonstrated that an improvement of mine water quality is likely in flooded areas, where rapid throughflow occurs. However, flushing alone is not an option. Flushing should be done in conjunction with mine water utilisation or water treatment, otherwise the salt is released into the environment.

An important negative consideration in terms of flushing is that it will also remove some of the base potential from the mine. This will, in theory, accelerate the process of acidification. Not enough information is, however, available to quantify, in full, the positive and negative influence of flushing on the base potential in the mines.

ACHIEVING THE GOALS OF THE INVESTIGATION

The six collieries have been studied in detail and the objectives of the study have, in the opinion of the authors, been met. The *status quo* at each of the mines has been investigated and described in full. Management options for mine water at each of the collieries have been identified and evaluated. This information is documented in Chapters 3 - 8 to serve as examples. From this, sufficient conclusions could be drawn to ensure that mistakes are not repeated.

TECHNOLOGY TRANSFER

All information generated during this investigation has been transferred electronically and through information sessions to the companies that participated in the investigation. Publishing this information through the WRC will make it available to a wide spectrum of individuals and companies.

PARTICIPATION AND UPLIFTMENT

Five B.Sc. (Hons) students completed tasks on this project. They are Ellis Thebe, Solo Masike, Nancy Motebe, Swama Ndengu and Samuel Phophi. All of them are currently employed as geohydrologists.

In 2003, Mr Danie Vermeulen submitted this work as fulfillment towards a Master's Degree in Geohydrology to the University of the Free State.