EXECUTIVE SUMMARY

1 BACKGROUND INFORMATION AND SCOPE OF INVESTIGATION

Over the past ten years, the issuing of closure certificates has dwindled to a point where very few closure certificates have been issued. Uncertainties in terms of the long-term water quality in these mines are often too great for the Government to issue closure certificates with confidence.

This research was initiated in view of this difficulty in issuing closure certificates. The scope of the investigation was as follows:

- To evaluate and document the current impact of closed underground mines on the quality and quantity of groundwater resources, in order to select suitable sites for further detailed investigation, thus generating an impact rating system that could also be applied to operating mines.
- To evaluate, with the aid of field observations, various credible preventative options to minimise the undesirable impacts of water quality deterioration and influx relating to underground mining.
- To select or design reliable tools for the prediction of water qualities and quantities during the post-closure phase, to provide information for closure and to assess the applicability of these tools to South African conditions.

The first research objective dealt with the evaluation and documentation of the current impact of closed underground mines on the quality and quantity of groundwater resources. This work formed part of the development of a risk assessment procedure. It provided a broad overview of the problems associated with mine water management, identifying the issues that could, in the long run, present serious problems when applying for closure of the mines.

The second objective stated the use of field trials to identify credible management options. Field trials are ongoing at all of the mines through variations in mining methods, monitoring and different solutions that have already been implemented. These solutions may be in terms of water and salt minimisation, impact prediction, alternative water supply for affected parties, desalination and use of mine water. In terms of achieving this aim of the investigation, three existing systems have been investigated. Aspects that should be explored in greater detail have been identified. A selection has been made of issues that will have a positive impact on water quality and quantity.

The third objective related to predictive tools. A wide selection of these tools is generally available. Most of these require expert knowledge of hydrochemical processes and flow dynamics. These tools have been used to model and understand the systems in question. A high priority in this research was the development of alternative and simplified methodologies that can be used as general tools by the mining community. These simplified methodologies are based on sound principles of flow dynamics, hydrochemistry and geology. They should go a long way in providing a better understanding of the systems investigated.

2 APPROACH

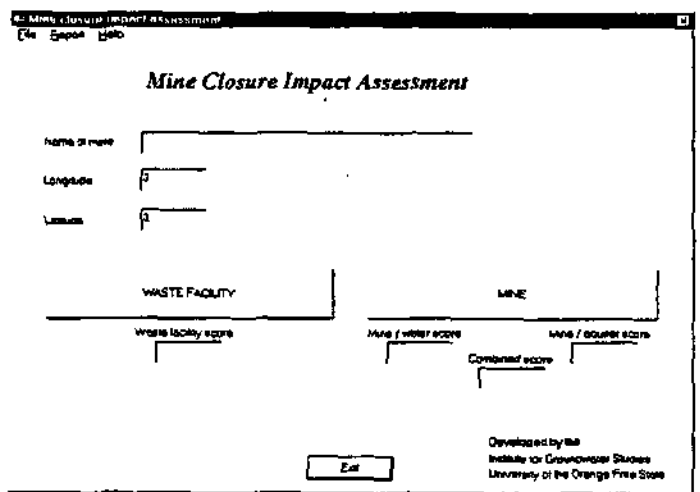
The first step in this research was to develop a risk assessment procedure that could be used to evaluate the risk of groundwater pollution from a mining operation. This enabled the classification of mines and mining activities according to their potential impact on groundwater resources in their vicinity.

Following this and based on the outcome of this risk classification, three issues were selected to be investigated in greater detail. These are:

- Underground high extraction of coal in the Mpumalanga Coal-field.
- Mining in coal outcrop areas of KwaZulu-Natal.
- Gold mining in the West Rand

3 RISK ASSESSMENT

A software package, called RISKY, has been developed as part of this research, to be used by the mining industry. The software should be used on various levels to screen mining activities in terms of its potential impact on groundwater resources. This evaluation takes place on three levels, namely the risk associated with surface disposal, the mine water character and the aquifer character. The software calculates a numeric score, called a risk factor. The higher these factors, the greater is the risk in terms of the potential long-term impact. As a trial study, the software has been applied to the collieries in the Mpumalanga area.



The following are the main conclusions from the application of the RISKY procedure:

- Categories and classes used for the evaluation of the mines are sufficiently general to be used for mines where a minimum of information is available. The evaluation may therefore be used as a first approximation, to either decide between various options or to evaluate the performance of one mine against another.
- As more information becomes available at mines, the quantification procedures used to evaluate each category or class can be refined. The RISKY software does not need to change, but accommodates input from more sophisticated systems.
- The weighting between categories and classes and the facility to fit non-linear distributions across classes should be sufficient to accommodate most situations. If these facilities prove to be inadequate, it is possible to program a suitable equation into the evaluation, so that the RISKY procedure does not become invalid.

- In the event that additional categories or classes need to be added to the system, this can also be done without jeopardising the operational simplicity of the RISKY software.
- The combination of the RISKY procedure with a Geographic Information System and the possibility of displaying any of the scores in each of the categories as GIS coverages, significantly enhance the applicability of the system. The power of spatial visualisation of specific issues has been extensively demonstrated in this research.
- It is recommended that the database on which these evaluations have been based, should be refined to incorporate information for all mines in South Africa. The quality of the information used for the Mpumalanga mines should also be verified. Through the introduction of this procedure to the industry and government departments, a common denominator will be created which may be used during mining, as well as after closure, to evaluate performances on a regional and in a comparative way.

4 UNDERGROUND HIGH EXTRACTION OF COAL

Underground high extraction of coal has been performed for many years in South Africa. The impact that this has on groundwater and surface water resources has been investigated in most instances, and this information is available as part of EMPR applications.

Much of this information is of a historic kind and does not allow prediction with confidence of the final geohydrological and hydrochemical outcomes of such systems. This complicates matters when applying for closure of a mine. Uncertainties associated with future water quantities and qualities are often too great. In view of these uncertainties, the investigation is aimed to:

- Provide a summary of the *status quo* for groundwater in underground high extraction areas.
- Investigate, through modelling, the recovery and decanting phases after mining has ceased.
- Provide recommendations into ways and means that the impact of underground high extraction can be minimised.

The following conclusions are drawn from this investigation:

- Underground high extraction of coal is a well-established practice in the South African Coal-mining Industry. For the next 30 years, some 40000 ha have been earmarked for extraction by this mining method.
- Underground high extraction of coal collapses the overlying strata and drains the groundwater from it. A typical projected influx rate is 15 ML/d for a mine of 12000 ha.

- This water is contaminated in mines to the extent that it cannot be disposed of in streams without special considerations. Neither can this water be used for agricultural purposes, predominantly because of its high sodium content.
- Operating high extraction mines encounter significant problems in underground water management, because of the large volumes of water involved. It has been demonstrated in this research that these problems are mainly the result of the sequence of mining. It is suggested that all mines should, on average, be able to cope with the influx of water on condition that they commence high extraction in the deepest part, retreating to higher ground.
- One of the current options for mine water handling is to pump it to surface, where it is desalinated. The disposal of the brine from the desalination process presents a problem for which there is currently no solution.
- It is suggested that longwall mining, as a mining practice, should seriously be re-evaluated. Of all high extraction mining methods, it inflicts the greatest impact on overlying aquifers. Longwall mining is also the least flexible mining method in terms of manoeuvring around structural discontinuities on the coal-seam horizon. Streambeds are often undermined for the sake of continuity in the development of a longwall panel. If at all possible, longwall mining should be replaced by shortwalling or, better still, stooping. The most environmentally friendly option would obviously be bord-and-pillar mining. Streambeds should not be undermined by high extraction unless the mining company can prove that this would have no impact on surface run-off and water infiltration.
- To date, mines have seriously neglected the importance of surface rehabilitation above collapsed high extraction areas. The importance of minimising rain-water ingress through collapsed areas cannot be stressed sufficiently. Surface cracks should be destroyed by ploughing across collapsed areas. In areas of rock outcrop, cracks should be filled in and surface run-off should be diverted around these areas.

- All mines performing underground high extraction should do proper planning for the post-closure phase. The quality of the water that will decant from these mines will be site-dependent and can be managed to some extent. Systems for water management should be based on current and proven technologies, which subscribe to the current objectives of water quality management by the DWA&F.

Based on our current knowledge of water ingress into areas of underground high extraction of coal, the following recommendations are made:

- Mines should seriously revise and motivate their life of mine plan for high extraction in the light of results obtained.
- Mines should do their utmost in minimising water influx into high extraction areas by instigating an active programme of surface rehabilitation, the most important of which should be:
  - A soils map of the total surface area above underground high extraction should be prepared.

- ➢ After collapses have occurred, areas with sufficient soil cover should be ploughed over as deeply as possible to destroy any cracks that penetrate to surface.
- ➢ Areas with insufficient soil cover should be inspected for cracks and these should be filled in. Rock outcrops are usually along slopes and surface run-off should be diverted around these areas, thus minimising the possibility of water cascading into the mines.
- ➢ Pans that develop above areas of high extraction should be provided with outlets by trenching. No water should be allowed to accumulate in the pans.
- ➢ Streams should, under no circumstances, be undermined by underground high extraction.
- ➢ Annual inspections should be made of rehabilitated areas to ensure that these areas are operating as was originally intended.

- Mines should submit a post-closure plan for water management during and after the recovery phase of the water levels. This plan should form part of their EMPR.
- Mines should have at least one dedicated, well-trained person in charge of mine water management. His job description should be the management of underground water to minimise volumes and pollution; plan and supervise surface rehabilitation; perform groundwater investigations and verify predictions. He should enter data into a database, process this data and extract information in a way that allows the identification of trends. He should understand processes - both chemical and hydraulically, and be able to report in a format acceptable by the DWA&F.

5 COAL MINING IN OUTCROP AREAS OF KWAZULU-NATAL

Significant topographic differences are present in the KwaZulu-Natal Coal-fields. Coal deposits have, in many instances, only been preserved within the mountains. Outcrops of coal are therefore plentiful along many of the mountain slopes. In these instances, the depth of the coal seams below surface typically ranges from 0 m to more than 100 m below surface. Access to these coal deposits has been gained by tunnelling into the mountainside. This is typical of the Vryheid Coal-field, but also applies to the Utrecht and Newcastle areas.

Mining in these areas has dominantly been of the bord-and-pillar type, followed by pillar extraction in many instances. As a result, the overlying strata have, in most instances, collapsed. The severity of these collapsed structures varies from area to area.

Many of these mines have very little holding capacity for water with the result that mine water often flows freely from the mines via adits into valleys below.

The Department of Water Affairs and Forestry extensively monitors water quality in streams of KwaZulu-Natal.

The area of particular interest to this study is the Vryheid Coal-field and the tributaries leading away from mines in this area. The results suggest that:

- The acid-generating potential of the coal mostly exceeds its base potential.
- The base potential, if any, is present in a variety of mineralogical forms, such as sodium carbonate, calcium/magnesium carbonate and iron carbonate. The latter only has a temporary neutralising impact. In many of the instances examined, most of the sodium and calcium/magnesium carbonate have already been depleted through leaching and reaction with acid water.
- In aerated environments, acid generation starts on the outer surface of a mine work face, boulder, rock or grain. Carbonates on the outer surface counteract acidification until they are depleted. Acidification of outer surfaces is therefore fairly rapid, while the inner portions are still unchanged. In flooded areas, water is in constant contact with the coal. Here, water siphons along fractures into and through the coal. Carbonate minerals are present in the fractures and react with the acid water. It is often observed that sections of mines that have historically been acid during mining, become alkaline when they are flooded. Whether or not this is a permanent change in the pH will depend on the amount of neutralising agent available, the degree of flooding and flow dynamics. In areas that are not flooded, reaction between the acid water and the carbonate veins cannot occur.
- In the Nkongolana area, only about 5 - 20% of the underground workings can be flooded with water. Only a small portion of the mines therefore has a potential to convert back into an alkaline phase. The neutralising potential of the coal in these areas is therefore inadequate for sustained neutralisation of all acid produced in the rest of the mines. The conclusion is that at some stage in the future, current alkaline sections of the mines are likely to become acid. To postulate about the time that this will take is not meaningful without significantly more information.
- To rehabilitate the top of the mountain, filling *all* cracks is not possible. The mountains are inaccessible over much of the area. Suitable material to fill the cracks is not available. Recharge as experienced in the past will therefore continue indefinitely.
- Therefore, very little remains that can be done to improve the long-term chemistry of the mine water in the Nkongolana area. Mining methods applied and the intensity are the main reasons for the current situation. In new mining areas: (1) Pillar extraction should not be allowed unless the mining company can guarantee minimal and manageable impacts on water quantities and qualities; (2) Access to underground workings should be from the highest topographic position, with the mine floor sloping away from the entrance. These recommendations are, however, too late in many respects, because most of the coal in mountainous and outcrop areas of KwaZulu-Natal has already been extracted. Many small fringe areas of coal still exist that can mainly be mined by opencast methods. It is important that the GME and the DWA&F keep proper control on mining in these areas thus limiting local environmental impacts.
- Apart from the fact that very little can be done to minimise mine water pollution at the source, other innovative schemes may be implemented where and when required. Lime dosing, wetlands, anoxic drains, dilution or mixing of mine waters or disposal into the sea are but a few possible

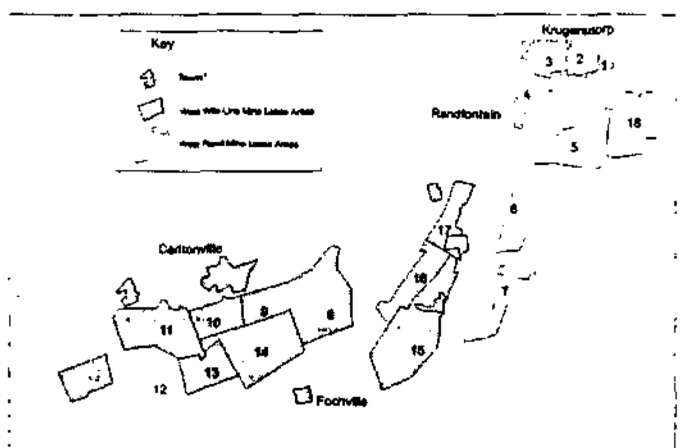
solutions. The detailed discussion of these is beyond the scope of this report.

- In terms of mine closure, it would not be reasonable for the authorities to insist that mining companies should take indefinite responsibility for water management at these collieries. The problems at this coal-field are clearly a legacy of circumstances born from ignorance in terms of the potential environmental impact. Legislative requirements have also become considerably tighter over the period in question. A workable solution should include responsibility on the part of the Government.
- It will be almost impossible for a single company to implement workable solutions on their own for mine water management in the Nkongolana Catchment. It is suggested that a collaborative approach should be adopted. This collaboration should include the authorities, without whose sympathetic and imaginative approach no solution will be forthcoming
- The quality of monitoring by the mines has improved tremendously over the past two to four years. They all have electronic databases (HydroCom) and process this information using the WISH software package. The development of both these packages was partially sponsored by the WRC. Individuals from the relevant mining houses have been on training courses at the IGS and are capable of performing monitoring and data processing themselves. It is recommended that monitoring should continue along the lines set by the mines during the past four years. Of particular interest would be the investigation of trends at the two VCC adits, at the Vrede Gap, discharge from Hlobane through the wetlands and from Wintershoek. From a compliance point of view, other localities will also have to be monitored.

6 GOLD MINING IN THE WEST RAND

6.1 Introduction

This research focussed on the post-operative hydrogeological impacts of the two gold-mining areas, west of Johannesburg, referred to as the West Rand and West Wits Line. The study investigated an area of over 2500 km^2, a large portion of which has been influenced by mining activity. At this scale, the investigation is an overview of the situation. There are many variables that could not be considered at this scale as their influence would require detailed investigation that was not possible within the constraints of this project.



Seventeen mines have been established in this area. They have varying life-spans and impacts on the groundwater resources in the area.

The principle aquifer under consideration is the dolomitic aquifer of the Malmani subgroup which has been compartmentalised by several north-south trending syenite dykes of Pilanesberg age. Groundwater moves rapidly in large volumes through large solution cavities in the dolomites. This groundwater flow, along with the Wonderfontein Spruit, forms a continuous link between the mining areas. These areas may warrant special protection due to the very valuable groundwater resource that they contain.

Due to the dolomites which occur across the area, problems have been experienced with water in the mines. Consequently, the mines pump out large volumes of water from the compartments to dewater the dolomites.

6.2 Mined Out Volume and Rewatering Rates

The method of volume *estimation* is based on mine production figures:

Total tonnage removed = Tailings + Ore + Waste Rock - Backfilled Tailings

$$\text{Volume of mine openings} = \frac{\text{Tonnage of rock removed}}{\text{Density}}$$

The wettest mines in this area were overlain by dolomite. Enslin *et al.* (1967) showed that rainfall recharge of the system was equal to the average annual flow of springs issuing from the dolomite. Thus after mining, recharge of the mine openings and the dewatered dolomites will be at the rate of the original springs flowed. The time to fill can be calculated from the mined volume and the steady state spring flows as shown in Table 1.

Additional time will be required to fill the dewatered karst. (This is given in Table 2.)

Table 1. Rewatering time estimates.

Mine Groups	Mined volume (ML)	Spring	Spring Flow ML/day	Time to Fill	
				Short (years)	Long (years)
Old West Rand (Champ D'Or, Luipaardsvlei etc.)	48221				
West Rand Randfontein	44402		30.0	8.4	
West Rand WAGM and REGM (Cooke and Doornkop)	114256	Gemsbokfontein (Zuurbekom leakage?)	8.9		36.9
West Wits Kloof	99511	Venterspost	21.2	6.1	13.1
West Wits Carltonville	217106	Bank Oberholzer	47.9 55.0	15.5	22.3

Table 2. Storage in the dolomites and additional time required to rewater the storage.

Compartment	Total Volume Removed		Dynamic volume from mine records		Dynamic volume from DWA records		Storage in compartments (ML)		Time to rewater Dolomites (years)	
	Period	(ML)	Constant dewatering rate (ML/day)	(ML)	Eye yields (ML/day)	(ML)	Mine Records	Eye Flows	Mine Records	Eye Flows
Bank	1969-1996	1009810	70	690323	47.9	472362	319488	537448	18.2	30.7
Oberholzer	1952-1996	1108150	50	803550	55.0	883884	304600	224265	15.1	11.1
Venterspost	1968-1996	412320	40	409080	21.2	216871	3240	195448	0.4	25.2
Gemsbokfontein	1986-1996	219000	?		8.9	42348		176651		54.2

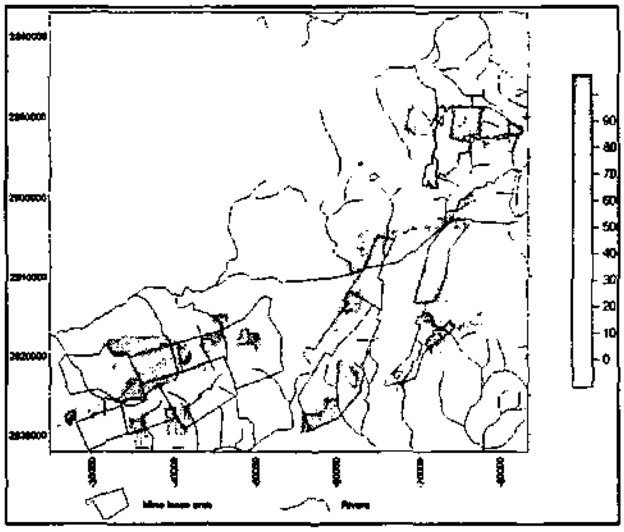
6.3 Sinkhole development

The stability of the dolomites was affected by dewatering. This resulted in catastrophic sinkhole development in the 1960's. Upon rewatering, the karstic caverns should fill with water allowing stability to increase. Under normal recovery and normal rainfall, the metastable conditions will be unaffected.

6.4 Sources of contamination

Many of the mine waste dumps are on the dolomites, because their underdrain characteristics increased dump stability. Mine waste disposal has allowed significant leachate to infiltrate the dolomite. Along with development of the area domestic and industrial wastes have been disposed of so adding another threat to the water resources of the dolomite. Water in the mines is of reduced quality. In some mines, it will discharge into the karst aquifer thus adding an additional pollution load.

6.4.1 The most important conclusions relating to water contamination in post-mining times are:



- The surface water entering the West Wits Line Area is, in many cases, contaminated before entering the area.
- Water polluted by leachate from mine dumps, so called *acid-mine drainage,* shows characteristically high sulphate concentration and high dissolved salts.
- Surface and groundwater show the same classification thus confirming what the hydrogeology suggests, i.e. that the waters are intimately related. This relationship and high recharge of groundwater from surface streams are relatively unique in this area and are due to the karst topography.

- The Boskop Dam, the receiving water body for the Wonderfontein Spruit, shows deteriorating q uality. Salinity and sulphate are mainly responsible.
- Conditions exist for uranium to be transported in solution in these waters. Thus radiogenic material may be migrating, dissolved in groundwater, to be consumed at some other point where radioactive contamination may not be expected.
- The mine waste sites, the source of this pollution plus other wastes are difficult to identify, isolate or control, thus the pollution is diffused. Because of this, pollution will continue even when the mines have ceased operations.
- Due to the presence of the dolomites, the final discharging water will have a neutralised pH but could have a high salinity
- Pollution which occurs while mining is in progress will, in spite of environmental concerns, continue or get worse after responsible authorities (owners or mining companies) have left the area.

6.4.2 The most important conclusions relating to the concerns about dolomite dissolution and instability in post-mining times are

- The mines influence on surface water is to increase all total dissolved solids as shown by the EC values; sulphate is increased by additional of acid water, a rise in chloride and sodium. Other constituents for example calcium and magnesium are characteristically high because of the dissolution of dolomite.
- Increased salinity and lowered pH of acid-mine drainage will increase the waters' ability to dissolve dolomite.
- Initially oxidising conditions will exist in the mine openings. The initial water will be of poor quality. The system will be dynamic preventing stratification. If this water recharges the dolomites significant dissolution of the dolomite could occur. If the water quality were that of the Blyvooruitzicht fissure and the rewatering rate was 60ML/day (an average between the dynamic records and the original eye flow), more than 6000 m^3 dolomite/year will dissolve. This will have two major implications:
  - Significant widening of preferred pathways causing greater overall transmissivity in the dolomites and greater storage volumes.
  - Possible stability problems, should excessive karstification result.

The karstic aquifer that exists in this area and widening of existing solution openings have implications for groundwater flow that follows preferred pathways. This has serious implications for any modelling that assumes that the dolomites are a porous medium[1].

6.5 Modelling

6.5.1 Modelling pollution from surface sources

Distribution and directions of mine waste-derived pollutant migration, with and without pumping, were modelled. The pollutants form a diffuse source that influences most of the catchments in this area. The pollution migration patterns corresponded closely with migration postulated by Coetzee *et al.* (1996), based on remote geophysics sensing and GIS modelling of a portion of this area.

Modelling of the West Rand mines was reported on by Krantz (1997) and gave predicted filling times of the mines between 4.2 and 7.2 years. His predictions correspond well with figures found in this investigation which gave estimates for the same area of 8.5 years. This independent approach confirmed the "expected time to fill" calculations by volume methods given in this report.

A three-dimensional model of the Bank compartment was developed to establish an approach and evaluate the aquifer parameters. The model was able to generate water levels that matched measured values for both deep dewatering and recovered water levels (or pre mining levels). The recovery of water in the system gave a recharge period of 21 years after pumping stops. This compared well with the calculations shown previously. Having achieved realistic results with the Bank model, the approach could be applied to neighbouring data poor compartments. This was done with success and the usefulness was applied in the scenario models.

6.5.2 Modelling pollution from rewatering

The possibility that water in the mines might pose a problem was considered. Conceptual, visual and numeric models were used to evaluate this section. Due to insufficient measured or known parameters, the conceptual model drives numeric models, and results obtained are a function of the conceptual model.

Two main models, synchronous and compartmentalised water rise, were envisaged with a third, thermal convection, modifying the two end members.

6.5.2.1 Impacts of Model 1

Some of the contaminated mine water is mixed with recharging water by the U-tube like flow. This continually contaminates the dolomites with the high salinity water.

6.5.2.2 Impacts of Model 2

All the original karst is recharged. The groundwater is stratified with the poorest quality, dense water at the bottom. Thus contaminants from the mine excavations do not affect the water quality of the aquifer. If leakage through the dykes occurs, the deep contaminated water will only affect the mines. Shallow leakage is between karst and has always occurred.

6.5.2.3 Impacts of Model 3 on 1 and 2

If thermal convection were to modify the Model 1 situation it would add to the U-tube effect, ensuring more complete mixing of mine water and the water in the dolomitic aquifer. This would ensure that the worst mine water continually moved into the aquifer. Thermal convection would work against density stratification so that good quality water exchange above the mines would be contaminated by thermally driven poor quality water rising from the shafts.

6.5.2.4 Feasibility of Model 3

This was evaluated using empirical relationships and graphical presentation. The temperature density driver is greater than the salinity stratification driver.

However, thermal convection is reduced by the porosity in the formation. An empirical calculation showed that thermal convection was unlikely.

6.5.2.5 Calculation of the impact

From the chemistry of the system it was shown that acid production and hence water degradation should stop after flooding of the mine openings. Thus the water trapped in the system at completion of rewatering will be the worst. Further exchange will dilute the water and concentrations will decrease logarithmically. From first principles and the average values given by large scale steady state pumping from the mines, loads and renewal times could be calculated. These are given in Table 3.

Table 3. Loads and renewal times.

	Original discharge load (kg/day)	Load after 6^{th} renewal (kg/day)	Renewal Time (years)
Bank	2.80E+04	4.38E+02	222
Oberholzer	1.58E+04	2.47E+02	393
Venterspost	1.50E+04	2.34E+02	37

The long renewal times imply that an ongoing problem might exist. In reality far less of the contaminated water will be flushed out due to incomplete mixing and dead end mine voids, thus the renewal time would be shorter. Three dimensional model results were in line with the conceptual and calculated results.

6.6 Scenario management

There are two option groups

- Full recovery of water levels and natural water passage through the system.
- Control of water recovery and discharge from the system by pumping.

The first option is appealing as it is self-managing and therefore sustainable. The second option offers an engineered type of control but has many disadvantages, including:

- The long-term (endless) pumping costs and responsibility would be impossible for any of the mines to take on. Mine-closure approval would be extremely difficult to obtain, as the state would have to be sure that pumping costs would never revert to them.

The continued pumping option could only be accepted if it were self-sustaining and cost-effective. Options to achieve this for the West Rand mines are part of a project that is currently being investigated.

Several permutations within each of these option groups were considered.

7 EVALUATION OF RESEARCH OBJECTIVES AND ACHIEVEMENTS

The following are opinions of the authors as to the degree to which the research objectives have been met:

7.1 To evaluate and document the current impact of closed underground mines on the quality and quantity of groundwater resources, in order to select suitable sites for further detailed investigation, thus generating an impact rating system that could also be applied to operating mines.

A mine risk assessment procedure has been developed which runs under Windows 95/98 or NT has been developed and demonstrated. It is user-friendly and has been applied with success to mining in the Mpumalanga area. This software is available free of charge from the IGS Web site (www.uovs.ac.za/igs). The rating system is based on the evaluation of 22 parameters, information generally known by mines. They should, without any difficulty, be able to calculate risk factors for specific situations.

7.2 To evaluate, with the aid of field observations, various credible preventative options to minimise the undesirable impacts of water quality deterioration and influx relating to underground mining.

Field trials on many levels are ongoing in the mining industry. Mines willingly participated by contributing their data and providing assistance in the generation of additional information. Three typical scenarios were investigated, all three being pressing issues in terms of their potential long-term regional impact. It is our opinion that information generated during this investigation contributes significantly to a better understanding of these systems and quantifies the long-term potential impacts.

7.3 To select or design reliable tools for the prediction of water qualities and quantities during the post-closure phase, to provide information for closure and to assess the applicability of these tools to South African conditions.

Many models are available for the prediction of pollution transport and chemical reactions. In this research, the focus has been on the understanding of processes, the extraction issues that really matter and the explanation of these issues in a way that the mining community can understand. Finite element models have been reduced to displays and graphs that can be used for first order evaluations. The power of this work lies in the simplification of the tools. If necessary, these can be supplemented by the sophistication of numerical and chemical modelling.

8 RECOMMENDATIONS FOR FURTHER WORK

The most important issue emanating from this study is that insufficient data is often available to evaluate the regional and long-term impact of mines, particularly for the period after closure. The details in the EMPR documents are mostly of a descriptive nature and insufficient for a scientific regional impact assessment. The following recommendations are made for further work:

Establish regional information systems

Regional information systems that combine relevant information from the mines should be established and maintained. The RISKY software, coupled with GIS, is a first step. The Intermine Flow Project, currently under way, would also serve as a sound basis for the establishment of such a regional information system.

Investigate areas of insufficient information

Regional risk factors should be extracted from the regional information system. Investigations should be launched into areas of insufficient information. These should be researched to the extent that they could serve as guide-lines for granting closure. The regional information system should be populated with relevant time series and other data that can be used for extrapolation purposes.

Integrate data

Integration of the numerous bits of information should be done. Water is an interrelated discipline. Many studies have been done to date on mine water deterioration. This information should be integrated to identify data deficiencies and allow the definition of solutions.

Define solutions

Definition of solutions at a very early stage is essential. The industry and the government should tackle problems from a futuristic point of view. Solutions that would be valid in 50 years from now should be identified, researched and implemented as a combined strategy.