THE DEVELOPMENT OF APPROPRIATE PROCEDURES TOWARDS AND AFTER CLOSURE OF UNDERGROUND GOLD MINES FROM A WATER MANAGEMENT PERSPECTIVE

Report to the
WATER RESEARCH COMMISSION

by

W Pulles, S Banister and M van Biljon

on hehalf of

PULLES HOWARD & DE LANGE INCORPORATED
RISON GROUNDWATER CONSULTING cc

WRC Report No: 1215/1/05
ISBN No: 1-77005-237-2

MARCH 2005

EXECUTIVE SUMMARY

A need was identified by the Water Research Commission to undertake research into the issue of mine closure planning from a water management perspective in the South African gold mining industry. Initially a project was conceived that was based on undertaking a more detailed study on the development of a coherent and integrated closure planning process for a case study region – the Klerksdorp-Orkney-Stilfontein-Hartebeestfontein (KOSH) area. This approach was eventually abandoned due to the unwillingness of the gold mines in this region (other than Anglogold) to participate in the project.

The project methodology was subsequently modified and approved by the project Steering Committee to rather study the complete South African gold mining industry and develop a closure planning methodology that would have application throughout the industry. In support of such an industry-wide study, an assessment would be undertaken of the current status of closure planning contained within the mine EMPRs.

Review of Mine EMPRs

An assessment was made of gold mining EMPRs on the basis of the approved EMPRs as at the end of 2001. It must be recognised that as EMPRs are regularly being updated, a number of the identified shortcomings would possibly be addressed in revised EMPRs that have been submitted since the review was undertaken. However, the conclusions that were reached are considered to be a valid reflection of the status as at the end of 2001. The review focused on those parts of sections 5 and 6 of the EMPRs that describe the decommissioning and closure phases of the mine's operations and can be summarised as follows:

- While most mines recognise the fact that tailings dams generate acid mine drainage, it is generally and incorrectly assumed that the impact will decrease to acceptable levels when mining operations cease. The assessment of long-term risks from tailings dams can at best be described as subjectively qualitative in nature and no proper quantitative assessments were reported in any of the EMPRs.

- It appears to be quite widely assumed that the larger particle size of waste rock dumps makes them a minor pollution risk. This view is erroneous as the waste rock dumps have very large inventories of fine material and they are much more permeable to oxygen than tailings dams. The secondary source of contaminants that remain in the soil after a dump has been removed appears to be universally ignored and it is assumed that removal of the dump removes all potential for pollution from that site.

- Most mines appear to have some monitoring programme to evaluate shallow aquifer and surface water impacts from the surface residue deposits. However, the monitoring programs are not clearly stipulated in the EMPR documents and hence it is not clear if the extent of contaminant plumes is known.

- Very few specialist investigations appear to have been done to identify the status of the geohydrological regime, the extent of contamination, preferential pathways and predictions regarding long – term migration. As a result there are very limited mitigation or management options described in the EMPRs that specifically deal with the containment / rehabilitation of contaminated groundwater.

- The potential impact on the groundwater from other surface contaminant sources such as the metallurgical plants, domestic and industrial waste sites are not described. Many of the EMPR documents state that these structures will be removed / rehabilitated during decommissioning, but it is not stated if they had an impact and if groundwater rehabilitation is required.

- Many of the older mines were subjected to amalgamations and changes in ownership and in many instances the surface infrastructure, including some tailings and rock dumps were sold to 3rd parties. Many of the current mine EMPR documents exclude infrastructure that has been sold and it is not clear if the new owners are required to address groundwater contamination and if it is in fact being done.

- All the goldfields and therefore most of the mines are exposed to the inflow of extraneous water into the underground workings. The aquifers affected by the subsequent dewatering vary from one basin to the next, as do the associated environmental problems. The dewatering of the different mining basins is briefly summarised.

  - **Far West Rand and KOSH area.** The inflow of water is derived from overlying dolomite aquifers and huge volumes have to be pumped from the mines for work to continue. The groundwater quality is generally good and the pumped water can be discharged into the natural environment. Many of the dolomite compartments have been dewatered over the years, which resulted in sinkhole formation and ground stability problems. This necessitated the establishment of vigorous groundwater and stability monitoring systems that are required to continue for some time after mine closure. After closure, the mine workings will flood and the dolomite aquifers will largely recover to pre – mining levels. Decant is expected to be limited. There are currently no management options in place to cope with contaminated decant water.

  - **Gauteng mines.** The three mining basins in Gauteng, i.e. the Eastern, Central Rand and West Rand basin are all at risk of being flooded or are already partially flooded. The water quality in the mine workings is of a poor quality and cannot be disposed into the natural environment without treatment. When mining ceases the basins will flood to the elevations of the lowest topographical shaft, where it will decant. The quality of the decant water is still a matter of debate, as is the ownership of the responsibility for rehabilitation. There is a school of thought suggesting that the water quality will improve over time and that the water can be allowed to decant into the environment. Another school of thought believes that the water quality will be poor and that treatment centres will be required at the decant points. Although some studies have been done, no management options are currently in place. Harmony's Randfontein Estates Mine has, however, indicated that they may pump and treat water from the West Rand basin until the water quality issue is better understood.

  - **Free State goldfield.** The Free State mines are exposed to the inflow of extraneous saline water from a deep connate aquifer. The isolated nature of this aquifer allowed for it to be dewatered effectively and the poor quality water was disposed of through evaporation. Many of the mines are of the opinion that after cessation of mining the workings will flood, but that the water table will stabilise below the Karoo strata and that none of this water will decant from any of the shafts. Although this statement is probably correct there is no reference to any geohydrological investigation confirming this. As a result of this perception there are no management plans in place to cope with decant water.

- The general conclusion of this situation analysis regarding post closure groundwater management is that not enough work has been done by the mines to fully understand groundwater flow, groundwater contamination and decant potential. As a result the management options to mitigate groundwater contamination after closure are very vague or non-existent.

There is a definite need for clear guidance on what type of technical investigations need to be undertaken to provide the following information:

- Understanding of the long-term risks (quantity and quality) associated with post-closure decant from gold mines.
- Understanding of the long-term risks (quantity and quality) associated with post-closure seepage from waste residue deposits (tailings, waste rock and footprints below removed dumps).
- Identification of proactive management measures that can be implemented to minimise the long-term risks associated with decant from mines.
- Identification of proactive management measures that can be implemented to minimise the long-term risks associated with seepage from waste residue deposits.

It is also clear that, to date, closure planning is not being undertaken on an integrated regional basis, resulting in those mines that have the longest remaining working life in each region being at the highest risk of being held responsible for dealing with the cumulative regional problem. This situation is clearly not equitable and it is therefore urgent that appropriate procedures be developed to ensure that effective closure planning occurs timeously and on an integrated regional basis.

Review of regional geology and identification of regional water management areas

A detailed review is presented in the report of the geology and geohydrology in the different mining areas. While issues relating to surface water management are taken into account, it was determined that the primary need for regional assessment was dictated by the geohydrological interconnections between mines as whereas surface water interconnections could easily be managed and modified, geohydrological interconnections could not.

We have identified ten major gold field regions currently mined in South Africa based on their depositional environment and geohydrological boundaries, rather than their provincial boundaries. The reasons being that in terms of long–term groundwater management systems, it is more sensible in some instances to implement this on a regional basis than an individual mine or provincial basis. This is in part due to the inter-connections that exist between the underground gold mines and the inflow of extraneous water into the underground workings. It is also important to note that more than one mine may impact on a certain geohydrological regime and that the mine boundaries will not necessarily coincide with geohydrological boundaries.

The gold mine regions have been divided as follows:

Witwatersrand Basin	• Free State goldfield • KOSH(Klerksdorp-Orkney-Stilfontein-Hartebeestfontein) area • Far West Rand • West Rand basin • Central Rand basin • East Rand basin • Evander goldfield
Non-Witwatersrand Basin	• Pilgrims Rest goldfield • Barberton goldfield • Kwazulu Natal - Klipwal

Of the above mine groupings, the Free State and KOSH mines fall into the Middle Vaal water management area, while the Far West Rand, West, Central and East Rand Basins and the Evander mines all fall into the Upper Vaal water management area. The Kwazulu Natal mine falls into the Usutu / Mhlatuze water management area. The Barberton mines fall into the Nkomati water management area with the Pilgrims Rest mines in the Olifants water management area.

The individual gold mining regions were investigated further in terms of their geology and geohydrology to establish whether further sub-divisions were required.

<u>*Free State goldfields*</u>
It was established that the Free State goldfields should be further subdivided into 5 sub-basins as set out below.

The **Theunissen sub-basin** consists of Joel and Beatrix gold mines, situated between the De Bron and Stuurmanspan Faults. These mines are not interconnected through mining, but hydraulic connectivity does exist through geological structures. Beatrix gold mine has pumped in the order of 30 megalitres per day (Ml/day) from the Witwatersrand aquifer during the 1990's. This has resulted in a dewatering cone developing in the aquifer, which has dewatered part of Joel mine as well, to the extent that groundwater inflows into Joel seldom exceeded 10 Ml/day during that time. Groundwater abstracted from the mines is evaporated on the mine property as well as piped to Welkom, where it is also evaporated.

The **Oryx sub-basin** consists of Oryx gold mine. This mine is isolated from the other mines and the Stuurmanspan Fault in the east and the Border Fault in the west mark its boundaries. This mine has been plagued by large groundwater inflows (~60 Ml/day). This water is also derived from the Witwatersrand aquifer and temperatures of as high as 60º Celsius are recorded. Groundwater pumped from the mine is evaporated.

The **Virginia sub-basin** consists of the Harmony gold mines (Harmony original, old Virginia, old Saaiplaas, old Erfdeel and old Merriespruit). These mines are all interconnected and the De Bron Fault marks its western boundary. The distal depositional environment and the disappearance of economical reef horizons form the eastern boundary of this sub-basin.

The **Welkom sub-basin** consists of the President Steyn (south), St. Helena, Harmony (President Brand and Unisel), Freegold (Matjhabeng, and Bambanani) and ARM gold mines. The Border Fault forms the western boundary and the Welkom goldfield is separated from the Virginia sub-basin by the De Bron Fault structure.

The **Odendaalsrust sub-basin** consists of the Freegold (Tshepong and Jeanette), President Steyn (north) and Target gold mines. The Border structure forms the western boundary and mining to the east is restricted by the Dagbreek fault.

For the Free State sub-basins a regional approach to dewatering may be more effective in reducing the groundwater levels to the benefit of all mines concerned. Pumping rates generally range from 2- 23 Ml/day. It does not seem likely that water will decant from any of the gold mine shafts in this region after cessation of mining and flooding of mine workings. However, the serious threat of contamination of the shallow, good quality water, the Karoo aquifer, through the residue deposition on surface or through the large-scale evaporation of saline water pumped from the deep Witwatersrand aquifer, needs to be addressed.

KOSH area

The KOSH area is underlain by dolomite. The goldfield can be subdivided into four groundwater compartments, but due to the interconnections existing between the mines, a closure water management strategy should be integrated across all the KOSH mines. The mine workings, after flooding are likely to decant. There is also significant surface-groundwater interactions that impact on water quality in terms of pumpage of water from the mines to surface water, recirculation of water in the mines, continuous seepage from surface tailings dams and return water dams, eye flow and seepage. The high sulphide ores in this area result in potentially high long-term risk of water pollution from both the underground workings and surface residue deposits. Pollutant prevention management strategies need to be included and transport of pollutants properly evaluated. Sinkhole formation and backfilling of these sinkholes also need to be addressed in the closure planning process.

Far West Rand

In terms of gold mine closure planning, the Far West Rand mines can be divided into three geohydrological management units viz. the eastern, central and western sub-basins. These sub-basins include the Gemsbokfontein (eastern sub-basin), Venterspost, Bank and Oberholzer (central sub-basin) and Turffontein (western sub-basin) groundwater compartments. While dykes, which are considered impermeable separate the compartments, there is still interaction between different compartments due to spillage from one compartment to the next in the form of “eyes” or fountains. Furthermore, some of the upper portions of the dykes are weathered causing flow from one compartment to another.

The groundwater is found in two distinct aquifers. The gold mines in this area are mainly situated underneath the deeper dolomitic aquifers. The deeper aquifer is significant in terms of future water supply sources and is vulnerable to contamination with poor mine water upon filling. The upper perched aquifer is at risk of contamination from surface waste residues and seepage from backfilled sinkholes. This contamination is however not thought to pose a serious threat to the lower aquifer. The dewatering of the dolomitic compartment and the subsequent lowering of the groundwater levels has resulted in significant sinkhole formation and widespread ground stability problems. Decanting is likely once mining ceases in this area. Poor decant water quality will impact on surface water resources. Groundwater stability levels will be dependent on the adequate sealing of the dykes.

West Rand basin

Mining in the West Rand basin caused the creation of an artificial aquifer. A single geohydrological unit for closure planning coincides with the mining boundaries. All the gold mines are interconnected as indicated by a flat groundwater gradient within the mined out workings. Groundwater quality is poor and the area has recently started to decant. There are also significant surface-groundwater interactions that impact on water quality in terms of continuous seepage from surface residue deposits.

Central Rand basin

The closure water management strategy for the Central Rand involves three sub-basins viz. the Central (including Rose Deep) sub-basin, the DRD and Rand Leases sub-basin and the ERPM sub-basin. These sub-basins are interconnected but are currently separated by mining pillars and the installation of plugs. Rainfall and stream flow where it crosses the reef outcrops are the predominant sources of water recharge and flooding into the aquifer and mine voids. Recharge rates of 99 Ml/day (summer) and 77 Ml/day in winter have been estimated.

The DME strategy involves closing all the ingress point. This is particularly true of the western (DRD) sub-basin. Many mines are already closed or abandoned in the Central Rand basin leaving the task of dewatering to only a few mines. Pumping from the two ends (DRD and ERPM) of the central Basin has also been suggested to maintain water levels.

There are also potentially long term surface and ground water pollution problems from decant water and seepage from surface residue deposits.

East Rand basin

The East Rand basin also consists of interconnected underground gold mines that are separated from the Central basin by the "Boksburg gap", which is just an unmined area. The task of dewatering is carried by only a few remaining mines, with the most significant volumes coming from the deeper mines. Two distinct dolomitic aquifers occur in this region, however, the northern aquifer plays the predominant role in terms of inflow to the gold mines. This inflow is attributed to mining induced fractures that obscure the exact inflow positions. The link is however believed to be the faults cutting across the Blesbokspruit. The area will decant once pumping ceases and groundwater will exit at Nigel.

Evander goldfield

The Evander goldfield groundwater management strategy will need to be integrated across the area since all the gold mines in Evander belong to one mining group and all the shafts are linked through underground workings. There may be three aquifers present in this area that may or may not be interconnected. They include an unconfined Karoo perched aquifer close to the surface; a confined or semi- confined aquifer within the underlying dolomite and the possibility of a confined Witwatersrand connate aquifer. The latter is usually characterised by saline water. A critical issue here is the presence of the Ventersdorp lava within this basin, which would form a barrier between the overlying aquifers and the mined out barrier.

Non-Witwatersrand basin

This section covers the Pilgrims Rest, Barberton and Kwazulu Natal (Klipwal) mining areas. Information has not been readily available and is limited for these last three areas. Moreover, a review of their geohydrological profiles indicates that these gold fields could each be managed as individual regional units with respect to closure planning. Pilgrims Rest and

Kwazulu Natal have only one operational mine in each region. Barberton has eight gold producing regions and over 130 mines. However, these Barberton mines are generally small, single adit operations that could also be managed as a combined unit. Moreover, due to budget constraints and time already spent in attempting to fill in the data gaps for these regions, it was decided that this aspect would not be further pursued. However, it is recommended that a separate study be conducted to better understand the interconnections and groundwater interactions of the Barberton mines.

A summary of the key elements raised in this situation assessment is presented in Table E1 below.

Table E1: Geohydrological assessment data summary for closure planning of underground gold mines

Goldfield	Free State	KOSH	Far West Rand	West Rand	Central Rand	East Rand	Evander	Pilgrims Rest	Barberton	KZN
Water Management Area	Middle Vaal	Middle Vaal	Upper Vaal	Upper Vaal	Upper Vaal	Upper Vaal	Upper Vaal	Olifants	Inkomati	Usutu to Mhlathuze
Geo-hydrological groundwater management units	5	1	3	1	3	1	1	1	1	1
Decanting	Not likely	Yes	Likely	Yes	Yes	Yes	No	Likely	Some	Unlikely
Decant rate	0	17-50 Ml/day	?	Estimated at 17 Ml/d	17 Ml/d	?	-	-	-	-
Physical instability (Subsidence/ sinkholes)	No	Yes	Yes	Yes	Yes	Yes	No	No	No	No
Pumping of flooded mines	Yes	Yes	Yes	Being flooded	Yes	Yes	No	No	Some	Yes
Pumping rates	34 Ml/d	Stilfontein	>150 Ml/d	-	99 Ml/d (summer)	90 Ml/d	-	-	-	-
Strong surface-groundwater interactions	Hydrochemical pollution sources (such as waste dumps, evaporation dams and slimes dams) Saline water pumped from deep connate aquifer and surface evaporated (Free State mines) Recharge water degradation of dolomites Transport routes such as surface run-off, primary aquifers, dolomitic aquifers, fractured rock aquifers and geological features such as faults and dykes									
Chemical stability (water quality e.g. AMD problems	A positive correlation exists between gold grade and the modal proportion of potentially acid producing sulphide minerals. Furthermore, gold grade correlates positively with the reef thickness. Thus by making use of isopach maps showing the distribution of reef thickness, meaningful planning and delineation of areas with a high acid producing potential is possible.									

? = missing data

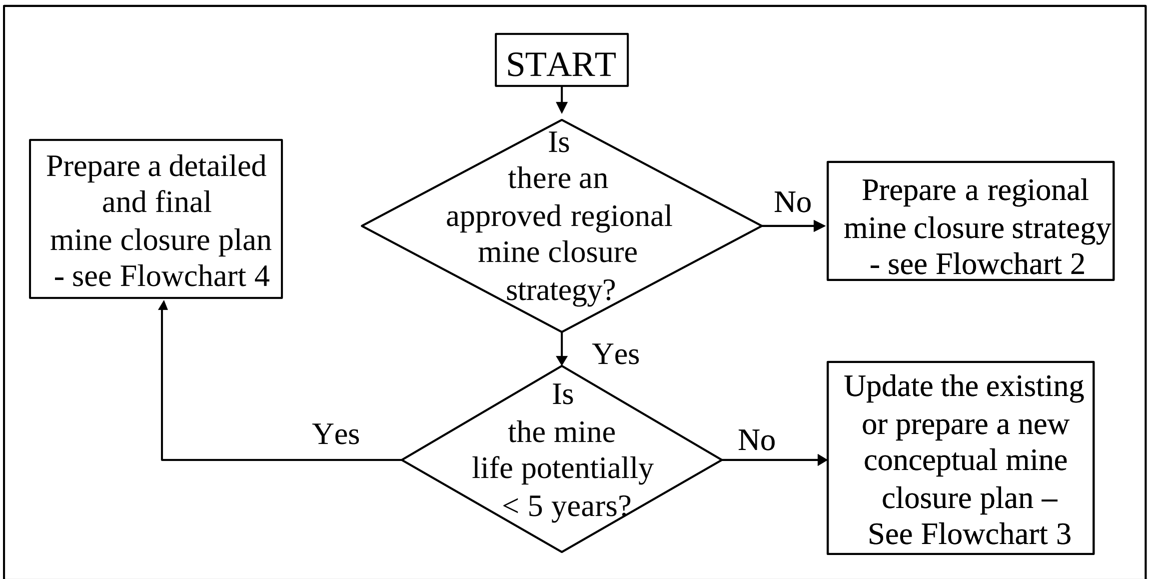
Proposed regional mine closure strategy

The principles of risk-based mine closure planning were adopted and a procedure was developed and presented to enable risk-based regional mine closure planning to be implemented. A detailed risk-based closure planning process is presented, together with flow charts aimed at the development of a regional closure planning process. In assessing the closure issues relating to water, the following important points need to be considered:

1. The source of water-related impacts on a gold mine can be divided into two primary components, i.e. aboveground features and underground features.
2. All South African gold mines are extracting ore and waste material that are associated with sulphide minerals (and a greater or lesser amount of neutralizing minerals) and other contaminants and there is, therefore, an inherent water quality risk associated with gold mines.

3. The gold mines are generally grouped together very tightly, resulting in hydrological interconnections between adjacent mines. This makes it difficult, if not impossible, to consider the water-related closure risks in isolation and consequently, a number of distinct hydrological groupings of mines has been defined, each of which should develop a regional mine closure strategy within which individual mine closure plans can be assessed.
4. The surface residue deposits (tailings dams and waste rock dumps) that remain after mine closure can never be maintained in a completely reducing environment and must be considered to pose a potential water related risk until shown otherwise by way of a suitable semi-quantitative or fully quantitative geochemical assessment.
5. Underground mine workings will fill up with water over time (slow or fast depending on geohydrological setting) and this water will be contaminated (either for a limited time or in perpetuity). A key element influencing the risk that these processes pose to the water resource is whether or not this contaminated water will decant into the underground aquifers or into the surface water resource and to what extent the natural water resource can assimilate this contamination. The underground workings must, therefore, be considered to pose a potential water related risk until shown otherwise by way of a suitable semi-quantitative or fully quantitative geohydrological and geochemical assessment.
6. In certain mining regions, underground dewatering activities and placement of surface residue deposits pose a long-term risk with regard to formation of sinkholes that in turn pose safety, water resource and land use risks that need to be assessed.

With the above in mind, a set of procedures have been developed to address the various elements of regional mine closure strategies and individual mine closure plans. The first step in the process is to define the nature of the closure plan that is required and this question is simply addressed in Figure E1 below.



FLOWCHART 1: IDENTIFY TYPE OF CLOSURE PLAN REQUIRED

Figure E1: Flowchart to identify type of closure plan required

Based on the flowchart process shown in Figure 6.4, three possible outcomes exist:

- Prepare a regional mine closure strategy
- Update the existing or prepare a new conceptual mine closure plan
- Prepare a detailed and final mine closure plan

The above process incorporates the principle that a conceptual mine closure plan can be developed in the absence of a regional mine closure strategy but that no final mine closure plan can be developed until an approved regional mine closure strategy is in place.

Preparation of a regional mine closure strategy

Due to the fact that most mines are hydrologically interconnected with the adjacent mines, the closure of one mine within a region will often have impacts on the remaining mines. There is also a risk that the cumulative impact from all the mines in a region could be imposed upon the last mine in the region to cease operations. This poses a secondary risk that this last mine could be held responsible and liable for the cumulative impact of all the mines or, as a minimum, that it would be difficult, if not impossible, to apportion liability to the contributing mines within a region. It must also be recognised that different mines within a region will cease operations at different times and some framework must be established within which these mines can plan for mine closure. It is, therefore, recommended that a number of regional mine closure strategies be developed for the different regions that have been identified.

In the development of a regional mine closure strategy the first step is to establish which mines are included within each region. While it is not the responsibility of the research team to dictate who funds the development of a regional mine closure strategy, it would clearly be reasonable that either all the mines within a given region jointly manage and fund the development of this strategy, or that the State take responsibility.

Based on the research undertaken as part of this project, 17 different regions have been identified as shown in Table E2 below. The grouping is essentially based on connections between the underground workings and the geohydrological units that apply. In all cases other than the Far West Rand Central sub-basin and Eastern sub-basin, mines grouped within a geohydrological region are also located within the same surface hydrological unit. Regional mine closure strategies developed for these 2 sub-basins will need to take cognisance of catchment management plans developed for the adjacent catchments.

Update the existing or prepare a new conceptual mine closure plan

Whereas the focus of a regional mine closure strategy is to understand interactions between adjacent mines and to find a basis for agreement on how much contamination (waste load allocation) is permitted for each mine, the focus of an individual mine closure plan is on how to manage the mine closure process to most optimally comply with the agreed waste load allocation. This process requires the mine to integrate the impacts that derive from its underground mining operations and those that derive from the surface waste residue deposits.

It is proposed that a new or updated conceptual mine closure plan can be developed at the same level of detail and using the same assessments that were undertaken for the regional mine closure strategy. This means that the mine will probably be able to meet the requirements for understanding and managing the impacts from the underground operations by using the geohydrological and geochemical studies undertaken for the regional mine closure strategy. With regard to the surface impacts, the mine will need to undertake a screening level assessment of the impacts associated therewith. For both the underground and surface impacts, the closure plan will then focus on evaluating various broad management strategies that are capable of reducing the total mine impact to an acceptable level as dictated by the approved waste load allocation. The conceptual mine closure plan should be reviewed and updated on the same frequency with which the mine undertakes its EMP performance assessments.

Table E2: Regions for regional mine closure strategies

Area	Geohydrological Unit	Mine	Quarternary Catchment	Tertiary Catchment Name
KOSH	KOSH	Stilfontein, Hartebeestfontein & Buffelsfontein	C24A	Schoonspruit
	KOSH	Vaal River Operations & ARM	C24H	Schoonspruit
Free State	Odendaalsrus sub basin	Target, Jeanette, Tshepong & PS North	C25	Makwassie spruit
	Welkom sub basin	PS South, St Helena, P Brand, Unisel, Matjhabeng, Banbanani & ARM	C43B	Vet
	Virginia sub basin	Harmony original, Old Virginia, Old Saaiplaas, Old Erfdeel, Old Merriespruit	C42J	Vet
	Oryx	Oryx	C42L	Vet
	Theunissen sub basin	Joel & Beatrix	C42K	Vet
Far West Rand	Western sub basin	Deelkraal, Driefontein, Blyvooruitzicht, Western Deep & Elandsrand	C23E	Mooi
	Central sub basin	Kloof	C22J	Klip
		Venterspost, Libanon	C23D	Mooi
	Eastern sub basin	Placer Dome	C22H	Klip
		Harmony Cooke	C23D	Mooi
Barberton	Barberton	New Consort	X23B	Krokodil
	Barberton	Sheba	X23G	Krokodil
	Barberton	Fairview, Agnes	X23F	Krokodil
Evander	Evander	Winkelhaak, Bracken, Leslie & Kinross	C12D	Waterval
West Rand	West Rand	Randfontein Operations & West Wits	A21D	Upper-Krokodil
Central Rand	DRD and Rand Leases	DRD, 5A shaft & Rand Leases	C22A	Klip
	Central	CMR, Crown, Rose Deep & City Deep	C22A&B	Klip
	ERPM	ERPM	C22B	Klip
East Rand	East Rand	Grootvlei & Modderfontein	C21D	Suikerbosrand
		Nigel	C21E	Suikerbosrand
Pilgrim's Rest	Pilgrim's Rest	Transvaal Gold Mining Estate	B60A	Blyde

Prepare a detailed and final mine closure plan

When it is anticipated that the mine's remaining operational life is in the order of 5 years, the mine will need to undertake a substantial review and overhaul of its conceptual mine closure plan and will need to significantly upgrade the level of certainty associated with the various assessments. While the process is essentially similar to that employed for the development of a conceptual mine closure plan, the level of detail and the depth of the assessment will vary. In particular, it is proposed that detailed mine closure plans should be probabilistic in nature, i.e. they should aim to define the uncertainty associated with the assessment.

The DWAF is in the process of developing Best Practice Guidelines for the prediction of pollution from mining sites and the methodologies set out in these guidelines should be used in undertaking the assessments required to develop mine closure strategies and mine closure plans.

Recommendations

The primary recommendation of the research project is that the basis of mine closure planning in South Africa should be modified. Whereas, mine EMPRs, mine authorisations and mine closure plans are drawn up, evaluated and approved on an individual mine basis, there is a need for this process to be modified to take account of regional issues. The following process has therefore been recommended:

1. Regional mine closure strategies should be drawn up for the 17 gold mining regions defined in the report. These strategies should establish the ground water and surface water interconnections between mines within a region and should be integrated with the catchment management plan drawn up for the relevant region. The regional mine closure strategy will need to be undertaken as a cooperative venture between all the mines and should result in a broad regional strategy that includes the equitable apportionment of waste load between mines. Details on the strategy development and content are provided in Chapter 6.

2. Individual mines will then be required to develop their individual mine closure plans, to be submitted to the DME as part of the mine's EMPR. These individual closure plans will need to be developed within the context of the approved regional mine closure strategy and could either be in the form of a conceptual mine closure plan if the mine has more than 5 years life remaining, or in the form of a detailed and final mine closure plan if the mine has 5 years or less of planned operational life remaining.

3. Interim procedures and policies need to be negotiated to enable the transition from the current status to the proposed new procedure. In this regard, it is proposed that an implementation period of say 5-10 years be agreed, within which a regional mine closure strategy must be developed and approved and mine closure plans be converted to conform top the approved closure strategy.

4. It is also recommended that no mine be permitted to switch off dewatering pumps or commence with flooding of portions of the mine without having an approved detailed and final mine closure plan that fits within an approved regional mine closure strategy. This is to ensure that any management actions that need to be implemented before a mine floods are timeously identified and implemented to reduce the risk of long-term water pollution problems.

5. It has been recommended that the regional mine closure strategy also address the issue of waste load allocation between mines on an equitable basis. Liability for long-term water management actions should then be apportioned on the same basis as the waste loads.

6. A recommendation has been made to the Department of Minerals and Energy that the proposed mine closure strategy be incorporated into the new Minerals And Petroleum Resources Development Act, 2002 (Act No 28 of 2002).

7. It is recommended that a separate study be conducted to better understand the interconnections and groundwater interactions of the Barberton mines.

ACKNOWLEDGEMENTS

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

"The development of an appropriate procedure for the closure of deep underground gold mines"

The Steering Committee responsible for this project, consisted of the following persons:

Mr HM du Plessis	Water Research Commission (Chairman)
Mr KC Pietersen	Water Research Commission
Mr W Pulles	Pulles Howard & de Lange Inc.
Mr EJ Amis	Anglogold
Ms S Hohne	Department of Water Affairs and Forestry, Free State
Mr C Khoza	Department of Minerals and Energy, Mine Rehabilitation
Dr AH Leuschner	Gold Fields Limited
Mr MC Moseki	Department of Water Affairs and Forestry, DWAF
Prof JS Ogola	University of Venda for Science & Technology
Dr AS Parsons	Chamber of Mines of South Africa
Mr R Schwab	Dept. of Water Affairs & Forestry, Water Quality Management
Mr U Sibilski	Anglogold
Ms E Swart	Department of Minerals and Energy, Mine Rehabilitation
Ms E van der Linde	Department of Water Affairs and Forestry, Geohydrology
Dr D Wymer	Chamber of Mines of South Africa

The financing of the project by the Water Research Commission and the contribution of the members is gratefully acknowledged.

We are grateful to each individual with whom we held discussions during the research period. We are in particular grateful to those mining groups and government departments that have supplied us with information. Their valuable contributions made this project possible.

The researchers that were involved in this project are listed below.

Mr W Pulles	:	Pulles Howard & De Lange Inc. (Project Leader)
Dr B Zhao	:	Pulles Howard & De Lange Inc.
Ms S Banister	:	Pulles Howard & De Lange Inc.
Ms T Germishuyse	:	Pulles Howard & De Lange Inc.
Mr Marius van Biljon	:	Rison Consulting cc

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

1. INTRODUCTION

1.1 BACKGROUND

The objective of mine closure is to provide long-term stabilization of the geochemical and geo-technical conditions of the disturbed mining areas, to protect public health, and minimise and prevent any additional or on-going environmental degradation. Stakeholder participation is also vital for successful closure of each mine and to ensure social and economic activities are maintained (MMSD, 2002).

Inadequate mine closure plans can result in severe environmental, social and economical consequences. More specifically, lack of proper closure procedures, water management and waste rock disposal plans have prompted unexpected and in some instances, unwarranted secondary environmental impacts statements or assessments (Mudder and Harvey, 1999).

It is now required practice today, that proper planning for closure be incorporated into the feasibility, design and permitting phases of a mine and be upgraded during operational life. Mine closure is, typically, addressed at a time when the operation is no longer economically viable, when cash flow is severely restricted or negative, or when the value of assets is below the expenditures required to achieve the environmental objective of mine closure. Securing mine closure funding at an early stage and including closure procedures at the onset and during operations is needed to ensure sufficient funds are available for mine closure activities, options are not limited and to mitigate against risk that an enterprise may pose to the environment and the sustainable post mining uses of the land.

Furthermore, different types of mines have different life spans. Closure of large gold mines could be a process that will span several decades. Some mine closure is as a result of the economic situation in the mineral industry. Some mines are interconnected with others. It is critical therefore to have an integrated closure plan that is proactive and will show the management strategies of resources during closure phase and the post-closure phase.

1.2 PROJECT AIMS

Pulles, Howard and de Lange Inc. (PHD) was appointed by the Water Research Commission (WRC) to undertake an investigation into the closure procedures of underground gold mines. The main aim of the project is to develop an appropriate and agreed procedure for the closure of underground gold mines. This procedure includes assessment techniques, apportionment of responsibility and long-term management aspects such as pumping and water treatment.

The new Minerals And Petroleum Resources Development Act, 2002 (Act No 28 of 2002) advocates a risk-based approach to mine closure planning and this project is aimed at delivering a research product that is compatible with this approach and that can assist in implementation of the Act.

1.3. RESEARCH PRODUCTS AND TARGET GROUPS

The primary research products are:

- A situation assessment of the **current status of closure planning** in the gold mining industry and key differences between the **major mining regions.**

- A defined and agreed **procedure** that can be used by **mines** and **regulators** in the **planning of closure** for **deep underground gold mines**.
- A **strategic level guideline** that can be used by **mines** and **regulators** to **apportion responsibility** for the **long-term management** of mine water issues **after closure**, including the pumping and treatment of water.

These research products will be invaluable to mines, regulators and consultants who are involved in the planning and review of mine closure.

1.4 RESEARCH METHODOLOGY

1.4.1 General

The primary technical factors that need to be considered when planning mine closure and post-closure water management are surface hydrology, geohydrology, geochemistry, mine voids, interconnections between mines, receiving water environment assimilative capacity and water pumping and treatment technologies. Although the precise solution to these variable factors will differ for each site-specific situation, experience indicates that there are generic procedures that should be followed in order to reach the site-specific solution.

This project is aimed at developing such a generic procedure through the application of specialist technical knowledge, coupled with the involvement and practical mining input of mining personnel and the legal and policy input of the relevant authorities viz. Department of Water Affairs and Forestry (DWAF) and the Department of Mineral and Energy Affairs (DME).

It was proposed that the procedure first be developed with reference to a case study gold mining region (Klerksdorp – Orkney – Stilfontein – Hartebeestfontein [KOSH area]) before being extrapolated to ensure applicability to all gold mining regions. This, however, was not possible due largely to issues relating to co-operation and data collection from some of the gold mines in the "KOSH" case study area. Despite several presentations, meetings and discussions with mine management, the project was unable to get co-operation from all the mines in this area. Since these mines are all hydrologically interconnected, it was not feasible to proceed with a detailed study without all the mines actively participating in the study. Moreover, concern had been raised by several stakeholders, regarding the project approach to extrapolate data collected from a detailed KOSH regional study to develop a generic closure planning procedure for all gold mines in the country.

In light of the above, the following **changes in methodology** were agreed to by the steering committee (reference: WRC letter dated 15 April 2002). It should be noted that the changes proposed to the methodology or approach did not alter the delivery of the research products specified in section 1.3.

The study area was extended to include all major gold mining regions and not just the KOSH area. We therefore proceeded by conducting a less detailed analysis and data collection exercise for all major geological gold mining regions i.e. Far West Rand; Eastern Basin; Central Rand Basin; West Rand Basin; Free State; Evander; Barberton and Pilgrims Rest.

The study therefore became largely a desktop exercise that used information available from regulators (DWAF; DME; DEAT) e.g. EMPRS, licences etc. and the public domain (e.g.

WRC reports, papers, publications, shareholder plans; geology maps, etc.). Key differences between different gold mining regions that could impact on closure planning and that would lead to differentiated closure procedures for each region were identified (see below).

The following relevant data were collected from each study area where available:

- Location of known or suspected connections between mines
- Water and salt balances and water quality of underground mines
- Pumping rates for all flooded sections
- Decant predictions
- Geo-chemistry / mineralogical data
- Location of past and current sinkholes
- Location and nature of strong interactions between surface and groundwater resources

Additional details on the methodology are given in the sections below. The sequence of the different steps is shown in Figure 1.1.

1.4.2 Literature survey

A literature survey of the current legislation and policy issues on gold mine closure was undertaken from both a South African and international perspective.

Mr. Gladstone Nzianda (M.Sc Student) and Mr. Musa Miyambu (B.Sc. (Hon) student) from the University of Venda, were seconded to PHD on separate occasions to undertake the literature survey and produce a report. They also assisted with population of the GIS database.

As part of this report, an up to date list of operational gold mines was collated with the assistance of the DME: Mineral Economics Directorate and Council for Geoscience.

A summary of the literature survey is provided in Chapter 2.

1.4.3 Situation assessment

1.4.3.1 Meetings with regulators

An initial meeting was held in May 2001 with the DME Director: Mineral Development. The project was discussed and the DME requirements noted. The DME endorsed the project and the regional directors of mineral development were informed of the project at an internal DME meeting in June 2001. The regional directors agreed to assist PHD with making the relevant EMPR's available. Follow up discussions were also held with new staff appointed at the DME head office on the project deliverables in June 2002.

A meeting was also held in June 2001 with the Directorate: Water Quality Management: Mines (WQM) to discuss the project and determine DWAF's requirements for this project.

Over the period July to October 2001, the following regional DME offices were visited viz. North-West (Klerksdorp), Gauteng, Free State (Welkom), Mpumalanga (Witbank) and KwaZulu Natal (Dundee). Discussions about the project were held with each regional director and the EMPRs were reviewed for all operating gold mines.

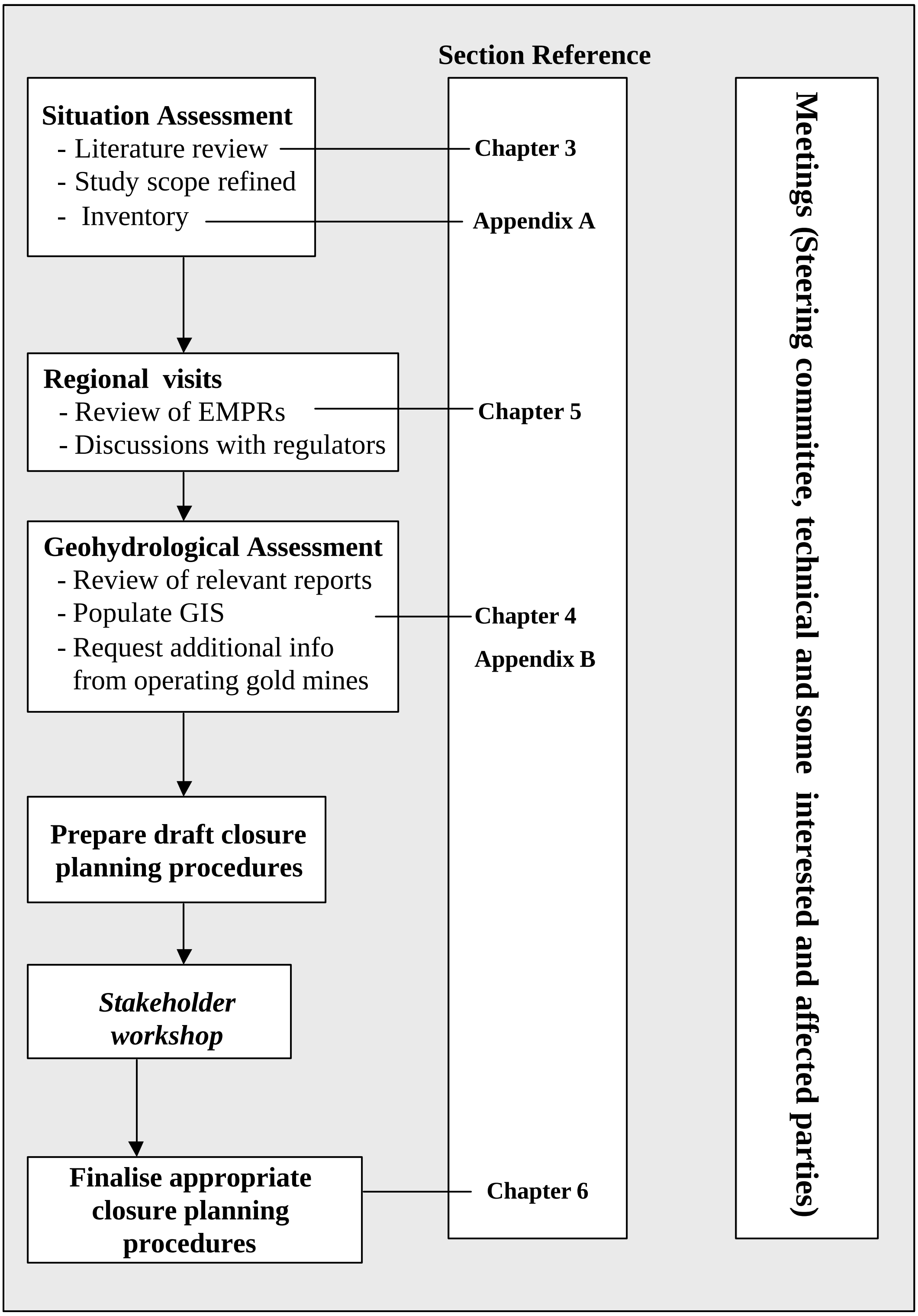


Figure 1.1: Task outcome flow diagram

1.4.3.2 Produce geohydrological situation assessment report

Rison Consulting was appointed by PHD to assist in the situation analysis based on their geohydrology expertise in the mining industry. Regulators, technical reports and other literature were also reviewed to assist in drawing up a geohydrological profile analysis for each of the major gold mining regions. Details regarding geological settings, geohydrological boundaries, inter-connectivity between sub basins, aquifer characteristics and current groundwater management procedures were compiled.

The situation report incorporating the information supplied by Rison Consulting and other studies is included as Appendix A1.

1.4.3.3 Review EMPR's of all currently operating underground gold mines

This report was aimed at assessing the current status and approach to decommissioning and post closure impacts. In particular Sections 5 and 6 of the EMPR, which describe the decommissioning and closure phases, were collected and examined. Approximately forty underground gold mine EMPRs were reviewed.

1.4.4 Develop and populate a basic GIS for the study area

The relevant information collected from the major gold mining areas was entered into a Geographic Information System (GIS) in order to facilitate the further tasks in the project. The GIS is not intended to reflect all available information for the study area but rather the critical information required to demonstrate the closure procedure being developed.

GIS data related to mine boundaries, key geological and hydrological features, lithological data and aquifer yields were populated for the case study areas.

1.4.5 Study area mines

A document summarizing the project, the data requirements, the deliverables and benefits to participating KOSH mines was prepared. It was sent to the managers of the gold mines in the study area namely Anglogold, African Rainbow Minerals (ARM) and Durban Roodepoort Deep (DRD) Ltd (who are also currently managing operations for Stilfontein mine). A presentation was given to the environmental managers on 20 November 2001 in Klerksdorp to outline the project aims and discuss any concerns participants may have.

However, in view of the fact that we could not get support for the project from all the mining companies (only Anglogold provided support) and the significant time that had been lost in pursuing their co-operation, a recommendation was presented and discussed with the steering committee members to change the project approach to achieving the research objectives.

It was then agreed by the steering committee to proceed with a less detailed analysis and data collection exercise but for all major geological gold mining regions i.e. Far West Rand; Eastern Basin; Central Rand Basin; West Rand Basin; KOSH area; Free State; Evander; Barberton and Pilgrims Rest. Findings would assist in identifying differences in specific mining regions e.g. dolomitic mine areas and put forward a proposal outlying a regional approach to underground closure management.

1.4.6 Develop a proposed closure planning procedure for gold mines

The primary factor that was considered in the development of a closure planning procedure was the recognition that there were critical regional hydrological interconnections between mines that required the development of a strategy that incorporated the concept of regional mine closure planning. The research programme also provided the data to enable the delineation of the different regions and to identify probable critical differences between regions with regard to their post-closure water impacts. A logic decision tree was developed to guide the closure planning activities.

1.4.6.1 Collect required information from study area mines

Follow up discussions were held with the DME regional offices in August –September 2002 to collect further data on interconnections between the mines and reports regarding gold mine groundwater management strategies or groundwater flow studies. Several specialist reports were also collected and studied to assist in our analysis.

Letters were also sent to all the gold mines describing the project and requesting information related to:

- Geological maps of their mining area
- Any groundwater study reports
- Information on the nature of interconnections between adjacent mines
- How would closure of each mine affect surrounding mines?
- How would closure of surrounding mines affect each mine?
- Current water levels
- Information on pumping volumes from underground

Several mines responded to initial letters and where information gaps were identified, this was followed up by telephone conversations or meetings with relevant mine personnel. In certain instances, section 2 and 4 of the EMPRs were also reviewed to determine the nature of connections between mines, pumping details, sinkhole potential, and the hydro-geological environment

1.4.6.2 Produce draft underground closure planning procedure report

Based on an interpretation of the information collected and GIS developed in Task 2 and 3, together with existing prior knowledge of the underground geochemistry, an underground gold mine closure plan was developed for discussion with stakeholders. A stakeholder workshop was held with mining industry and government representatives where the proposed procedures were presented and discussed and recommended changes have been incorporated into the procedures. Based on recommendations made at this stakeholder workshop, a formal submission was made through the WRC to the DME as input to the draft Minerals and Petroleum Resources Development Bill.

1.4.7 Technical committee

Individual discussions with various specialists, regulators and mining personnel have been conducted during the course of the project.

2. BACKGROUND AND LITERATURE REVIEW

2.1 MINE CLOSURE WATER MANAGEMENT PLANS

Most of the South African gold mining regions are faced with serious current and long-term water pollution risks, both from the above ground residue deposits and underground mine workings. Mine water management problems exist both in terms of water quality and quantity. In terms of quality, gold mining has been associated with the contamination of water by heavy metals, pH, salts and toxins. Furthermore, the volumes of water used in the operation of gold mines are also substantial (Pulles, 1992).

The relative impacts on our water resources depend inter alia on the number of mines operating in close proximity in the same region. The impact can be significant and cumulative if the parameters such as geology and hydrogeology are interrelated with interflow between and amongst the mines. Moreover, underground mines that occur in different mining regions may have different levels of impacts on the water resources because of differences in the geological characteristics, for example the Karoo aquifers may have a less significant impact than the aquifers that occur in a dolomite area. The key difference between the major gold mining regions is controlled by the technical factors such as hydrology, mineralogy, geochemistry and geohydrology in a particular area where mining is being undertaken.

Primary water management issues for underground gold mine closure therefore include long term decant risk, acid mine drainage, water pumping and treatment, and allocation of responsibility. Conceptually, the system can be depicted as a complex interaction between different components. These components comprise of hydrochemical pollution sources (such as waste rock dumps, evaporation dams and slimes dams) and hydrological / hydrogeological transport routes (such as surface runoff, primary aquifers, dolomitic aquifers, fractured rock aquifers, and geological features such as faults and dykes, interconnections between mines). The challenge is to develop appropriate and comprehensive mine closure systems and procedures.

2.2 MINE CLOSURE POLICY

Legislation in South Africa governing mining has been in existence for many years. The new Minerals and Petroleum Resources Development Act, 2002 (Act No 28 of 2002) has also just been released. One important consideration is that any decisions on closure requirements and whether proper closure has taken place is done co-operatively within government e.g. by an inter-governmental institution including representatives of government/state departments who have the responsibility for the protection of the environment, water, soil etc, and social issues. In a recent review of mine closure policy (MMSD, 2002), it was noted that many mine closures have been arrested due to the inability of mines to provide adequate levels of assurance to government departments (specifically DWAF) that operational risks have been adequately managed, and that possible residual risks have been identified, quantified and sufficient financial provision and or technical measures are in place to manage them, should they manifest. It is important to remember that liability on mine closure is transferred to the State. In many instances government and State have inherited and have been burdened with poor legacies from old abandoned mines.

2.2.1 South African legislation

The Department of Minerals and Energy (DME) and Department of Water Affairs and Forestry (DWAF) have placed certain requirements on mines before a closure certificate is granted. The main requirement is the EMP, which is compulsory for any mine. EMP's are compiled in accordance with the requirements of the *Aide-Mémoire* for the Preparation of Environmental Management Programme Reports for Prospecting and Mining which provides for the decommissioning and closure of a mine in Section 5 and Section 6 respectively. The DME is the lead agent in terms of issues concerning the granting of a closure certificate but interested and affected parties (including other governmental departments) are also involved in the approval of the EMP and mine closure process (Section 39, Minerals Act 1991).

A mine can be considered closed once a certificate as contemplated in section 12 of the Minerals Act 1991, has been issued by the Regional Director concerned. A certificate is issued if the results of the final assessment indicate that all the provisions of the Act have been complied with and that all closure objectives stipulated in the EMP or closure plan have been met. If residual impacts have been identified, these must also be described in the EMP or closure plan.

The Regional Director, after consultation with the relevant government departments and the mine, shall seek to have negotiated and finalised, adequate and irrefutable arrangements in terms of which the State and the mine are satisfied that these impacts will be adequately dealt with, before a certificate is issued. This may include the need for a mine to make financial provision for the financing of post-closure environmental management or maintenance. A competent third party, which could include the State, could assume responsibility for such management or maintenance and utilise the available funds for this purpose.

All arrangements made and agreements reached between the mine and the State to adequately deal with such post-closure maintenance and/or the management of residual impacts shall be incorporated into an amendment to the EMP or closure plan.

Disputes are to be resolved in terms of section 57 of the Minerals Act, 1991.

2.2.2 Mine closure legislation

Environmental legislation and regulations incorporate both resource directed and source directed measures. Resource directed regulation aims to protect and manage the receiving environment. Examples of resource directed actions are the formulation of resource quality objectives and the development of associated strategies to ensure ongoing attainment of these objectives; catchment management plans and the establishment of catchment management agencies (CMAs) to implement these plans.

Source directed regulation aims to control the pollution at source through the identification and implementation of pollution prevention, water reuse and water treatment strategies. The water management policy for mining is source directed.

2.2.2.1 Legal provisions applicable to mine closure

The most important legislation, which have direct and important bearing on the environmental effects of mining, are the National Environmental Management Act of 1998 (NEMA,), Environment Conservation Act of 1994, the Minerals Act of 1991, the Minerals and Petroleum Resources Development Act of 2002 and the National Water Act of 1998.

All this legislation draws attention to sustainability principles and "Integrated Environmental Management" (IEM). They require the mining industry to have a detailed understanding of the effects of mining on the environment and to apply adequate environmental protection measures.

Mines have to comply with the South African constitutional and common law by conducting their operational and closure activities with due diligence and care for the rights of others. Everyone has the right to an environment, which is not harmful to his or her health and well being (Section 24(a); Constitution 1996). For example, a person suffering harm as a result of mining activities may still claim damages from the mine and its directors once the mine has closed.

All mines abandoned before 1956 are considered to be the responsibility of government or state and those mines belonging to the companies, which have been liquidated before 1976, are the responsibility of the state. In the case of those mining companies liquidated after 1976, the responsibility is on the respective owners who should apply for the closure certificate in terms of the Mineral Act 50 of 1991. During the last ten years the government has turned down many applications for closure. The biggest concern was possible uncontrolled pollution of water resources in the vicinity of the mines after they have re-watered the mine cavities.

2.2.2.2 The Constitution of South Africa Act of 1996 (Bill of Rights)

This Act focuses mainly on the Bill of Rights. The salient feature of the Bill of Rights that has an implication on the mining industry includes the following:

- Third party to access to information
- The individuals right to have an environment which is good to his or her health and well being
- The directors of those mines may be held criminally liable
- Limitation clause, which may assist a mine in justifying the infringement of rights under certain circumstances (Wendel, 1991)

2.2.2.3 National Environmental Management Act, Act 107 of 1998 (NEMA)

This Act focuses mainly on the issue of Integrated Environmental Management (IEM), wherein all the government spheres and all organs of the state have to co-operate, consult and support one another for the purpose of <u>sustainable development</u> and use of natural resources while promoting justifiable economic and social developments.

2.2.2.4 Environmental Conservation Act, Act 73 of 1989

This Act requires that land use and development be undertaken in an environmentally sustainable manner. It also focuses on the activities that are directed at or likely to affect the environment. The regulations also cover the clean up liability, where if any mining activity causes the environment to be seriously damaged, endangered or detrimentally affected, the mine can be ordered to halt such activity. The task of rehabilitating the damaged environment can be given to the mine concerned. The department may claim from the mine, all such expenditure incurred in carrying out any clean up tasks on behalf of the mine.

2.2.2.5 Common law

This law concerns not only the rights of third parties (employees), but also that of the environment. Closure plans and activities must be conducted with the necessary care that is expected from the reasonably prudent miner (Wendel, 1991).

2.2.2.6 Minerals Act, Act 50 of 1991 and regulations

Section 39 of the Minerals Act 50 of 1991 requires mines to submit an EMP that looks at the environment before the operation, and addresses environmental impacts during the operation, closure and post-closure phases. Compliance with the EMP will result in a closure certificate in terms of Section 12 of the Mineral Act. Mines are however, not likely to be absolved of environmental impact management responsibilities at closure. The current DME Policy also requires the responsibility for environmental management post-closure be defined in the closure agreement.

The existence of the residual impacts described in the EMP should be confirmed and other possible residual impacts must be identified. The agreement must be reached between the mine and regional director on mechanisms to deal with the long-term residual impacts of mining on the environment.

Furthermore, the placing of a prescriptive financial provision requirement on the mining industry is a regulatory option, which is used too manage exposure to the environmental risk, associated with mine operation and closure. This financial provision is therefore a process in which the holder of a mining authorisation demonstrates its ability to meet its obligations pertaining to the execution of its EMP (refer to Section 2.2.3 for details regarding DME closure policy).

2.2.2.7 Minerals and Petroleum Resources Development Act, Act 28 of 2002

Section 39 of the Mineral and Petroleum Resources Development Act (MPRDA) also requires mines to conduct environmental impact assessments and to submit an environmental management programme to the DME for approval. In developing the environmental management programme or plan (EMP), the mine must : establish baseline information for the site; undertake an impact assessment with regard to the environment, socio-economic factors and national heritage resources; develop an environmental awareness plan for the employees; and describe and present appropriate management actions to manage negative impacts. The DME remains the lead agent for the EMP but must take into consideration comments from any other State department charged with the administration of any environmental laws.

Before the DME is permitted to approve an EMP, the mine in question must make the prescribed financial provision for the rehabilitation or management of negative environmental impacts and this provision must be reviewed and updated annually. This need to maintain a financial provision remains until the DME issues a closure certificate in terms of Section 43 of the MPRDA, whereafter the DME may still retain such portion of the financial provision as is required to rehabilitate the closed mining operation in respect of latent or residual environmental impacts.

A mine closure certificate can be issued in terms of Section 43 of the MPRDA and provision is made to transfer liability and responsibility for residual environmental impacts to an approved third party. A mine is obliged to apply for a closure certificate within 180 days of ceasing mining operations and this application must be accompanied by an environmental risk report. An important point in the MPRDA is contained in Section 43(5) which stipulates that “no closure certificate may be issued unless the Chief Inspector and the Department of Water Affairs and Forestry have confirmed in writing that the provisions pertaining to health and safety and management of potential pollution to water resources have been addressed.” While the approval of an EMP simply requires the DME to consult with DWAF, the DME is expressly prohibited from approving a closure certificate without the written approval of DWAF.

2.2.2.8 National Water Act, Act 36 of 1998

The purpose of the National Water Act of 1998 is to ensure that the nation’s water resources are protected, used, developed, conserved, managed and controlled in ways that take into account, amongst other factors:

- meeting the basic human needs of present and future generations,
- promoting equitable access to water,
- facilitating social and economic development,
- protecting aquatic and associated ecosystems and their biological diversity,
- reducing and preventing pollution and degradation of water resources
- meeting international obligations, and
- promoting dam safety and managing floods and droughts.

The mining sector management strategy of DWAF has been developed at a number of different levels as follows:

1. A detailed <u>Management Plan</u> (M3: Policy and strategy for management of water quality regarding the mining industry in the RSA), that sets out strategic objectives, broad strategies and functional and organizational arrangements.

2. <u>Operational Guidelines</u>, that define and document specific operational procedures (six Guidelines have been completed to date).

3. <u>Technical Guidelines</u>, that define and document best practices for pollution prevention and impact minimization from mining operations.

The Technical Guidelines consist of *Best Practice Guidelines* (BPGs) and *Regulations*. Regulations dealing with mining operations were published in Government Notice No. 704 on 4 June 1999.

Refer to Section 2.2.4 for details regarding DWAF’s groundwater quality management policy.

2.2.2.9 National Nuclear Regulator Act, Act 47 of 1999

The South African gold mines are associated with radioactive elements such as uranium and its decay products due to chemical leachates or oxidation of pyrites. Uranium is soluble in water and when dissolved in water at high concentrations, becomes tenacious and highly toxic. In terms of mine closure, radiological requirements may also have to be met before a closure certificate is issued.

2.2.3 DME mine closure regulations

Draft regulations in terms of the MPRDA have been issued by the DME for comment in Government Notice 1520 on 6 December 2002. These regulations give practical effect to the provisions of the MPRDA and a number of these draft regulations have a direct bearing on the subject matter of this research report.

Firstly, section 33 of the MPRDA regulations require that mines must determine the cumulative environmental impacts in a number of cases, including where there are a number of mines in the same geographic area; where other activities have similar environmental impacts on the specific resource. Section 33(2) also states that the selection of geographic boundaries and time periods for consideration of such cumulative impacts, should, wherever possible, be based on the natural boundaries of the resources of concern. This requirement is completely consistent with the principles of regional closure strategies, based on geohydrological and hydrological connections as recommended in this research report.

Section 42 of the MPRDA regulations set out general requirements for mine closure, which require that the holder of a mining permit must ensure that:

- the closure of a mining operation incorporates a process that starts at commencement of the operation and continues throughout the mine life cycle;
- risks to the environment must be quantified and managed proactively;
- safety and health of humans and animals must be safeguarded;
- environmental damage and residual impacts must be minimised to the satisfaction of all interested and affected parties;
- the land must be rehabilitated as far as is practicable to it's natural state or to a predetermined and agreed standard or land use;
- the optimal exploitation and utilization of mineral resources are not adversely affected; and
- operations are closed efficiently and cost-effectively

The application for a closure certificate must be accompanied by a closure plan and the final environmental management programme performance assessment. The closure plan itself forms part of the EMP and must include:

- a description of the closure objectives and how these relate to the operation and its environmental and social setting;
- a summary of the regulatory requirements and conditions for closure negotiated and documented in the EMP;
- a summary of the results of the environmental risk report and details of identified residual and latent impacts;
- a summary of the results of any progressive rehabilitation undertaken;

- a description of the decommissioning methods for each mining component and the mitigation or management strategy proposed to avoid, minimise and manage residual or latent impacts;
- details of any long-term management or maintenance expected;
- details of financial provisions for monitoring, maintenance and post-closure management;
- an appropriate scale plan describing final land use proposal and site arrangements; a record of interested and affected parties consulted; and
- technical appendices if any.

The closure objectives referred to above must be incorporated into the EMP and must identify the key objectives for mine closure; must provide broad future land use objectives; and provide proposed closure costs.

The environmental risk report referred to above is a document that describes a risk assessment process essentially identical to that described in Chapter 5 of this research report. Details on this environmental risk report are given in Section 46 of the draft MPRDA regulations.

2.2.4 DWAF groundwater management policy

In the year 2000, DWAF published their policy and strategy for groundwater quality management. The logical unit for groundwater quality management is an aquifer. Since aquifers are, in general, contained within a surface water catchment, and since the surface water catchment represents the most logical surface management unit, the Department has adopted the catchment as the basic groundwater management unit. Catchments may, however, be subdivided into groundwater management areas for better resolution where appropriate. Inter-catchment influences and interactions will be managed by exception. This will specifically apply to aquifers, which transcend catchment boundaries.

Groundwater quality management cannot be carried out without intimate knowledge of the nature, extent, potential yield and vulnerability of the resource. The relationship between groundwater and surface water must also be understood in order to facilitate effective management.

Some key aspects of this policy document are discussed below.

2.2.4.1 Differentiated approach

In South Africa’s situation of widespread and highly localised groundwater occurrence and use, it will be physically and economically impossible to protect all groundwater resources to the same degree. It is also important to note that South Africa’s water policy does not aim to prevent impacts to the water environment at all costs since this would not allow the country to achieve much-needed social and economic growth. For effective and focused intervention, a differentiated protection approach is necessary, based on the vulnerability - and regional, as well as local importance - of aquifers.

Each aquifer will be assigned a management class on the basis of the importance of that aquifer. The importance accorded will be based on the potential yield as well as the level to which communities depend on the aquifer (see Table 2.1). Aquifers, which represent the sole source of water for communities, will be afforded special status irrespective of their potential yield and will enjoy the highest level of protection.

Table 2.1: Classes that will be differentiated for groundwater quality management

Aquifer Type	Description
Sole-source aquifer	An aquifer used to supply 50% or more of urban domestic water for a given area and for which there are no reasonably available alternative sources of water.
Major aquifer	A high-yield aquifer system of good quality water.
Minor aquifer	A moderate-yield aquifer system of variable water quality.
Poor aquifer	A low- to negligible-yield aquifer system of moderate to poor water quality.
Special aquifer	An aquifer system designated as such by the Minister of Water Affairs and Forestry, after due process.

The essence of groundwater quality management is to be able to choose and deploy those source controls or remediation measures that would be most effective in protecting the resource. Aquifer management strategies will be required only for large and continuous aquifers. Localised and poorly defined aquifers will generally be taken care of as part of a catchment management strategy.

2.2.4.2 Groundwater abstraction and dewatering

DWAF assumes responsibility in terms of the National Water Act of 1998 for the control of abstraction of groundwater in order to prevent:

- depletion or damage to the reserve;
- temporary or permanent loss of the use of aquifers through over-abstraction or unnecessary dewatering;
- loss of surface water base flow or damage to wetlands and riverine environments which depend on groundwater;
- deterioration of groundwater quality; and
- intrusion of saline or contaminated groundwater into otherwise uncontaminated aquifers.

The Department will intervene directly to control abstraction and dewatering where appropriate. The utilisation of groundwater for private domestic consumption and animal-watering purposes will, however, not specifically be controlled unless community interests are at stake. Abstraction control for the purposes of water quality management will also be also integrated with the resource management regulatory controls.

2.2.4.3 Disturbance of aquifers by mining and related activities

DWAF recognises that a variety of activities may impact adversely on aquifers or otherwise disturb them. The most significant activities that could disturb groundwater are:

- opencast mining and quarrying;
- underground mining;
- land drainage; and
- mine de-watering.

The Department recognises that disturbance and impact are an inevitable consequence of mining activities. It will, however, be subject to the approval of an EMP, or the granting of a temporary authorisation to commence with mining prior to the approval of an EMP in terms of the Minerals Act, under the following circumstances:

- reduction in, or the total loss of, a groundwater resource which constitutes part of the reserve and sustains surface water base flow or environmental features such as wetlands and sensitive riverine ecology;
- reduction in, or total loss or contamination of, groundwater which is or could be exploited on adjoining properties to sustain land use which is consistent with the land capability; and
- permanent reduction or loss of groundwater on the mine property that will preclude the remediation of groundwater supplies to sustain the post-mining land use.

The Department will adopt a precautionary approach in its evaluation of applications for authorisations. The proponent will be required to ascertain the extent of the impact, which will be associated with the mine and will implement appropriate mitigatory measures where necessary. The Department will permit the impact only if this and other required conditions have been met. The measures required to protect the groundwater resource will depend on the importance and vulnerability of the resource being threatened.

2.2.4.4 Damage to aquifers by waste disposal and related activities

DWAF will follow a differentiated approach to the control of waste and wastewater disposal activities. Activities which will receive specific attention include: - mining and industrial residue disposal (waste deposits); irrigation with wastewater, evaporation and storage of mining and industrial effluent and sludges and stockpiles of potentially polluting substances.

The Department will not issue licences in terms of Section 20 of the Environment Conservation Act unless land has been zoned for waste disposal. For the purposes of licensing of waste disposal sites the Department will base its regulatory response upon the importance and vulnerability of the aquifer which is threatened by waste disposal activities i.e.

- ***Major aquifers and vulnerable sole-source aquifers****:*
  The Department will place a general ban on waste disposal and other polluting activities within 200 metres of the recharge zone for major aquifers and sole-source aquifers.

- ***Minor aquifers*****:**
  The Department will generally not object to licensing or authorisation of waste disposal within the recharge zone of minor aquifers provided that adequate pollution control measures will be implemented. Such measures as may be necessary for the most commonly practised waste disposal methods may be published by the Department in the form of Best Practice guidelines from time to time or may be published in regulations.

- ***Poor aquifers*****:**
  The Department will not normally object to waste disposal activities on areas that are underlain by poor aquifers. Minimum standards of Best Practice will nevertheless be a pre-requisite in these cases.

2.3 MINE WATER MANAGEMENT

Authors like Strongman (2000) state that a generally accepted guiding principle is avoiding mining and waste disposal methods that will have impacts on water quality for generations to come e.g. acid mine drainage, toxic material release, riverine disposal of mine wastes.

In South Africa the National Water Act (Act 36 of 1998), is enabling legislation that contains wide provisions particularly related to responsibility for the integrity of water resources. The basis of water management at mines is the DWAF mine water management hierarchy. This hierarchy is based on a precautionary approach and sets the following order of priority for mine water management actions (BPG 1.1, DWAF):

Pollution prevention

Water reuse / reclamation

Water Treatment

Discharge

This hierarchy is valid whether the mine is preparing an EMPR, water licence, is undertaking closure planning or is motivating for an exemption from Regulation GN704.

2.3.1 Pollution prevention

In terms of the precautionary approach, it is required that all mines must be able to demonstrate that all reasonable measures have been taken to prevent clean water from becoming polluted. The fundamental principle is to prevent, inhibit, retard or stop the hydrological, chemical, microbiological, radioactive or thermodynamic processes, which result in the contamination of the water environment, at the point where the deterioration in water quality originates, or to implement physical measures to prevent or retard the transport of the generated contaminants to the water resource. This principle can be applied in many different ways, with the following examples illustrating but a few for underground gold mines:

1. Apply water management measures e.g. seals; water diversion away from “hotspots” within the underground operations that are aimed at minimising the potential for water quality deterioration due to the oxidation of sulphide minerals.
2. Locate waste residue deposits in areas where there is a minimum potential for contamination of the ground and surface water resource and construct water management facilities to intercept and contain any contaminated runoff and/or seepage.
3. Apply appropriate geochemical assessment techniques to the design of mine closure strategies for underground mines in order to identify those options that will minimise the long-term pollution risks of such facilities.

The common thread throughout the pollution prevention options is to prevent or minimise pollution through the application of appropriate assessment techniques, the application of appropriate design and the ongoing and effective management and re-evaluation of the installed pollution prevention measures. This project assesses and describes appropriate procedures for closure planning for underground gold mines.

2.3.2 Water and salt balances

Underground gold mine water management problems exist both in terms of water quality and quantity. In terms of quality, gold mining has been associated with the contamination of water by heavy metals, acidity, salts and radio nuclides. Furthermore, the volumes of water used in the operation of gold mines are also substantial (Pulles, 1992). Water quantity in some gold mines is due to the inflow of fissure water into mine workings. Fissure water problems are particularly high in areas situated in dolomitic areas that dissolve and form karst aquifers.

2.3.3 Integrated mine water management

In order to successfully implement integrated mine water management in a manner that complies with the source and resource directed measures required by the relevant legislation, certain essential principles must be adhered to, as listed below (DWAF, BPG 1.1).

- *Compliance with the water management hierarchy.*
- *Compliance with all legislation***.**
- *Life-cycle approach***.** This means that a holistic view should be taken over the life cycle of a mine and that integrated mine water management must address all these phases from feasibility studies and authorisation through mine construction, mine operations, mine decommissioning and closure and the long term residual and latent water impacts after mine closure.
- *Cradle to grave principle***.** The mine must retain responsibility for all its waste streams and their consequential impacts.
- *Precautionary principle***.** Integrated mine water management must be conservative and must use appropriate and accepted techniques to anticipate all potential impacts.
- *Consideration of temporal variability of water quality and quantity***.** Integrated mine water management must make use of accepted techniques that are capable of qualitatively and quantitatively defining water quality and quantity variations and their impact on surface and ground water systems, currently and in the future.
- *Risk-based approach***.** The mine should apply appropriate risk assessment techniques to quantify the potential current and long-term risks associated with its practices or activities and then apply appropriate management actions to minimise or mitigate the potentially significant risks.

Integrated mine water management plans and actions must clearly demonstrate that they have incorporated **all** of the above principles or, alternatively, must clearly motivate why any of the above principles are not relevant

2.3.4 Water pollution in gold mining

The typical underground sources of water contamination are pyrite oxidation, inadequate underground settling, fissure water, waste explosive and faecal contamination. The understanding of geology, hydrogeology and chemistry of the underground mine environment is important, since these parameters determine the water pollution potential from underlying geological formations, reaction rates and flow of contaminants within the aquifer. Moreover, if the area comprises rocks with high porosity, the mine area will be subjected to fissure water ingress and this can increase the volume of water and contaminant load from the mine.

Leaching of the old mine rock dumps, slimes dams and other waste materials in the mine will also contribute to the increase of both surface water and groundwater contaminants. The waste material infiltrates during the period of groundwater recharge. Underground water that has become polluted and is pumped to the surface, may also negatively impact on surface water quality.

2.3.4.1 Pyrite oxidation

South African gold mines are classified as Category A mines due to the fact that they have sulphide minerals in their orebodies and or waste deposits, most commonly pyrite (FeS_2). Sulphide minerals are inherently geochemically unstable and will, in the presence of oxygen, spontaneously begin to oxidize. Pyrite oxidation can therefore be a significant problem in gold mines that leads to the deterioration of both surface and groundwater resources. The oxidation of pyrite produces the following water contaminants:

- High acidity and low pH
- Very high sulphates
- High dissolved metals and radionuclides

All gold mines should therefore be considered as posing a potential long-term risk with regard to water quality, which requires assessment using appropriate techniques and tools.

A positive correlation exists between gold grade and the modal proportion of potentially acid producing sulphide minerals. Furthermore, gold grade correlates positively with the reef thickness. Thus by making use of isopach maps showing the distribution of reef thickness, meaningful delineation of areas with a high acid producing potential may be possible.

2.3.4.2 Physical Impacts

The following may occur in underground gold mines: surface subsidence and seismic disturbance.

Surface subsidence

Surface subsidence is related to the geology of the area, particularly where the area is characterised by dolomites, fracture zones, faulting and dykes. In dolomitic [$CaMg_2(CO_3)$] areas the recharging water tends to dissolve the rock and subsidence is likely to occur. Dolomites are also associated with karst topography and considered to be a good aquifer.

Seismicity

Most of the South African deep gold mines are associated with seismic disturbances, which can lead to surface subsidence. The change in temperature with depth (geothermal gradient) also poses a problem in these mines. Temperature variations can range between 10^0C/km and 22^0C/km.

2.4 INTERNATIONAL PERSPECTIVE

Discharges of contaminated groundwater from abandoned deep mines are a major environmental problem in many parts of the world. Canadian, American and Australian mining law now all require some form of acceptable "closure plan" prepared by the proponent before commencement of mining operations. The intent of the above is to ensure that upon closure of a mine there is no threat to the environment or the public. The closure plan should also address rehabilitation and future use of the land. Acceptance of the closure plan does not affect requirements under other statutes. For example, a proponent must meet the statutory requirements of many laws.

Mackasey (2002) from Mining Watch in Canada states that the closure plan is in reality an opening plan, as it requires a comprehensive and technical public review of the proposed mining activities before production can start. The proponent must report on the current state and use of the land before a mine is developed. The review of the closure plan could also, for example, bring out concern for acid mine drainage and threats to underground water. Having a single set of rules and regulations for mine development for use throughout the country would be very difficult, because each site has its own characteristics and setting. A number of factors need to be taken into consideration, including - type of minerals; geology; size; geometry of the mineral deposits; rock strength and structural features; value of mineral deposits; amount and type of waste products produced; value of surface and civic structures; and other related features.

Skousen (2000) in his article for “Green lands Magazine” highlights the problems associated with acid mine drainage (AMD) in older underground mines and discusses water management techniques for acid drainage control. He notes that AMD problems can be aggravated by inadequate barrier pillars between mines, inadequate outcrop barriers, and hydraulic interconnection of adjacent mine complexes. Water management techniques for controlling AMD include water diversion, soil covers and plastic liners, dewatering, inundation, underground mine sealing, barriers, grout curtains and walls, and underground mine filling by injection. Each method is however suited for specific situations and good success can be realized when adequate planning, design, and construction are practiced. Water diversion is one of the easiest and cheapest methods for reducing the amount of water in contact with acid-producing materials. Special care and planning is also essential in designing and constructing mine seals and when using grouting techniques for underground mine filling or barrier construction.

In the United Kingdom, Younger (2000) notes that while process-based models of pollutant generation have been successfully developed for certain surface mines and waste rock piles of relatively simple geometry and limited to a real extent, such models are not readily applicable to large systems of laterally extensive, interconnected, abandoned deep mines. He suggests that as a first approximation for such systems, hydrological and lithological factors, which can reasonably be expected to influence pollutant release, should be assessed. Other considerations may include

- Hydrogeological consequences of closure of area and conception of water drainage from area
- Updating dewatering conception
- Flow direction change of underground waters together with hydrogeological analysis of mine workings under liquidation

- Dynamics and directions of changes of underground water quality in areas of closed mines
- Principles of maintenance of existing and construction of new water intakes in closed underground mines
- Testing and analysis of hydrogeological conditions as regards determination of areas (troughs) of formation of natural underground water reservoirs in consequence of mine closure

Tepper *et al* (1995) reported that a regional groundwater management initiative was developed in response to the formation of collapse features of the Retsof Salt mine in New York. Hydraulic connections were formed between aquifers and the mines that had been previously isolated from each other by confining units. These new connections provided routes for rapid migration of groundwater downward to the mine level. This aquifer drainage had caused inadequate water supplies in a number of local wells and some wells have actually gone dry. A **regional groundwater monitoring network** was established to observe rate, magnitude and extent of aquifer drainage relate to mine collapse.

In the description of the history of the Bending Gold fields of Australia it was reported that some mines closed prematurely when neighbouring interconnected mines stopped dewatering forcing the remaining operations to cope with unmanageable inflow rates. It is also noted here, that even if inflow rates are low, costs associated with pumping or bailing water were a major factor in profitability.

The management of groundwater of interconnected mines has also recently been supported by the EPA Research Fund (2001). The project involves the study of a set of mine water discharges associated with abandoned, interconnected underground coal mines in the Uniontown-Connellsville area of Western Pennsylvania. The overall goal for the project is to identify the hydrological and geochemical factors responsible for improvements over time in the quality of water discharges from abandoned deep mines. A related goal is to evaluate the effects of mining methods and abandoned mine management practices on long-term changes in mine water quality.

3. GEOHYDROLOGICAL SITUATION ASSESSMENT

3.1 MAJOR GOLDFIELDS IN SOUTH AFRICA

The gold mines in South Africa are mainly concentrated along the edges of the Witwatersrand Sedimentary Basin. For the purpose of this investigation the gold mines are classified in two major categories, i.e. Witwatersrand and Non-Witwatersrand Gold Mines. The different goldfields are further sub-divided into distinct geohydrological zones based on natural and geological boundaries. The main aim of this investigation was to identify such boundaries and to describe the geohydrology within each geohydrological zone, referred to as mining basins.

We have identified ten major goldfield areas currently mined in South Africa based on their depositional environment and geohydrological boundaries, rather than their provincial boundaries. The reasons being that in terms of long–term groundwater management systems, it is more sensible in some instances to implement this on a regional basis than an individual mine or provincial basis. This is in part due to the inter-connections that exist between the underground gold mines and the inflow of extraneous water into the underground workings. It is also important to note that more than one mine may impact on a certain geohydrological regime and that the mine boundaries will not necessarily coincide with geohydrological boundaries.

The gold mine areas have been divided as follows:

Witwatersrand Basin

- Free State Gold Field
- KOSH(Klerksdorp-Orkney-Stilfontein-Hartebeestfontein) area
- Far West Rand
- West Rand Basin
- Central Rand Basin
- East Rand Basin
- Evander Gold Field

Non-Witwatersrand Basin

- Pilgrims Rest Gold Field
- Barberton Gold Field
- Kwazulu Natal(Klipwal).

Their locations are indicated in Figure 3.1. Table 3.1 lists all the gold mines operating in these ten goldfield areas and their relative provincial and district locations. Figure 3.2 relates these gold mine locations to the water management areas, identified by DWAF, as part of their national water resource management strategy (GN 1160, 1999). The majority of gold mines fall within the Upper Vaal, Middle Vaal and Inkomati catchments.

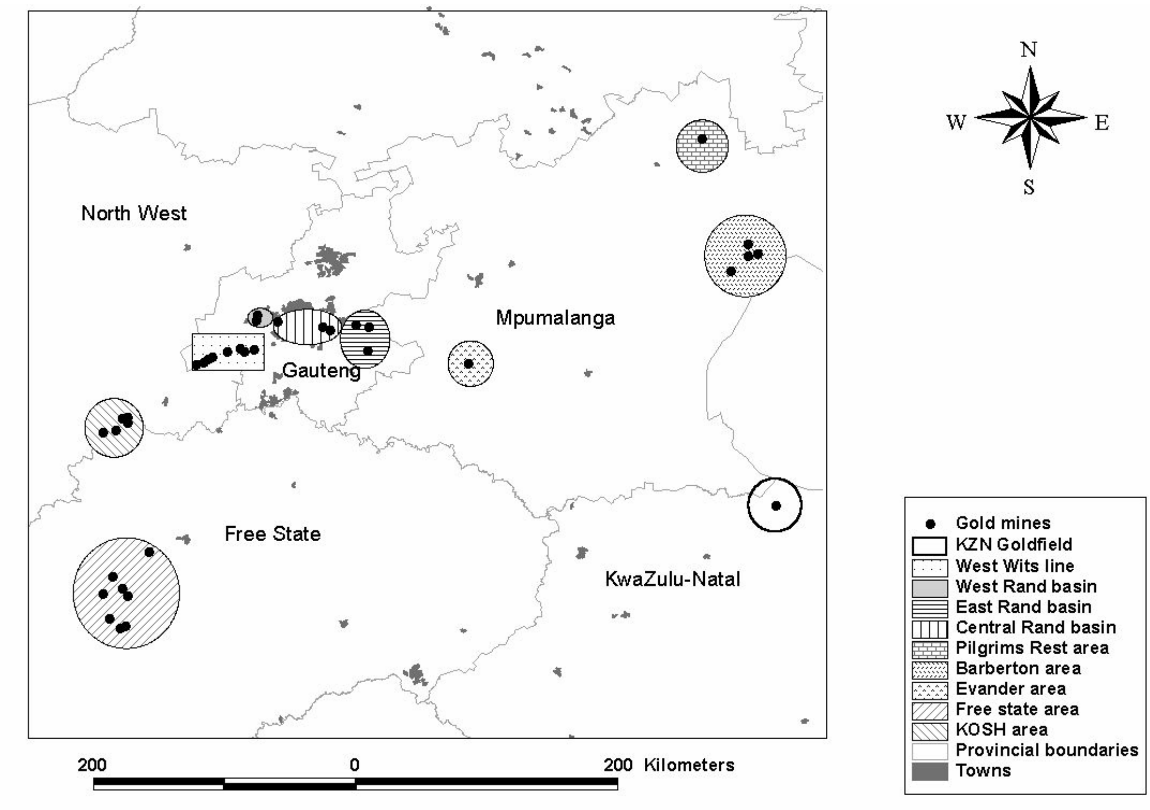


Figure 3.1: Goldfields and gold mines locality plan

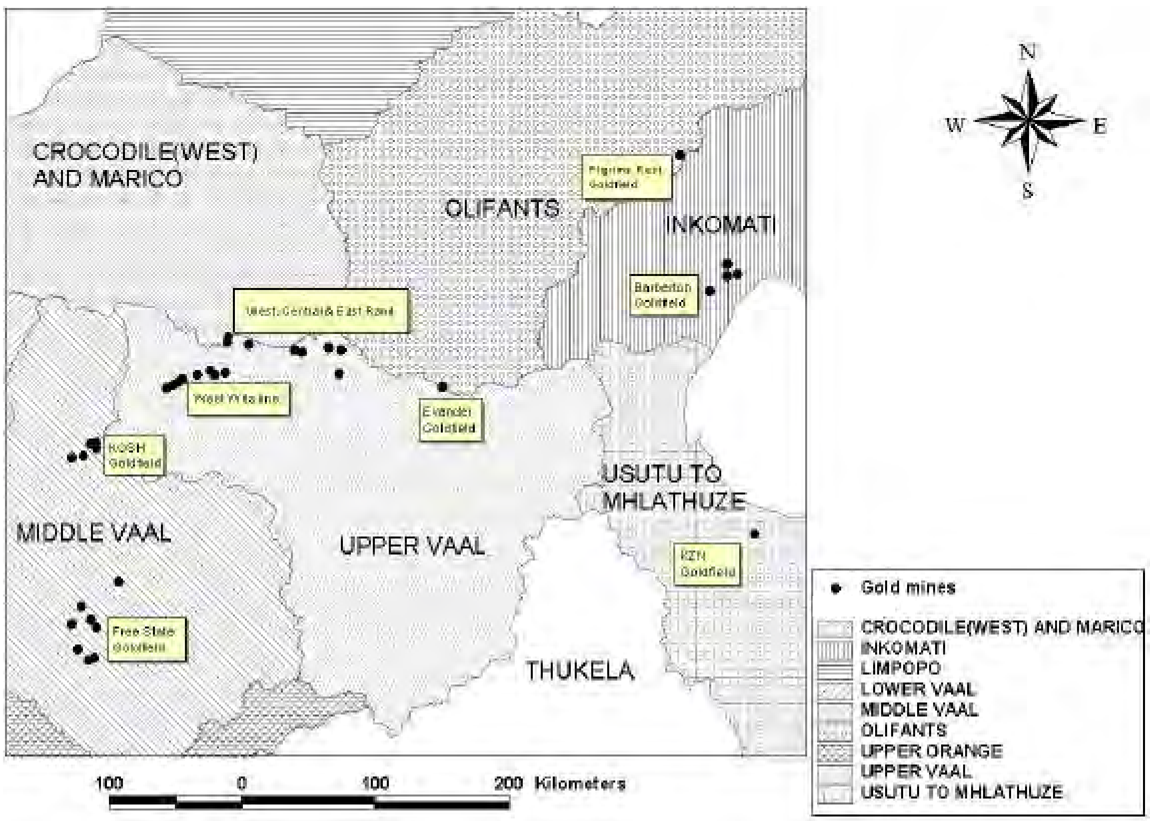


Figure 3.2: Water management areas for the gold mines

Table 3.1: List of gold mines <u>operating</u> in each goldfield area grouped according to province and district (*may change as ownership changes*)

Gold field	Mine	District	Province	Owner
Free State	Freegold Operations (Tshepong, Matjhabeng, Bambanani & Joel)	Welkom	Free State	Joint Venture ARM & Harmony
	Harmony FS Operations (President Brand, old Unisel, old Virginia, old Merriespruit, old Saaiplaas & old Erfdeel)	Ventersburg		HGMC
	Target Division-Loraine Mine	Odendaalsrus		Avgold
	President Steyn Gold Mine (North and South sections)	Welkom		PSGM Ltd
	St Helena Gold Mine	Welkom		Gold Fields Ltd
	Oryx mine	Theunissen		Gold Fields Ltd
	Beatrix Mine	Theunissen		Gold Fields Ltd
	ARM	Welkom		ARM
KOSH	Vaal River Operations	Klerksdorp	North West	Anglogold
	African Rainbow Minerals &Expl. (Pty) Ltd	Klerksdorp		ARM
	Buffelsfontein Section	Klerksdorp		DRD Ltd
	Hartebeesfontein Section	Klerksdorp		DRD Ltd
	Stilfontein	Stilfontein		Mine Waste Solutions
Far West Rand	Deelkraal Gold Mine	Potchefstroom	North West	Harmony Gold
	Elandsrand Gold Mine	Potchefstroom		Harmony Gold
	West Wits Operations-Western Deep Level	Oberholzer	Gauteng	Anglogold
	Driefontein Consolidated (East &West)	Oberholzer		Gold Fields Ltd
	Blyvooruitzicht Section	Oberholzer		DRD Ltd
	Kloof Gold Mine (Venterspost)	Westonaria		Gold Fields Ltd
	Leeudoorn Mine	Westonaria		Gold Fields Ltd
	Western Areas (South Deep & Randfontein Estates)	Westonaria		Placer Dome WAJV
	Libanon Gold Mine	Westonaria		Gold Fields Ltd
West Rand Basin	Randfontein operations	Randfontein	Gauteng	Harmony Gold Mining Co.
	West Witwatersrand GM Co Ltd	Krugersdorp		DRD Ltd
Central Basin	Durban Roodepoort Deep Ltd	Roodepoort	Gauteng	DRD Ltd
	Enderbrooke-ERPM	Boksburg		Enderbrooke Investments (Pty)
	Gravelotte Mines Ltd	Benoni		Salene Mining (Pty) Ltd
East Rand Basin	Grootvlei Proprietary Mines Ltd	Springs	Gauteng	Petra Mining Ltd
	Consolidated Modderfontein Mines 1979 Ltd	Benoni		Petra Mining Ltd
	Nigel Gold mining Co-ltd	Nigel		Petra Mining Ltd
Barberton	New Consort Gold Mine	Barberton	Mpumalanga	Avgold
	Fairview Gold Mine			Avgold
	Sheba Gold Mine			Avgold
	Agnes Gold Mine			Cluff Mining (SA)Pty Ltd
	Makonjwaan Imperial Mining Co (Lily mine)			Simmer and Jack Mines Ltd
Pilgrims Rest	Tvl Gold Mining Estates Ltd	Pilgrims Rest	Mpumalanga	TGME
Evander	Evander Operations	Highveld Ridge	Mpumalanga	Harmony Gold Mining Co Ltd
KZN	Klipwal Gold-Bosveld Mines Pty Ltd	Simdlangentsha	KZN	Matt Trading (Pty) Ltd

***KZN – KwaZulu Natal**

The operating gold mines were overlain on the general surface lithology, rock type and groundwater yield maps provided by DWAF (2002). These are simplified geological maps based on the 1:250 000 geological maps. The surface lithology for each mine, as read from the simplified maps, is given in Table 3.2. This table shows that all the mines within a group are situated on one surface geological group which strengthens the reasoning to group them together. The only exception is found in the East Rand basin where the Nigel mine is situated on arenaceous rocks and the other mines on calcareous rocks. Figure 3.3 shows the spatial distribution of the different surface lithologies.

Table 3.2: Goldfields and their general surface lithology (DWAF, 2002)

Group	Mine	Surface Lithology
Free State	Freegold Operations (Tshepong, Matjhabeng, Bambanani & Joel)	Predominantly argillaceous rocks
	Harmony FS Operations (President Brand, old Unisel, old Virginia, old Merriespruit, old Saaiplaas & old Erfdeel)	
	Target Division-Loraine Gold Mine	
	President Steyn Gold Mine (N & S sections)	
	St Helena Gold Mine	
	Oryx mine	
	Beatrix Mine	
	ARM	
KOSH	Vaal River Operations	Predominantly calcareous rocks, with the western side predominantly meta-argillaceous
	African Rainbow Minerals &Expl. (Pty) Ltd	
	Buffelsfontein Section	
	Hartebeestfontein Section	
	Stilfontein	
Far West Rand	Deelkraal Gold Mine	Predominantly arenaceous rocks
	Elandsrand Gold Mine	
	West Wits Operations-Western Deep Level	
	Driefontein Consolidated (East &West)	
	Blyvooruitzicht Section	
	Kloof Gold Mine (Venterspost)	
	Leeudoorn Mine	
	Western Areas (South Deep & Randfontein Estates)	
	Libanon Gold Mine	
West Rand Basin	Randfontein operations	Predominantly meta-arenaceous rocks
	West Witwatersrand GM Co Ltd	
Central Basin	Durban Roodepoort Deep Ltd	Predominantly arenaceous rocks
	Enderbrooke-ERPM	Predominantly meta-arenaceous rocks
	Gravelotte Mines Ltd	
East Rand Basin	Grootvlei Proprietary Mines Ltd	Predominantly calcareous rocks
	Consolidated Modderfontein Mines 1979 Ltd	
	Nigel Gold mining Co-ltd	Predominantly arenaceous rocks
Evander	New Consort Gold Mine	Predominantly meta-arenaceous rocks
Pilgrims Rest	Fairview Gold Mine	Predominantly calcareous rocks
Barberton	Sheba Gold Mine	Undifferentiated & various lithologies
	Agnes Gold Mine	
	Makonjwaan Imperial Mining Co (Lily mine)	
	Tvl Gold Mining Estates Ltd	
	Evander Operations	
KZN	Klipwal Gold-Bosveld Mines Pty Ltd	

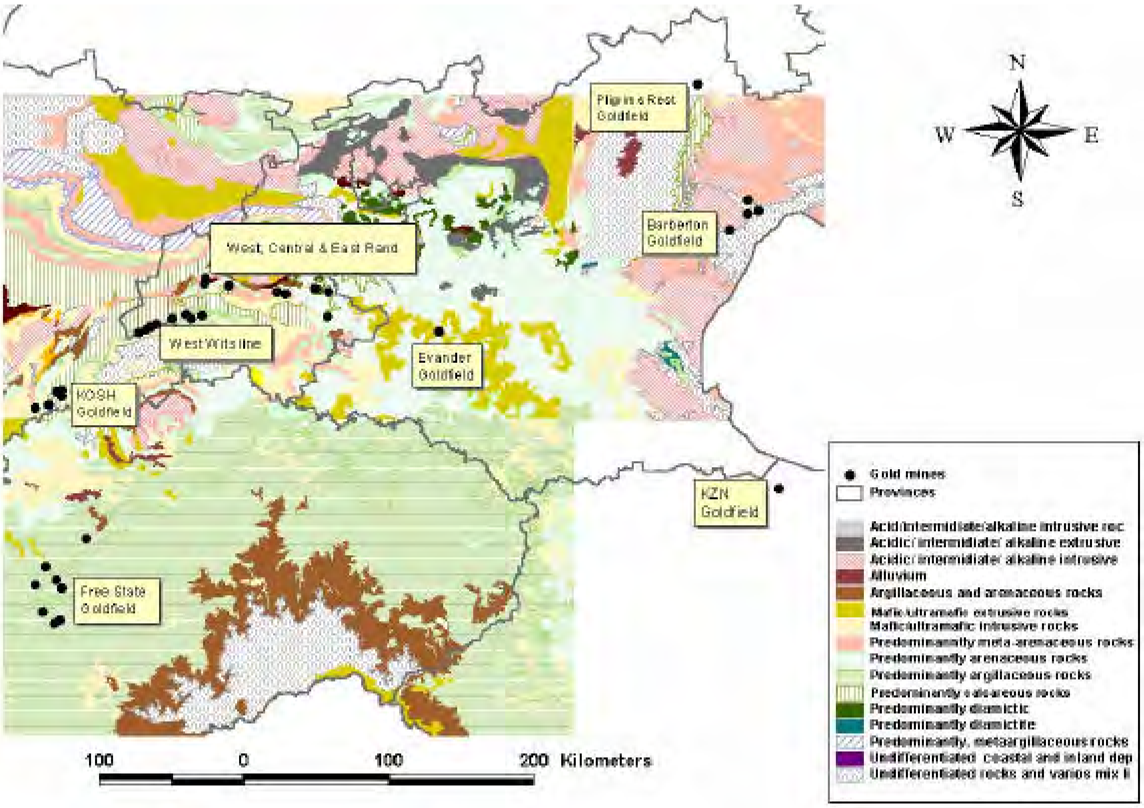


Figure 3.3: Map showing surface lithology for the major goldfields

Table 3.3 contains a list of the aquifer type and groundwater yield for each gold mine, as read from the simplified maps. The maps were created by DWAF (2002) and depict the type of aquifers and their (expected) immediate borehole yields - i.e. governed by transmissivity, but ignoring storage and recharge. The classification by mode of occurrence of groundwater is based on groundwater flow only. The divisions to be used are as follows:

- Intergranular
- Fractured
- Karst; and
- Intergranular and fractured;

Groundwater yields are given in litre/second (l/s). Table 3.3 shows that all the mines within a group are also situated on one aquifer type and have the same yields which further strengthens the reasoning to group them together. Exceptions are found

- in the East Rand basin where the Nigel mine is situated on intergranular and fractured and the other mines on karst aquifers
- in the Free State where Harmony and President Steyn mines have lower yields than the other mines in the area.

Table 3.3 relates to Figures 3.4 and 3.5 that show the regional surface lithology and regional groundwater yield (in l/s). It is clear that high groundwater yields correspond with the dolomitic areas shown in Figure 3.5.

Table 3.3: Goldfields and their general rock type description and groundwater yields (DWAF, 2002)

Gold Field	Mine	Aquifer type	Ground-water Yield (l/s)
Free State	Freegold Operations (Tshepong, Matjhabeng, Bambanani & Joel)	Intergranular and fractured	0.1 - 0.5
	Harmony FS Operations (President Brand, old Unisel, old Virginia, old Merriespruit, old Saaiplaas & old Erfdeel)		
	Target Division-Loraine Gold Mine		0.5-2
	President Steyn Gold Mine (North and South sections)		
	St Helena Gold Mine		
	Oryx mine		
	Beatrix Mine		
	ARM		
KOSH	Vaal River Operations	Karst (dolomitic) and fractured	>5
	African Rainbow Minerals &Expl. (Pty) Ltd		
	Buffelsfontein Section		
	Hartebeestfontein Section		
	Stilfontein		
Far West Rand	Deelkraal Gold Mine	Mines plot on the border between (1) Intergranular and fractured and (2) Karst (dolomitic).	2.0 - 5.0
	Elandsrand Gold Mine		
	West Wits Operations-Western Deep Level		
	Driefontein Consolidated (East &West)		
	Blyvooruitzicht Section		
	Kloof Gold Mine (Venterspost)		
	Leeudoorn Mine		
	Western Areas (South Deep & Randfontein Estates)		
	Libanon Gold Mine		
West Rand Basin	Randfontein operations	Fractured	0.5-2
	West Witwatersrand GM Co Ltd		
Central Basin	Durban Roodepoort Deep Ltd	Fractured	0.5-2
	Enderbrooke-ERPM		
	Gravelotte Mines Ltd		
East Rand Basin	Grootvlei Proprietary Mines Ltd	Karst (dolomitic).	>5
	Consolidated Modderfontein Mines 1979 Ltd		2.0 - 5.0
	Nigel Gold mining Co-ltd	Intergranular and fractured	0.1 – 0.5
Evander	New Consort Gold Mine	Intergranular and fractured	2.0 - 5.0
Pilgrims Rest	Fairview Gold Mine	No data, probably Karst	2.0 - 5.0
Barberton	Sheba gold Mine	Intergranular and fractured	0.5-2
	Agnes gold Mine		
	Makonjwaan Imperial Mining Co (Lily mine)		
	Tvl Gold Mining Estates Ltd		
	Evander Operations		
KZN	Klipwal Gold-Bosveld Mines Pty Ltd	No data	No data

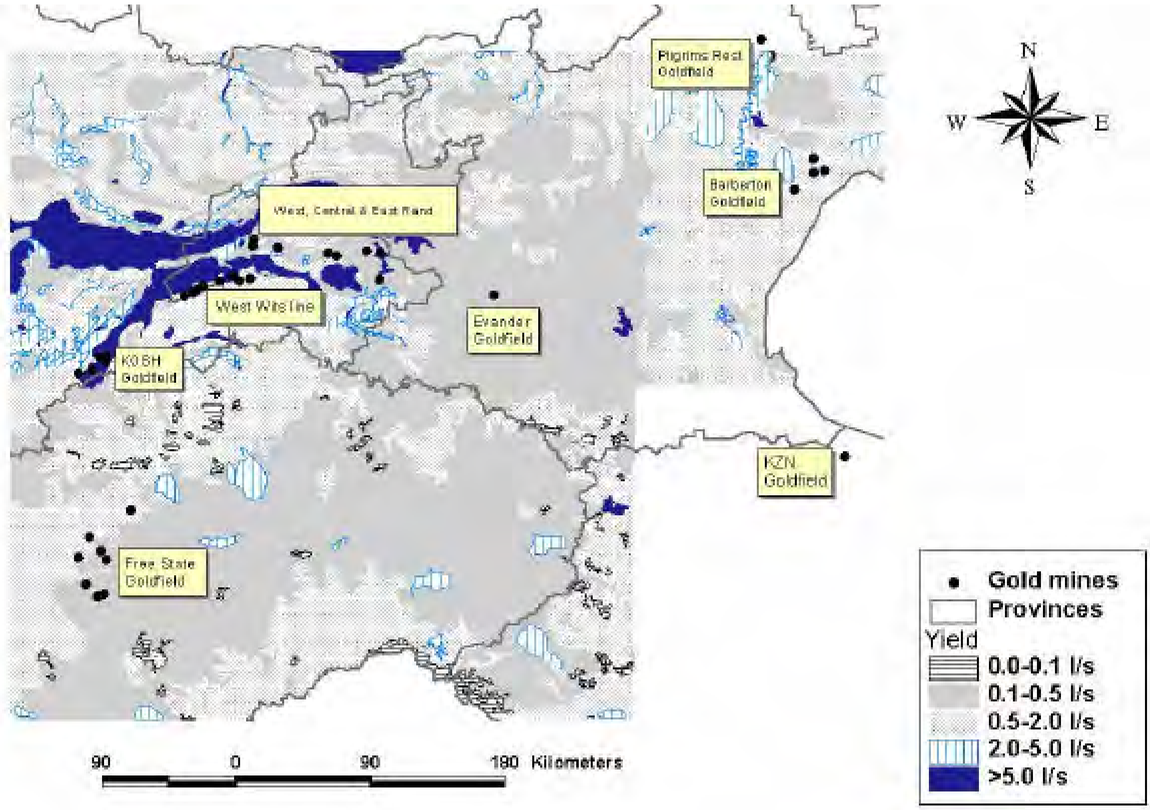


Figure 3.4: Map indicating groundwater yield in l/s

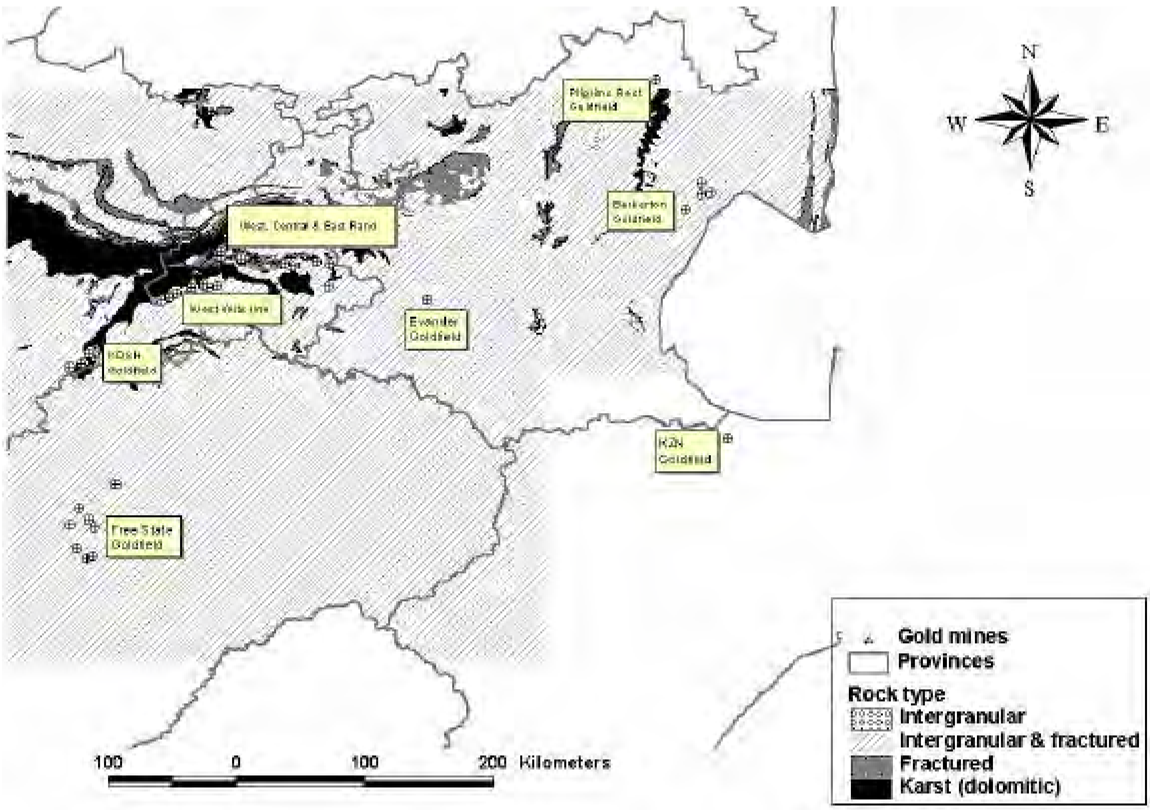


Figure 3.5: Map indicating rock types in relation to the goldfields of South Africa

3.2 GEOLOGICAL AND GEOHYDROLOGICAL DESCRIPTIONS OF THE VARIOUS GOLDFIELDS

The gold mines in South Africa are mainly concentrated along the edges of the Witwatersrand Sedimentary Basin. For the purpose of this investigation the gold mines are classified into two major categories, i.e. **Witwatersrand and Non-Witwatersrand** Gold Mines. The different goldfields are further sub-divided into distinct geohydrological zones based on natural and geological boundaries. The main aim of this investigation was to identify such boundaries and to describe the geohydrology within each geohydrological zone.

The most important and deepest gold mining occurred on the boundary of the Witwatersrand Basin, where seven significant gold mining areas are found as shown in Figure 3.6. These are:

1. Free State goldfields
2. KOSH or Klerksdorp goldfields
3. Far West Rand
4. West Rand Basin
5. Central Rand Basin
6. East Rand Basin
7. Evander goldfields

The three remaining basins investigated are the Barberton, Pilgrims Rest and Klipwal goldfields.

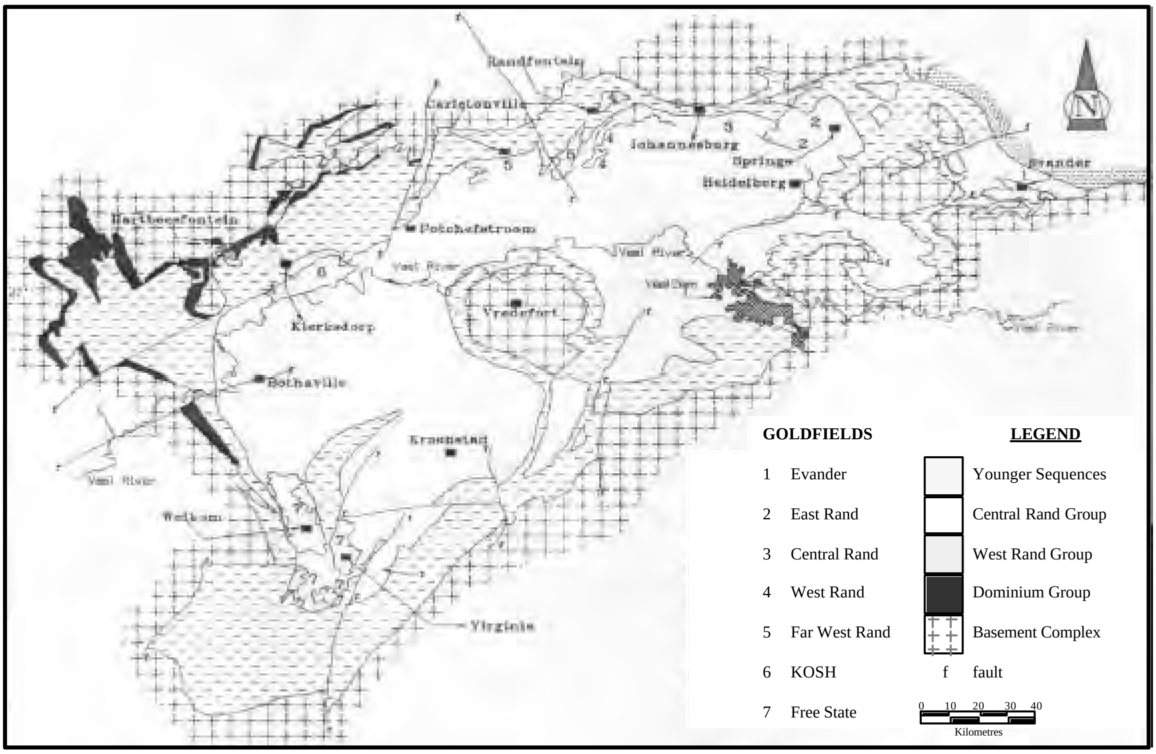


Figure 3.6: The Witwatersrand basin (Conradie, 1996)

3.3 WITWATERSRAND BASIN

3.3.1 Free State Goldfields

3.3.1.1 Introduction

Gold exploration of the Free State goldfields started during 1933 on the farm Aandenk. Mining commenced during 1956. The Free State goldfields extend from Theunissen in the south to Odendaalsrust in the north (Figure 3.7). The Free State goldfields can be separated into different sub-basins although the geological and geohydrological setting is similar throughout. Groundwater contamination originates from slimes dams and not from underground mining (Grimsley, 2002).

3.3.1.2 Geological setting

In the Free State goldfields the Archean Basement (granite and schist) is unconformably overlain by the Witwatersrand Supergroup, consisting of thick clastic sediments and shales with some intercalated lava flows (Lower Witwatersrand), as well as a thick sedimentary succession with auriferous and economic gold placers (Upper Witwatersrand). Volcanic and sedimentary rocks of the Ventersdorp Supergroup in turn unconformably to conformably overlie the Witwatersrand Supergroup. The early Precambrian Witwatersrand and Ventersdorp Supergroups are concealed by the sedimentary succession of some 600m – 800m of flat lying Phanerozoic sandstones and shales of the Karoo Supergroup.

The structural geology of the Free State goldfields is dominated by two N-S trending faults namely the Border Fault and the De Bron Fault (Figure 3.8). The Southern Free State goldfield is preserved in a broad, N-S trending syncline, which plunges gently to the north and appears to mark the southern closure of the Witwatersrand Basin (Grant, 1989).

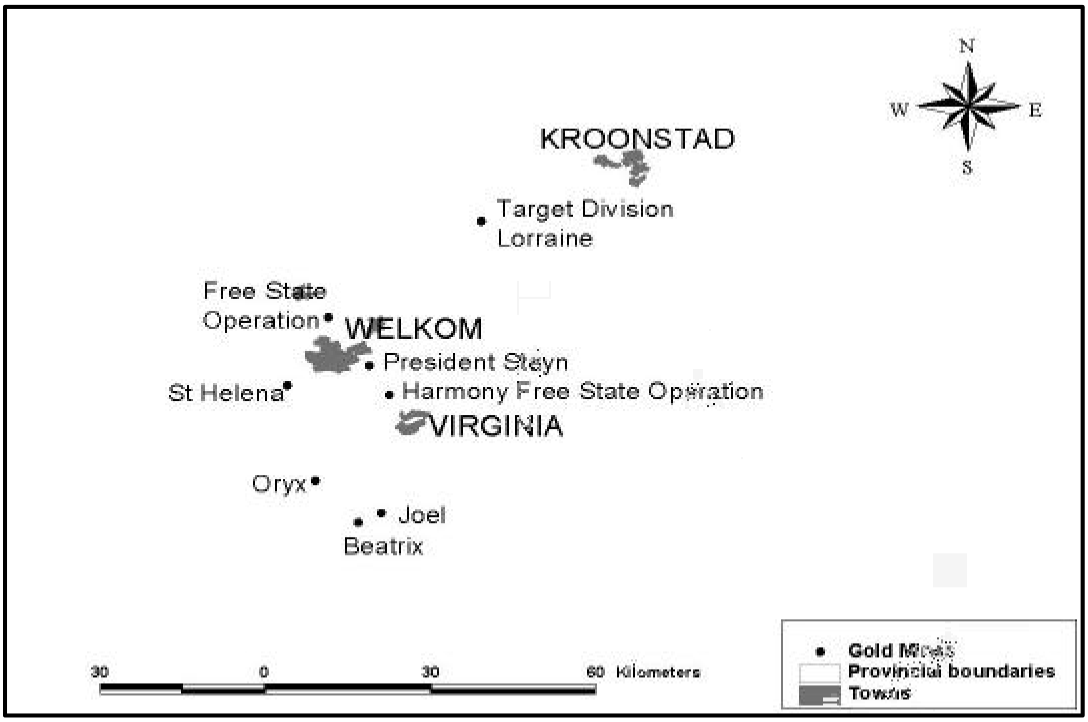


Figure 3.7: Operating mines in the Free State area

3.3.1.3 Geohydrological boundaries and interconnectivity between sub-basins

With reference to Figure 3.8 the Free State goldfield can be divided into five sub-basins.

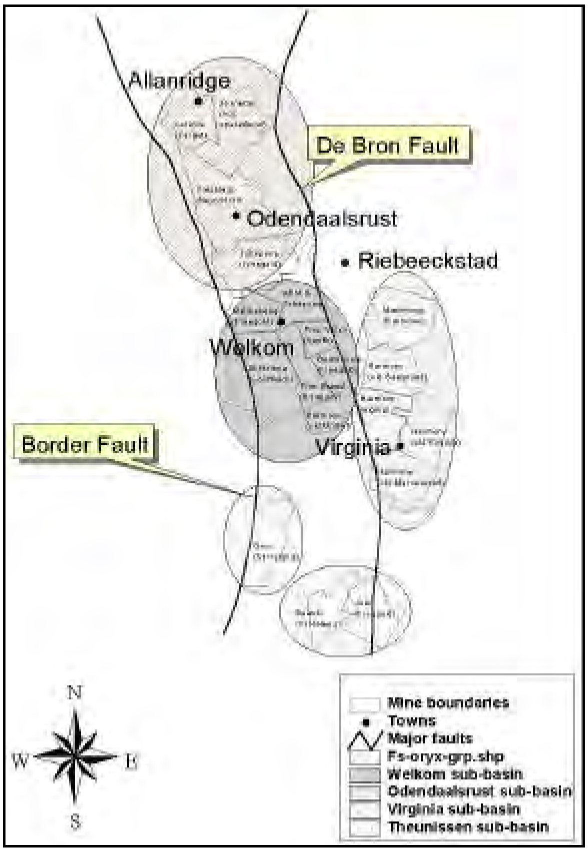


Figure 3.8: Mine lease boundaries and groundwater compartments of mines in the Free State area

The **Theunissen sub-basin** consists of Joel and Beatrix gold mines, situated between the De Bron and Stuurmanspan Faults. These mines are not interconnected through mining, but hydraulic connectivity does exist through geological structures (Van Biljon, 1995). Beatrix gold mine has pumped in the order of 30 megalitres per day (Ml/day) from the Witwatersrand aquifer during the 1990's. This has resulted in a dewatering cone developing in the aquifer, which has dewatered part of Joel mine as well, to the extent that groundwater inflows into Joel seldom exceeded 10 Ml/day during that time. Groundwater abstracted from the mines is evaporated on the mine property as well as piped to Welkom, where it is also evaporated.

The **Oryx sub-basin** consists of Oryx gold mine. This mine is isolated from the other mines and the Stuurmanspan Fault in the east and the Border Fault in the west mark its boundaries. This mine has been plagued by large groundwater inflows (~60 Ml/day). This water is also derived from the Witwatersrand aquifer and temperatures of as high as 60º Celsius are recorded. Groundwater pumped from the mine is evaporated.

The **Virginia sub-basin** consists of the Harmony gold mines (Harmony original, old Virginia, old Saaiplaas, old Erfdeel and old Merriespruit). These mines are all interconnected and the De Bron Fault marks its western boundary. The distal depositional environment and the disappearance of economical reef horizons form the eastern boundary of this sub-basin.

The **Welkom sub-basin** consists of the President Steyn (south), St. Helena, Harmony (President Brand and Unisel), Freegold (Matjhabeng, and Bambanani) and ARM gold mines. The Border Fault forms the western boundary and the Welkom goldfield is separated from the Virginia sub-basin by the De Bron Fault structure.

The **Odendaalsrust sub-basin** consists of the Freegold (Tshepong and Jeanette), President Steyn (north) and Target gold mines. The Border structure forms the western boundary and mining to the east is restricted by the Dagbreek fault.

3.3.1.4 Aquifer description

The time gap between the end of the Central Rand Group (Upper Witwatersrand) and the start of the Karoo deposition was in the order of 2.3 Ma. In these interim periods the older rocks were uplifted and exposed to erosion and the ground closer to surface exposed to pressure release. This formed fractures in approximately the top 150m of the succession. Subsequent land surface changes and inundation allowed marine water to percolate into this network of fractures in the Ventersdorp and Witwatersrand rocks (Young, 1987). The extensive major fractures that formed during Ventersdorp tectonic events were filled with water to several kilometres in depth. This formed the aquifer that is commonly intersected in all the Free State Mines, producing a very saline type of groundwater. The aquifer is composed of a brine solution with approximately 4000 mg/l of total dissolved solids, the major salt being NaCl. The average pH is 9.7 with a range from 8.1 to 11.5 (Van Biljon, 1995). It has a high corrosion potential and will corrode unprotected steel. On average 34 million m^3 of water is pumped to the surface (DWAF, 1997).

Weathering and fracturing of the upper Karoo strata resulted in a fresh water aquifer developing at depths of 1m – 60m below surface. Post – Karoo tectonic events along fracture planes and igneous intrusions may in certain areas link the good quality Karoo aquifer water with the Witwatersrand aquifer. These linkages are, however, regarded as negligible and the Witwatersrand aquifer is described as a confined connate aquifer with little or no recharge (Van Biljon, 1995). It is therefore possible to effectively drain the Witwatersrand aquifer and the huge evaporation ponds in and around Welkom were used in the past to dispose of the saline water. Water pumped from the Southern Free State goldfield was either disposed of by evaporation or piped to Welkom, where it is disposed of through evaporation.

Groundwater modelling in the Theunissen sub-basin (Van Biljon, 1995) suggested the following calibrated aquifer parameters for the Witwatersrand aquifer:

- Transmissivity: 40.16 m^2/day.
- Storativity: 0.005.

The aquifer parameters are believed to be representative of the entire Free State goldfield with some minor variations.

The mines in the Free State goldfields have to address the potential contamination of a shallow, good quality water, Karoo aquifer. Contamination of this aquifer can occur through the residue deposition on surface or through the evaporation of saline water pumped from the deep Witwatersrand aquifer.

3.3.1.5 Current groundwater management procedures

In terms of the near surface Karoo aquifer the individual mining companies implemented their own groundwater management procedures. This included the drilling of groundwater monitoring boreholes in the vicinity of potential contaminant sources such as tailings and rock dumps. The mine's EMPR documentation, however, generally lacks detailed descriptions of any monitoring and remediation programs that may have been put in place.

The deeper Witwatersrand aquifer is managed on a more regional scale although dewatering of individual mines is implemented without detailed regional considerations. In other words a regional approach may be more effective in reducing the Witwatersrand groundwater levels, to the benefit of all mines concerned. Groundwater pumped from the mines is either evaporated on mine property, but where capacity is lacking, the water is piped to Welkom, where it is also evaporated.

3.3.1.6 Flooding of mine workings

Most of the Free State Mines are exposed to the inflow of extraneous saline water from a deep connate aquifer. The isolated nature of this aquifer allowed for it to be dewatered effectively and the poor quality water was disposed of to evaporation pans. The mines that refer to this aquifer in their EMPR documents are all of the opinion that after cessation of mining the workings will flood, but that the water table will stabilise below the Karoo strata and that none of this water will decant from any of the shafts. Although this statement is probably correct there is no reference to any geohydrological investigation confirming this. As a result of this perception there are no management plans in place to cope with decant water.

Pumping rates from the Free State gold mines are indicated in Table 3.4

Table 3.4: Pumping rates from underground for the Free State gold mines

Mine	**Amount pumped**	**Reference**
Pres Steyn North 3#		
Pres Steyn North 9# & 7#	6 Ml/day	Barnes (2002)
Pres Steyn South 2#	2 Kl/day (areas are sealed when water is struck)	Barnes (2002)
Pres Steyn South 1#	~1.7 Ml/day	Barnes (2002)
Freegold (entire area)	Estimated @ 6 Ml/day	Freegold rejected EMPR
Target	5 Ml/day	Avgold EMPR (1999)
Beatrix	15 Ml/day	St Helena EMPR (2002)
Oryx	23 Ml/day	St Helena EMPR (2002)
Harmony sub catchment	13 Ml/day	Harmony EMPR (2002)
Virginia sub catchment	6 Ml/day	Harmony EMPR (2002)
Merriespruit sub catchment	23 Ml (per month)	Harmony EMPR (2002)
ARM	Quote yields of 0.9 Ml/day, not sure what is pumped	Du Toit (2001)

3.3.1.7 Conclusions

In terms of mine closure planning, the Free State goldfield region can be subdivided into five groundwater management sub-basins viz. Theunissen, Oryx, Virginia, Welkom and Odendaalsrust. A regional approach to dewatering may be more effective in reducing the groundwater levels to the benefit of all mines concerned. Pumping rates generally range from 2- 23 Ml/day. It does not seem likely, that after cessation of mining and flooding of mine workings, that water will decant from any of the gold mine shafts in this region. However, the serious threat of contamination of the shallow, good quality water, the Karoo aquifer, through the residue deposition on surface or through the large-scale evaporation of saline water pumped from the deep Witwatersrand aquifer, needs to be addressed.

3.3.2 KOSH Area

3.3.2.1 Introduction

The KOSH (Klerksdorp – Orkney – Stilfontein – Hartebeestfontein) area is located approximately 160km southwest of Johannesburg. The first recorded gold mining in the area took place in 1890 (Whiteside et.al., 1976). Currently the remaining operating mines include Anglogold's Vaal River Operations, African Rainbow Minerals and DRD's Buffelsfontein and Hartebeesfontein (see Figure 3.9).

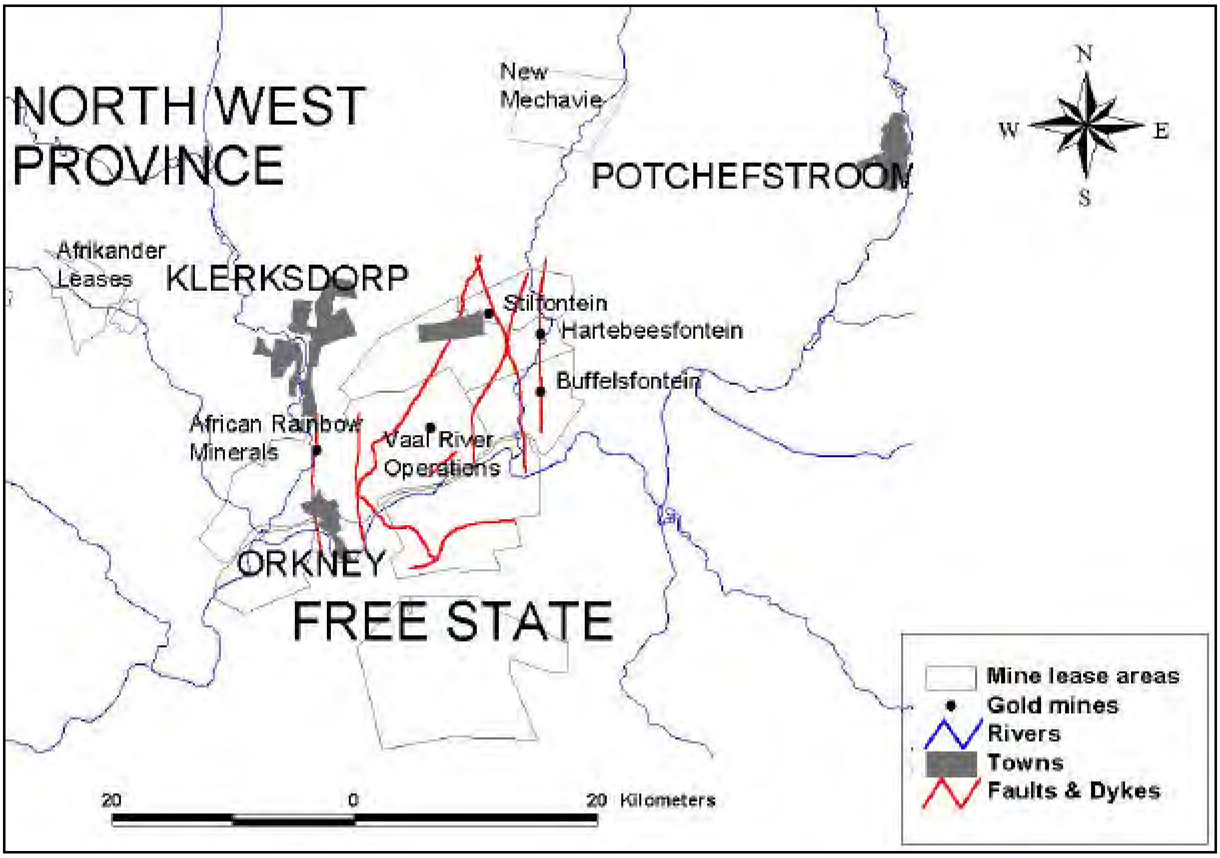


Figure 3.9: Gold mines in the KOSH area

3.3.2.2 Geological setting

The area is underlain by dolomite, which is renowned for its aquifer development and huge groundwater storage capacity. The Witwatersrand rocks outcrop in the vicinity of Klerksdorp, but no outcrop is found east of the Buffelsdoorn Fault. In this area the Witwatersrand rocks are covered by lava and dolomite of up to 1500m thick. According to Whiteside et.al. (1976)

most of the faulting affecting the gold bearing conglomerates occurred during Ventersdorp times with very little activity during Transvaal times.

3.3.2.3 Geohydrological boundaries and interconnectivity between sub-basins

From a geohydrological point of view the relative fault ages is an important concept since it is mainly the Transvaal age faults that could link the mine workings with the dolomite aquifers.

3.3.2.4 Aquifer description

The north-south trending Pilanes dyke is water-bearing when encountered underground at Stilfontein, Buffelsfontein and Hartebeestfontein. This dyke is Kimberlitic in composition and its high temperature/high pressure mineralogy is prone to extensive weathering, which enhances the transmissive capabilities of this feature (DWAF, 2002b).

Buffelsfontein Gold Mine is separated into two major groundwater compartments by a diabase dyke in the vicinity of the Koekemoerspruit. Water levels in the eastern compartment are influenced by the cone of depression that extends into Hartebeestfontein Gold Mine and Stilfontein Mine areas (Durban Roodepoort Deep - North West Operations, 2001).

The main horizon mined is the Vaal Reef. A second reef mined is the C Reef, which occurs approximately 280 m above the Vaal Reef. This C Reef is confined to the south western portion of Buffelsfontein Gold Mine. Several dykes are present, but in general they do not act as significant aquifers.

The Ventersdorp lavas act as a host for development of aquifers. However, the Ventersdorp lavas are also developed below the dolomite rocks at depth and in these environments, act as an impermeable aquiclude of importance in the KOSH area. The dolomitic rocks form the shallow aquifer. The deep aquifer, in the Witwatersrand Supergroup, has groundwater yield potential that ranges from moderate to poor. The West Rand group can host high yielding boreholes, often associated with more deeply weathered shales (DWAF (2002b).

The connection between this aquifer and surface water is described in the section on surface water – groundwater interaction.

A geohydrological cross-section through the KOSH mines is shown in Figure 3.10 below.

3.3.2.5 Current groundwater management procedures

Flooding of mine workings

It is assumed that there is geohydrological continuity between the four mines in the KOSH area (Durban Roodepoort Deep - North West Operations, 2001). The only EMPR that addresses the potential impact from mine water decant is DRD's Buffelsfontein and Hartebeestfontein. Groundwater levels will rise when the mine workings are flooded after cessation of mining at Orangia Shaft. The potential impact can at this stage not fully be quantified since the quality and quantity of decant water is not known.

The current understanding, although not confirmed through detailed water quality geochemical studies, is that:

- Water currently entering the mines is primarily in the region of Stilfontein Gold Mine. However, the depth of mining at Stilfontein is elevated above the other three mines in the area.
- Until the mined out volume is flooded, oxidising conditions will exist and groundwater quality deterioration will occur. This process will stop when the workings are completely flooded.
- Initially the decant water will be of poor quality, but this will improve to a steady state (albeit over decades or even centuries), where what goes in will almost equal what comes out.
- Upon complete flooding of the mine workings, interaction between the contaminated water and perched aquifers will occur, particularly along the southern borders of the Vaal River. This may cause contamination of the surface and groundwater in the area.
- The decant volumes are estimated between 17 to 50 megalitres per day (Ml/day).

No clear management strategy to deal with the decant water is described in the EMPR documents.

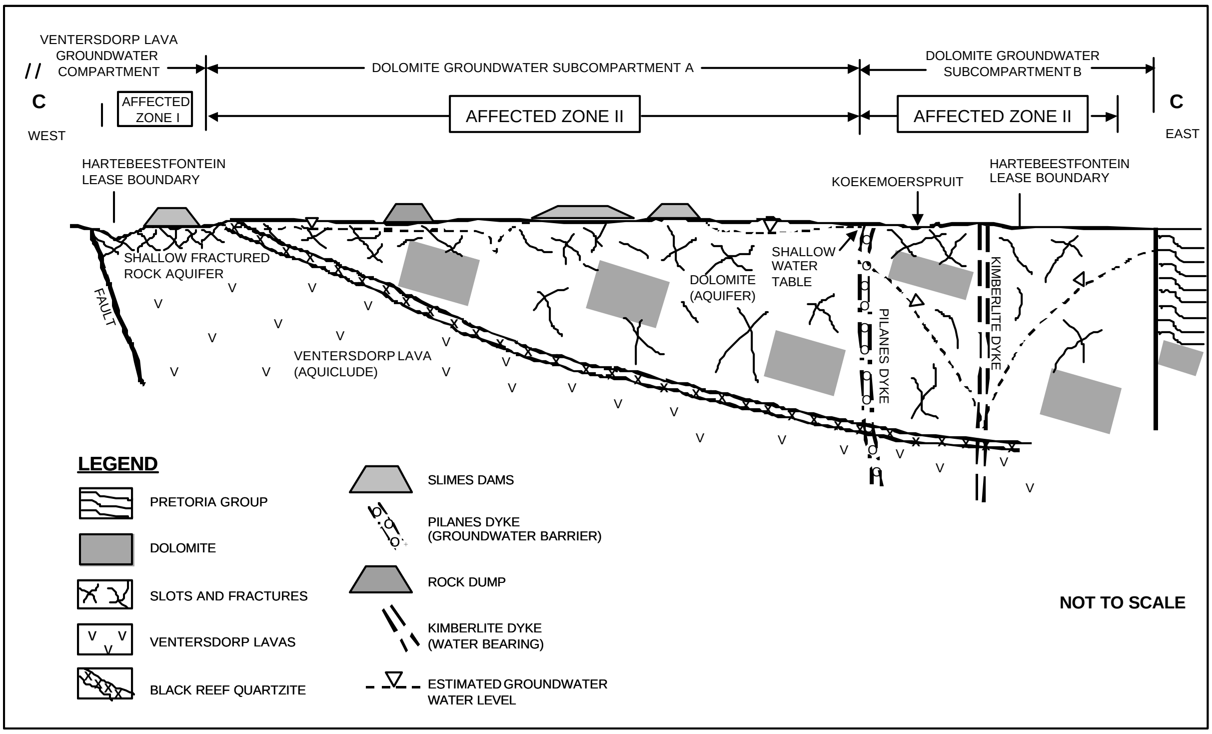


Figure 3.10: Cross section through KOSH region (Darcy, 2002)

<u>Water quality</u>

Rösner, *et al* (2001) produced a WRC report on the assessment of pollution contained in the unsaturated and saturated zones below reclaimed tailings and rock dumps.

In the unsaturated zone the following hazardous trace elements were detected at significant concentrations in gold mine tailings: As, Cr, Cu, Ni, Pb, U and Zn. Soil underneath reclaimed tailings dams shows typical contamination due to AMD. Acidic conditions (pH 3-4) in near surface soil samples become less acidic to a nearly neutral pH with depth. Carbonates that could react as buffer agent and/or a fluctuating groundwater table (dilution effects) could explain this decline in acidity. High bio-availability of the hazardous elements will complicate rehabilitation because of limiting the soil function. Heavy metals as mentioned above are soluble and highly mobile in fracture flow (preferred pathways) and this is reflected by high concentrations of contaminants at greater depths (DWAF, 2002b).

In the saturated zone, the same hazardous elements apply as for the unsaturated zone. Groundwater beneath and in vicinity of tailings dams is of the Ca-Mg-SO4 type. High salt loads are present in the groundwater but pH values are fairly neutral due to the neutralisation capacity of the dolomite in the area. With distance, the effect of tailings on the groundwater environment becomes reduced because of dilution effects and high precipitation due to neutralisation capacity of dolomite. In close proximity to the tailings dam, the groundwater quality is expected to exceed drinking water standards. Tailings dams do have a negative impact on water quality on nearby surface water systems. In terms of groundwater abstraction at mines, concerns arise from the pumping of fissure water within the workings and also from activities such as the dewatering at Margaret shaft to prevent Stilfontein from flooding. The dewatering results in less water being available in the rivers and to groundwater users in the immediate proximity of the mine, who fall within the cone of depression that results from the dewatering (DWAF, 2002b).

<u>Surface water – groundwater interaction</u>

Ways in which groundwater finds it's way into the surface waters include:

- *<u>Pumpage from mines into surface water</u>*. The most pronounced of these is probably the Stilfontein mine water, which is pumped from Stilfontein mine's Margaret shaft into the Koekemoerspruit. Winde (2001) explains in detail how the pumping influences the flow, temperature, and hydrochemical interactions and consequent contaminant transport within this spruit. It also is shown that in times of higher surface water flow and groundwater abstraction, flow reversals could occur (DWAF, 2002b). Morris *et al* (1992) reported a water loss from the point of discharge of the water from Margaret shaft in the north to the Buffelsfontein weir in the south. The loss is attributed to infiltration into the beds and banks of the river caused by macro-pores and in some areas a lack of fine clay minerals to seal the channel.

- *<u>Recirculation of water in the mines overlain by dolomite</u>*. In the northerly KOSH mines this is a particular problem leading to heightened salination and increased pumping with the associated costs. This circulation is also suspected of increasing the dissolution of subsurface dolomites and may lead to sinkhole formation (DWAF (2002b)).

- *<u>Continuous seepage from tailings dams and return water dams</u>*. These seepages together with runoff from rock dumps and metallurgical plants has created artificial recharge of polluted water into the aquifer. This may negatively impact on the water quality of the dolomite aquifer. The localised increase in groundwater levels will cause an increase in diffuse seepage into the Vaal River (L&W Environmental, 1993).

- *<u>Eye flows.</u>* Two separate types of eye flow are important. Firstly the eyes below the mining areas are important in the overall seepage of groundwater, much of it with elevated sulphates and TDS into the Vaal River. Observed yields of the "eye" are reported to fluctuate considerably with season and available records indicate that the flow in recent years has ranged between a maximum of 23 775 m^3/day in April 1989 and 3 583 m^3/day in November 1989 (DWAF (2002b)).

- *Seepages into the streams*. Hearne and Bush (1996) estimate that approximately 73 Ml/day of groundwater finds its way into the Vaal and its tributaries. This adds approximately 211 tons of dissolved solids and 121 tons of sulphate to the Vaal. The well field currently used by Vaal River Operations was established to reduce this impact.

Durban Roodepoort Deep - North West Operations (2001) suggest that it is probable that there will be some interaction of mine and perched aquifers in the low lying areas if complete flooding is allowed and that contaminated groundwater may seep to the Vaal River.

Sinkholes

L&W Environmental (1993) suggests that the development of sinkholes in the KOSH area is a result of increasing infiltration at the surface (e.g. from slimes dams, return water dams, spillage and leaking services). A number of sinkholes in the vicinity of Buffelsfontein's Eastern Shaft have developed as a result of lowering the water table due to dewatering.

3.3.2.6 Conclusions

The KOSH area is underlain by dolomite. The goldfield can be subdivided into four groundwater compartments, but due to the interconnections existing between the mines, a closure water management strategy should be integrated across all the KOSH mines. The mine workings, after flooding are likely to decant. There is also significant surface-groundwater interactions that impact on water quality in terms of pumpage of water from the mines to surface water, recirculation of water in the mines, continuous seepage from surface tailings dams and return water dams, eye flow and seepage. The high sulphide ores in this area result in potentially high long-term risk of water pollution from both the underground workings and surface residue deposits. Pollutant prevention management strategies need to be included and transport of pollutants properly evaluated. Sinkhole formation and backfilling of these sinkholes also needs to be addressed in the closure planning process.

3.3.3 Far West Rand

3.3.3.1 Introduction

The Far West Rand together with the West Rand, Central Rand and East Rand Basins are generally referred to as the "Rand Area" and are shown in Figure 3.11 below. The Far West Rand extends from Westonaria in the east to Carletonville in the west.

The most prominent characteristic of the Far West Rand mining area is the presence of several dolomitic groundwater compartments and the large inflows of groundwater into the underground workings

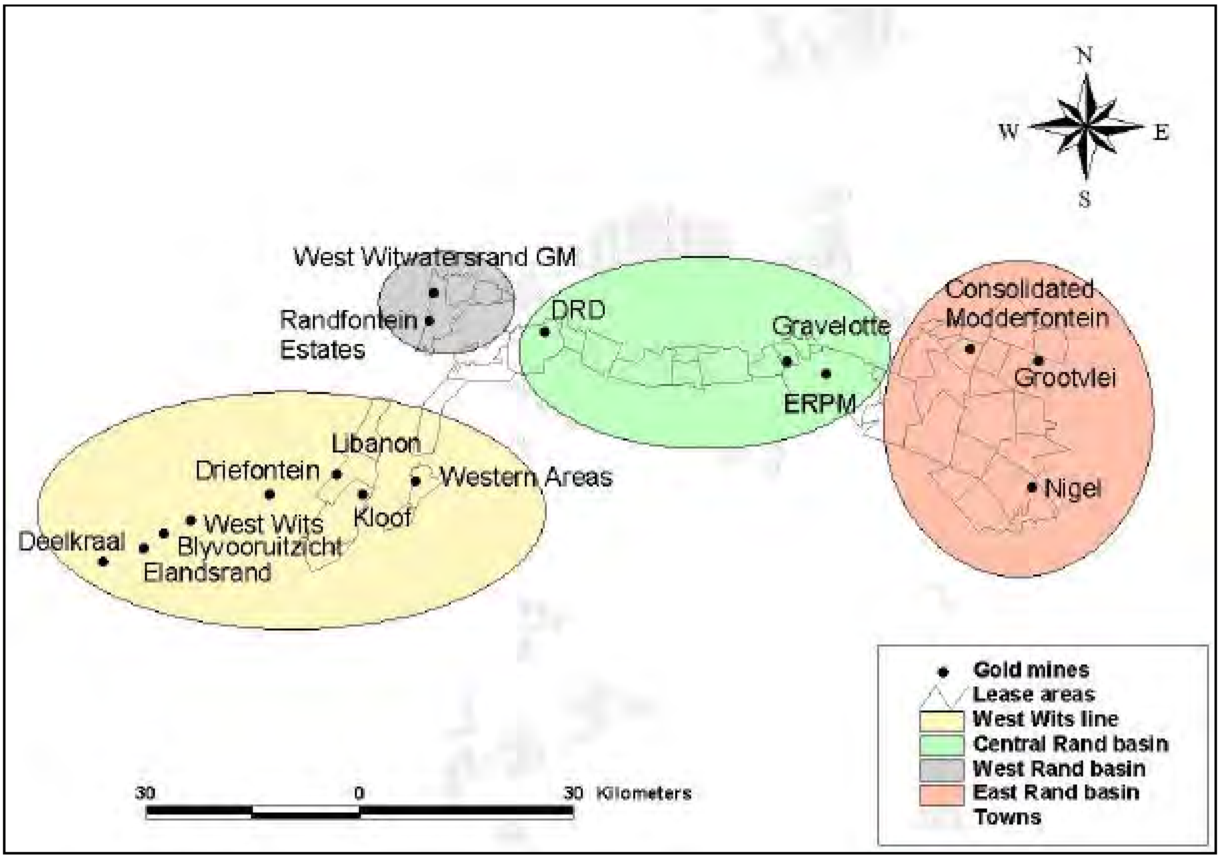


Figure 3.11: Gold mines and goldfields in the Rand area

3.3.3.2 Geological setting

The lithology and stratigraphy of the surface and near surface geology comprises the Transvaal and Karoo Supergroups superimposed by Tertiary and Quaternary deposits. The Transvaal Supergroup overlies the older Ventersdorp Lava (Klipriviersberg Group) and the gold bearing conglomerates of the Witwatersrand Supergroup.

The **Witwatersrand Supergroup** is a thick succession of shale, quartzite and conglomerate. It has been subdivided into a lower, predominantly argillaceous unit and an upper unit composed almost entirely of quartzites and conglomerates. This upper unit, referred to as the Johannesburg Group contains all the economic reef horizons.

Overlying the Witwatersrand strata is the **Ventersdorp Supergroup**. This mass of predominantly volcanic rock is younger than the Witwatersrand, but older than the succeeding Transvaal. The Ventersdorp lava is composed of green to black amygdoloidal andesitic lava, agglomerates and tuffs. The Ventersdorp lava, in particular the Klipriviersberg Group, is extensively exposed underground as it forms the immediate hangingwall of the Ventersdorp Contact Reef (VCR), which is mined extensively in parts of the basin.

Overlying the Ventersdorp Supergroup is the younger Black Reef Quartzite, consisting of dark coloured quartzite and carbonaceous shale. According to Parsons and Killick (1985) the Black Reef Formation is relatively undisturbed by the tectonic events that affected the overlying dolomites.

The contact between the Black Reef Formation and the over lying Chuniespoort Dolomite is gradational. Very little dolomitic rock is exposed along the Far West Rand (except along the Gatsrante), although the entire area is underlain by dolomite. Dolomite bands occur intercalated with black, carbonaceous shale and chert bands. The dolomite is typically dense, medium to dark grey rock with an uneven weathering surface. Some of the dolomite Formations, especially the Monte Christo and Eccles, have been subjected to extensive karstification prior to the deposition of the overlying Karoo sediments. It is this uneven weathering that mainly controls the groundwater flow within the dolomitic aquifer.

The dolomites are partly overlain by the Pretoria Group rocks. The Rooihoogte Formation forms the basal member of the Pretoria Group, consisting of the Bevets conglomerate, shale and quartzite. Bevets conglomerate varies in thickness between 3m and 60m (Parsons and Killick, 1985). Overlying the Bevets conglomerate is shale and sporadically developed quartzite, referred to as the Pologround quartzite. Where developed, the Pologround quartzite is overlain by 150m - 200m of pink to purple shales, forming the basis of the Timeball Hill Formation. The shale is overlain by quartzite, which forms the linear northwesterly trending ridges that characterise this goldfield.

Pebble and boulder beds as well as clayey deposits belonging to the Dwyka Formation of the Karoo Supergroup, overlie parts of the Transvaal rocks especially the dolomite. In addition to Karoo outliers, the dolomite outcrop area is covered in parts by accumulations of hillwash and transported sediments.

Tertiary and Quaternary deposits e.g. Kalahari Sands, ferricrete, gravelly clays and pebble beds are concentrated in palaeo drainage depressions, palaeo sinkholes, drainage systems and on the foothills of the Gatsrante

The intrusion of the Vredefort Dome had a significant impact on the structural and geological setting of the Far West Rand. It has resulted in the strata being folded and sequences duplicated due to thrust faulting. The regional structure has been interpreted as a dome and cusp (basins) [“egg box”] structural terrain, typical to an interference folded terrain. Two fold axes have been recognised from the surface geology, earlier easterly to westerly axes, which have been refolded by northerly trending axes. The folds are asymmetric *z-folds*, describing a larger synclinal structure to the south and west, the refolded Potchefstroom Syncline.

The Pilanesberg dykes are sub–vertical and divided the dolomite into seven major groundwater compartments. These are from east to west the Zuurbekom, Gemsbokfontein, Venterspost Sub-compartment, Venterspost, Bank, Oberholzer, and Boskop-Turffontein Compartments (Figure 3.12). The Gemsbokfontein, Venterspost, Bank and Oberholzer compartments have been dewatered by mining activities. The nature of the compartment forming dykes is such that the compartments can be dewatered separately, without affecting the neighbouring groundwater levels. The overlying dolomite aquifers are renowned for their groundwater storage capacity and several of the mines have had major groundwater intersections in their workings.

3.3.3.3 Geohydrological boundaries and interconnectivity between sub-basins

The mines and the groundwater compartments are indicated in Figure 3.13. With reference to both Figure 3.12 and Figure 3.13, the Far West Rand can be divided into three sections, based primarily on interconnections between adjacent mines. These are:

The **Eastern sub-basin** includes the mines east of the Witpoortjie and Panvlakte faults, Placer Dome Western Areas Joint Venture's South Deep Mine and Harmony's Cooke Section. These mines are linked through underground workings and form a single geohydrological unit.

The **Central sub-basin** includes the mines east of the Bank Fault, Gold Fields' Venterspost, Libanon and Kloof. These mines are all interlinked underground.

The **Western sub-basin** includes the mines that lie primarily west of the Bank Fault, East- and West– Driefontein (Gold Fields), Blyvooruitzicht and Doornfontein (DRD), West Wits Operations [Tautona, Savuka and Mponeng mines] (Anglogold), Elandsrand and Deelkraal (Harmony).

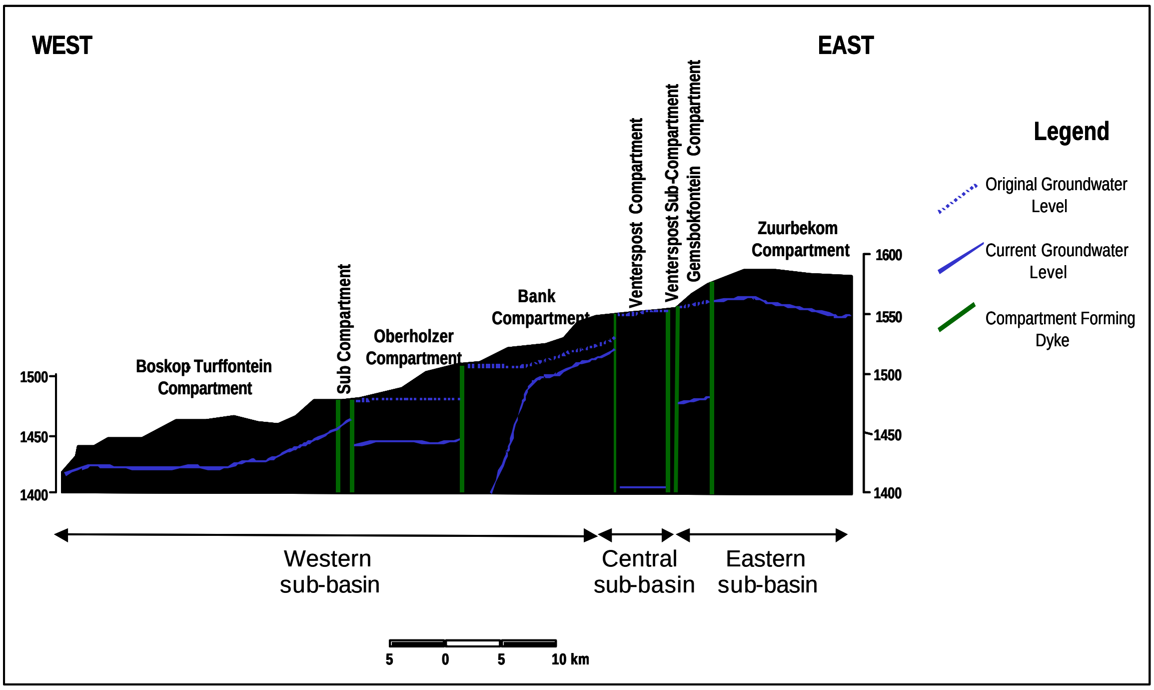


Figure 3.12: Pre and post mining groundwater levels along the Far West Rand

3.3.3.4 Aquifer description

Groundwater occurrences along the Far West Rand and environs can be divided into two distinct aquifers, namely:

- ***Perched aquifers.*** This aquifer is situated in the Karoo and Upper Transvaal (especially Pretoria Group) strata and consists of a weathered zone some 0m to 30m below surface as well as a deeper fractured aquifer system to approximately 70m. The deeper fractured aquifer may or may not be in hydraulic connection with the upper weathered aquifer. The water table in this aquifer varies between 0m – 56m.

- ***Dolomite aquifers.*** Prior to the deposition of the overlying Pretoria Group sediments, the dolomites were exposed to weathering of the upper 100m to 200m, to the extent that significant storage capacity exists within this zone. The dolomite aquifers pose the greatest challenge to the mining industry in terms of future rehabilitation strategies. This is mainly due to the significance of dolomite aquifers as future water supply sources.

Many of the dolomite compartments have been dewatered and several of the compartment forming dykes are punctured, which will make the recovery of the groundwater levels to the original elevations, as depicted in Figure 3.12, unlikely.

The perched aquifer is vulnerable to contamination from pollution sources such as the tailings dams. In certain areas this aquifer may be hydraulically connected to the dolomite aquifer, but in general the clay and shale successions in the Karoo and Transvaal prevent the downward percolation of groundwater.

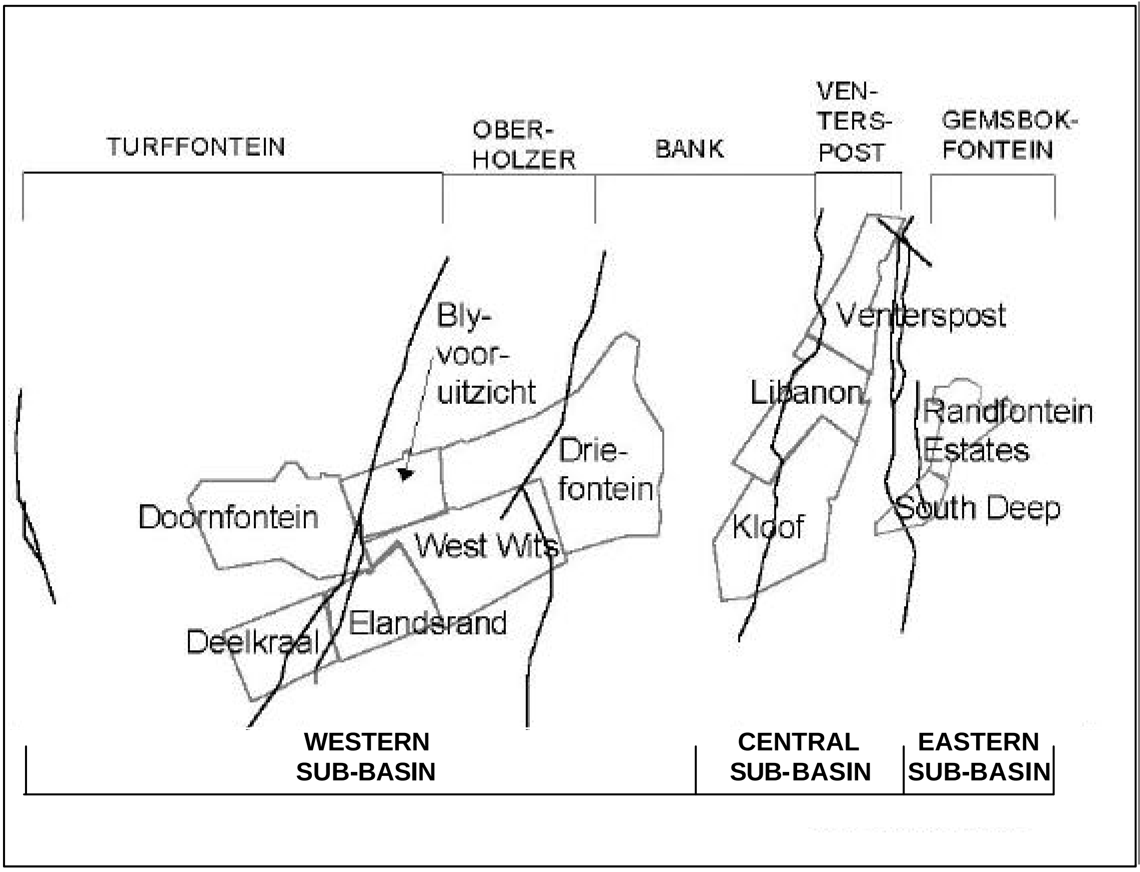


Figure 3.13: Mine boundaries, compartments and sub-basins in the Far West Rand

Diabase and syanite dykes have intruded the stratigraphic succession, which have resulted in the compartmentalisation of the dolomite formations. The **Eastern sub-basin** is largely situated in the Gemsbokfontein West and Venterspost Sub- Groundwater Compartments. The Panvlakte Dyke forms the northern boundary of the Gemsbokfontein West Compartment, the Gemsbokfontein No. 1 and Magazine Dykes form the western and eastern boundaries respectively. The southern boundary of the compartment is taken as the sub – outcrop position of the dolomite against the impermeable lava and shale of the Pretoria Group.

Harmony's Randfontein No. 4 Shaft is dewatering the Gemsbokfontein West Compartment. Pumping rates from this compartment are in the order of 50 – 70 Ml/day. Due to the good quality of the water, it is disposed of into the surface streams. Recharge to this compartment was calculated to be 67 Ml/day (Krantz and Van Biljon, 1999). The South Deep Shaft is situated in the narrow, non – dewatered Venterspost Sub-Compartment. This compartment is situated between the Gemsbokfontein and Venterspost compartments. The Venterspost Sub-Compartment lies between the Gemsbokfontein No. 1 and No. 2 Dykes.

The **Central sub-basin** is situated within the Venterspost and Bank groundwater compartments. The Venterspost Compartment is dewatered by Kloof Gold Mine, specifically the Libanon North Section (previously known as the Venterspost Mine). Pumping from this compartment is still in progress from Libanon No. 5 Shaft and the water is discharged some 20 km further west into the Wonderfontein Spruit. Due to the permeable nature of the dolomite outcrop areas and the re-circulation of water back into the dolomite compartments, the Wonderfontein Spruit has been piped / canaled from the Donaldson dam to the Boskop dam. This pipeline extends to the Oberholzer Compartment where the water discharges into a concrete canal, which continues to the Boskop Dam.

Total (average) reported pumping rates from the entire Venterspost Compartment are in the order of 28 Ml/day. Abstraction takes place from 4 Shafts, Libanon North (21-32Ml/d) (Venterspost), Libanon South (1Ml/d), Bank Compartment Kloof (7 Ml/d) and Leeudoorn (0.008Ml/d). The pumping depth from Libanon South is 1950m below collar, and from Kloof Division it is 2850m below collar. The elevations of the Libanon North pumping stations are as follows:

- 7 Level; 540m below collar
- 10 Level; 960m below collar
- 24 Level; 1800m below collar.

A pumping rate of 28 Ml/day maintains the water table at a fixed elevation, suggesting this to be the recharge rate to the Venterspost compartment. The Libanon North (old Venterspost) Gold Mine discharges 28 Ml/day into the Lower Wonderfontein Spruit.

The pumping capacities of the three main pumping centres are as follows:

- Libanon North - 63 Ml/day
- Libanon South - 80 Ml/day
- Kloof - 76 Ml/day

The mining pillars between the different divisions are reported to be mined out. Should pumping at the Libanon Divisions cease, an additional 28 Ml/day will report to the Kloof Division, putting the available pumping capacity under considerable strain. It would also lead to an increase in the pumping costs due to the increase in depth.

Even though the dykes are considered to be impermeable there is still interaction between the different compartments due to spillage from one compartment to the next in the form of "eyes" or fountains (although some of these are reported to be dry). Some of the upper portions of the dykes are weathered, especially where they are bisected by faults, and due to this, localized sub-surface flow from one compartment to the next occurs. One view is that once mining ceases the groundwater levels within each compartment will recover to their original level, provided that the compartment forming dykes have not been punctured by underground mining or that the holings through the dykes can be sealed. Another view is that once the mines are flooded, the groundwater table in the different compartments will return to its original elevation. This scenario is more favourable, provided that the underlying assumption is correct.

Figure 3.14 shows how the mines of the **Western sub-basin** of the Far West Rand are interconnected. The mines for this area include Deelkraal, Blyvooruitzicht, Driefontein, West

Wits operations and Elandsrand. The three main groundwater compartments that are of concern are the Bank, the Oberholzer and the Boskop Turffontein compartments. Only the Bank and Oberholzer compartments of this sub-basin are dewatered (see Figure 3.12).

Groundwater occurs in the inter-connected conduits within the dolomite. The water level in each compartment is nearly horizontal with the height controlled by the level of an eye or spring, which occurs at the western end of each compartment. The eye emerges at the point where the dyke intersects the deepest surface drainage point in the area (SRK, 1996).

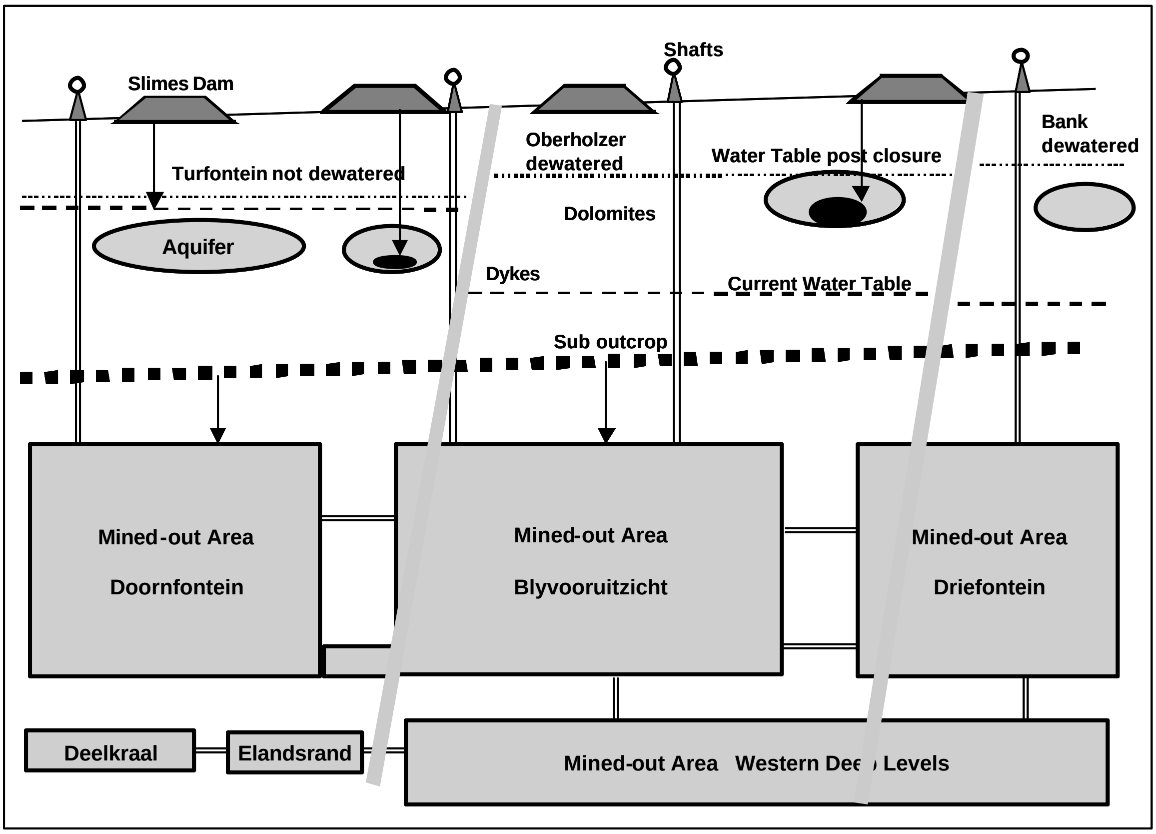


Figure 3.14: Interconnection between the mines of the western section of the Far West Rand area

Mining at or close to the Pilanesberg dykes has destroyed the compartment forming of the dykes. It may therefore be assumed that all the compartments between the Klip River in the east and the Turffontein dyke in the west will eventually function as a single large mega compartment (SRK, 1996).

3.3.3.5 Dewatering of dolomite aquifers and flooding of mine workings

The amount of groundwater and or fissure water pumped from each mine is summarised in Table 3.5.

Table 3.5: Pumping from Far West Rand mines

Mine	Groundwater Compartment	Pumping (Ml/day)	Discharged into	Reference
Harmony #4 shaft	Gemsbokfontein	~60	Klein Wes Rietspruit	Swart, 2003
Western Areas South Deep	Gemsbokfontein East	8	Leeuspruit	Swart, 2003
Kloof Gold Mine	Venterspost, Venterspost Bank	28 1 7	Wonderfonteinspruit Farmer Loopspruit	Swart, 2003
Leeudoorn	Venterspost	unknown	Recycled	Mhlangu, 2002
Libanon	Venterspost, Bank			
Blyvooruitzicht (including Doornfontein)	Oberholzer Turffontein	5 8	Mooi River Mooi River	Swart, 2003
Driefontein	Bank	34	Mooi River	Swart, 2003
West Wits Operations	Oberholzer, Bank			
Deelkraal	Turffontein			
Elandsrand	Turffontein			

Dewatering of groundwater compartments was also examined by DWAF (1999). It is mentioned that the discrepancies between older data and more recent data are large, but only the values of Fleisher (1981) are given (see Table 3.6). Water volumes stored in the different compartments prior to dewatering were also summarized in this report and are given in Table 3.7

Table 3.6: Abstraction rates for the Far West Rand (Fleisher, 1981)

Mine	Rate of water abstracted from underground (l/s)
Venterspost	259
East Driefontein	65
West Driefontein	1734
Western Deep Levels	Used on mine
Doornfontein	52
Blyvooruitzicht	46

Table 3.7: Water volumes stored in the different compartments of the Far West Rand

Compartment	Volume (million cubic metres)
Zuurbekom	234
Gemsbokfontein	171 - 600
Venterspost	460
Bank	2200
Oberholzer	700 - 1000

3.3.3.6 Current groundwater management procedures

The presence of the dolomite aquifers overlying the mining operations along the Far West Rand is relatively well described.

The dewatering of these dolomite compartments and the subsequent lowering of the groundwater levels resulted in sinkhole formations and widespread ground stability problems. The dewatering of the dolomite compartments and associated monitoring programs took place under the strict supervision of the State Co-ordinating Technical Committee on Sinkholes and

Subsidence. As a result, detailed monitoring programs and procedures were designed as part of the dewatering permits. These permits stipulate that monitoring should continue during the flooding of the mine workings and rewatering of the dolomite aquifers. In some instances individual mines may be in a position to cease operations and allow the flooding of the mine, provided that the underground holings can be safely sealed and that the compartment forming dyke's integrity has not been breached. Such an example is Randfontein No. 4 Shaft, which is situated in the Gemsbokfontein West groundwater compartment. This mine can potentially be separated from the neighbouring South Deep mine through a series of plugs, which are currently being constructed. Once the plugs are in place Randfontein No. 4 Shaft can potentially be flooded without affecting mining operations at South Deep. Most of the mines on the Far West Rand are, however, linked to the extent that they will have to remain open for pumping purposes. However, none of the EMPR's discuss the potential impacts from flooding and decant, if any, after closure.

3.3.3.7 Sinkholes

The Far West Rand area has numerous sinkholes. In the early sixties, sinkholes caused major disasters at Venterspost, West Driefontein and Blyvooruitzicht mines (EMPR, 1996). Jenner (2002) suggests that there are currently 104 sinkholes in the Blyvooruitzicht and Doornfontein areas. SRK (1996) reported three old sinkholes that became active again, nine new sinkholes in areas where no movement had previously occurred and four of thirteen known paleo-sinkholes in Westonaria that showed accelerated subsidence.

Sinkhole information obtained from Metago (2002) is summarized in Table 3.8.

Table 3.8: Number of sinkholes and volume of backfill in the Far West Rand

Compartment	No. of backfilled Sinkholes	No. of open Sinkholes	Method of Backfill
Venterspost		170 (270 000 m^3)	Tailings or Tailings & Waste Rock
Venterspost (in the Wonderfontein Spruit [1]	115 (450 to 500 000 m^3)	91 (161 578 m^3)	
Bank [2]		70 (69 000 m^3)	Soil
Oberholzer [2]		15 (1500 m^3)	Soil

1) Data from a survey undertaken in 1997
2) Data from a survey undertaken in 1993 multiplied by 1.5 – which represent the increase in the rate of sinkhole formation in the Venterspost department between 1993 and 1997

3.3.3.8 Conclusions

In terms of gold mine closure planning, the Far West Rand mines can be divided into three geohydrological management units viz. the eastern, central and western sub-basins. These sub-basins include the Gemsbokfontein (eastern sub-basin), Venterspost and Bank (central sub-basin) and Bank, Oberholzer and Boskop-Turffontein (western sub-basin) groundwater compartments. While dykes, which are considered impermeable separate the compartments, there is still potential for interaction between some of the different compartments due to spillage that may occur from one compartment to the next in the form of "eyes" or fountains. Furthermore, some of the upper portions of the dykes are weathered causing flow from one compartment to another.

The groundwater is found in two distinct dolomitic aquifers. The gold mines in this area are mainly situated beneath both the dolomitic aquifers. The deeper aquifer is significant in terms of future water supply sources and is vulnerable to contamination with poor mine water upon filling. The upper perched aquifer is at risk of contamination from surface waste residues and seepage from backfilled sinkholes. This contamination is however not thought to pose a serious threat to the lower aquifer. The dewatering of the dolomitic compartment and the subsequent lowering of the groundwater levels has resulted in significant sinkhole formation and widespread ground stability problems. Decanting is likely once mining ceases in this area. Poor decant water quality will impact on surface water resources. Groundwater stability levels will be dependent on the adequate sealing of the dykes (if possible) and the subsequent recovery of the groundwater tables to their original levels.

3.3.4 West Rand Basin

3.3.4.1 Introduction

Mines in the West Rand basin are shown in Figure 3.15.

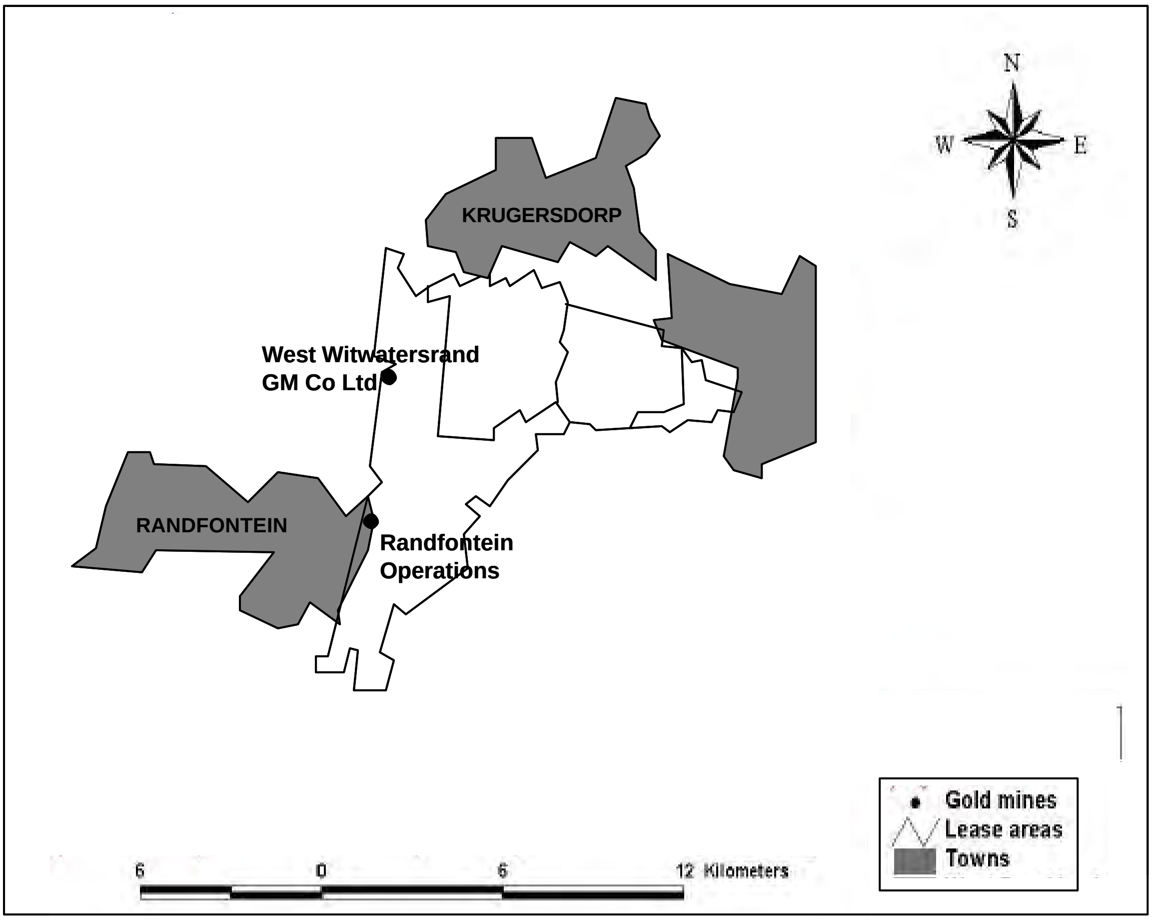


Figure 3.15: Mines in the West Rand basin

3.3.4.2 Geological setting

Due to the mining of the gold bearing reefs deposited in the Witwatersrand Supergroup, an artificial aquifer was created. Since cessation of mining, these voids started flooding at a rate which is largely dependent upon the geological setting. The geology includes, in chronological order;

- Halfway House Granite Suite (Johannesburg Dome)
- Witwatersrand Supergroup
- Ventersdorp Supergroup
- Transvaal Supergroup

The Halfway House Granite Suite or the Johannesburg Dome, as it is known, forms the northern boundary of the study area. The rock types include gneiss, migmatite, porphyritic granodiorite and granite. The intrusion of this suite is responsible for the upliftment of the Witwatersrand rocks and faulting is often associated with this contact.

The geology of the **Witwatersrand Supergroup** is well understood and documented as a result of extensive mining and exploratory drilling. Truswell (1977) describes the geology in the region of the mine aquifer.

The development and preservation of the Witwatersrand Basin is structurally controlled. The structural patterns control the influx of groundwater into the mine void and as a result it is important to understand which features act as conduits and which features act as flow barriers. Dykes and sills of at least four different ages have also intruded the Witwatersrand strata. The intrusion of the dykes has often taken place along fault planes. The oldest dykes are usually diabase, representing feeder dykes to the overlying Ventersdorp lavas. There are intrusions of pyroxenite, gabbro and dolerite probably of Bushveld age. A third group belongs to the basic or alkaline dyke swarm (large number of dykes together) related to the Pilansberg alkaline complex. Finally the youngest intrusions are of Karoo dolerite.

The Witwatersrand Basin is a thick sequence of shale, quartzite and conglomerate. The average dip of the strata is 30° South, although localised dips of up to 80° have been encountered in the mine workings. There are two main divisions, a lower predominantly argillaceous unit, known as the West Rand Group and an upper unit, composed almost entirely of quartzite and conglomerates, known as the Central Rand Group. The West Rand Group is divided into three subgroups namely the Hospital Hill, Government Reef and Jeppestown. These rocks comprise mainly shale, but quartzite, banded ironstones, tillite and intercalated lava flows are also present. The rocks were subjected to low - grade metamorphism causing the shale to become more indurated and slaty. The original sandstone was recrystallised to quartzite.

The Hospital Hill Subgroup is some 1500m thick. It comprises the Orange Grove and Hospital Hill Quartzites, which are separated by a thick argillaceous sequence. This sequence comprises the Water Tower Slates at the base, overlain by the red shales and at the top are the Hospital Hill Shales.

The Orange Grove Quartzite forms the actual Witwatersrand, where it nonconformably rests on the Halfway House Granite. There has been significant movement along this contact. The quartzite is dense, recrystallised orthoquartzite.

The Water Tower Slates are hard, ferruginous strata displaying varying fissility. The Red Shales are easily weathered and occupy low ground. At depth the shales are grey, grey – green or dark bluish – green in colour. All, however, tend to weather to a red or reddish – brown colour.

The Hospital Hill Slates are normally hard and darkish, are often slaty and usually ferruginous. The Hospital Hill Quartzites forms three layers separated by argillaceous material. The quartzites are similar to the Orange Grove Quartzite and can usually be distinguished from the latter by a greenish colour, due to the presence of chrome – bearing mica fuchsite.

The Government Subgroup is 1930m thick. It is an alternation of predominantly arenaceous and argillaceous formations, with the former accounting for some two – thirds of the total thickness. The shaly rocks are also ferruginous and red – weathering. The quartzites are less mature and less quartz – rich than the orthoquartzite of the underlying Hospital Hill quartzite. The Promise, Coronation and Government Reefs are associated with this formation. These reefs are, however, all narrow and uneconomic. The base of the Coronation Reef marks the top of the West Rand Shales. The shales are dark purple, slaty and contain significant amounts of magnetite.

The Jeppestown Subgroup is 1140m thick. Reddish – weathering shales alternate with yellow, red or dark coloured sandstones. Within the Central Rand Basin the shales form the bulk of the succession, although the quartzite thickens towards the west. The incompetent Jeppestown Subgroup is a structurally weak zone and the strata are sheared and have frequently been subjected to thrust and high – angle faulting. The faulting is usually parallel to the strike.

The Central Rand Group is divided into the Johannesburg and Turffontein Subgroups and is composed largely of quartzites, within which there are numerous conglomerate zones. The conglomerate zones may contain any number of conglomerate bands, with individual bands interbedded with quartzite. The upper conglomerates are usually thicker with coarser fragments. The important conglomerate zones on the Central Rand are the Main Reef, Bird Reef, Kimberley Reef and the Elsburg Reefs. An argillaceous zone known as the Booysens Shale (also known as the Kimberley Shale) separates the Johannesburg and Turffontein Subgroups.

The younger **Ventersdorp Supergroup** overlies the Witwatersrand rocks. Although acid lavas and sedimentary intercalations occur, the Ventersdorp is composed largely of andesitic lavas and related pyroclastics. The Ventersdorp Supergroup consists of the Platberg Group and the Klipriviersberg Group. The Klipriviersberg Group consists of the Alberton and Westonaria Formations.

The Alberton Formation is composed of green – grey amygdaloidal andesitic lavas, agglomerates and tuffs. The thickness amounts to 1500m. The lack of sediments in this sequence indicates a rapid succession of lava flows, which probably came from fissure eruptions. Material of similar composition forms the oldest dykes that have intruded the Witwatersrand rocks. The abundant agglomerates provide indications of periodic explosive activity. The removal of huge volumes of volcanic material from an underlying magma chamber gave rise to tensional conditions and as a result a number of faulted structures, horst and grabens, were formed. Some Platberg Group, which consist mainly of breccia, conglomerate, greywacke and shale is preserved to the north of the mining region.

Overlying the Ventersdorp Lavas are the Black Reef Quartzite and dolomites of the **Transvaal Supergroup**. The close proximity of the dolomites, known for their huge water storage potential, raised the question whether any linkage to the mine workings exists.

3.3.4.3 Geohydrological boundaries and interconnectivity between sub-basins

The West Rand Basin mines are all interlinked as indicated by a flat groundwater gradient within the mined out workings. The aquifer was created through mining, but the geological setting controlled the mining. The mining and geohydrological boundaries therefore coincide. The outcrop of the various reef horizons on surface formed the northern and western boundaries. The Witpoortjie Fault and the impermeable shale of the Witpoortjie Horst mark the southern and eastern boundaries. The geohydrological boundaries are illustrated in Figure 3.16.

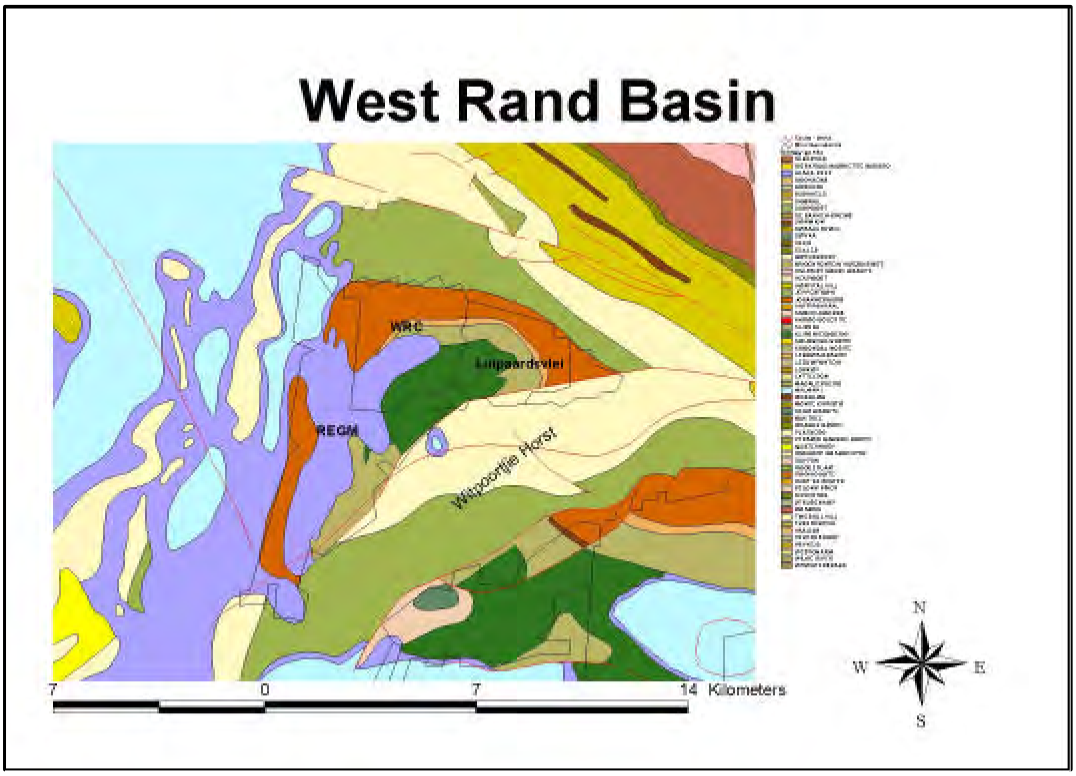


Figure 3.16: Geological setting of the West Rand basin

3.3.4.4 Aquifer description

The mine void represents the aquifer, which was determined by the extent of the mining operations. The Witwatersrand Reefs outcrop on surface and dip steeply towards the east (Randfontein Estates) and the south (West Rand Cons and Luipaardsvlei), before flattening out at depth. The reefs were mined through a series of vertical and incline shafts, but extensive opencast mining was done during latter years. The opencast mining was mainly on the younger Black Reef, but interconnectivity with the Wits reefs is evident. The relationship between the groundwater levels and mining configuration is graphically illustrated in Figure 3.17.

3.3.4.5 Current groundwater management procedures

The mined out area is in the process of being flooded and predictions were that the decant elevation of 1670m amsl would be reached during September 2002 (Rison Consulting, 1999) – this was subsequently confirmed and decant did start in September 2002. The lowest point is in the vicinity of 18 Winze, which is a Black Reef Incline Shaft situated on Randfontein Estates property. Decant from this shaft will flow in the Tweelopie East stream towards the Krugersdorp Game Reserve and Cradle of Humankind World Heritage site. Preliminary indications are that the decant volume will be in the order of 17 Ml/day (Rison Consulting, 1999). Harmony has indicated that the decant water will be collected at source or through appropriately situated shafts, from where it will be pumped to a treatment facility. Although not yet finalised, the treatment facility will probably entail a HDS plant and an engineered wetland system. Groundwater quality is poor and is characterised by low pH, high salt content, especially SO_4 and generally elevated metal content.

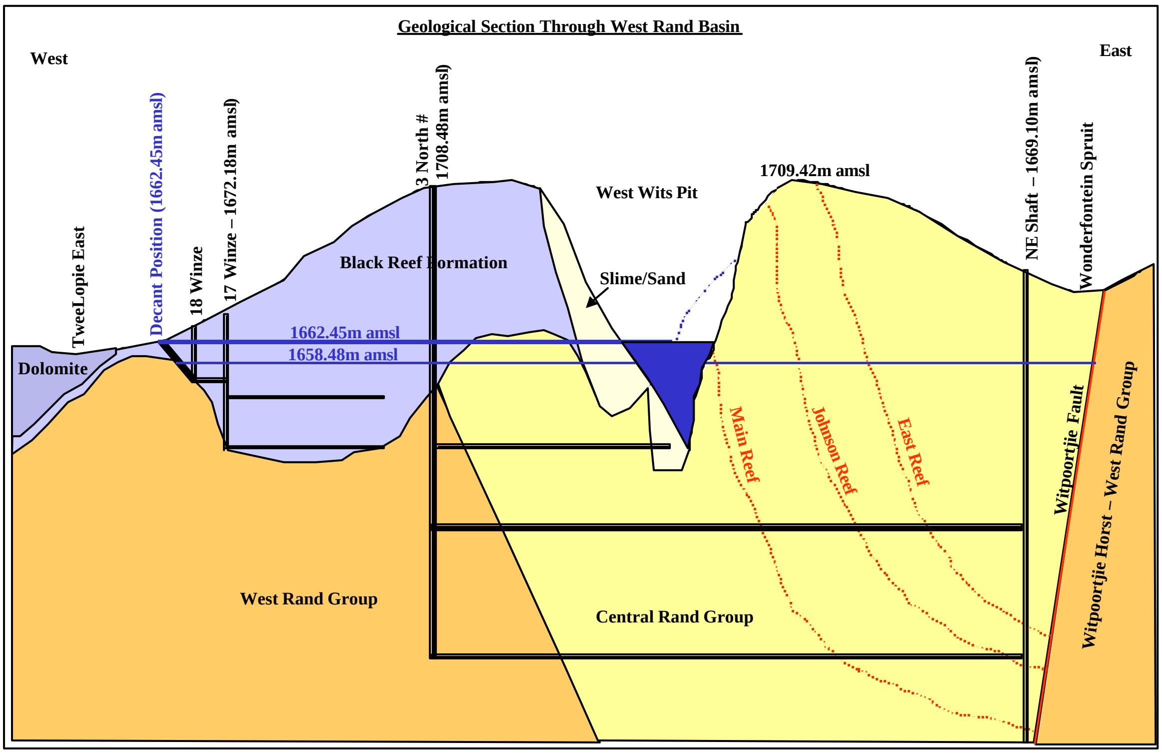


Figure 3.17: Geological cross-section through the West Rand basin

3.3.4.6. Conclusions

Mining in the West Rand basin caused the creation of an artificial aquifer. A single geohydrological unit for closure planning coincides with the mining boundaries. All the gold mines are interconnected as indicated by a flat groundwater gradient within the mined out workings. Groundwater quality is poor and the area has just started to decant. There is also significant surface-groundwater interactions that impact on water quality in terms of continuous seepage from surface residue deposits.

3.3.5 Central Rand Basin

3.3.5.1 Introduction

The area under investigation extends some 46 km from Roodepoort (Durban Roodepoort Deep Mine) in the west to Boksburg (East Rand Propriety Mine) in the east and is collectively known as the Central Rand Basin. The operating gold mines along this stretch are East Rand Propriety Mine (ERPM), DRD and Gravelotte. The Central Rand mines were dewatered until 1974 at which time most of the mines in the central portion of the basin stopped working. In 1977 the deeper workings were flooded to a level of 745mamsl (Scott, 1995). With the cessation of mining, the workings will be allowed to flood completely, at which point contaminated mine water will decant into the surface environment, a similar situation to that facing the West Rand Basin at the moment. The locality plan of the mines is presented in Figure 3.18.

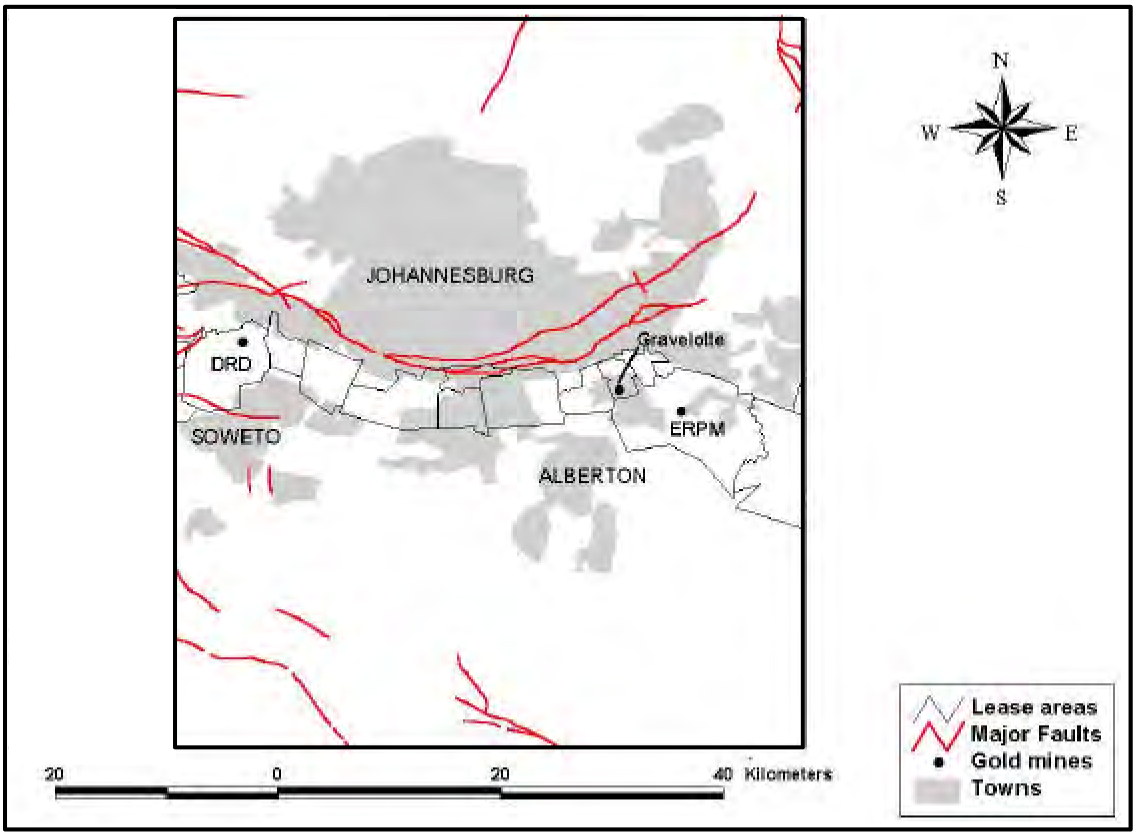


Figure 3.18: Mines in the Central Rand basin

3.3.5.2 Geological setting

The geological setting is similar to that described for the West Rand Basin. The setting of the mines in relation to the geology is shown in Figure 3.19. The Central Rand Group of the Witwatersrand Supergroup contains the economic gold deposits within conglomerate zones. On the Central Rand, the important conglomerate zones (reefs) are the Main Reef, Bird Reef, Kimberley Reef and Elsburg Reefs running across the entire basin in an east-west direction. The reefs outcrop on surface in an east-west trending zone, which dips to the south at an initial steep gradient of approximately 80° to a depth of approximately 150 m below surface where it flattens to 30°. At the deepest workings on Crown Mines, some 3000 m below surface, dips of 16° are encountered. The reef outcrops on surface over zones ranging from a few meters up to approximately 30 m in width. The Main Reef outcrop forms the northern boundary of the mining operations. The reefs were disturbed and displaced in depth by younger faulting which, to a large degree, control the movement of groundwater and in places extends all the way to surface.

The Main Reef gold bearing ore body was discovered in 1886 and has been mined ever since. This has resulted in a continuous band of mining activity following the Main Reef outcrop, which runs in an east-westerly direction roughly from Roodepoort in the West to Germiston and Boksburg in the East. Initially mining was undertaken by trenching along the reef. The first thirty meters, or so, in the oxidised zone, was very rich with free gold (about 32 g/ton). Below the oxidised zone mining and metallurgical conditions became more difficult and only the technologically advanced operators were able to continue. As mining operations became progressively deeper, the open trench mining methods were gradually replaced by incline shafts following the dip of the reef and later by vertical shafts. As the shafts became deeper, increasing problems with water ingress into the mine workings were experienced. Initially, the water was bailed, but as electric pumps became available pumps replaced these bailing methods.

After the initial open trench mining was replaced by more conventional underground mining methods, large portions of these open trenches were backfilled mainly with waste rock and processed sand and tailings.

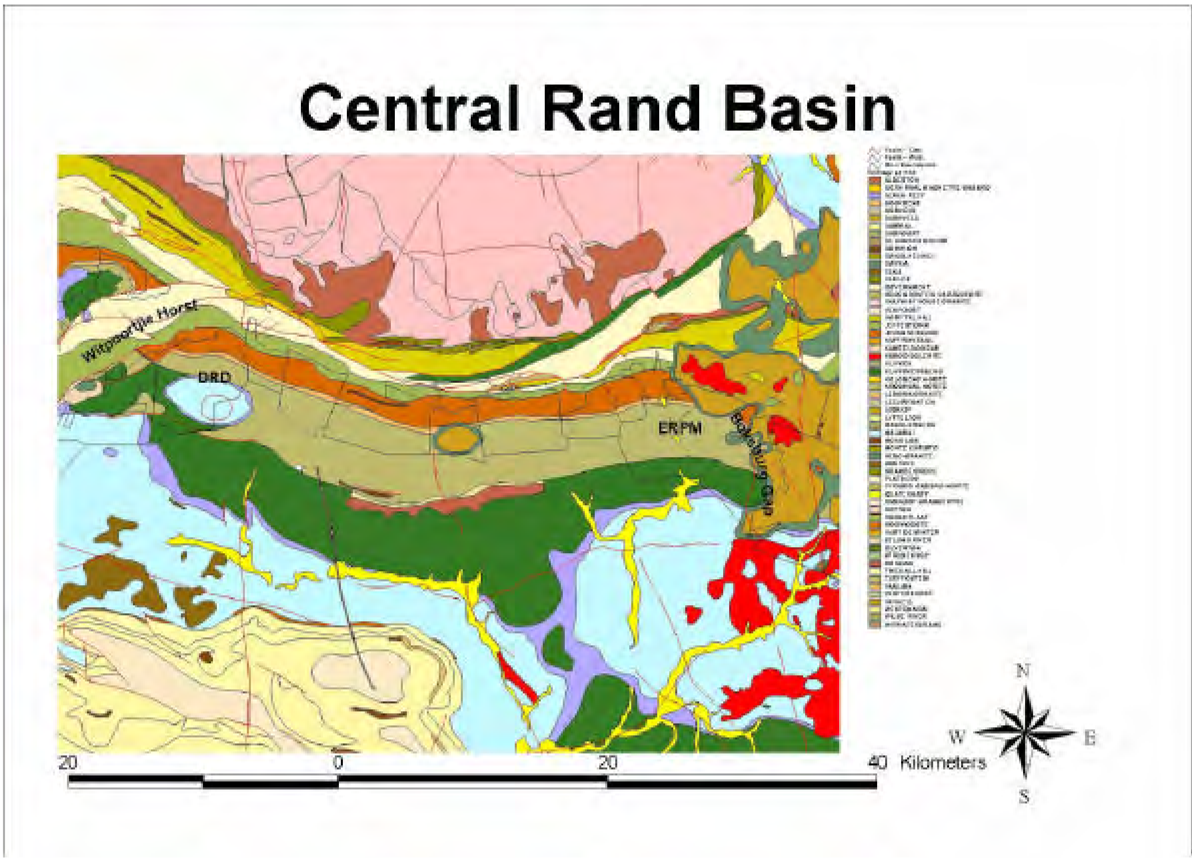


Figure 3.19: Geological setting of the Central Rand basin

3.3.5.3 Geohydrological boundaries and interconnectivity between sub-basins

The Central Rand Basin can be divided into three sub – basins. These are;

- The **Central** Basin (including Rose Deep)
- The **DRD and Rand Leases** Basin
- The **ERPM** Basin

These basins are all connected but they currently act independently due to mining pillars and the installation of plugs. The relationship between the different sub – basins is illustrated in Figure 3.20.

Rainfall recharge to the basin is considered to be the predominant source of water. This can be either directly through stream losses where it crosses the reef outcrops, or indirectly via the perched aquifer. Surface and groundwater drainage (in the perched aquifer) is generally towards the south. This groundwater and some of the surface water is intercepted by the reef and reef outcrop. For the purpose of the recharge model, the catchment areas were identified which would directly contribute to the groundwater and surface water ingress to the mine voids.

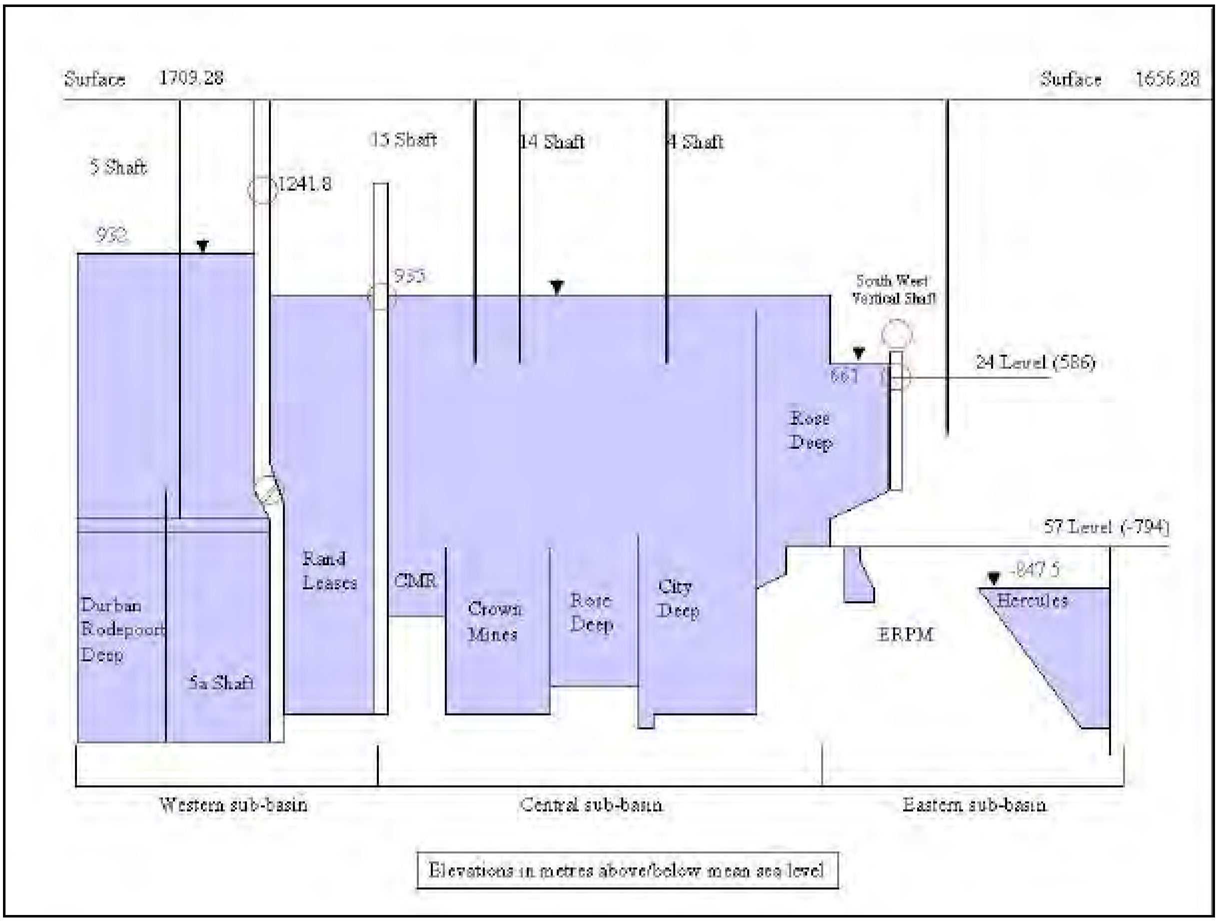


Figure 3.20: Cross-section through the Central Rand basin

3.3.5.4 Aquifer description

A geohydrological model (Rison Consulting, 1999) was developed to predict the long-term inflows and water table rise within the Central Rand Basin. The basis of this geohydrological model is the groundwater balance, which includes three main components.

- Ingress via openings such as the reef outcrops, open shafts and mining related sinkholes.
- Seepage from the perched aquifer, which, in turn, is recharged by rainfall.
- Losses through seepage from stream beds.

While recharge via the deeper fractured aquifer does occur it was not quantified specifically for this model but included in drainage from surface streams and the perched aquifer. Based on the water balance and field investigations, it was concluded that losses via seepage from streambeds is the single largest contributor to the flooding of the void that could be managed. This is true for the western part of the basin, but may not necessarily be the case in the eastern part thereof.

The reef outcrops are drained on surface by several tributaries of the Klip River following a roughly north to south direction and draining the parallel ridges to the north of the outcrop. As these streams cross, and in places run parallel to the reef outcrop, it is inevitable that surface stream loss will occur through the backfilled and disturbed mined-out areas. This is regarded as a major contributor to the recharge of the mine void. This was confirmed by site visits throughout the year, where visible reductions of the flow in the streams were observed. The Klip River has four main tributaries that cross the various reef outcrops. Based on preliminary field estimates the stream losses and salt loading to the underground workings are shown in Table 3.9 (Krige, 2001).

Table 3.9: Estimated salt balance for Upper Klip River tributaries

Stream	Volume lost to mine void (Ml/day	Estimated average TDS (mg/l)	Salt Load (Ton/day)
Klip River	5.62	425	4.07
Klipspruit	6.92	615	4.26
Natalspruit	8.74	1360	11.89
Elsburgspruit	11.23	2500	28.08
Total	**32.51**		**48.29**

Based on the surface investigations, a groundwater balance was established. It was calculated that stream flow contributes 42% to the total volume of water reaching the underground workings during summer and 50% during winter. The other major contributor is seepage from the perched aquifer, overlying the mine void, which contributes 35% during summer and 45% during winter. The balance of the water reaching the underground workings is derived from open areas such as the outcrop area, open shafts and sinkholes.

The variations in summer and winter volumes are attributed to the variations in rainfall during the wet and dry seasons. One would therefore expect that the stream flow contribution would greatly reduce during the winter as very little rainfall occurs during the winter months. However, it was noted that even during the winter months the stream flow was significant and the conclusion was reached that flow in the streams is not derived from rainfall alone, but that extensive urbanisation is responsible for the bulk of the water flow in all of these streams. In fact, it is estimated that rainfall only contributes to 23% of the flow in the streams.

The groundwater balance for the entire basin is summarised in Table 3.10. It should be noted that stream losses in this balance include losses via geological structures. These, however, have not been quantified.

Table 3.10: Central Rand basin – groundwater balance

Sub - Basin	Holings (Ml/day)	Perched Aquifer (Ml/day)	Surface Streams (Ml/day)	Net Influx (Ml/day)
DRD	1.74	5.71	9.84	17.29
Rand Leases	0.81	4.00	12.12	16.93
Central	14.35	15.30	8.74	38.39
ERPM	5.05	10.00	11.23	26.28
Total Wet Season	**21.95**	**35.01**	**41.93**	**98.89**
DRD	0.25	5.71	8.4	14.41
Rand Leases	0.11	4.00	10.4	14.51
Central	2.03	15.30	8.74	26.07
ERPM	0.72	10.00	11.23	21.95
Total Dry Season	**3.11**	**35.01**	**38.77**	**76.94**

Currently ERPM is pumping an average of 66 Ml/day from Hercules Shaft and 22 Ml/day from South West Vertical Shaft (Fourie, 2001). The latter increased by some 10 Ml/day during August 2001 when the Rand Leases sub – basin started to decant into the Central sub – basin. The water from the DRD sub – basin will decant into the Rand Leases sub – basin in December 2002, which is predicted to increase the pumping volume at ERPM by an additional 17 Ml/day.

3.3.5.5 Current groundwater management procedures

Many mines in the area between ERPM and DRD have been closed or abandoned. Metago (1999) has suggested that pumping from DRD and ERPM maintains water levels over the Central Rand mines (including CMR, Crown Mines Robinson Deep, City Deep, Simmer and Jack, Rose Deep). Water pumped from ERPM's SW vertical shaft is derived from as far west as CMR, however a large portion is believed to be made in the vicinity of Rose Deep and Witwatersrand Gold Mining Company.

<u>Surface water – groundwater interaction</u>

Surface water infiltrates into the underground workings at several places in the Central Rand basin. The DME is currently drawing up a strategic plan to close all these ingress points (van Deventer, 2002). Scott (1995) documented the following occurrences of stream losses to the reefs and surface workings:

- The stream from Bloudam at Amalgam had been channelled since early mining days due to losses to the reef outcrop at Langlaagte.
- Burger (1992) indicated that an estimated 0.37 Ml/day entered the underground workings where the outflow from the Florida Lake (the Klipspruit West) crosses the Bird Reef. Furthermore, an estimated 0.67 Ml/day is lost where the same stream crosses the Main Reef.
- The stream from the Witfield Dam has been reported to loose to the underground workings (Lazig, 1993)

- Much of the water leaving the Florida Lake into the vlei area joining the Florida Lake with the Rand Leases Dam disappears into a heavily mined-out area (Botha, 1993).

From the above as well as from other observations, the following assumptions have been made:

- Losses to the Main Reef outcrops are double the losses to the Bird Reef.
- Losses to the Kimberley Reef outcrop are 25% of the losses to the Bird Reef.
- Losses to the Elsburg and other reef outcrops are negligible.

Scott (1995) estimated that if all streams crossing the reef outcrop, had equal flow rates (equal to the Florida Lake outflow of approximately 2.2 Ml/day), and the above assumptions were followed, 8.22 Ml/day could be derived from streams losing to outcrops. This estimation is, however, considered to be a very conservative figure, since it does not take losses via structures in stream valleys into account. Losses to groundwater derived from this source could be significant and lateral movement from groundwater to the highly transmissive mine aquifer with its steep hydraulic gradient could account for a maximum of 23.05 to 24.30 Ml/day (Scott, 1995).

A total of 32.52 Ml/day can therefore be accounted for using Scott's assumptions. Krige (2001) demonstrates in his report that these assumptions may prove to be quite accurate figures.

Figure 3.21 shows a picture of one of the locations where water disappears from the surface stream into the subsurface. The location of the ingress point shown in Figure 3.19 is where the Klipspruit crosses the Bird Reef (Krige, 2001).

Figure 3.21: Ingress point where water disappears into the ground at the point where the Klipspruit crosses the Bird Reef (Krige, 2001)

3.3.5.6. Conclusions

The closure water management strategy for the Central Rand involves three sub- basins viz. the Central (including Rose Deep) sub-basin, the DRD and Rand Leases sub basin and the ERPM sub-basin. These sub-basins are interconnected but are currently separated by mining pillars and the installation of plugs. Rainfall and stream flow where it crosses the reef outcrops are the predominant sources of water recharge and flooding into the aquifer and mine voids. Recharge rates of 99 Ml/day (summer) and 77 Ml/day in winter have been estimated.

The DME strategy involves closing all the ingress points. This is particularly true of the western (DRD) sub-basin. Many mines are already closed or abandoned in the Central Rand Basin leaving the task of dewatering to only a few mines. Pumping from the two ends (DRD and ERPM) of the central Basin has also been suggested to maintain water levels.

There are also potentially long term surface and ground water pollution problems from decant water and seepage from surface residue deposits.

3.3.6 East Rand Basin

3.3.6.1 Introduction

This basin extends from the eastern boundary of the East Rand Propriety Mines (ERPM) to Heidelberg. Mining in this basin commenced at the Nigel Gold Mine in 1888 (Whiteside et.al., 1976). Currently Grootvlei Mine, Consolidated Modderfontein and Nigel are the only operating mines in the basin. Mines in the East Rand basin are shown in Figure 3.22

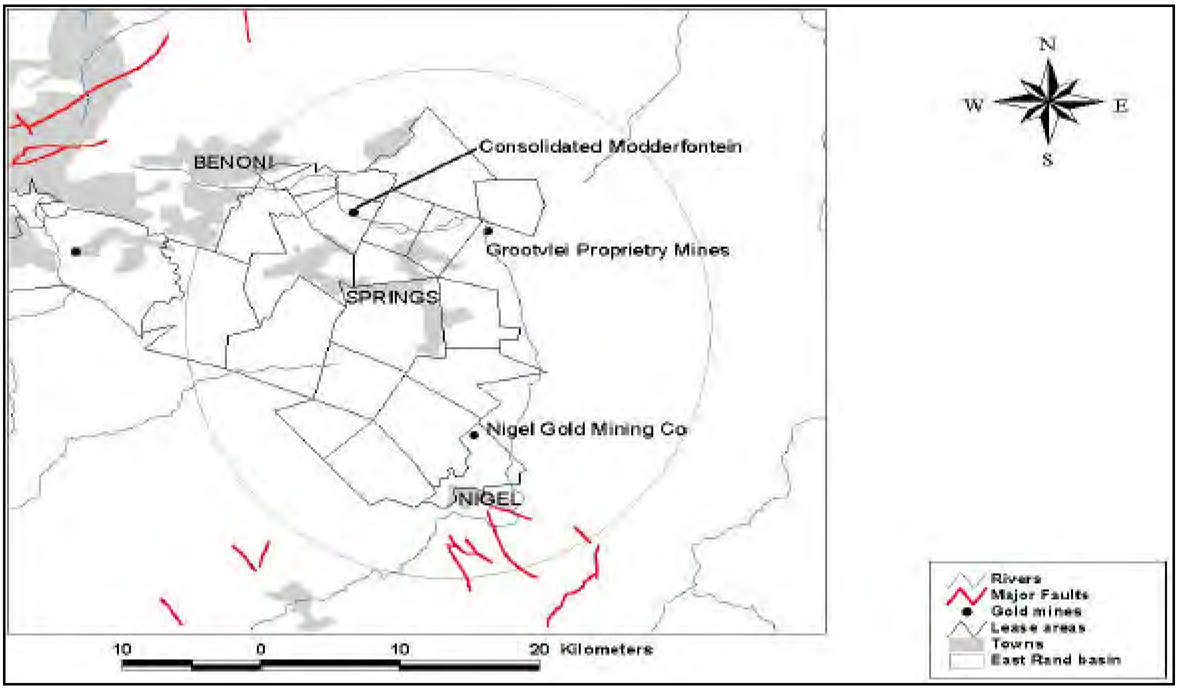


Figure 3.22: Mines in the East Rand basin

3.3.6.2 Geological setting

The thickness of the gold bearing Upper – Witwatersrand formations decreases from approximately 1500m in the north to some 850m in the south of the basin. The general structure of the basin consists of a syncline dipping to the southwest. The Van Dyk Anticline and Marievale Anticline strike NW-SE with steep gradients on their southwestern flanks. A third major structure is the Vogel Shear Fault that displaces the gold bearing reefs by some 900m on the eastern side.

The Ventersdorp lava overlies the Witwatersrand rocks in the central part of the basin, but is limited in extent. The overlying Transvaal rocks consist of the Black Reef Formation and the dolomite formations. These are mainly restricted to the central and eastern portions of the basin. The dolomite is seldom thicker than 450m. The Black Reef Formation has been mined by the Government Gold Mining Areas, Geduld Propriety Mines and Modderfontein Deep Levels (Whiteside et.al., 1976).

Most of the area is covered by Karoo lithologies such as clay, shale sandstone carbonaceous shale and coal. Mining of coal seams has taken place in the area. The Karoo succession seldom exceeds a thickness of 75m. Intrusive rocks, ranging in age between Ventersdorp to post – Karoo, are widespread throughout the area - see Figure 3.23 below.

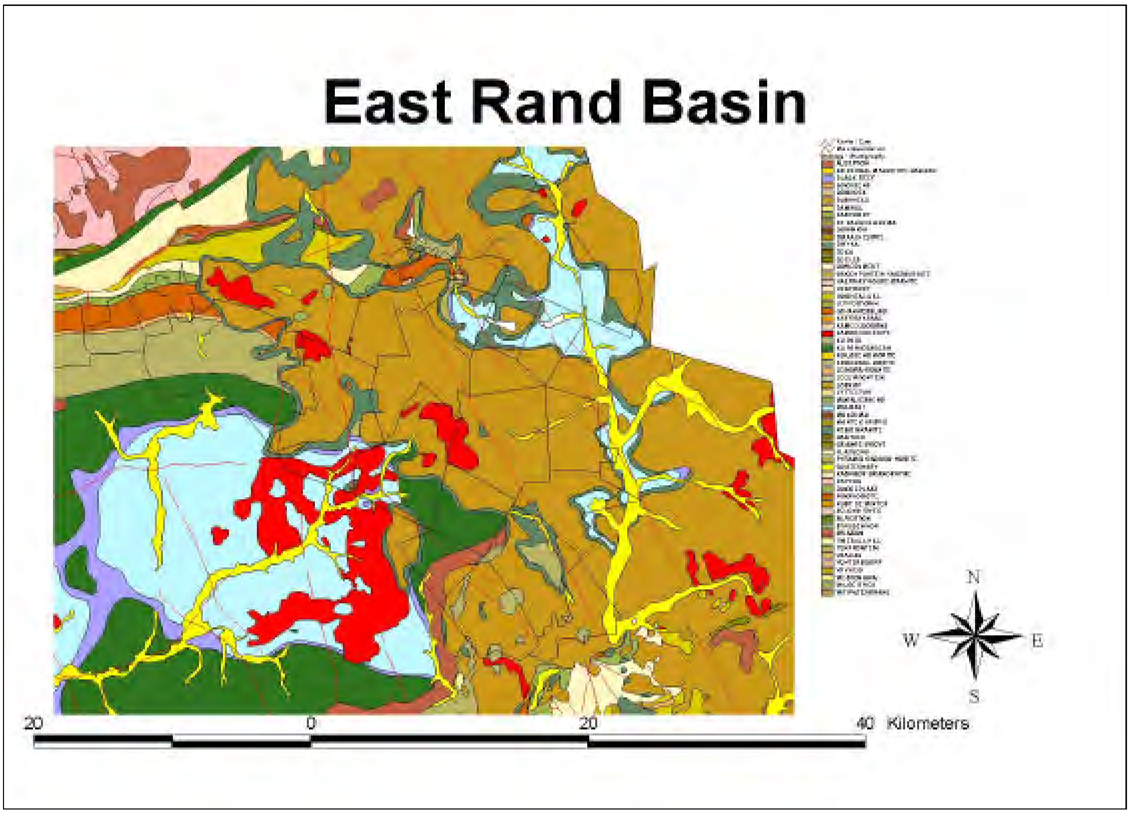


Figure 3.23: Geological setting of the East Rand basin

3.3.6.3 Geohydrological boundaries and interconnectivity between sub-basins

The East Rand Basin consists of several mines, all of which are interconnected. The Boksburg Gap separates the East Rand Basin from the Central Basin. Grootvlei is currently the only operating underground mine in the basin pumping water from the basin. Some opencast mining is taking place at Consolidated Modderfontein mine.

Grootvlei is currently pumping in the order of 90 Ml/day, but records of water ingress into these mines date back to 1909 when Grootvlei abandoned the sinking of their No. 1 Shaft at 112 metres due to an estimated 10 Ml/day ingress. Table 3.11 shows the average pumping rate from the East Rand mines since 1916.

Table 3.11: Pumping rates to dewater East Rand mines

Period	Pumping Rate (Ml/day)
1916 to 1920	38
1925 to 1931	31
1952 to 1959	93
1983 to 1986	58.22
1987 to 1990	63.65
1990- now	90

The increase in pumped volume in the 1950's was due to the fact that the number of mining companies increased. This was the time of the greatest mining activity on the East Rand. The mining depth increased, as did the cone of influence, drawing on a wider and thus greater source of water. When mining stops the reverse will happen, in other words the rate of recharge will reduce as the mines fill up. As mining developed and the underground operations became interlinked, so the task of dewatering was carried by fewer mines. Those mines operating in the deeper parts of the basin had to continuously pump large volumes of water, while those located nearer the perimeter of the basin pumped relatively insignificant volumes.

3.3.6.4 Aquifer description

Two distinct dolomite aquifers occur in the study region:

- One in the northern part of the area overlies the Witwatersrand sediments, it is up to 200m thick (Briggs, 1992). A prominent set of sills occurs in this dolomite below 60m, referred to as the Green Sill. These sills have resulted in the development of a perched water table characterised by relatively shallow water levels. Major fissures occur from the dolomites into the mine workings. These are more significant in Black Reef workings since much of the off reef development is in dolomite.

- The other occurs in the south-western portion of the area, this dolomite aquifer overlies the Ventersdorp Supergroup rocks which forms a hydraulic barrier between it and the Witwatersrand sediments. The Witwatersrand sediments have not been mined in this area since it is a barren part of the basin, referred to as the Boksburg Gap. These dolomites are cavernous in places with sinkhole development adjacent to the Alberton/Heidelberg road. These sinkholes are not related to mine dewatering, but, according to Brink (1979), have developed due to poor run-off control and water accumulation in borrow pits adjacent to the paved road surface. Because this dolomitic aquifer plays little part in inflows into the mines, most of the attention has been focused on the northern aquifer.

3.3.6.5 Current groundwater management procedures

Several investigations into the geohydrological setting have been undertaken in the past, the most prominent that of Scott in 1995. The Grootvlei mine also undertook a number of investigations, specifically to identify the positions and sources of groundwater inflow (Griffiths, 1994). It appears that the bulk of the groundwater inflow manifests itself in the underground workings as a diffuse source. This is attributed to the fact that mining induced fractures link with water conduits, obscuring the exact inflow position. Several investigations to date, including Scott, attempted to quantify the inflow into the basin. Most of the conclusions, however, were based on the recorded pumping rates and although reference is made to the possibility of recirculating the water, no attempt has yet been made to quantify this postulation. Rison Groundwater Consulting (2002) did calculate a groundwater balance based on measured and calculated recharge parameters. This groundwater balance included the possibility of water circulation and can be summarised as follows.

The surface and near-surface geology of the Grootvlei region consists of a variety of rock types, each with its own hydrogeological characteristics (Figure 3.22). It is important to note the large number of mapped geological disturbances bisecting the Blesbokspruit and of specific importance is where this is underlain by dolomite. Based on the geology of the region and investigations in similar terrains, recharge to the groundwater was calculated (Table 3.12).

Table 3.12: East Rand basin – groundwater balance

Month	Calculated Recharge Ml/day	Pumping Rates Ml/day	Difference Ml/day
January	156.29	73.63	-82.66
February	115.37	81.63	-34.10
March	108.57	99.03	-9.54
April	58.46	103.73	45.27
May	22.67	107.90	85.23
June	9.54	84.90	75.36
July	8.35	90.00	81.65
August	7.16	69.20	62.04
September	27.44	66.63	39.19
October	83.52	79.40	-4.12
November	141.98	94.17	-47.81
December	134.82	90.17	-44.65
Average	**72.88**	**86.70**	**13.82**

The average calculated recharge rate (based on rainfall records and rock characteristics) compares favourably with the average pumping rates. This is an indication that the basic assumptions in calculating the groundwater balance are correct. The following deductions can be made with reference to Table 3.12.

- The highest recharge volume occurs during January, but the highest recorded pumping volumes occur during May. A three-month lag is therefore noticed. This suggests that recharge to the mine void is dampened by the overlying aquifers, probably the dolomite aquifer. The transmissivity at the base of this aquifer is regarded as relatively low, based on the fact that the aquifer is not dewatered. There is, however, still a link with the underlying mine workings resulting in a fairly constant inflow rate into the mine, even during dry cycles.

- This link is believed to be the faults cutting through the Blesbokspruit. It is estimated that recirculation via geological features can be as high as 32 Ml/day. This assumption is based on long-term monitoring that was conducted in the Far Western Dolomite basins where losses of up to 30% were measured. At a maximum pumping rate of 107 Ml/day (see Table 4.8) this amounts to 32 Ml/day.
- Ideally the flow rates within the Blesbokspruit should be measured, but due to the flow profile of the stream such measurements will be inaccurate. The following investigations are proposed to quantify potential leakage via geological features.
  - Flow measurements where possible.
  - The pumping rates, void volume and groundwater recharge parameters should be incorporated into a calibrated groundwater model.

3.3.6.6 Surface water – groundwater interaction

The current rate of abstraction from Grootvlei is 80 Ml/day (du Preez, 2002). Scott (1995) suggests that 64 Ml/day of water is made in the East Rand Mines.

Surface water infiltrates into the underground at several places in the East Rand basin. Du Preez (2002) suggests that water from the Kels dam and Blesbokspruit infiltrates into the dolomitic aquifer (approximately 30 Ml/day) and seeps into the deep underground workings from where water is pumped out.

When Grootvlei pumping ceases at closure, the basin will fill and the water will decant on surface at a low point on the surface, namely the No 3 shaft at Southgo Mine in the Nigel area (Scott, 1995). After pumping ceases, groundwater from Consolidated Modderfontein Mines will establish pathways to the exit point at Nigel (Consolidated Modderfontein Mines, 2000). The initial water quality will be of a poor, but indeterminate quality and can be expected to improve (albeit in an unquantified manner) over the long term.

3.3.6.7 Conclusions

The East Rand Basin also consists of interconnected underground gold mines which are separated from the Central basin by the “Boksburg gap”, which is just an unmined area. The task of dewatering is carried by only a few remaining mines, with the most significant volumes coming from the deeper mines. Two distinct dolomitic aquifers occur in this region, however, the northern aquifer plays the predominant role in terms of inflow to the gold mines. This inflow is attributed to mining induced fractures which obscure the exact inflow positions. The link is however believed to be the faults cutting across the Blesbokspruit. The area will decant once pumping ceases and groundwater will exit at Nigel.

3.3.7 Evander goldfield

3.3.7.1 Introduction

The Evander goldfield, which is situated near the town of Kinross, is a fault – bounded sub – basin of the Witwatersrand Basin. Mining in this basin only started towards the end of 1955 (Whiteside et.al., 1976) at the Winkelhaak Mine. The mines that were registered during that time included the Winkelhaak Mine, Bracken Mine, Leslie Gold Mine and Kinross Gold Mine. Currently the remaining operating mines all belong to the Harmony Group. Figure 3.24 shows the mine boundaries and geological faults in the Evander goldfield.

3.3.7.2 Geological setting

The flat lying, horizontal shale and sandstone layers of the Karoo Supergroup cover the gold bearing Witwatersrand strata. The Karoo thickness varies between 70m to 220m. The Witwatersrand rocks dip towards the north where the Ventersdorp lava, Transvaal Dolomite and Black Reef also cover it. The Witwatersrand strata has a minimum thickness of 1052m, the Upper Witwatersrand is approximately 625m thick (Whiteside *et.al*., 1976).

The Evander goldfield is situated on the southern edge of a northerly dipping arch that extends 24km east – west. The northern boundary of the basin has not been established with certainty due to the considerable depth. The gold deposition has been affected by flat dipping normal faults with a NE-SW and N-S strike. These faults have in places been displaced by E-W orientated, steeply dipping normal faults. Some of these faults have a significant horizontal movement, with the displacement in a northerly direction. The south-eastern edge of the basin is bounded by an ENE-WSW fault, dipping to the north. Most of the faults in the basin are believed to be of Post – Ventersdorp and Pre – Transvaal age, although some have been reactivated during Post – Transvaal and Post – Karoo age.

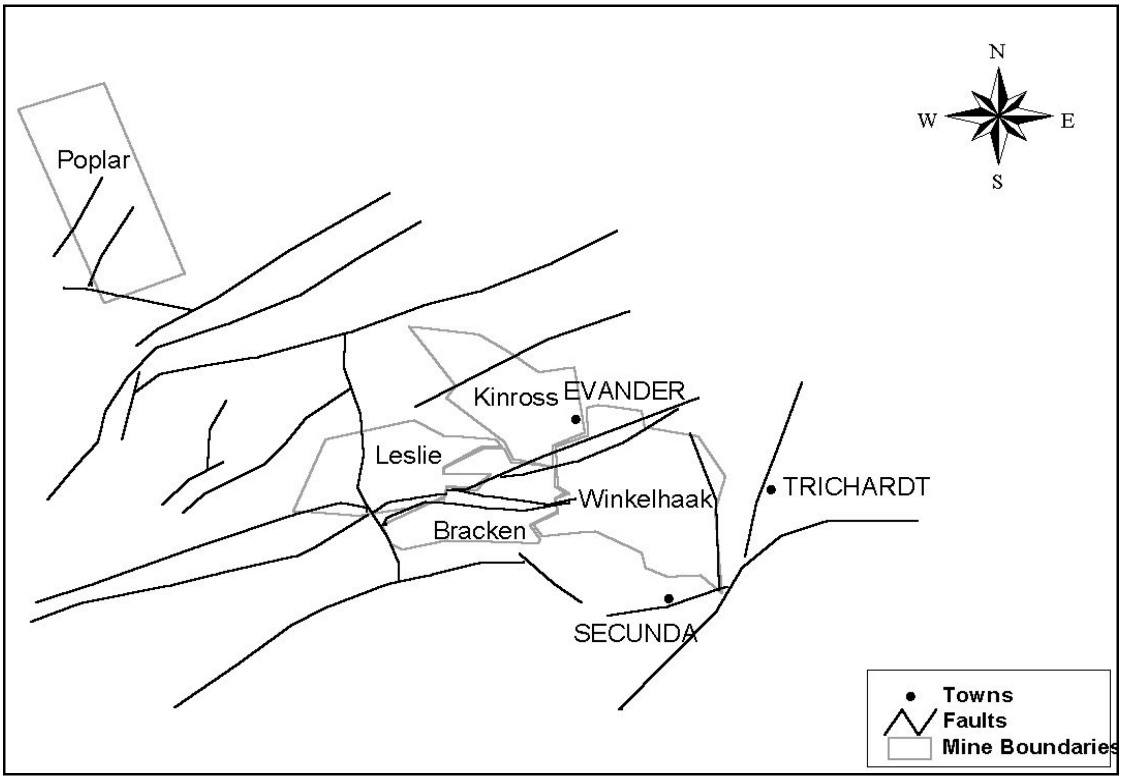


Figure 3.24: Evander gold mines

3.3.7.3 Geohydrological boundaries and interconnectivity between sub-basins

The Evander Basin is a structurally controlled gold deposit and the geohydrological boundaries are marked by faults that truncated the gold deposition, hence affecting the extent of mining. All the mines in the area belong to the Harmony group and all shafts are linked through underground workings.

3.3.7.4 Aquifer description

The nature of the geological formations suggests that the following important concepts should be considered.

There may be as many as three aquifers present in the area. It is expected that a near surface, perched aquifer may be present within the Karoo rocks. This aquifer would be unconfined and recharged by rainfall. The Karoo aquifer is situated above the dolerite sills that are prominent in the Evander area. The groundwater levels are described as very shallow, varying between 0m – 20m below surface. The groundwater levels within this perched aquifer have not been affected by mining, i.e. the aquifer has not been dewatered. An aquifer within the underlying dolomite may also be present. Dolomite aquifers are characterised by huge storage capacities and high transmissivity. This aquifer will be confined or semi – confined and recharge will mainly be via geological structures. The existence of a Witwatersrand connate aquifer, such as is found in the Free State Goldfield, is also possible. This aquifer is likely to be confined, although recharge from the overlying dolomite and Karoo aquifers may be possible. The groundwater quality in such an aquifer is usually characterised by saline water.

The abovementioned aquifers may or may not be hydraulically connected. The thick shale successions within the Karoo Supergroup, the "Green Sill" and other dolerite sills that are extensive over the area and the Dwyka Tillite are all low to impermeable zones that may reduce the recharge to the underlying dolomite aquifer. The dolomite aquifer is normally restricted to the upper 200m of the dolomite succession, where weathering is most extensive. The non – weathered dolomite is largely impermeable and groundwater flow is restricted to faults and fractures. The presence of the Ventersdorp lava is also a critical issue since it was found at other, similar mines, that groundwater inflow from the overlying dolomite is more pronounced in areas where the lava is absent. The lava, where present, would therefore form a significant barrier between overlying aquifers and the mined – out aquifer.

3.3.7.5 Current groundwater management procedures

There is currently no detailed groundwater management program in place, other than the monitoring of potential contamination from surface sources such as tailings dams.

3.3.7.6 Conclusions

The Evander goldfield groundwater management strategy will need to be integrated across the area since all the gold mines in Evander belong to one mining group and all the shafts are linked through underground workings. There may be three aquifers present in this area that may or may not be interconnected. They include an unconfined Karoo perched aquifer close to the surface; a confined or semi- confined aquifer within the underlying dolomite and the possibility of a confined Witwatersrand connate aquifer. The latter is usually characterised by saline water. A critical issue here is the presence of the Ventersdorp lava within this basin, which would form a barrier between the overlying aquifers and the mined out barrier.

3.4 NON-WITWATERSRAND BASIN

This section covers the Pilgrims Rest, Barberton and Kwazulu Natal (Klipwal) mining areas. Information has not been readily available and is limited for these last three regions. Moreover, a review of their geohydrological profiles indicates that these gold fields could each be managed as individual regional units with respect to closure planning. Pilgrims Rest and KwaZulu Natal have only one operational mine in each region. Barberton has eight gold producing regions and over 130 mines. However, these Barberton mines are generally small, single adit operations that could also be managed as a combined unit. Moreover, due to budget constraints and time already spent in attempting to fill in the data gaps for these regions, it was decided that this aspect would not be further pursued. However, it is recommended that a separate study be conducted to better understand the interconnections and groundwater interactions of the Barberton mines.

3.5 SUMMARY

A summary of the key elements raised in this situation assessment is presented in Table 3.13 below.

Table 3.13: Geohydrological assessment data summary for closure planning of underground gold mines

Goldfield	Free State	KOSH	Far West Rand	West Rand	Central Rand	East Rand	Evander	Pilgrims Rest	Barberton	KZN
Water Management Area	Middle Vaal	Middle Vaal	Upper Vaal	Upper Vaal	Upper Vaal	Upper Vaal	Upper Vaal	Olifants	Inkomati	Usutu to Mhlathuze
Geo-hydrological groundwater management units	5	1	3	1	3	1	1	1	1	1
Decanting	Not likely	Yes	Likely	Yes	Yes	Yes	No	Likely	Some	Unlikely
Decant rate	0	17-50 Ml/day	?	Estimated at 17 Ml/d	17 Ml/d	?	-	-	-	-
Physical instability (Subsidence/ sinkholes)	No	Yes	Yes	Yes	Yes	Yes	No	No	No	No
Pumping of flooded mines	Yes	Yes	Yes	Being flooded	Yes	Yes	No	No	Some	Yes
Pumping rates	34 Ml/d	Stilfontein	>150 Ml/d	-	99 Ml/d (summer)	90 Ml/d	-	-	-	-
Strong surface-groundwater interactions	Hydrochemical pollution sources (such as waste dumps, evaporation dams and slimes dams) Saline water pumped from deep connate aquifer and surface evaporated (Free State mines) Recharge water degradation of dolomites Transport routes such as surface run-off, primary aquifers, dolomitic aquifers, fractured rock aquifers and geological features such as faults and dykes									
Chemical stability (water quality e.g. AMD problems	A positive correlation exists between gold grade and the modal proportion of potentially acid producing sulphide minerals. Furthermore, gold grade correlates positively with the reef thickness. Thus by making use of isopach maps showing the distribution of reef thickness, meaningful planning and delineation of areas with a high acid producing potential is possible.									

? = missing data

Table 3.14 presents a summary of all the 17 different groundwater units or regions that have been identified for the South African gold mining industry in this chapter.

Table 3.14: Geohydrological units (regions) for South African gold mines

Area	Geohydrological Unit	Mine
KOSH	KOSH	Stilfontein, Hartebeestfontein & Buffelsfontein
	KOSH	Vaal River Operations & ARM
Free State	Odendaalsrus sub basin	Target, Jeanette, Tshepong & PS North
	Welkom sub basin	PS South, St Helena, P Brand, Unisel, Matjhabeng, Banbanani & ARM
	Virginia sub basin	Harmony original, Old Virginia, Old Saaiplaas, Old Erfdeel, Old Merriespruit
	Oryx	Oryx
	Theunissen sub basin	Joel & Beatrix
Far West Rand	Western sub basin	Deelkraal, Driefontein, Blyvooruitzicht, Western Deep & Elandsrand
	Central sub basin	Kloof
		Venterspost, Libanon
	Eastern sub basin	Placer Dome
		Harmony Cooke
Barberton	Barberton	New Consort
	Barberton	Sheba
	Barberton	Fairview, Agnes
Evander	Evander	Winkelhaak, Bracken, Leslie & Kinross
West Rand	West Rand	Randfontein Operations & West Wits
Central Rand	DRD and Rand Leases	DRD, 5A shaft & Rand Leases
	Central	CMR, Crown, Rose Deep & City Deep
	ERPM	ERPM
East Rand	East Rand	Grootvlei & Modderfontein, Nigel
Pilgrim’s Rest	Pilgrim’s Rest	Transvaal Gold Mining Estate

4. STATUS OF GOLD MINE CLOSURE PLANNING - REVIEW OF EMPs

A review of the Environmental Management Programme Reports (EMPRs) for each of the operating gold mines was conducted. In particular, sections 5 and 6 of the EMPRs, which describe the decommissioning and closure phases, were examined for this situation assessment. Note that in terms of the Minerals and Petroleum Resources Development Act of 2002, EMPRs are now referred to as EMPs (Environmental Management Plans).

A distinction should be made between surface impacts and underground impacts. Surface impacts are mostly from tailings and rock dumps and adversely affect the groundwater and surface water quality. This occurs during the operational phase as well as after closure. Underground impacts are generally characterised by the inflow of water into the underground workings and the subsequent dewatering of the aquifer.

A review of the individual mine EMPR documents has shown that groundwater management is very seldom described in any detail and that groundwater monitoring is at best ad hoc. The following discussion of the EMPR documents illustrates the deficiencies in closure planning with regard to long-term groundwater and surface water issues on South African gold mines.

4.1 FREE STATE PROVINCE

EMPR documentation from the following mines in the Free State Province was examined.

Table 4.1: Free State province gold mines

District	Mine	Owner	Status
Welkom Goldfield	Pres. Brand No.1, 2, 3 and 5 Shafts	Harmony Gold Mining Ltd.	Operating
	Unisel Gold Mine	Harmony Gold Mining Ltd.	Operating
	Loraine Gold Mine	Avgold	Operating
	Loraine Gold Mine – Target Division	Avgold	Operating
	St. Helena Gold Mine	Gold Fields Ltd	Operating
	African Rainbow Minerals	African Rainbow Minerals	Operating
Southern Free State Goldfield	Oryx Gold Mine	Gold Fields Ltd	Operating
	Beatrix Gold Mine	Gold Fields Ltd	Operating
	Joel Gold Mine	Anglogold	Operating

The mines in the Free State Goldfields have to address the potential contamination of a shallow, good quality water, Karoo aquifer. Contamination of this aquifer can occur through the residue deposition on surface or through the evaporation of saline water pumped from the deep Witwatersrand aquifer.

4.1.1 Mine infrastructure

The perception derived from the EMPR documents is that the surface residue deposits such as tailings dams do not have a significant impact on the groundwater quality. This is mainly due to the foundation material (Karoo strata) being fairly impervious. A number of mines therefore make the assumption that groundwater contamination will be limited to the immediate vicinity of the tailings dams. Specialist investigations at the Loraine mines mainly agree with this postulation, but have also shown that preferential flowpaths can increase the migration rate and extent of the contamination.

Although most of the mines acknowledge the usefulness of specialist investigations to better understand groundwater and contaminant migration, it appears that only Loraine and Oryx have attempted to utilise long-term prediction techniques.

The potential groundwater contamination from surface infrastructure such as the metallurgical plants, domestic and industrial waste sites is not described in any of the EMPR's.

The current status of closure planning to reduce the groundwater impact from surface contaminant sources, as described in the EMPR documents, is summarised in Table 4.2.

4.1.2 Flooding of mine workings.

Most of the Free State mines are plagued by the inflow of extraneous saline water from a deep connate aquifer that is dewatered and evaporated at surface. After cessation of mining the EMPRs state that the workings will flood, but that the water table will stabilise below the Karoo strata and that none of this water will decant from any of the shafts. Although this statement is probably correct there is no reference to any geohydrological investigation confirming this (also refer to section 3.3.1.6)

4.1.3 Groundwater monitoring.

There is an indication that groundwater monitoring is conducted on a regular basis at most of the Free State mines. The frequency of monitoring and the monitoring programs after closure are, however, not clearly stipulated.

Table 4.2: Status of closure planning (in EMPRs) to reduce groundwater impact from surface contaminant sources – Free State province

Mine	Perceived Impacts after Closure			Amelioration and Preventative Measures		
	Tailings Dams	Rock Dumps	Evaporation / Return Water Dams	Tailings Dams	Rock Dumps	Evaporation / Return Water Dams
Pres. Brand No.1, 2, 3 and 5 Shafts	Harmony Brand Shafts do not operate any tailings dams.	AMD is anticipated, but the long-term effect cannot be quantified.	Not Applicable.	Not Applicable.	-Groundwater monitoring should continue. -The source will be permanently removed, which will lead to a gradual improvement of the water quality.	Not Applicable.
Unisel Gold Mine	Due to the fact that Unisel has no tailings dams, which is the main contributor to AMD, there will be no AMD.	The size of the material as well as the low erodibility of the rock will reduce AMD to very small quantities.	No evaporation dams on the property.	Not Applicable.	-Impact perceived to be very low. -Rock dumps may be sold to 3rd party.	Not Applicable.

Table 4.2: Status of closure planning (in EMPRs) to reduce groundwater impact from surface contaminant sources – Free State province - continued

Mine	Perceived Impacts after Closure			Amelioration and Preventative Measures		
	Tailings Dams	Rock Dumps	Evaporation / Return Water Dams	Tailings Dams	Rock Dumps	Evaporation / Return Water Dams
Loraine Gold Mine	-Contamination is usually contained within close proximity of the site, but depends on the age of the site as well as the groundwater gradients. -Although Karoo sediments (Ecca) are relatively impermeable, limited spread of pollution is possible. Preferential pathways can accelerate the rate and extent of the pollution.		Included in tailings dam management.	-Detailed specialist investigations were undertaken to better understand groundwater movement and measures were implemented accordingly.		Included in tailings dam management.
Loraine Gold Mine – Target Division	-The potential for AMD is a significant residual impact of the Mine's waste disposal system. -Preliminary predictions on migration rates suggest a contaminant plume up to a distance of 2km away from the tailings dam.	Rock dumps will continue to generate poor quality seepage from rainwater percolating through the rock pile. However, as oxidation is limited to the surface of coarse waste rock particles, the pollution threat is less severe than in tailings dams.	Included in tailings dam management.	-Detailed specialist investigations are undertaken to better understand groundwater movement and to implement measures accordingly.		Included in tailings dam management.
St. Helena Gold Mine	The potential for AMD exists. However, the pollution spread from the tailings dams is limited to the immediate vicinity due to the fact that the dam is situated on the Ecca Group (clay material).	Potential long – term impacts on groundwater not described	Boreholes west of the tailings dam show contamination due to the evaporation system.	The position and location of the dam and the fact that it will be vegetated suggests that the generation and spread of AMD will be reduced.	Waste rock dumps may be sold to 3rd parties for re-working.	After closure the evaporation dams will no longer be used and groundwater quality should improve.
African Rainbow Minerals	After closure no more slimes will be deposited, thus eliminating the major source of recharge (with saline water) to the aquifer. A general improvement of the overall water quality and a decrease in seepage flow from the tailings dam is expected to occur in the long term.	Potential long – term impacts on groundwater not described	Potential long – term impacts on groundwater not described	-Rehabilitation and grassing will reduce infiltration. -Monitoring will continue. -Geohydrological study is in progress to predict long-term impacts.	No Mention	No Mention
Oryx Gold Mine	-The potential for AMD after closure is a real possibility. -Contaminant plumes are currently present.	-The potential for AMD after closure is a real possibility.	-Contaminant plumes are currently present.	-Long-term impacts not clearly understood. -Recommend continued monitoring, seepage control and geohydrological investigations		

Table 4.2: Status of closure planning (in EMPRs) to reduce groundwater impact from surface contaminant sources – Free State province - continued

Mine	Perceived Impacts after Closure			Amelioration and Preventative Measures		
	Tailings Dams	Rock Dumps	Evaporation / Return Water Dams	Tailings Dams	Rock Dumps	Evaporation / Return Water Dams
Beatrix Gold Mine	-A potential for AMD after closure exists. -It is predicted that the dolerite sill, draining east to the Theronspruit, will control groundwater contamination. -An impact on the Sandriver may also be possible.	-A potential for AMD after closure exists.	Poor quality seepage will affect groundwater quality.	-Interception measures were implemented to collect seepage. -Continued long-term monitoring.	-Continued long-term monitoring.	-Continued long-term monitoring. -Decommissioning of the dams will improve water quality.
Joel Gold Mine	-The potential for AMD after closure exists. -Contaminant plumes are currently present.	-A potential for AMD after closure exists.	Poor quality seepage will affect groundwater quality.	-Recommend continued monitoring, seepage control and the separation of clean and dirty water.	-Recommend continued monitoring, seepage control and the separation of clean and dirty water	-Recommend continued monitoring, seepage control and the separation of clean and dirty water

4.2 NORTH WEST PROVINCE

EMPR documentation from the following mines in the North West Province was examined. The North West Province includes two of the gold mine areas identified for this project namely: KOSH and Far West Rand.

Table 4.3: North West province gold mines

District	Mine	Owner	Status	Comment
KOSH Area	Vaal River Operations	Anglogold	Operating	
	African Rainbow Minerals & Exploration (Pty) Ltd.	ARM	Operating	
	Buffelsfontein Section	DRD Ltd	Operating	
	Hartebeestfontein Section	DRD Ltd	Operating	
	Stilfontein Gold Mine	Mine Waste Solutions	Operating	Reprocessing of No. 2 Tailings Dam
Far West Rand	Deelkraal Gold Mine	Harmony	Operating	
	Elandsrand Gold Mine	Harmony	Operating	
	West Wits Operations – Western Deep Levels	Anglogold	Operating	
	Driefontein Consolidated	Gold Fields Ltd	Operating	
	Blyvooruitzicht Section	DRD Ltd	Operating	
	Kloof Gold Mine	Gold Fields Ltd	Operating	Kloof, Libanon and Venterspost now operating as Kloof Gold Mine
	Libanon Gold Mine			
	Leeudoorn Mine	Gold Fields Ltd	Operating	
	Western Areas	Placer Dome Western Areas Joint Venture	Operating	Gauteng Province
	Randfontein Estates	Harmony	Operating	Gauteng Province

Two significant mining impacts on the groundwater can be distinguished. The first is the potential for Acid Mine Drainage (AMD) from mine infrastructure, notably from tailings dams, rock dumps and return water dams. Acid generation is caused by the exposure of rock containing certain sulphide minerals, most commonly pyrite (FeS_2), to air and water, resulting in the production of acidity and elevated concentrations of sulphate and metals. Tailings dam material with AMD potential will have water quality implications during the operational and post – closure phases of the tailings dam (Mine Waste Solutions EMPR). The pH of the penstock and interstitial water percolating into the tailings dam will always be neutral to alkaline during the operational phase. This implies that the seepage quality produced during the operational phase will be neutral to alkaline pH and that the sulphate levels will be slightly elevated due to sulphide oxidation at the surface of the tailings dam. At closure the phreatic surface will subside and aerobic conditions will prevail at the top 1 to 1.5m of the tailings dam. AMD will actively take place in this zone and will be mobilised by rainfall recharge to the tailings dam. Low pH associated with high metal and sulphate concentrations characterise the interstitial water. Since the subsidence of the phreatic level will be quicker than rainfall recharge and it can take between 30 – 100 years for the AMD to reach the bottom of the tailings dam.

Geochemical investigations will enable a more accurate estimate of the AMD process. The second impact will result from the flooding of the mine workings after closure and the potential decant from certain shaft areas.

4.2.1 KOSH area

4.2.1.1 Mine infrastructure.

It appears that the general consensus by all the mining companies is that after closure of the mining operations the deposition of slimes will cease, resulting in a general improvement in the groundwater quality due to a reduction of seepage volumes. The potential groundwater contamination from surface infrastructure such as the metallurgical plants, domestic and industrial waste sites is not described in any of the EMPR's. The current status of closure planning to reduce the groundwater impact from surface contaminant sources, as described in the KOSH EMPR documents, is summarised in Table 4.4.

4.2.1.2 Flooding of mine workings.

The only EMPR that recognises the potential impact from mine water decant is DRD's Buffelsfontein and Hartebeestfontein (refer to Section 3.3.2.5). However, no clear management strategy to deal with the decant water is described in the EMPR document.

4.2.1.3 Groundwater monitoring.

Although some EMPR's refer to groundwater monitoring data the current and closure monitoring and auditing program is not clearly stipulated.

Table 4.4: Status of closure planning to reduce groundwater impact from surface contaminant sources – KOSH area

Mine	Perceived Impacts after Closure			Mitigation and Preventative Measures		
	Tailings Dams	Rock Dumps	Evaporation / Return Water Dams	Tailings Dams	Rock Dumps	Evaporation / Return Water Dams
Vaal River Operations	Reduction in recharge and improvement in quality.	No mention	No Mention	Further Investigations. Tailings dams will be grassed to reduce impacts.	No mention	No Mention
Buffels-fontein and Hartebeest-fontein	Seepage from Buffelsfontein tailings dams to the Vaal River has occurred in the past. After closure the quantity of leachate will reduce and groundwater quality will improve.	The rock dumps represents a source for AMD but has not created groundwater contamination to date.	The Evaporation Dam at Buffelsfontein and paddy fields at Hartebeesfontein are seen as contaminant sources.	Seepage currently controlled by dewatering boreholes adjacent to tailings dams.	Dumps will be processed and source removed.	The evaporation dam seeps into underground workings and is addressed under decant.
ARM	General improvement in groundwater quality and decrease in seepage volume.	No mention	Return Water Dams the responsibility of Vaal River Operations	No mention	No mention	Return Water Dams the responsibility of Vaal River Operations
Stilfontein Gold Mine – Mine Waste Solutions	The re-mining of the No.2 Dam and subsequent re-commissioning of the No.5 Dam will impact on the groundwater quality south of No.5 Dam. Seepage will be via a perched aquifer to the dolomite aquifer. The decommissioning and closure of No. 5 Dam will reduce the potential effect on the groundwater.	Not Applicable	Not Applicable	Rehabilitation will include reshaping of the site to promote run-off, topsoil and vegetation cover. This will reduce recharge significantly and improve groundwater quality.	Not Applicable	Not Applicable

4.2.2 Far West Rand

4.2.2.1 Mine infrastructure

Most of the mine EMPRs acknowledge the fact that mine residue deposits such as tailings dams and rock dumps have a detrimental affect on the groundwater, but none commented on the likely long – term changes in groundwater flow and quality after closure. The potential groundwater contamination from surface infrastructure such as the metallurgical plants, domestic and industrial waste sites is not described in any of the EMPR's. The current status of closure planning to reduce the groundwater impact from surface contaminant sources, as described in the Far West Rand EMPR documents, is summarised in Table 4.5

4.2.2.2 Dewatering of dolomite aquifers and flooding of mine workings

The Far West Rand mines are mainly situated underneath Dolomitic aquifers. The dewatering of the groundwater compartments and the subsequent lowering of the groundwater levels has resulted in sinkhole formations and widespread ground stability problems (also refer to section 3.4.1.5). However, none of the EMPR's discuss the potential impacts from flooding and decant, if any, after closure.

Table 4.5: Status of closure planning to reduce groundwater impact from surface contaminant sources – Far West Rand

Mine	Perceived Impacts after Closure			Mitigation and Preventative Measures		
	Tailings Dams	Rock Dumps	Evap./ Return Water Dams	Tailings Dams	Rock Dumps	Evaporation / Return Water Dams
Deelkraal Gold Mine	Potential long – term impacts on groundwater not described.	Potential long – term impacts on groundwater not described.	Potential long – term impacts on groundwater not described.	-Tailings dams to be grassed to reduce impacts. -Groundwater monitoring will continue.	No mention	No mention
West Driefontein	-Tailings dam are likely to generate acid seepage after closure, the duration depending on the available sulphide mass and management activities to control infiltration. -No data are presently available on the quality of seepage from dams.	-AMD emanating from Carbon Leader sorted waste rock dump. -No. 2 Shaft rock dump has high AMD potential and is situated in a watercourse.	Potential long – term impacts on groundwater not described.	The implementation of groundwater monitoring programs is in progress.	- The implementation of groundwater monitoring programs is in progress. -Dumps will be processed and source removed.	No Mention
East Driefontein	-Tailings dam are likely to generate acid seepage after closure, the duration depending on the available sulphide mass and management activities to control infiltration. -No. 1 and 2 tailings dams are situated on dolomite. The high permeability of the foundation is likely to result in groundwater contamination.	-No.1 Shaft E rock dump is situated close to a sinkhole and run-off may contaminate groundwater. -No. 2 Shaft E rock dump has potential for AMD.	Potential long – term impacts on groundwater not described.	Groundwater monitoring and auditing system to be implemented.	Groundwater monitoring and auditing system to be implemented.	No Mention
Blyvoor-uitzicht Gold Mine	Potential long – term impacts on groundwater not described.	Potential long – term impacts on groundwater not described.	Potential long – term impacts on groundwater not described.	Seepage will be controlled by the pollution control dams and paddocks. Monitoring of the effects of the control will be conducted on a regular basis for a period of three years after closure.		
Kloof Gold Mine	-No. 1 tailings dam has affected groundwater quality, effects are likely to continue for many years, but current extent of pollution plume is unknown. -No. 2 tailings dam is less likely to affect groundwater quality as it is on less permeable strata. Contamination of the surface water is, however, a possibility.	The effect of rock dumps on groundwater quality depends on the underlying geological formation, but is likely to be less than tailings dams.	Potential long – term impacts on groundwater not described	-Solution trenches and seepage control facilities will be retained. -Groundwater monitoring boreholes will be retained if necessary, until closure.		No mention

Table 4.5: Status of closure planning to reduce groundwater impact from surface contaminant sources – Far West Rand

Mine	Perceived Impacts after Closure			Mitigation and Preventative Measures		
	Tailings Dams	Rock Dumps	Evap./ Return Water Dams	Tailings Dams	Rock Dumps	Evaporation / Return Water Dams
Libanon Gold Mine (A division of Kloof)	-Southern Tailings dam: Contaminations risk low to shallow aquifer and high to fissure aquifer. -Northern Tailings dam: Contaminations risk medium to shallow aquifer and high to fissure aquifer. -No.1 Shaft Tailings dam: Contaminations risk medium to shallow aquifer and high to fissure aquifer.	-Southern Rock Dump: Contaminations risk low to shallow aquifer and high to fissure aquifer. -No.1 Shaft Rock Dump: Contaminations risk medium to shallow aquifer and high to fissure	Potential long – term impacts on groundwater not described	-Design water-monitoring system and install boreholes. -Monitor quality and plume movement.	-Design water-monitoring system and install boreholes. -Monitor quality and plume movement.	No mention
Leeudoorn Gold Mine (A division of Kloof)	Potential long – term impacts on groundwater not described	Potential long – term impacts on groundwater not described	Potential long – term impacts on groundwater not described	Continue groundwater monitoring as required until closure	Continue groundwater monitoring as required until closure	Assess whether return water dam can evaporate all seepage and upgrade if required.
Western Areas	Contamination from tailings dam complex is localised, but may impact on surface water streams.	Groundwater monitoring indicated that impact is minimal.	Included in tailings dam management and monitoring.	-Rehabilitation and groundwater containment measures to be implemented. -Groundwater monitoring to continue.	-Source to be removed and used for cladding of tailings dams. -Groundwater monitoring to continue.	-Rehabilitation and groundwater containment measures to be implemented. -Groundwater monitoring to continue.
Randfontein Estates – Cooke Section	-Contamination from three tailings dams is monitored by a number of monitoring boreholes. -Groundwater quality and extent of pollution plumes were established.	All waste rock dumps were removed for road aggregate and tailings dam cladding.	Included in tailings dam management and monitoring	Continue with monitoring program.	Continue with monitoring program	Continue with monitoring program

4.2.2.3 Groundwater monitoring

Groundwater monitoring at surface infrastructure appears to be in place and many EMPR's stipulate the monitoring period as five years after closure. The monitoring frequency is, however, not as clearly defined. Although the dewatering of the dolomites and the discharge of the pumped water into the natural environment has an impact on the geohydrology, the monitoring programs that are currently in place are regarded by the mines as sufficient.

4.3 GAUTENG PROVINCE

EMPR documentation from the following mines in the Gauteng province was examined.

Table 4.6: Gauteng province gold mines

District	Mine	Owner	Status
Eastern Basin	Grootvlei Propriety Mines Ltd.	Petra Mining Ltd.	Operating
	Consolidated Modderfontein Mines Ltd.	Petra Mining Ltd.	Operating
	Gravelotte Mine Limited	Salene Mining (Pty) Ltd	Operating
	Nigel Gold Mining Co. Ltd.	Petra Mining Ltd.	Operating
Central Rand Basin	East Rand Propriety Mines Ltd.	Enderbrooke Investments (Pty)	Operating
West Rand Basin	Randfontein Estates (Old Section)	Harmony	Closed

All three mining basins are faced with similar groundwater related problems. These are the potential contamination of the perched aquifers by surface infrastructure as well as the flooding of mine workings and decant of contaminated water into the natural environment.

The bulk of the mines that exploited the reefs have been closed and the only remaining mines are those listed in Table 4.6 (excluding Randfontein Old Section that closed some years ago). Due to the similarities in potential impacts the status of the groundwater monitoring programs will be discussed together.

4.3.1 Mine infrastructure

Due to the long history of mining in these areas and the historical lack of environmental legislation, several contaminant sources have apparently become the responsibility of the state. The operating mines have been characterised by amalgamations and changes in ownership, sometimes on several occasions. Many of the surface residue deposits have been sold to 3rd parties for reworking. The result is that the EMPR documentation is incomplete and does not address all potential surface contaminant sources.

The available EMPR documentation suggests that the remaining surface residue deposits such as tailings dams do not have a significant impact on the groundwater quality. The biggest argument in support of this conclusion is that when the impact of tailings dams is compared to the regional impact from urbanisation and industrialisation, the impact is small and can therefore be disregarded. The exception appears to be Randfontein Estates – Old Section where potential contaminant sources are actively monitored.

Most of the waste rock dumps have apparently been sold and reworked for road and building aggregate. The potential groundwater contamination from surface infrastructure such as the metallurgical plants, domestic and industrial waste sites is not described in any of the EMPR's. The current status of closure planning to reduce the groundwater impact from surface contaminant sources, as described in the EMPR documents, is summarised in Table 4.7.

Table 4.7: Status of closure planning to reduce groundwater impact from surface contaminant sources – East Rand, Central Rand and West Rand basins

Mine	Perceived Impacts after Closure			Amelioration and Preventative Measures		
	Tailings Dams	Rock Dumps	Evaporation / Return Water Dams	Tailings Dams	Rock Dumps	Evaporation / Return Water Dams
Grootvlei Propriety Mines Ltd.	The No. 3 tailings dam is the only remaining tailings dam. The impact of leachate emanating from the tailings is difficult to assess, but not considered to be significant at this stage.	All rock dumps have been sold to Hippo Quarries.	All rock dumps have been sold to Hippo Quarries.	All paddocks and solution trenches to be maintained to prevent water overflow to Blesbokspruit.	Respons-ibility of 3rd party	No Mention
Consoli-dated Modder-fontein Mines Ltd.	The problem of poor quality leachates emanating from residue deposits is expected to be temporary and to diminish, as most of these deposits are being removed and treated by ERGO.	All rock dumps have been sold to Hippo Quarries.	All rock dumps have been sold to Hippo Quarries.	To become the responsibility of 3rd party	Respons-ibility of 3rd party	No Mention
Gravelotte Mine Limited	Gravelotte's activities are confined to underground mining operations. It does not treat any material or deposit any mine residues on surface.					
Nigel Gold Mining Co. Ltd.	Nigel Gold Mine does not operate any tailings dam or residue deposit.					
East Rand Propriety Mines Ltd.	There is a potential for leachate generation at tailings dams and sand dumps unless effective rehabilitation is implemented to minimise infiltration.	Potential long – term impacts on groundwater not described	Potential long – term impacts on groundwater not described	-Seepage water will be channelled to evaporation paddocks. -The possibility of reworking and removing sources is considered.	-The possibility of reworking and removing sources is considered.	No Mention
Rand-fontein Estates	-Contamination from Millsite tailings dam is monitored by a number of monitoring boreholes. -Groundwater quality and extent of pollution plumes were established.	All waste rock dumps were removed for road aggregate and tailings dam cladding.	Included in tailings dam management and monitoring	Continue with monitoring program.	Continue with monitoring program	Continue with monitoring program

4.3.2 Flooding of mine workings

The East Rand, Central Rand and West Rand basins are all plagued by the inflow of extraneous water into the underground workings. Grootvlei Mine is probably the best known in this regard and is currently receiving state assistance to pump water from the underground workings and therefore maintain the water levels below the working levels. ERPM is the only remaining operating mine in the Central Rand basin and is pumping in the order of 55 Ml/day. ERPM is, however, partially separated from the rest of the Central Rand basin by strategic underground plugs. The water level in the remainder of the basin continues to rise and is expected to decant in approximately eight years (Rison Consulting, 1999). No pumping is taking place from the West Rand basin and contaminated water is expected to decant late in 2002.

During 1999, the operating mines in the three basins decided to develop a Strategic Water Management Plan for the region to prevent adverse impacts on the environment. The aim was further to develop this groundwater resource as a potential drinking water supply to the Gauteng region. Studies that were conducted during this time included groundwater level recovery predictions as well as limited geochemical estimates of the decant water qualities. Unfortunately the closure of some companies saw the withdrawal of financial support and the groundwater management reverted back to the remaining companies and possibly the state. Although the Harmony Group is not the only mine owner in the West Rand basin, Randfontein Estates plans to pump and treat the water for a period until the decant water quality can be determined (Schwartz, Pers. Comm. 2001).

Although all the EMPR documents refer to the flooding of the mine workings and the potential decant risk, only ERPM proposes certain management options.

4.3.3 Groundwater monitoring

Groundwater monitoring at surface infrastructure appears to be lacking or at best is ad hoc. No formal groundwater-monitoring program is described in any of the EMPR documents (Randfontein excluded).

The remaining operating mines take groundwater level measurements in the flooded mine workings, but this is perceived to be inadequate, especially in the Central Rand Basin. A wider database is required to accurately predict water level rise and decant position that will allow for the timeous and optimum management strategy.

The Gauteng Mining Pollution Forum (GMPF) was formed by DME and the Gauteng provincial government Department of Agriculture, Conservation, Environment and Land Affairs. This was done to address public concerns about risks of mine tailings dams. Crous (2002) suggests that the purpose of the GMPF is not to take steps, but to co-ordinate. The GMPF has an information working group and a technology working group.

4.4 MPUMALANGA PROVINCE

EMPR documentation from the following mines in the Mpumalanga Province was examined.

Table 4.8: Mpumalanga province gold mines

District	Mine	Owner	Status
Evander Goldfield	Kinross Mines Ltd.	Harmony Gold Mining Ltd	Closed
	Winkelhaak Mines Ltd	Harmony Gold Mining Ltd	Operating
Barberton Goldfield	New Consort Gold Mine	Avgold	Operating
	Agnes Gold Mine	Cliff Mining SA	Operating
	Mokjonjwaan Imperial Mining Co.	Simmer & Jack Mines	Operating
Pilgrims Rest Goldfield	Morgenzon / Clewer Underground Mine	Transvaal Gold Mining Estates Limited	Operating

The Evander goldfield differs from the Barberton and Pilgrims Rest goldfields in the sense that it is a sub – basin of the Witwatersrand Basin, whereas the latter two goldfields are mainly structurally controlled deposits.

Due to the similarities between the Barberton and Pilgrims Rest goldfields in terms of potential impacts, the status of the groundwater monitoring programs will be discussed together. The Evander goldfield will be discussed separately.

4.4.1 Evander goldfield

4.4.1.1 Mine Infrastructure

Specialist investigations were conducted to establish the status of the geohydrological regime and it was found that although the impacts of the tailings dams on the groundwater quality will be significant, the aquifer parameters are very low. Vertical flow rates are estimated at 1m per annum and the horizontal migration rate is estimated at 5m per annum. In view of this, no after closure management is therefore recommended, or discussed.

Most of the waste rock dumps are planned to be sold and reworked for road and building aggregate. The potential groundwater contamination from surface infrastructure such as the metallurgical plants, domestic and industrial waste sites is not described in any of the EMPR's. The current status of closure planning to reduce groundwater impact from surface contaminant sources, as described in the EMPR documents, is summarised in Table 4.9.

Table 4.9: Status of closure planning to reduce groundwater impact from surface contaminant sources – Evander goldfield

Mine	Perceived Impacts after Closure			Amelioration and Preventative Measures		
	Tailings Dams	Rock Dumps	Evaporation / Return Water Dams	Tailings Dams	Rock Dumps	Evaporation / Return Water Dams
Kinross Mines Ltd.	-Significant long-term impacts with regard to groundwater quality may be expected. -The hydraulic parameters of the aquifers are, however, low and flow rates are 5m/annum.	All rock dumps are to be sold to 3rd parties.	Included in tailings dam management.	There will be very little seepage after closure due to the high porosity of the slimes. Seepage from toe paddocks is expected to be negligible due to the fact evaporation exceeds rainfall by more than two times.	Responsibility of 3rd party	Included in tailings dam management.
Winkelhaak Mines Ltd.	-Significant long-term impacts with regard to groundwater quality may be expected. -The hydraulic parameters of the aquifers are, however, low and flow rates are 5m/annum.	Acid base accounting yielded a marginal negative net neutralising potential, indicating a slight potential for acidity.	Included in tailings dam management.	-The hydrogeological environment will take many years after closure to attain hydraulic equilibrium. -The impact is, however, believed to be localised.	- All rock dumps are to be sold to 3rd parties. -Responsibility of 3rd party	Included in tailings dam management.

4.4.1.2 Flooding of mine workings

Specialist investigations suggested that there is no hydraulic connection between the Karoo strata and the underlying lava and quartzite. Deep level mining has therefore had no impact on the shallow aquifer, but influx into the underground mines is expected to fill the mine workings over the medium to long – term. It is stated that the water level in the shafts, which are to be sealed some 10m below surface, is unlikely to rise to a level significantly above the bottom of the Karoo strata at 200m below surface. No management options to cope with decant water are proposed.

4.4.1.3 Groundwater monitoring.

Reference is made to regular groundwater quality monitoring at surface residue deposits. The frequency of monitoring and the monitoring programs after closure are, however, not clearly stipulated.

4.4.2 Barberton and Pilgrims Rest goldfields

4.4.2.1 Mine infrastructure

The mineralogy of the ore and waste in these goldfields appears to vary considerably and as a result, so does the impact on the groundwater and the proposed mitigation measures. The New Consort mine included specialist investigations in the EMPR and the perceived impacts and management options are fairly clearly defined. The impact from each mining site is somewhat unique and management or mitigation measures are designed accordingly.

The potential groundwater contamination from surface infrastructure such as the metallurgical plants, domestic and industrial waste sites is not clearly described, but reference is made to the after closure rehabilitation of infrastructure other than the residue deposits. The current status of closure planning to reduce the groundwater impact from surface contaminant sources, as described in the EMPR documents, is summarised in Table 4.10.

4.4.2.2 Flooding of mine workings

The influx of groundwater into the mine workings appears to be a problem in both the Barberton and Pilgrims Rest goldfields. The groundwater flowing into the mine is controlled by the structural geology and is currently dealt with through sealing, but dewatering is also taking place in certain areas.

At the New Consort mine the groundwater levels in the underground mining area are believed to recover to pre – mining levels when mining ceases. The rate of re-bound is not known, but estimates based on the mine void volume and current abstraction volumes suggest a period between 20 – 50 years. Based on the current topography and the location of shafts it is unlikely that surface decant will occur. Pre–mining groundwater levels are calculated to be between 5 – 10m below the surface of the current shafts.

At the Agnes mine the groundwater table is not expected to return to pre – mining conditions. The reason being that decant will occur at 22 Level Adit, creating a permanent dewatering cone towards that level. The quality of the adit water is expected to improve over time as existing areas of exposed sulphide mineralisation are flooded or oxidised. This will require close monitoring to ensure that that the water complies with the general effluent standards.

Table 4.10: Status of closure planning to reduce groundwater impact from surface contaminant sources – Barberton and Pilgrims Rest goldfields

Mine	Perceived Impacts after Closure			Amelioration and Preventative Measures		
	Tailings Dams	**Rock Dumps**	**Evaporation / Return Water Dams**	**Tailings Dams**	**Rock Dumps**	**Evaporation / Return Water Dams**
New Consort Gold Mine	-At present leachate is generated by rainfall or process water infiltrating through the dumps, tailings dam, evaporation facilities and calcine dams. -It is highly likely that the mine will continue to impact on the groundwater quality after closure. -When no more water is put into the dams, the contamination plume will continue to migrate towards the Noordkaap River.			-Removal or capping of the contaminant sources will reduce the total contaminant load to the groundwater. Due to the slow leaching process it will take years before the contamination ceases, but it will become gradually less. -A study will be conducted and management actions will depend on the outcome of the study.		
Agnes Gold Mine	-AMD from the Princeton Section is possible due to the relatively high sulphide content of portions of the banded iron formation immediately adjacent to the ore body. -Given that to date AMD has not realised, it is probable that the residual impact will be low in the long-term. -The Woodbine-Giles ore bodies contain relatively low sulphide and the potential for AMD is reduced.	Potential long – term impacts on groundwater not described	Included in tailings dam management.	The tailings dam areas will be rehabilitated to wilderness status.	-The dump will be re-contoured and toe paddocks constructed. -Water monitoring will continue until closure.	Included in tailings dam management.
Mokjonjwaan Imperial Mining Co.	The mine is only mining oxidised ore and due to the fact that all the sulphides have already been leached out of the host rock there will be no AMD. The analysis of the waste rock and the ore shows that there is very little in the way of soluble salts in the rocks. The analysis also shows very low levels of sulphur.			The mine will not affect the quality of the groundwater and no mitigation is necessary.		
Morgenzon / Clewer Underground Mine	-No significant impact to the groundwater is expected beyond the immediate confines of the rock dump. -The rock dumps have been generated from mining oxidised reefs and the host rock is chert and dolomite. There is thus no potential for AMD -Seepage from underground workings may, however, generate AMD.			The tailings dam complex will be vegetated and long – term stormwater facilities left in place.	The waste rock dumps are not expected to generate acid seepage, but this will be verified by monitoring.	Included in tailings dam management.

4.4.2.3 Groundwater monitoring.

Groundwater monitoring and the monitoring programs after closure are not clearly stipulated and the extent of groundwater monitoring is unknown.

4.5 SUMMARY

Deep underground gold mining and mining in general has an adverse impact on the groundwater and surface water resources in the immediate vicinity of the mine workings. These impacts include the deterioration of groundwater and surface water quality and dewatering of aquifers.

The gold mines in South Africa are mainly concentrated along the edges of the Witwatersrand Sedimentary Basin. In this investigation the mines were grouped together according to the province in which they are situated. However, the different goldfields as well as the geohydrological and catchment boundaries do not necessarily coincide with provincial boundaries and in some instances it is more sensible to develop water management programs for clearly defined geohydrological regions or catchments, rather than individual mines (see Chapter 4). Where applicable, provincial boundaries were ignored.

The current status (end 2001) of the gold mines closure planning, as described in their EMPRs, can be summarised as follows:

- While most mines recognise the fact that tailings dams generate acid mine drainage, it is generally and incorrectly assumed that the impact will decrease to acceptable levels when mining operations cease. The assessment of long-term risks from tailings dams can at best be described as subjectively qualitative in nature and no proper quantitative assessments were reported in any of the EMPRs.

- It appears to be quite widely assumed that the larger particle size of waste rock dumps makes them a minor pollution risk. This view is erroneous as the waste rocks have very large inventories of fine material and they are much more permeable to oxygen than tailings dams. The secondary source of contaminants that remain in the soil after a dump has been removed appears to be universally ignored and it is assumed that removal of the dump removes all potential for pollution from that site.

- Most mines appear to have some monitoring programme to evaluate shallow aquifer and surface water impacts from the surface residue deposits. However, the monitoring programs are not clearly stipulated in the EMPR documents and hence it is not clear if the extent of contaminant plumes is known.

- Very few specialist investigations appear to have been done to identify the status of the geohydrological regime, the extent of contamination, preferential pathways and predictions regarding long – term migration. As a result there are very limited mitigation or management options described in the EMPR's that specifically deal with the containment / rehabilitation of contaminated groundwater.

- The potential impact on the groundwater from other surface contaminant sources such as the metallurgical plants, domestic and industrial waste sites are not described. Many of the EMPR documents state that these structures will be removed / rehabilitated during decommissioning, but it is not stated if they had an impact and if groundwater rehabilitation is required.

- Many of the older mines were subjected to amalgamations and changes in ownership and in many instances the surface infrastructure, including some tailings and rock dumps were sold to 3rd parties. Many of the current mine EMPR documents exclude infrastructure that has been sold and it is not clear if the new owners are required to address groundwater contamination and if it is in fact being done.

- All the goldfields and therefore most of the mines are exposed to the inflow of extraneous water into the underground workings. The aquifers affected by the subsequent dewatering vary from one basin to the next, as do the associated environmental problems. The dewatering of the different mining basins is briefly summarised.

- **Far West Rand and KOSH area.** The inflow of water is derived from overlying dolomite aquifers and huge volumes have to be pumped from the mines for work to continue. The groundwater quality is generally good and the pumped water can be discharged into the natural environment. Many of the dolomite compartments have been dewatered over the years, which resulted in sinkhole formation and ground stability problems. This necessitated the establishment of vigorous groundwater and stability monitoring systems that are required to continue for some time after mine closure. After closure, the mine workings will flood and the dolomite aquifers will largely recover to pre – mining levels. Decant is expected to be limited. There are currently no management options in place to cope with contaminated decant water.

- **Gauteng mines.** The three mining basins in Gauteng, i.e. the Eastern, Central Rand and West Rand Basin are all at the risk of being flooded or are already partially flooded. The water quality in the mine workings is of a poor quality and cannot be disposed into the natural environment without treatment. When mining ceases the basins will flood to the elevations of the lowest topographical shaft, where it will decant. The quality of the decant water is still a matter of debate, as is the ownership of the responsibility for rehabilitation. There is a school of thought suggesting that the water quality will improve over time and that the water can be allowed to decant into the environment. Another school of thought believes that the water quality will be poor and that treatment centres will be required at the decant points. Although some studies have been done, no management options are currently in place. Harmony's Randfontein Estates Mine has, however, indicated that they may pump and treat water from the West Rand Basin until the water quality issue is better understood.

- **Free State goldfield.** The Free State mines are exposed to the inflow of extraneous saline water from a deep connate aquifer. The isolated nature of this aquifer allowed for it to be dewatered effectively and the poor quality water was disposed off through evaporation. Many of the mines are of the opinion that after cessation of mining the workings will flood, but that the water table will stabilise below the Karoo strata and that none of this water will decant from any of the shafts. Although this statement is probably correct there is no reference to any geohydrological investigation confirming this. As a result of this perception there are no management plans in place to cope with decant water.

- The general conclusion of this situation analysis regarding post closure groundwater management is that not enough work has been done by the mines to fully understand groundwater flow, groundwater contamination and decant potential. As a result the management options to mitigate groundwater contamination after closure are very vague or non-existent.

There is a definite need for clear guidance on what type of technical investigations need to be undertaken to provide the following information:

- Understanding of the long-term risks (quantity and quality) associated with post-closure decant from gold mines.

- Understanding of the long-term risks (quantity and quality) associated with post-closure seepage from waste residue deposits (tailings, waste rock and footprints below removed dumps).
- Identification of proactive management measures that can be implemented to minimise the long-term risks associated with decant from mines.
- Identification of proactive management measures that can be implemented to minimise the long-term risks associated with seepage from waste residue deposits.

It is also clear that, to date, closure planning is not being undertaken on an integrated regional basis, resulting in those mines that have the longest remaining working life in each region being at the highest risk of being held responsible for dealing with the cumulative regional problem. This situation is clearly not equitable and it is therefore urgent that appropriate procedures be developed to ensure that effective closure planning occurs timeously and on an integrated regional basis.

It must also be clearly stated that the assessment of EMPRs as presented in this chapter is based on the status of the EMPRs at the time that they were assessed. The review and updating of EMPRs is an ongoing process and a number of the shortcomings in the EMPRs reviewed have already been addressed in updates that have been prepared subsequent to the writing of this chapter.

5. GOLD MINE CLOSURE PROCEDURES

5.1 GENERAL BACKGROUND

Mine closure planning and liability assessment is a critical process that may have significant financial implications for the mines. The process of developing accurate assessments is hampered by the following uncertainties:

- Uncertainty with regard to the legal requirements for closure and the standards that will apply at closure.
- Uncertainty with regard to the precise point in time when mine closure will occur.
- Uncertainty with regard to the long-term environmental impacts of mining at mine closure and after mine closure.
- Uncertainty with regard to the costs of environmental management measures at the time of closure.

An additional complicating factor at mine closure is that there are numerous stakeholders who may each have different objectives such as listed below.

- **The mine:** objective is to optimise decommissioning expenditure, make optimal financial provisions for post-closure maintenance and operation of water treatment works and obtain closure certificate (with no remaining obligations) approved by all relevant authorities.
- **The authorities:** objective is to minimise exposure to long-term risk and ensure that there are no latent or residual impacts leading to remediation measures that require financing from the State.
- **Labour & employees:** objective is to prevent or delay mine closure and prevent job losses.
- **Communities:** objective is to preserve a viable socio-economic structure after mine closure.

Bearing the above factors in mind, successful mine closure planning and liability assessment requires a structured and methodical approach that accommodates the various uncertainties. The following elements can be associated with successful mine closure planning:

1. Mine closure planning should begin at the earliest stage and it should be reviewed in accordance with a predefined schedule over the life of the mine.
2. A risk-based approach that is capable of ensuring that effort is correctly focused on the priority issues and that supports a phased reduction in uncertainties is required.
3. An understanding that mine closure is not about "greening" but about long-term pollution control and risk/hazard management.
4. One of the primary focus issues throughout all phases of the mine life cycle (mine planning, operations, decommissioning and closure) should be pollution prevention, as this will minimise the closure liabilities.
5. Management measures at closure should primarily be of a "passive" nature with minimal long-term maintenance and operating costs.

The information presented in this chapter is to be used as a planning tool to enable mines to implement a logical, step-wise approach to mine closure planning that can be progressively refined. As such it is not to be used as a prescriptive tool but rather to be adapted to meet specific circumstances as required.

The purpose of the procedures set out in this chapter is to provide technical guidance on the sequence, extent and nature of investigations that should be undertaken in order to establish the risk of long-term impacts of the mining operations on the national water resource (ground water and surface water). In all cases, the mine should make use of suitably qualified persons (mine employees or consultants) who will be capable of motivating their methodologies and work to independent suitably qualified persons.

5.2 MINE LIFE CYCLE CONSIDERATIONS

As pollution prevention management actions that could potentially be implemented to reduce the long-term risk to the water resource generally need to be implemented while access to the relevant underground workings is still possible, it is necessary that the investigations be started at an appropriate early stage when such access is still possible. While the level of detail and accuracy of the investigations can be refined and improved upon at a later stage, the early development of a closure plan will ensure that the identification and application of pollution prevention measures can be optimized.

The development and application of mine closure related actions over the mine life cycle is illustrated in Figure 5.1 below. This figure can be interpreted as follows:

1. The figure has both vertical and horizontal axes. The horizontal axis presents the environmental life cycle activities while the vertical axis shows the actual life cycle phases of the mine. For the purpose of this document four life cycle phases are distinguished:
   - Pre-mining phase
   - Operational phase (includes mine construction activities)
   - Decommissioning phase
   - Post-closure phase

2. During the **pre-mining phase** which precedes the actual operation of the mine, the mine will undertake the following actions:
   - *Planning, feasibility and authorization activities*: undertake detailed planning and feasibility studies and prepare mine EMPR
   - *Operational activities*: prepare detailed operational environmental management plans for the construction
   - *Decommissioning and closure activities*: undertake a first post-closure impact assessment and prepare an initial mine closure plan
   - *Post-closure activities*: none

   This phase ends when the mine has received an approved EMPR and has a mining authorization.

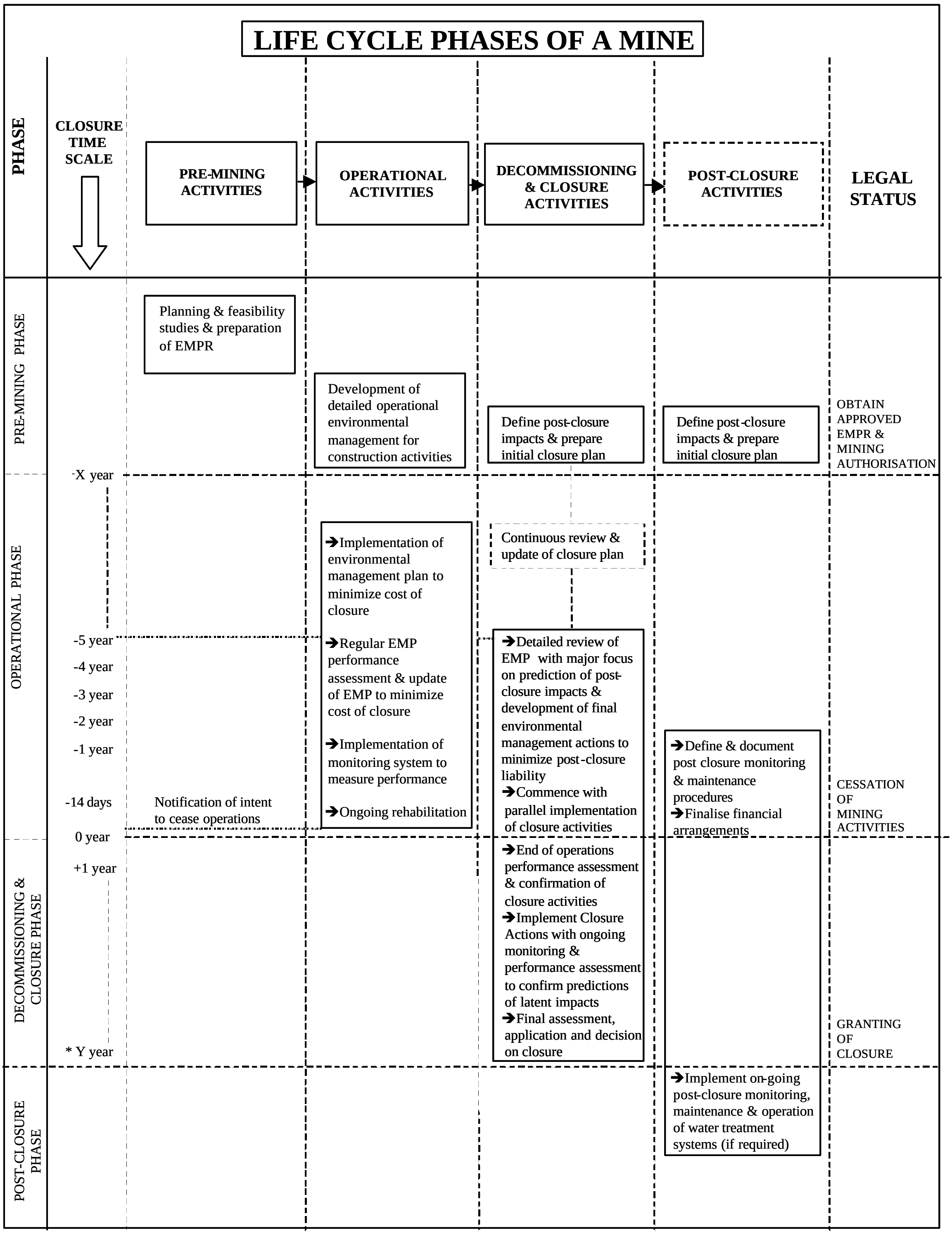


Figure 5.1: Closure activities over the mine life cycle

3. During the **<u>operational phase</u>** of the mine, which will generally be the longest phase, the mine will undertake the following actions:
   - *Pre-mining activities*: none, except to notify the DME of intent to cease operations at least 14 days before the end of the operational phase
   - *Operational activities*: implement the environmental management plan (EMP) on an ongoing basis to minimize the cost of closure; undertake regular EMP performance assessments and update the EMP to minimize the cost of closure;

implement appropriate monitoring systems to measure performance of EMP actions; undertake ongoing rehabilitation where possible

- *Decommissioning and closure activities*: continuously review and update the mine closure plan during the operational phase of the mine; undertake a thorough and detailed review of the closure plan at a point when there is an anticipated 5 years of productive mine life remaining and focus on the quantitative prediction of post-closure impacts and develop final environmental management actions to minimize post-closure liability; commence with parallel implementation of final closure activities.
- *Post-closure activities*: none

This phase ends when the mine ceases all mining related activities.

4. During the **decommissioning phase** of the mine, the mine will undertake the following actions:
   - *Pre-mining activities*: none
   - *Operational activities*: none
   - *Decommissioning and closure activities*: undertake and end of operations performance assessment and confirm the appropriateness of the planned closure activities; implement the approved closure actions with ongoing monitoring and performance assessment to confirm the prediction of latent impacts; undertake a final environmental assessment and apply for mine closure.
   - *Post-closure activities*: define and document post-closure monitoring and maintenance procedures; finalise financial arrangements for post-closure management actions

   This phase ends when the mine is formally granted mine closure.

5. During the **post-closure phase** of the mine, the mine no longer has any formal responsibilities and the appointed third parties will undertake the following actions:
   - *Pre-mining activities*: none
   - *Operational activities*: none
   - *Decommissioning and closure activities*: none
   - *Post-closure activities*: implement ongoing post-closure monitoring, maintenance and operation of water treatment systems (if required).

   This phase will continue until the residual impact of the mine has reached acceptable levels and no further ongoing maintenance work is required.

The progressive improvement in the level of detail of the mine closure plan and its associated technical investigations is shown schematically in Figure 5.2 below.

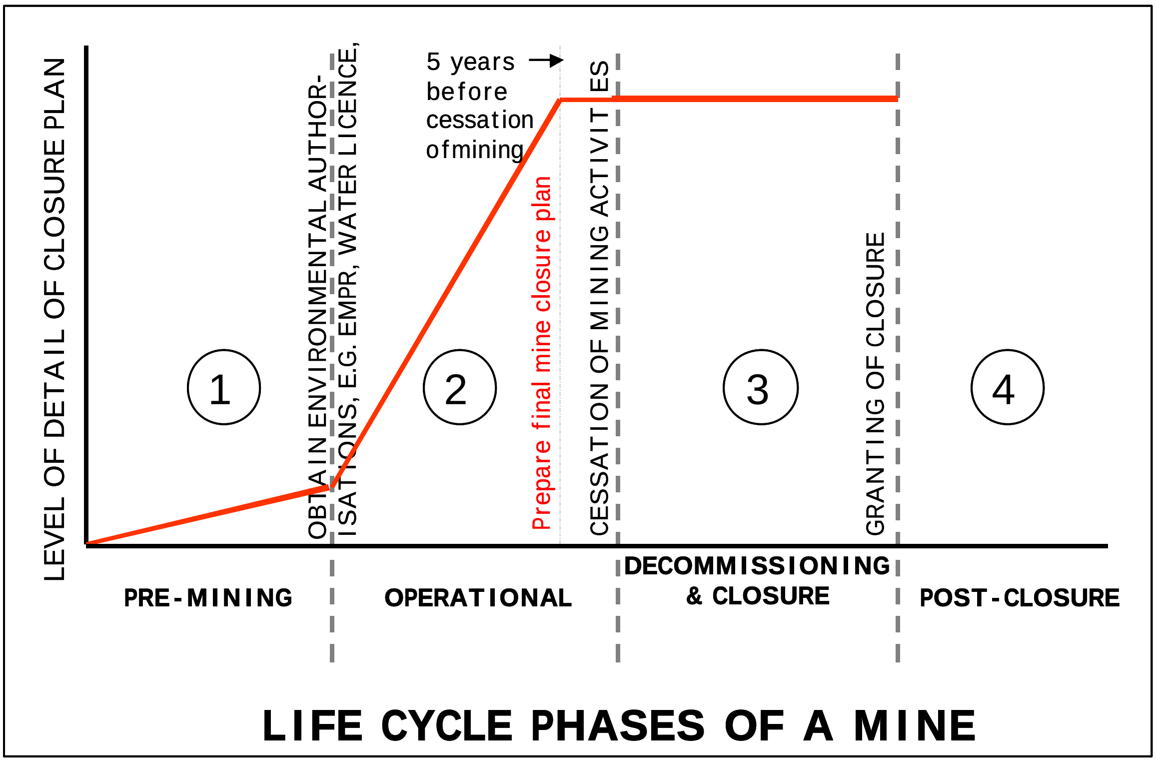


Figure 5.2: Progression in closure plan detail over mine life cycle

5.3 RISK-BASED MINE CLOSURE PLANNING

5.3.1 Objectives of risk-based closure planning

The objectives of the risk-based closure planning process are:

1. To ensure that mines correctly identify the relevant environmental risks relating to mine closure.
2. To ensure that mines have the information required to provide adequate financial resources to undertake the necessary management actions that will ensure legal compliance, will minimise long-term financial risk and/or will enable the approval of a mine closure certificate by the relevant authorities.
3. To ensure that the most significant liability risks are identified at an early stage in order to enable the identification and implementation of pollution prevention measures, wherever possible, to avoid or minimise those risks.
4. To ensure that there is a consistent and defensible procedure for identifying and assessing the environmental risks, for reducing uncertainties in the assessment and for determining the financial provisions that need to be made to address the environmental risks.

5.3.2 Principles relating to risk-based closure planning

Principles that need to be adhered to when undertaking the risk-based closure planning assessment include the following:

1. The closure planning process and management actions must comply with all relevant environmental laws.

2. Environmental management actions should be in compliance with accepted best practice, e.g. the Best Practice Guidelines prepared by the Department of Water Affairs and Forestry, unless alternative actions can be motivated or have been approved by duly authorised persons within the relevant government departments.
3. A final detailed mine closure plan should be prepared no later than 5 years before the planned cessation of mining activities.
4. In the absence of reliable data, consciously conservative assumptions must be made when undertaking any risk assessment or cost estimate.
5. For mines that exploit orebodies containing sulphide minerals, the closure planning and liability assessment should pay particular attention to long-term water quality issues.
6. Wherever required, specialist investigations and prediction of long-term pollution from mines should be finalised no later than 5 years before planned cessation of mining activities in order to allow a monitoring and verification period concurrent with the last years of mining.

5.4 METHODOLOGY FOR IDENTIFICATION OF GENERAL CLOSURE ENVIRONMENTAL RISKS AND LIABILITIES

5.4.1 The ERA process for mine closure

As the mine closure process essentially involves the application of significant financial resources for final environmental management actions followed by the transfer of residual environmental liability to the State, it is considered critical that the environmental risk assessment (ERA) process that is followed when developing a mine closure strategy, should follow a consistent and structured process. The basic principle incorporated into the proposed approach is that the **level of detail of ERA should be appropriate to the risks that exist,** i.e. minor risks need not be subjected to a detailed quantitative risk assessment process, while significant risks should not stop at a simple qualitative assessment.

The specific procedure that is proposed for mine closure risk assessment is shown in Figure 5.3 below. In many cases, the mine may wish to start the process with a screening-level ERA where not all the Steps shown in Figure 5.3 are undertaken. In particular, the more detailed and quantitative assessments shown in Steps 2, 4, 9 etc are not undertaken. For such a screening level ERA, the identification and assessment of alternative strategies is based on professional judgement rather than quantitative data. Subsequent more detailed studies will aim to review the appropriateness of the alternative strategies and provide quantitative assessments as the basis for closure costing.

The mine closure risk assessment process shown in Figure 5.3 has been subdivided into the following 12 steps:

Step 1: Undertake a screening level environmental risk assessment
Step 2: Undertake level 2 risk assessment on potential risks
Step 3: Assess whether potential risks are acceptable without further mitigation
Step 4: Define and implement data collection programme on uncertain risks
Step 5: Re-evaluate uncertain risks
Step 6: Document insignificant / acceptable risks and consult with I&APs
Step 7: Design and implement compliance monitoring programme
Step 8: Identify alternative risk prevention / management strategies

Step 9: Undertake quantitative assessment of risks and management alternatives
Step 10: Define and consult on acceptable impacts with I&APs
Step 11: Agree on management measures to be implemented
Step 12: Prepare and submit closure assessment report
Step 13: Design and implement verification monitoring programme
Step 14: Obtain closure certificate

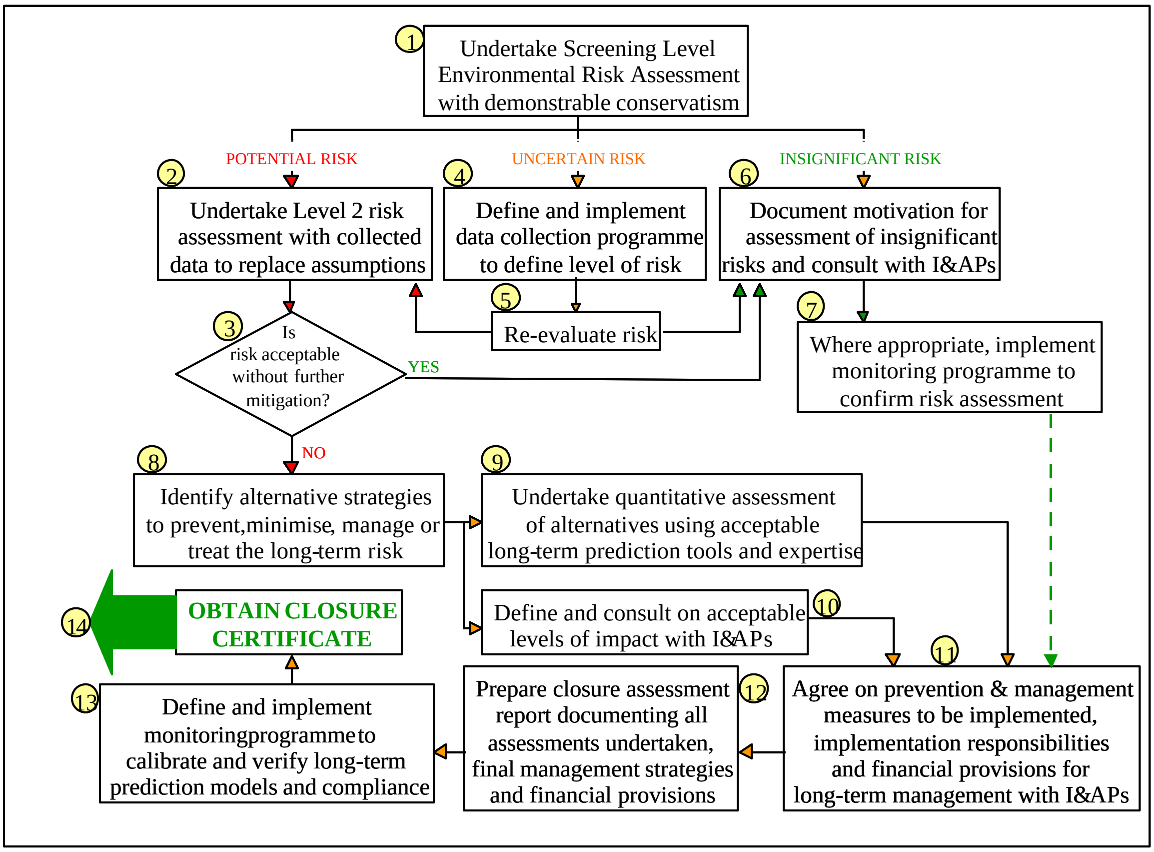


Figure 5.3: Flow diagram of the mine closure risk assessment process

While there are different risk assessment methodologies and approaches that can be followed to arrive at the required end result, it is important that any adopted approach comply with the following requirements:

1. Demonstrable conservatism must be built into any assumptions that need to be made in lieu of appropriate data sets - this must be accompanied by a detailed written report giving, wherever appropriate, detailed motivations as to why the assumptions are, in fact, conservative.
2. The environmental risk assessment should be carried out by suitably qualified persons with the necessary environmental qualifications and experience - this is to ensure that the results of the assessment are credible and unbiased.
3. All interested and affected parties should be involved in the risk assessment process (not necessary for a screening-level ERA) and be given the opportunity to voice their opinions on the assessment process and its results - this requires that the risk assessment process should include a risk communication component.
4. The process should be fully documented and all assumptions and decisions made should be clearly traceable and be thoroughly motivated.

5. Wherever quantitative environmental risk assessments are made, the mine should, through prior consultation with the relevant authorities, obtain agreement on the modelling techniques and tools to be used in the assessment. This is to ensure that they are appropriate and that the results will be acceptable, provided it can be demonstrated that the persons applying the models are suitably qualified to do so.

The steps in the mine closure risk assessment process shown in Figure 5.3 are briefly discussed below.

Step 1: Undertake a screening level environmental risk assessment

The screening-level assessment, which is relatively quick and inexpensive, is characterised by the following elements:

- all possible environmental risks are identified, including those which appear at the outset to be insignificant;
- the process is based on the input from existing data, credible and recognised specialists and persons with a detailed long-standing knowledge of the mine's operations and history;
- in the absence of actual data, consciously conservative assumptions are made and documented;
- I&APs (including the authorities) may be involved;

The **adoption of consciously conservative assumptions in the absence of data is an essential component** of the process. The reason for this is that during the screening-level assessment, the issues that are considered are qualitatively ranked as follows:

- potential significant risk (rating 3)
- uncertain risk (rating 2)
- insignificant risk (rating 1)
- zero risk (rating 0)

It is important to realise that those issues that are identified as posing potential significant risk during the conservative screening-level assessment process, may not in fact, be significant risks. As conservative assumptions are replaced with more realistic assumptions (Step 2) and measured data, both the level of conservatism, and the estimated risk, decrease.

Step 2: Undertake level 2 risk assessment on potential risks

Those issues, which are classified as **potential risks are taken forward into the next phase of the assessment process** where the following activities are undertaken:

- based on the specific identified risks, an appropriate data collection / sampling / monitoring programme is defined and carried out;
- conservative assumptions are replaced with more realistic assumptions and actual measurements; and
- A more quantitative risk assessment is undertaken, again classifying issues as posing potential risk or insignificant risk.

The process of collecting additional data to replace conservative assumptions continues until all risks that can be regarded as significant can be eliminated. The residual risks are then subjected to detailed, fully quantitative risk assessments that have a high degree of certainty and are typically supported by extensive site-specific data – see Step 9. However, the number of issues subjected to a detailed fully quantitative risk assessment is typically a small fraction of the total range of issues that were initially evaluated in the screening-level assessment.

Step 3: Assess whether potential risks are acceptable without further mitigation

After the level 2 risk assessment undertaken in Step 2, it may be found that issues identified in Step 1 as potential risks are no longer assessed as such and they can therefore move forward to Step 6. It is also possible that certain issues may be identified (and agreed by the I&APs) as posing a potential residual risk but that the risk is either acceptable without any mitigation being applied or that current mitigating measures are considered appropriate and adequate. In this case, it will not be necessary to subject such issues to a more detailed risk assessment, provided this is agreed upon by the I&APs in Step 6.

Step 4: Define and implement data collection programme on uncertain risks

Those issues that are classified as posing an uncertain risk would typically require that a **simple** data-gathering programme be defined and undertaken to provide key data to enable a re-assessment of risk to be made – see Step 5.

Step 5: Re-evaluate uncertain risks

Once additional data have been collected in Step 4, the issues earlier characterised as "uncertain risks" will be re-evaluated and reclassified as either potential or insignificant risks. This means that these issues will either join Step 2 or Step 6 of the process.

Step 6: Document insignificant / acceptable risks and consult with I&APs

As the issues that have been classified as insignificant risks (Step 1) could have been classified as such with little concrete data, the adoption and motivation of demonstrable conservative assumptions will ensure that any errors in the assessment will be in favour of the environment. This means that a more detailed assessment, based on actual collected data will, by definition, result in an assessment of reduced risk. This will ensure that there is full confidence that these issues indeed do constitute insignificant risk and do not warrant any further attention. This assessment of insignificant risks should be communicated to and discussed with all stakeholders concerned. The insignificant risk issues are then documented with a detailed description and substantiation of their status. In order to ensure transparency, this documentation is structured so that the assessment trail can clearly and easily be followed by all stakeholders (both the lay person and specialist reader).

Step 7: Design and implement confirmation monitoring programme

In order to confirm that those issues assessed as posing insignificant or acceptable risk have been correctly assessed, it will be necessary to develop and implement an appropriate confirmation monitoring programme, in consultation with the I&APs. For the purpose of this report, this type of monitoring is termed confirmation monitoring, as its intent is to confirm the level of assessed risk.

Step 8: Identify alternative risk prevention / management strategies

For those issues which have passed through Step 3 as still posing potentially significant or unacceptable risk, additional detailed studies will be required (see Steps 9 to 13). As a first step in this exercise, it is necessary to identify alternative management strategies that can be applied to mitigate against the risks. In identifying these alternative strategies, it is important to consider options in the following order of priority:

1. strategies that can prevent or minimise the risk and its impacts
2. strategies and measures that can manage the risk or impact with minimal long-term maintenance requirements
3. strategies and measures that can manage the risk or impact but that require active, regular and long-term maintenance and management

The alternative strategies that are to be considered in Step 9 must be clearly defined and agreement must be obtained from the I&APs that all the appropriate strategies have been included amongst the alternatives.

Step 9: Undertake quantitative assessment of risks and management alternatives

The next step in the mine closure risk assessment process is to quantify the long-term impacts of the different alternative management strategies. Depending on the issue to be addressed, different assessment tools will be required. For example, the prediction of long-term subsidence / sinkhole risks will require specific expertise and modelling techniques. The assessment of long term water quality from mines containing sulphide minerals will require a combination of kinetic and equilibrium geochemical models (a Best Practice Guideline is being developed by the Department of Water Affairs and Forestry on how to undertake predictions of long-term water quality). As the objective with this step is to predict the future consequences of current or historical actions, it is unavoidable that predictive models will have to be used.

It is strongly recommended that, wherever appropriate, use be made of probabilistic modelling techniques and sensitivity analyses. This is to ensure that the level of uncertainty within the model results is defined as well as to ensure that the most critical data inputs and variables are identified and included in the monitoring programme defined in Step 13.

Before undertaking these quantitative assessments, it is advised that the mine submit a detailed assessment plan for discussion and agreement with the I&APs. Such an assessment plan should, inter alia, present the proposed methodology, data collection and monitoring programmes, assessment tools and models to be used and the capabilities of the specialists who will undertake the assessments. This process is important in order to ensure that the I&APs agree with the assessment methodology and that they will therefore have confidence in the results of the assessment and to ensure that the mine does not waste time and money on assessments that are later rejected as being inappropriate.

This part of the risk assessment process is typically the most difficult and costly to undertake and it is, therefore, important to ensure that it is done correctly. Important and costly decisions will need to be made on the basis of the results of these assessments.

Step 10: Define and consult on acceptable impacts with I&APs

In order to be ultimately able to evaluate the acceptability of alternative management strategies, it is necessary to define and agree what level of impact is acceptable. This is often a difficult process as it is necessary to obtain agreement with I&APs as to what is acceptable at the specific location of the mine seeking closure. Although the acceptable impact may be generically defined for certain environmental aspects, others, such as water quality, are very site specific and will need to be defined and agreed separately for each site, taking into account factors such as downstream users, the class of river, sensitive ecology, etc. and other applicable legislation.

Wherever possible, it is desirable to consult with and preferably reach agreement with the I&APs at an early stage on the factors and techniques that will be considered in making the decision as to what level of impact is considered acceptable. For example, use could be made of cost-benefit assessments, coupled with consideration of socio-economic and environmental effects and rights.

It is also most probable that steps 9 and 10 will be undertaken in an iterative manner before agreement is reached in Step 11.

Step 11: Agree on management measures to be implemented

On the basis of an iterative and simultaneous consideration of the results of Steps 9 and 10, agreement will need to be reached between the mine and authorities as appropriate on what the acceptable management strategies are that will be implemented on mine closure. The hierarchy and prioritisation of strategies set out in Step 8 will be considered here, i.e. pollution prevention measures should be applied wherever possible, and low maintenance and sustainable mitigation measures are preferred above those that require active and ongoing management. The agreement should include agreement on the following:

1. Precise specification of the management measures to be applied.
2. The predicted long-term result of the applied management measures.
3. The residual impact after successful implementation of the management measures.
4. Time frame and schedule for implementation of the management measures.
5. Responsibilities for implementation and long-term maintenance of the management measures.
6. Financial provisions for long-term maintenance.
7. Monitoring programmes that should be implemented (see Step 13).

Step 12: Prepare and submit closure assessment report

A detailed closure plan / assessment report should be prepared and submitted to the authorities for approval. This report should be written in such a manner that it is understandable by both laypersons and specialists. The report should clearly document all the work undertaken in the mine closure risk assessment process (Steps 1 to 13) and should clearly document all decisions and agreements that were reached. The report must be formally approved by the authorities, with the proviso that there will be a final update after completion of Step 13.

Step 13: Design and implement verification monitoring programme

An appropriate monitoring programme must be defined and implemented with the primary objective of verifying that the assessment techniques applied in Step 9 are accurate and appropriate, i.e. to provide data to calibrate the prediction models. This type of monitoring is quite different from compliance monitoring as, in addition to monitoring the predicted end-result (e.g. decant water quality), it is also necessary to obtain data to confirm that the data inputs into the model are correct. For example, with regard to long-term trends in water quality from sulphide-containing materials, simple trend analysis of water quality will most probably not give a reliable indication of future changes in water quality – changes in the geochemical driving forces will affect the long-term water quality and these should be monitored as well.

The monitoring programme must clearly specify factors such as the objectives of the monitoring programme, the monitoring points, the parameters to be monitored and measured, responsibilities, reporting requirements, etc. With regard to water quality monitoring, use should be made of the Best Practice Guideline on Water Monitoring Systems, obtainable from the DWAF.

Step 14: Obtain closure certificate

Once the monitoring programme defined in Step 13 has been implemented and the stated and agreed objectives of the monitoring programme have been met, the closure report (Step 12) will be updated and submitted to the authorities for final approval and issuing of a mine closure certificate. Provided that the mine has properly followed all the above steps, and has obtained prior approval from the authorities regarding the quantitative assessment tools (as set out in Step 10 above) used, and provided the agreement reached in Step 11 has been successfully implemented and verified (Step 13), mine closure should be granted to the mine. Any unforeseen residual or latent impacts that arise after mine closure has been granted will then become the responsibility of the State and not the previous mine owner.

5.4.2 Modification of the ERA methodology for screening-level assessments

For the initial screening level ERA, not all the steps described above will be followed. The above approach is modified for a screening-level ERA as follows, assuming that the more detailed approach described in 5.4.1 above will be followed in the next round of the ERA process:

Step 1: Undertake as described above.
Step 2: Ignore now but identify action plan for implementation.
Step 3: Undertake on the basis of specialist's experience and professional judgement rather than on the basis of a quantitative assessment.
Step 4: Ignore now but identify action plan for implementation.
Step 5: Ignore.
Step 6: Undertake as described but involvement of I&APs is optional.
Step 7: Undertake if possible or identify action plan for implementation.
Step 8: Undertake on the basis of specialist's experience and professional judgement rather than on the basis of a quantitative assessment. Involvement of I&APs is optional.
Step 9: Ignore.

Step 10: Undertake on the basis of specialist's experience and professional judgement rather than on the basis of negotiation with I&APs.
Step 11: Undertake on the basis of an internal workshop involving the ERA team.
Step 12: Prepare on the basis as described in Chapter 6 of this report.
Step 13: Ignore.
Step 14: Ignore.

It is important that the ERA process **start but not stop** with a screening-level ERA. The uncertainties identified during the screening-level ERA should be addressed in follow-up studies that are undertaken according to a defined schedule. This should then lead to a progressive improvement in the level of the ERA, such that within 5 years of undertaking the screening-level ERA, the mine has undertaken a full ERA in accordance with all the steps described in Section 5.4.1 above.

5.4.3 Example of environmental risk assessment methodology

The approach that is recommended for the ERA is to divide the mine into distinct geographical, environmental and infrastructural features on which the ERA is undertaken. For example, an underground gold mine could be divided into the following components:

- Underground workings and overlying surface
- Shafts
- Beneficiation plant, including stockpiles and rail loading areas
- Waste residue deposits (tailings dams, waste rock dumps)
- Domestic waste disposal facilities
- Offices and other surface infrastructure
- Water treatment and management facilities

Each of these components would then be assessed in terms of the long-term risk that they would pose to the environment before and after mine decommissioning actions have been implemented. The assessment would, *inter alia*, consider the following aspects of the environment:

Water issues:
- prediction of long-term water quality – surface, underground, seepages, ground water, etc.
- prediction of long term quantity and availability of ground and surface water
- prediction of ground water re-establishment rates and residual impacts
- prediction of the impact on hydrodynamics of surface water systems

Land issues:
- land capability and use (specifically agricultural use potential)
- erosion
- compaction
- soil contamination

Subsidence/sinkhole issues (underground mines and backfilled pits):
- effect on water drainage
- effect on land use
- effect on safety

Ecological issues:

- vegetation succession during rehabilitation
- aquatic and riparian ecology

Air quality issues:

- dust generation, transport and fallout
- radioactive gas release and transport

Other issues:

- Safety aspects relating to shafts, dams, remaining structures, etc.
- Structural failure of facilities (e.g. tailings dams, pollution control dams, etc.)

The different issues are then rated as described in Step 1 above. The risk assessment process could take account of the probability and consequence of each of the following aspects when deciding on the risk rating:

- risk of safety / failure events
- risk of human health effects
- risk of action in terms of common law and Director's liability
- compliance with environmental (ecological) protection objectives
- compliance with regulatory standards
- perceived cost/benefit relationship for remediation
- compliance with "best practice" norms for the mining industry

A typical phased process that could be followed in obtaining screening-level risk ratings and prioritisation of these risks at a mine is detailed below.

Step 1: Compile a site assessment team that includes all the relevant fields of expertise

Step 2: Detailed site assessment covering the following aspects:

- initial meeting with site Environmental Management personnel
- review of EMPR and relevant available environmental reports
- site inspection of mine area
- development of site assessment matrix and programme
- environmental risk assessment of site with risks being assessed as no risk (0); low risk (1); moderate risk (2); and high risk (3)
- identification of required environmental management actions (worst, best and most probable scenarios where uncertainty exists) to reduce risks
- identification of knowledge gaps and required additional investigations
- compilation of detailed site assessment reports

Step 3: Internal review of all environmental risk assessments and holding of internal workshops to prioritise risk issues for the mine

Step 4: Preparation of final reports

Step 5: Evaluate the final screening level ERA report and develop an action plan and schedule to undertake the necessary work required to move towards a full and final ERA as described in Section 5.4.1 above.

5.5 METHODOLOGY FOR IDENTIFICATION OF WATER-RELATED CLOSURE RISKS AND LIABILITIES

The steps set out in Section 5.4.1 above relate to general environmental risks, including but not limited to those that relate to the water resource. This chapter provides additional detail on methodologies that should be applied to assess those closure risks that specifically relate to water. In assessing the closure issues relating to water, the following important points need to be considered:

1. The source of water-related impacts on a gold mine can be divided into two primary components, i.e. aboveground features and underground features.
2. All South African gold mines are extracting ore and waste material that are associated with sulphide minerals (and a greater or lesser amount of neutralizing minerals) and other contaminants and there is, therefore, an inherent water quality risk associated with gold mines. Additionally, gold mine ore bodies are associated with radionuclides.
3. The gold mines are generally grouped together very tightly, resulting in hydrological interconnections between adjacent mines. This makes it difficult, if not impossible, to consider the water-related closure risks in isolation and consequently, a number of distinct hydrological groupings of mines has been defined, each of which should develop a regional mine closure strategy within which individual mine closure plans can be assessed.
4. The surface residue deposits (tailings dams and waste rock dumps) that remain after mine closure can never be maintained in a completely reducing environment and must be considered to pose a potential water related risk until shown otherwise by way of a suitable semi-quantitative or fully quantitative geochemical assessment.
5. Underground mine workings will fill up with water over time (slow or fast depending on geohydrological setting) and this water will be contaminated (either for a limited time or in perpetuity). A key element influencing the risk that these processes pose to the water resource is whether or not this contaminated water will decant into the underground aquifers or into the surface water resource and to what extent the natural water resource can assimilate this contamination. The underground workings must, therefore, be considered to pose a potential water related risk until shown otherwise by way of a suitable semi-quantitative or fully quantitative geohydrological and geochemical assessment.
6. In certain mining regions, underground dewatering activities and placement of surface residue deposits pose a long-term risk with regard to formation of sinkholes which in turn pose safety, water resource and land use risks that need to be assessed. The aspect of sinkhole formation is the subject of a separate Water Research Commission investigation and will not be further covered in this document.

With the above in mind, a set of procedures can be developed to address the various elements of regional mine closure strategies and individual mine closure plans. The first step in the process is to define the nature of the closure plan that is required and this question is simply addressed in Figure 5.4 below.

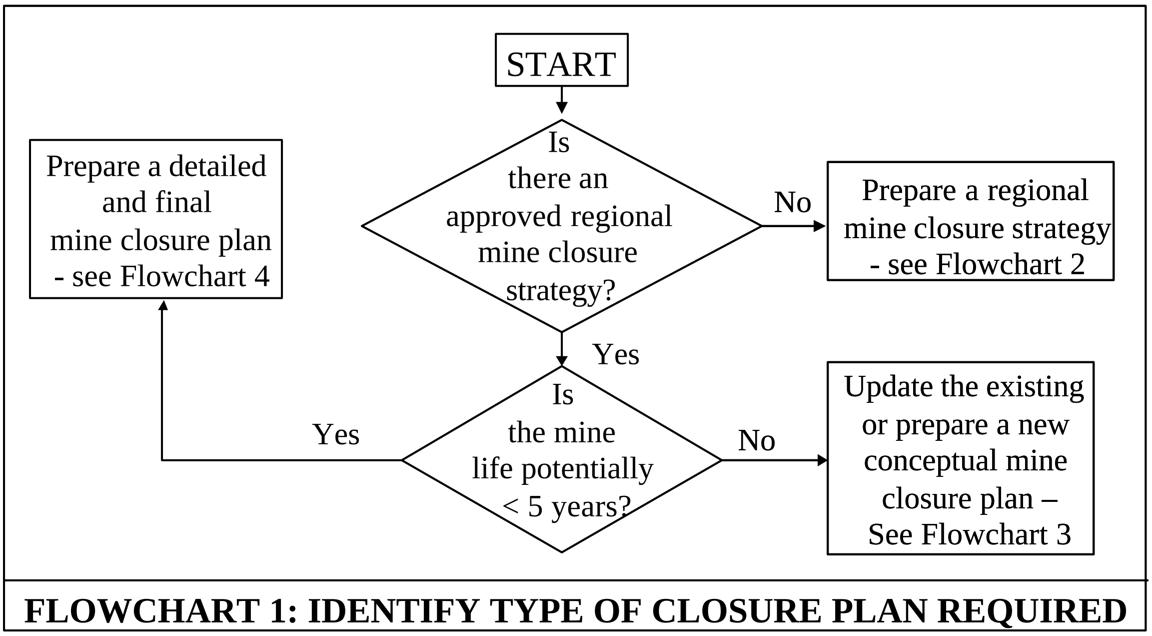


Figure 5.4: Flowchart to identify type of closure plan required

Based on the flowchart process shown in Figure 5.4, three possible outcomes exist:

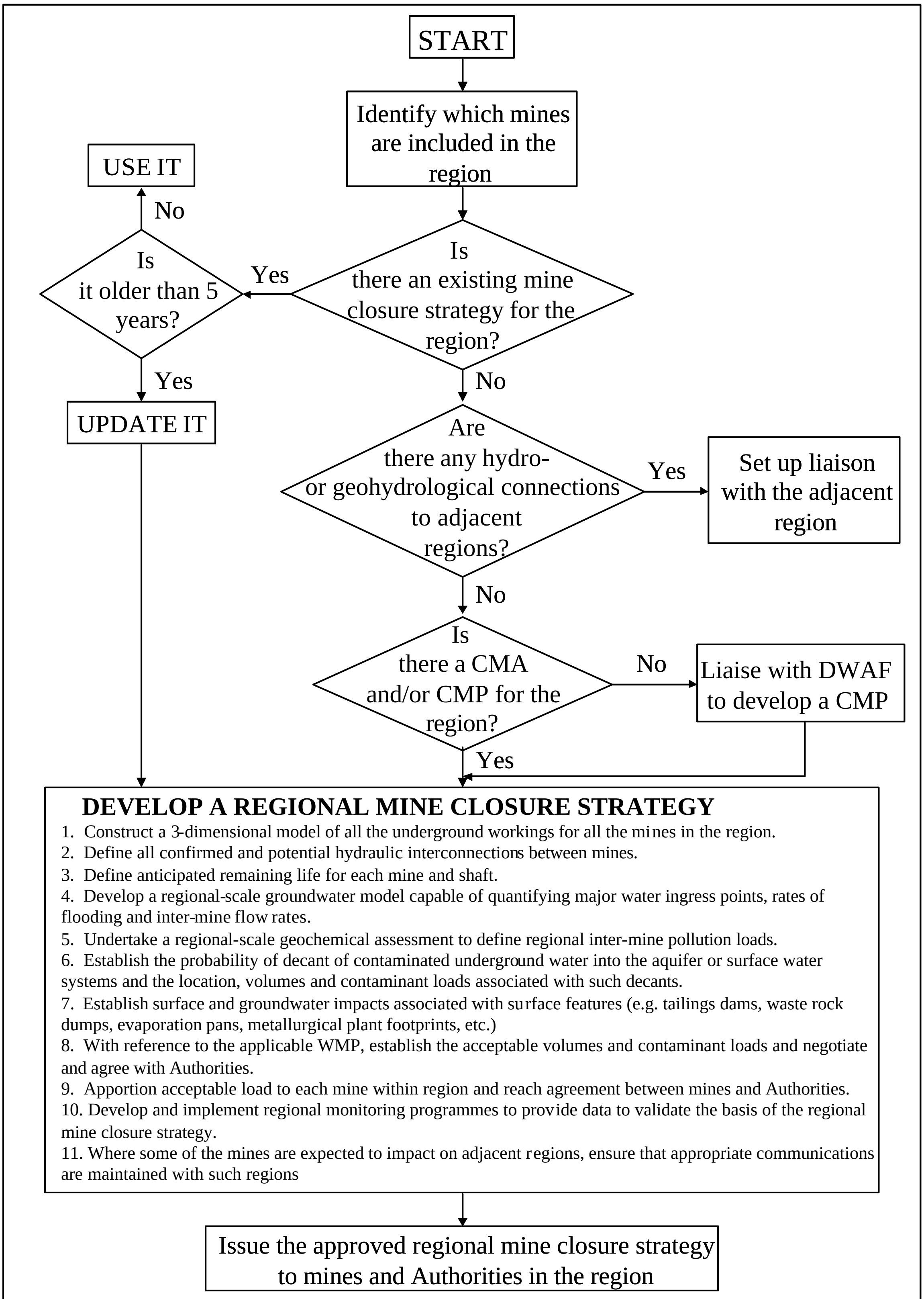
- Prepare a regional mine closure strategy
- Update the existing or prepare a new conceptual mine closure plan
- Prepare a detailed and final mine closure plan

Each of these outcomes is dealt with separately in the following sections. The above process also incorporates the principle that a conceptual mine closure plan can be developed in the absence of a regional mine closure strategy but that no final mine closure plan can be developed until an approved regional mine closure strategy is in place.

5.5.1 Preparation of a regional mine closure strategy

Due to the fact that most mines are hydrologically interconnected with the adjacent mines, the closure of one mine within a region will often have impacts on the remaining mines. There is also a risk that the cumulative impact from all the mines in a region could be imposed upon the last mine in the region to cease operations. This poses a secondary risk that this last mine could be held responsible and liable for the cumulative impact of all the mines or, as a minimum, that it would be difficult, if not impossible, to apportion liability to the contributing mines within a region. It must also be recognised that different mines within a region will cease operations at different times and some framework must be established within which these mines can plan for mine closure.

It is, therefore, recommended that a number of regional mine closure strategies be developed for the different regions that have been identified. The proposed procedure for the development of such a regional mine closure strategy is shown in Figure 5.5 below.



FLOWCHART 2: DEVELOP A REGIONAL MINE CLOSURE STRATEGY

Figure 5.5: Flowchart to develop a regional mine closure strategy

In the development of a regional mine closure strategy the first step is to establish which mines are included within each region. While it is not the responsibility of the research team to dictate who funds the development of a regional mine closure strategy, it would clearly be reasonable that either all the mines within a given region jointly manage and fund the development of this strategy, or that the State take responsibility there for.

Based on the research undertaken as part of this project, 17 different regions have been identified as shown in Table 5.1 below (also refer to Appendix B).

Table 5.1: Regions for regional mine closure strategies

Area	Geohydrological Unit	Mine	Quarternary Catchment	Tertiary Catchment Name
KOSH	KOSH	Stilfontein, Hartebeestfontein & Buffelsfontein	C24A	Schoonspruit
	KOSH	Vaal River Operations & ARM	C24H	Schoonspruit
Free State	Odendaalsrus sub basin	Target, Jeanette, Tshepong & PS North	C25	Makwassie spruit
	Welkom sub basin	PS South, St Helena, P Brand, Unisel, Matjhabeng, Banbanani & ARM	C43B	Vet
	Virginia sub basin	Harmony original, Old Virginia, Old Saaiplaas, Old Erfdeel, Old Merriespruit	C42J	Vet
	Oryx	Oryx	C42L	Vet
	Theunissen sub basin	Joel & Beatrix	C42K	Vet
Far West Rand	Western sub basin	Deelkraal, Driefontein, Blyvooruitzicht, Western Deep & Elandsrand	C23E	Mooi
	Central sub basin	Kloof	C22J	Klip
		Venterspost, Libanon	C23D	Mooi
	Eastern sub basin	Placer Dome	C22H	Klip
		Harmony Cooke	C23D	Mooi
Barberton	Barberton	New Consort	X23B	Krokodil
	Barberton	Sheba	X23G	Krokodil
	Barberton	Fairview, Agnes	X23F	Krokodil
Evander	Evander	Winkelhaak, Bracken, Leslie & Kinross	C12D	Waterval
West Rand	West Rand	Randfontein Operations & West Wits	A21D	Upper-Krokodil
Central Rand	DRD and Rand Leases	DRD, 5A shaft & Rand Leases	C22A	Klip
	Central	CMR, Crown, Rose Deep & City Deep	C22A&B	Klip
	ERPM	ERPM	C22B	Klip
East Rand	East Rand	Grootvlei & Modderfontein	C21D	Suikerbosrand
		Nigel	C21E	Suikerbosrand
Pilgrim's Rest	Pilgrim's Rest	Transvaal Gold Mining Estate	B60A	Blyde

The grouping is essentially based on connections between the underground workings and the geohydrological units that apply. In all cases other than the West Wits Line Central sub-basin and Eastern sub-basin, mines grouped within a geohydrological region are also located within the same surface hydrological unit. Regional mine closure strategies developed for these 2 subbasins will need to take cognisance of catchment management plans developed for the adjacent catchments.

The steps to be followed in actually developing the regional mine closure strategies are set out in Figure 5.5 above and are elaborated on below.

Construct a 3-dimensional model of all the underground workings for all the mines in the region

The objective of this step is to develop a physical model that will assist in identifying where current interconnections between mines exist or, where there is a high risk that flooding of one mine will cause the development of new interconnections, thereby posing a risk to the adjacent mine. This model may be developed in an appropriate computer package and should be verified by all mines within the region as being correct.

Define all confirmed and potential hydraulic interconnections between mines

In this step, all the known hydraulic connections between shafts and adjacent mines must be identified. Where actual connections do not exist but where it is known or suspected that relatively thin boundaries exist between mines that could potentially become hydraulic connections in the event of mine flooding, these must also be identified. Rock mechanics expertise should be sought to provide expert opinion on the likely integrity of these areas.

Define anticipated remaining life for each mine and shaft

While it is understood that the precise details of remaining life may be considered as confidential information, agreement will need to be reached on what degree of disclosure would be acceptable to enable the development of a regional mine closure strategy without compromising mine's commercial interests. This information is needed to establish the potential progression of mine / shaft flooding and directions of inter-mine flow.

Develop a regional-scale groundwater model capable of quantifying major water ingress points, rates of flooding and inter-mine flow rates

For the purpose of developing a regional mine closure strategy, it is necessary that a groundwater model be developed on a regional scale that takes account of major water ingress points. This model should, based on first-order calculations of mine void space, be able to make first predictions of the rate of flooding of different shafts and mines, given the planned remaining life of mines and shafts. The model should also be capable of predicting the rates of flow of water between adjacent shafts and mines.

Undertake a regional-scale geochemical assessment to define regional inter-mine pollution loads

In order to understand the probable quality of water that will establish within the flooded mines / shafts and that will flow between shafts and mines, it will be necessary to undertake a regional-scale geochemical assessment of the different mines and shafts. Such an assessment will incorporate the taking of rock samples from the underground areas, based on a review of the type of reefs being mined at each location and bearing in mind the location of the probable major water inflow points. The objective of the sampling will be to ensure that samples are taken along the primary water flowpaths and that samples represent the range of reefs being mined.

Samples will then need to be subjected to a thorough geochemical analytical programme in order to obtain reliable average values for the screening level regional geochemical assessment. This programme would probably entail taking and analyzing between 5 and 10 samples per shaft system and analyzing for acid potential, neutralizing potential, XRD-mineralogy and ICP-MS scans of metals from water and aqua-regia leachates. This data would then be used to undertake screening-level but kinetic geochemical modelling of the interconnected region such that water quality deterioration from each shaft and mine can undergo a first quantification. These results should then be coupled with the predicted inter-mine flow rates to generate predicted inter-mine contaminant loads.

Establish the probability of decant of contaminated underground water into the aquifer or surface water systems and the location, volumes and contaminant loads associated with such decants

Using the regional-scale geohydrological model, make first predictions on the likelihood of decant of mine water into the surface or ground water resource. Where such decant is predicted to occur, specify the location and the volume of decant that applies. Using the regional-scale geochemical model, predict the likely contaminant loads that will be discharged and obtain a first estimate of the relative apportionment of volume and contaminant load between mines. Note that at this stage, this assessment only considers the contribution from water decanting from flooded underground workings and the contribution from waste rock dumps and slimes dams is ignored. These surface sources are ignored, not because they are unimportant, but because the apportionment of responsibility and liability is a simpler issue.

With reference to the applicable WMP, establish the acceptable volumes and contaminant loads and negotiate and agree with Authorities

To complete this step, there is a requirement that the DWAF or the local CMA will have developed an agreed and approved catchment management plan and a reserve determination will have been undertaken that can serve as the basis for defining an acceptable maximum level of contamination of the water resource. This statement is made on the basis that all the existing gold mines have been in operation for many years and that it, in cases where the local geohydrology will result in a decant of water from the underground workings, and where surface waste residue deposits are not ideally located, zero pollution will generally not be attainable and the target should be to minimize pollution and reduce it to some agreed level.

Apportion acceptable load to each mine within region and reach agreement between mines and Authorities

Once agreement has been reached on what the acceptable loads are that the local water resource can assimilate without undue negative impacts on downstream users, it then becomes necessary to apportion this load amongst contributory mines. While there are different ways of achieving this apportionment, it is proposed that consideration be given to incorporating the following components:

Total production of ore and waste during the life of mine should serve as the primary basis for apportioning load, i.e. a mine that has produced 25% of the total ore and waste produced in that region should be entitled to 25% of the waste load.

Credits should be allocated to mines that are actively importing contaminated water (e.g. sewage or mine water from an adjacent mine) thereby reducing the load being discharged to the water environment (or alternatively, increasing their measured load because they are taking contaminants from an adjacent mine. The actual procedure eventually adopted and agreed upon will need to be negotiated by the mines in each region.

Develop and implement regional monitoring programmes to provide data to validate the basis of the regional mine closure strategy

The persons who undertook the regional geohydrological and geochemical studies should also develop appropriate long-term monitoring programmes that will provide the data to validate their assessments. In terms of this monitoring programme, it is also proposed that it become mandatory to thoroughly review and update the regional mine closure strategy every 5 years, using the data collected in the preceding 5 years.

Where some of the mines are expected to impact on adjacent regions, ensure that appropriate communications are maintained with such regions

As discussed previously, other than for the West Wits Line Central sub-basin and Eastern sub-basin, all mines within a given region appear to have their impacts largely confined within that region. However, it must be recognised that this is a broad statement that may be violated in a number of specific areas. For example, dewatering cones from one region may impact on an adjacent region's water balance or mines may transfer pumped mine water from one mine to another in an adjacent region. Where these interactions do take place, it is necessary for appropriate communications to take place to ensure that each regions mine closure strategy takes cognizance of these interactions.

5.5.2 Update the existing or prepare a new conceptual mine closure plan

Whereas the focus of a regional mine closure strategy is to understand interactions between adjacent mines and to find a basis for agreement on how much contamination (waste load allocation) is permitted for each mine, the focus of an individual mine closure plan is on how to manage the mine closure process to most optimally comply with the agreed waste load allocation. This process requires the mine to integrate the impacts that derive from its underground mining operations and those that derive from the surface waste residue deposits.

It is proposed that a new or updated conceptual mine closure plan can be developed at the same level of detail and using the same assessments that were undertaken for the regional mine closure strategy. This means that the mine will probably be able to meet the requirements for understanding and managing the impacts from the underground operations by using the geohydrological and geochemical studies undertaken for the regional mine closure strategy. With regard to the surface impacts, the mine will need to undertake a screening level assessment of the impacts associated therewith. For both the underground and surface impacts, the closure plan will then focus on evaluating various broad management strategies that are capable of reducing the total mine impact to an acceptable level as dictated by the approved waste load allocation. The proposed process to be followed is shown in the flowchart in Figure 5.6 below.

The procedures and steps set out in Figure 6.6 also correspond with Steps 2, 3, 8, 9, 10, 11, 12 and 13 as set out in Figure 5.3.

The conceptual mine closure plan should be reviewed and updated on the same frequency with which the mine undertakes its EMP performance assessments.

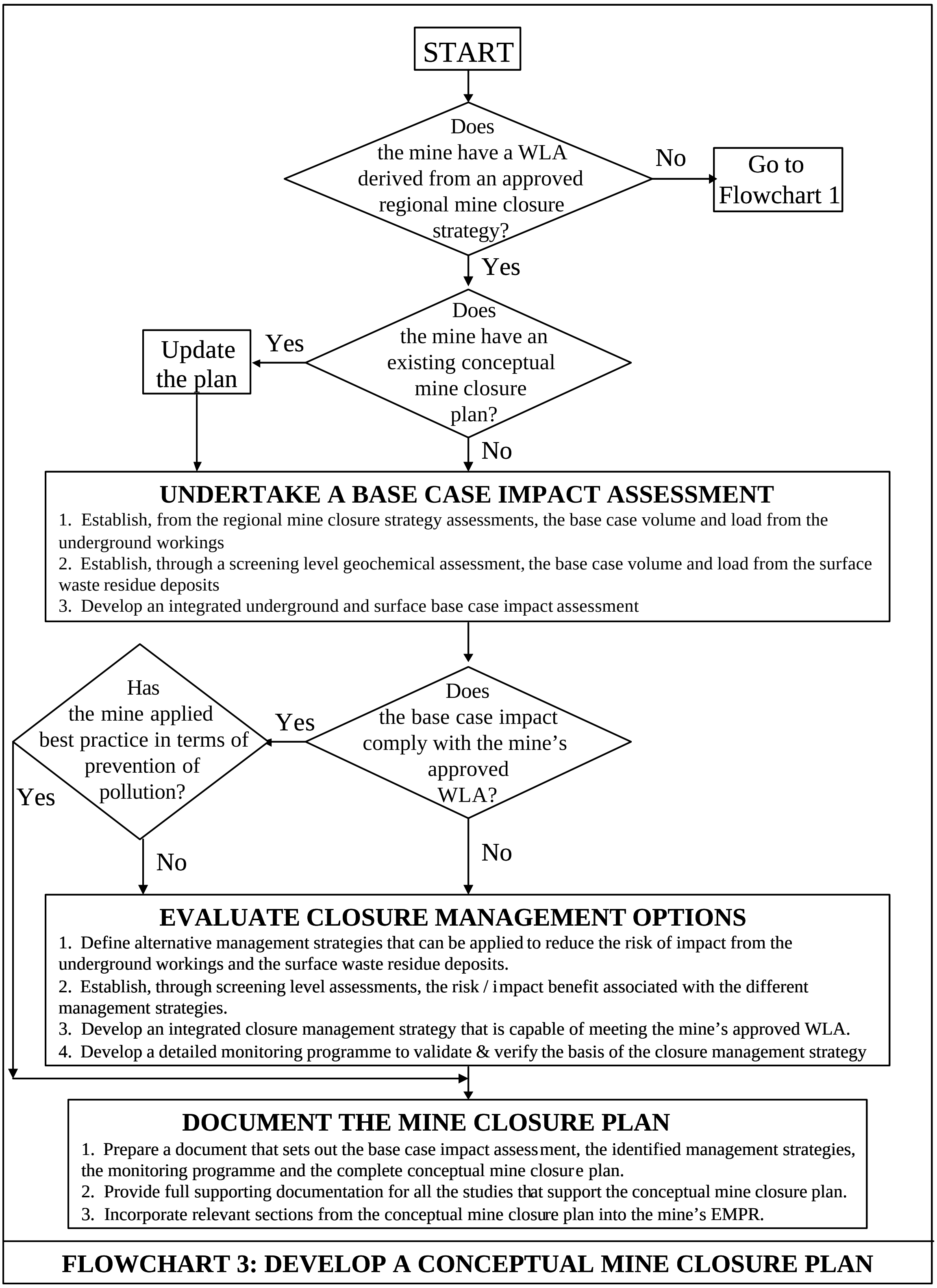


Figure 5.6: Flowchart to develop a conceptual mine closure plan

5.5.3 Prepare a detailed and final mine closure plan

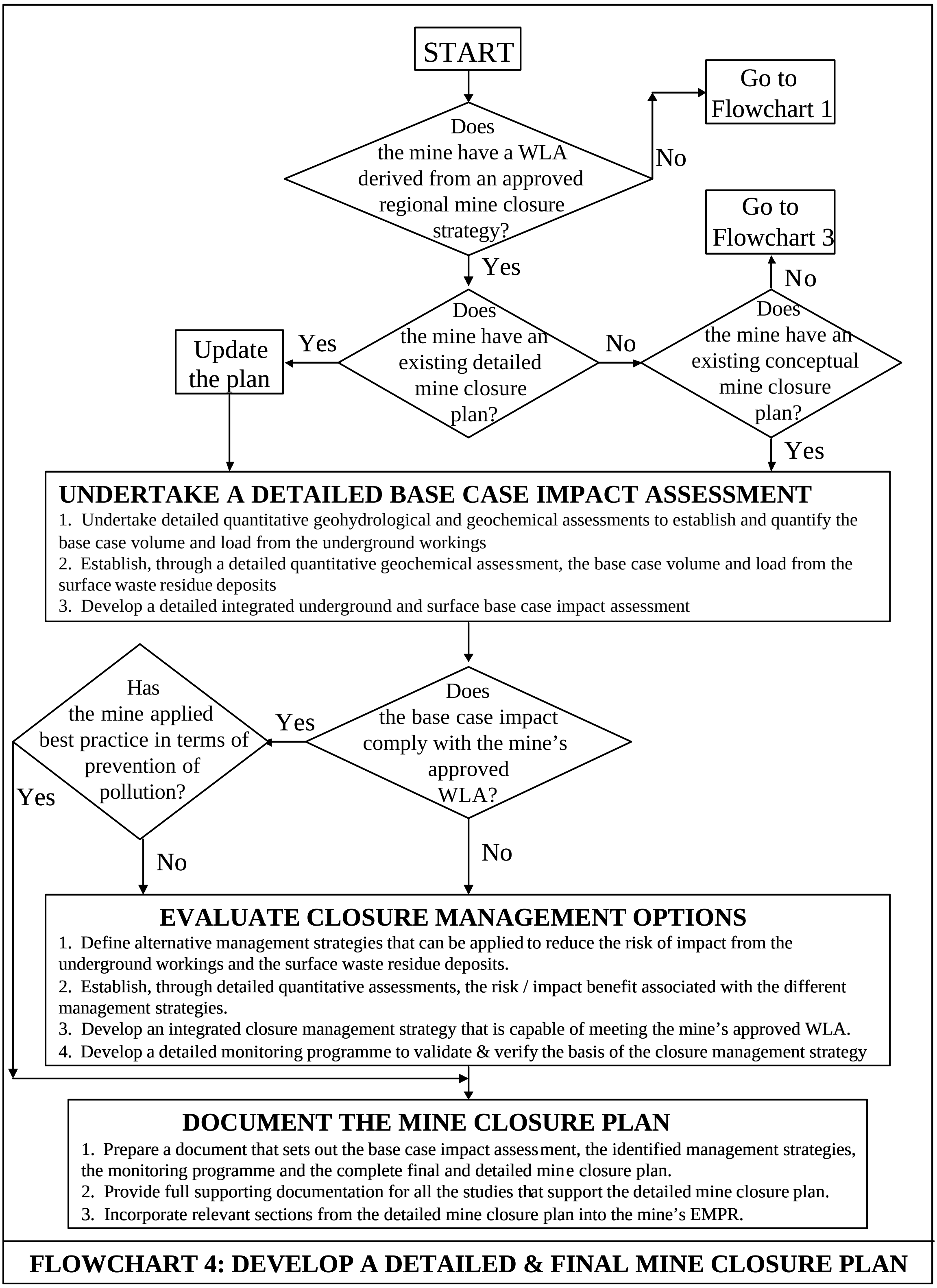


Figure 5.7: Flowchart to develop a detailed and final mine closure plan

When it is anticipated that the mine's remaining operational life is in the order of 5 years, the mine will need to undertake a substantial review and overhaul of its conceptual mine closure plan and will need to significantly upgrade the level of certainty associated with the various assessments. While the process is essentially similar to that employed for the development of a conceptual mine closure plan, the level of detail and the depth of the assessment will vary. In particular, it is proposed that detailed mine closure plans should be probabilistic in nature, i.e. they should aim to define the uncertainty associated with the assessment.

The DWAF is in the process of developing Best Practice Guidelines for the prediction of pollution from mining sites and the methodologies set out in these guidelines should be used in undertaking the assessments required to develop mine closure strategies and mine closure plans.

6. CONCLUSIONS AND RECOMMENDATIONS

This project has covered a fairly wide scope of work insofar as it attempted to address the state of closure planning in the total South African mining industry. The study was based on an assessment of the existing approved EMPRs as of 2001 and it must be recognised that as the updating of EMPRs is an ongoing process, many of the deficiencies noted in the EMPRs may have been addressed in subsequent updates.

The overall conclusion that was reached, based on a review of the existing EMPRs, is that the state of mine closure planning is inadequate when it comes to planning for the long-term impact on the national water resource. Major problems are as follows:

1. The long-term impact of tailings dams on the water resource is either ignored or it is incorrectly assumed that cessation of operation will rapidly result in cessation of pollution potential. The long-term pollution risks have not been assessed in a scientific and quantitative manner and all conclusions presented in the EMPRs are at best of a qualitative nature.

2. The long-term impact of waste rock dumps on the water resource is essentially ignored or assumed to be negligible without any quantitative assessment to support such assumptions.

3. The long-term impact of metallurgical plant footprints and surface infrastructure on the water resource is universally ignored by all gold mines.

4. The problems of inter-mine flow between mines that are hydraulically interconnected and the risks of ultimate decant into the water resource are often acknowledged but are not addressed in a quantitative manner. There is no formalized procedure in place to ensure that the flow and quality profiles and behaviour of this water is understood and that appropriate management measures are put in place to address the problems. At best, inter-mine plugs are installed to prevent ingress of water when an adjacent mine floods. This lack of knowledge and planning for long-term water management in the underground mine voids poses severe threats to those mines that have the longest remaining operational life and ultimately to the State.

Based on these conclusions, a number of recommendations have been made and it has been established that there is a definite need for clear guidance on what type of technical investigations need to be undertaken to provide the following information:

- Understanding of the long-term risks (quantity and quality) associated with post-closure decant from gold mines.
- Understanding of the long-term risks (quantity and quality) associated with post-closure seepage from waste residue deposits (tailings, waste rock and footprints below removed dumps).
- Identification of proactive management measures that can be implemented to minimise the long-term risks associated with decant from mines.
- Identification of proactive management measures that can be implemented to minimise the long-term risks associated with seepage from waste residue deposits.

The primary recommendation of the research project is that the basis of mine closure planning in South Africa should be modified. Whereas, mine EMPRs, mine authorisations and mine closure plans are drawn up, evaluated and approved on an individual mine basis, there is a need for this process to be modified to take account of regional issues. The following process has therefore been recommended:

1. Regional mine closure strategies should be drawn up for the 17 gold mining regions defined in the report. These strategies should establish the ground water and surface water interconnections between mines within a region and should be integrated with the catchment management plan drawn up for the relevant region. The regional mine closure strategy will need to be undertaken as a cooperative venture between all the mines and should result in a broad regional strategy that includes the equitable apportionment of waste load between mines. Details on the strategy development and content are provided in Chapter 6.

2. Individual mines will then be required to develop their individual mine closure plans, to be submitted to the DME as part of the mine's EMPR. These individual closure plans will need to be developed within the context of the approved regional mine closure strategy and could either be in the form of a conceptual mine closure plan if the mine has more than 5 years life remaining, or in the form of a detailed and final mine closure plan if the mine has 5 years or less of planned operational life remaining.

3. Interim procedures and policies need to be negotiated to enable the transition from the current status to the proposed new procedure. In this regard, it is proposed that an implementation period of say 5-10 years be agreed, within which a regional mine closure strategy must be developed and approved and mine closure plans be converted to conform to the approved closure strategy.

4. It is also recommended that no mine be permitted to switch off dewatering pumps or commence with flooding of portions of the mine without having an approved detailed and final mine closure plan that fits within an approved regional mine closure strategy. This is to ensure that any management actions that need to be implemented before a mine floods are timeously identified and implemented to reduce the risk of long-term water pollution problems.

5. It has been recommended that the regional mine closure strategy also address the issue of waste load allocation between mines on an equitable basis. Liability for long-term water management actions should then be apportioned on the same basis as the waste loads.

6. A recommendation has been made to the Department of Minerals and Energy that the proposed mine closure strategy be considered in the drafting of regulations for the new Minerals and Petroleum Resources Development Act, 2002 (Act No 28 of 2002).

7. It is recommended that a separate study be conducted to better understand the interconnections and groundwater interactions of the Barberton mines.

7. REFERENCES

Annhaeusser, C.R. (1969). *The Stratigraphy, Structure and Gold Mineralization of the Jamestown and Sheba Hills Area of the Barberton Mountain Land.* PHD Thesis, University of the Witwatersrand. Unpublished.

Avgold (1999) *Environmental Management Programme Report*

Barnes, T. (2002) President Steyn Gold Mine. Personal communications

Botha, V (1993). Mine Superintendent. Rand Leases Gold Mine. Personal Communications.

Briggs, G. (1992). Chief Geologist. Grootvlei Gold Mining Company Pty. Ltd. Personal Communications.

Brink, A.B.A. (1979). *Engineering Geology of Southern Africa. Volume 1.* Building Publications. Silverton South Africa.

Burger, V. (1992). Department of Mineral and Energy Affairs. Personal Communications.

Conradie, A.S. (1996/97). South Africa's Mineral Industry 1996/97. Department of Minerals & Energy, ISBN 0-7970-3569-9

Consolidated Modderfontein Mines. (2000). *Environmental Management Programme Report.*

Crous, H (2002). Gauteng Mining Pollution Forum. Personal communications.

Darcy (2002). *A Catchment Management Plan for the Schoonspruit and Koekemoerspruit Catchments: A Situation Assessment.* Report to DWAF

Du Preez, F. (2002). *PETMIN*. Personal communications

Du Toit (2001) *ARM4 Hydrogeological Investigation.* Addendum to ARM EMPR (2002)

Durban Roodepoort Deep - North West Operations. (2001). *Environmental Management Programme Report. Rev.3*. January 2001.

DWAF (1995) *Impact of Witwatersrand Gold Mines on Water Quality in the Vaal Barrage Catchment. Phase 1: Preliminary Situation Analysis.*

DWAF (1997) *Free State Goldfields and Lower Vet River Catchment- Development of a Water Management Plan Vol 8*

DWAF (1999) *Mooi River catchment management study: Phase 1 Situation assessment*

DWAF. (2002). GIS data from Department of Water Affairs and Forestry.

DWAF. (2002b). *A Catchment Management Plan For The Schoonspruit And Koekemoerspruit Catchments: A Situation Assessment*. Report to DWAF.

DWAF (2002c). *A Catchment Management Plan For The Schoonspruit And Koekemoerspruit Catchments: A Situation Assessment*. Report to DWAF

Fleisher, J.N.E. (1981) *Geohydrology of the dolomite aquifers of the Malmani Subgroup in the south-western Transvaal, Republic of South Africa*. Technical Report GH3169, DWAF Pretoria.

Forum. (1997). *Investigation for the Klerksdorp Mine Manager's association. Forum To Develop A Water Management Strategy For The Klerskdorp Gold Field*

Fourie, H.J. (2001). *Water increase and Control Mechanisms for: Central Mining Basin: Gauteng Gold Mines: Geldenhuys Interchange to DRD.* Report to ERPM

Grant, D. (1989). *A Summary of the Structure of the Welkom Goldfield In the Witwatersrand Basin*. A Memorandum of Presentation to JCI Technical Services. Unpublished.

Griffiths, G. (1994). Geologist Consolidated Modderfontein. Personal Communications.

Grimsley, T. (2002) Freegold. Personal communications

Hammersbeck, E.C.I. (1976). *Goud Buite die Witwatersrand Drietal*. Paper written and included in "Delfstowwe van die Republiek van Suid – Afrika". Geological Survey Report – ISBN 0 621 06436 X.

Harmony (2002) *Environmental Management Programme Report*

Hearne, C.N and R.A. Bush. (1996). *Investigation Into The Impact Of Diffuse Seepage From Gold Mines In The Klerksdorp Region On Water Quality In The Vaal River.*

Jenner, D. (2002). Blyvooruitzicht. Personal communications.

Klipwal Gold Mine. (1998). Ammendment to Environmental Management Programme Report.

Krantz, R. and van Biljon, M. (1999). Groundwater Model for the Far West Rand Basin. Rison Consulting Internal Report prepared for JCI Projects. Unpublished.

Krige, W.G. (2001). *A Quantification Of Water Volumes Recharging The Central Rand Mine Void, Associated With Direct Ingress From Surface Water Sources.* African Environmental Development report to DME.

Lazig, M. (1993). Report on a field visit to the Knights Gold Mine. Internal Report DWA&F.

L&W Environmental. (1993). *Klerksdorp regional groundwater baseline study.* Report No. 252/623/1/E for the Klersdorp Mine Managers Association.

Mackasey (2002) Page 2.12
Mackasey (2002) from Mining Watch in Canada states that the closure plan is in reality an opening plan, as it requires a comprehensive and technical public review of the proposed mining activities before production can start.

Metago Environmental Engineers (Pty) Ltd. (1998). *Environmental Management Programme Report:* New Consort Gold Mine.

Metago Environmental Engineers (Pty) Ltd. (1999). *The Amanzi Water Treatment Venture Strategic Environmental Impact Assessment*.

Metago Environmental Engineers (Pty) Ltd. (2002). *The Assessment Of Short, Medium And Long Term Impacts On Groundwater Quality Associated With The Filling Of Dolomitic Cavities.* Progress Report to Water Research Commission.

Mhlangu. (2002). Kloof Mine. Personal communications

MMSD (2002). *Mining, Minerals and Sustainable Development in southern Africa. 2002. The report of the Regional MMSD Process.* Published by MMSD SOUTHERN AFRICA. School of Mining engineering, University of Witwatersrand. Johannesburg

Morris, J., Schultz, C.B. and le Roux, W.J. (1992*)* *Hartebeestfontein Gold Mine.*

Mudder & Harvey (1999) Page 1.1
Inadequate mine closure plans can result in severe environmental, social and economical consequences. More specifically, lack of proper closure procedures, water management and waste rock disposal plans have prompted unexpected and in some instances, unwarranted secondary environmental impacts statements or assessments (Mudder and Harvey, 1999).

Nazeri (1999). Page 1.1
The objective of mine closure is to provide long-term stabilization of the geochemical and geo-technical conditions of the disturbed mining areas, to protect public health, and minimise and prevent any additional or on-going environmental degradation (Nazeri,1999).

Parsons C.F. and Killick A.M., (1985). *The Surface Geology of Part of the W.A.G.M. Property and Environs.* J.C.I. Research Unit Report 200, unpubl. Report.

PHD. (2002). *Rietspruit Catchment Study. Phase 1. Situation Assessment.* Report to DWAF, Pulles Howard & De Lange Inc. PHD Report No P###

PHD. (1996). *Development of Strategies to control pyrite oxidation in underground gold mine deposits – phase 1.* PHD Report Number P053.

Pulles (1991) Page 2.1
Furthermore, the volumes of water used in the operation of gold mines are also substantial (Pulles, 1991).

Ramsay, J.G. (1963). *Structural Investigations in the Barberton Mountain Land, Eastern Transvaal.* Transactions from the Geological Society of South Africa No. 66.

Randfontein Estates. (1994). *Environmental Management Programme Report*

Rison Consulting. (1999). *Far Western Basin Groundwater Modelling Exercise.* Rison Consulting Internal Report prepared for JCI Projects. Unpublished.

Rison Groundwater Consulting. (2002). *Water License Application for the Grootvlei Mine.*

Rösner, T., Boer R., Reyneke, R., Aucamp,P., Vermaak J. (2001*)* *A Preliminary Assessment of Pollution Contained in the Unsaturated and Saturated Zone Beneath Reclaimed Gold - Mine Residue Deposits* WRC report 797/1/01

Schwartz, K. (2001). ***Environmental Manager Harmony Gold Mining Company Ltd.***

Scott, R. (1995). *Flooding of Central and East Rand Gold Mines: An Investigation into Controls over the Inflow Rate, Water Quality and the Predicted Impacts of Flooded Mines.*

Skousen (2000) Page 2.12
Skousen (2000) in his article for "Green lands Magazine" highlights the problems associated with acid mine drainage (AMD) in older underground mines and discusses water management techniques for acid drainage control.

SRK. (1996). *East Driefontein Environmental Management Programme Report*. SRK report 196369/D

SRK. (1999). *Environmental Management Programme Report for Grootvlei Propriety Mines Ltd.* SRK report 222699/1

St. Helena Gold Mines Limited (1997*).* *Environmental Management Programme Report*

St. Helena Gold Mines Limited (2002*).* *Environmental Management Programme Report*

Strongmen (2000) Page 2.9
Authors like Strongmen (2000) state that a generally accepted guiding principle is avoiding mining and waste disposal methods that will have impacts on water quality for generations to come e.g. acid mine drainage, toxic material release, riverine disposal of mine wastes.

Swart, C.G.U. (2003*).* *GSG - Comments and edits with regard to "The development of an appropriate procedure for the closure of deep underground gold mines".* Memorandum provided to Project team, dated 9 October 2003

Tepper D.H., Kappel W.M., Miller T.S. and Williams J.H. (1995) *Hydrogeoligcal effects of flooding in the partially collapsed Retsof salt mine, Livingston County, New York* US Geological Survey Subsidence Interest Group Conference, Nevada,.

Truswell, J.F. (1977). *The geological evolution of South Africa*. Purnell, Cape Town, p. 21.

Van Biljon, M. (1995). *The Use of Groundwater Modelling and a Predictive Tool for Groundwater Management at HJ Joel Gold Mine*. MSc. Thesis, University of the Free State, Unpublished.

Van Deventer, J. (2002). DME. *Personal communications*.

Walmsley Environmental Consultants (2000). *Environmental Management Programme Report for Agnes Mine (Cluff SA). Water loss assessment for the Koekemoerspruit*. SRK report no 189518/1.

Wates, J.A. (1992). *Geohydrological Assessments***.** Department of Water Affairs and Forestry. Directorate of Water Quality Management – Mining Strategy.

Wendel, G. (1997). *Mine closure - the process.* SAIMM Colloquium on mine closure on 6 November 1997

Western Deep Levels Limited and Elandsrand Gold Mining Company Limited. (1996). Environmental Management Programme Report:

Whiteside, H.C.M., Glasspool, K.R., Hiemstra, S.A., Pretorius, D.A. and Antrobus, E.S.A. (1976). *Goud in die Witwatersrand Drietal***.** Paper written and included in "Delfstowwe van die Republiek van Suid – Afrika". Geological Survey Report – ISBN 0 621 06436 X.

Winde, F (2001) *Slimes dams as source of uranium - contamination of streams – the Koekemoer Spruit (Klerksdorp gold-field) as a case study*, Proceedings Conference on Environmentally Responsible mining in Southern Africa.

Younger PL (2000) *Predicting temporal changes in total iron concentration in groundwaters flowing from abandoned deep mines; a first approximation* Journal of Contaminant hydrology Vol 44 No 1 pp 47-69.

APPENDIX A

LISTS OF OPERATING AND DEFUNCT GOLD MINES

A1: LIST OF OPERATING GOLD MINES

Province /District	Mine	Owner	MB #	Approved EMPR		
				Y/N	Year	Comments
North West						
Klerksdorp	Vaal River Operations	Anglogold	670	Y	1994	EMPR-Revised 2001
Klerksdorp	African Rainbow Minerals & Expl. (Pty) Ltd	ARM	3172	Y	2001	
Klerksdorp	Buffelsfontein Section	DRD	80	Y	2001	
Klerksdorp	Hartebeesfontein Section	DRD	263	Y	2001	
Potchefstroom	Deelkraal Gold Mine	Harmony Gold Mining Co.	148	Y	1996	To update EMPR^^^
Potchefstroom	Elandsrand Gold Mine	Harmony Gold Mining Co.	192	Y	1996	"^^^
Stilfontein	Stilfontein	Mine Waste Solutions		Y	2001	
Gauteng						
Westonaria	Western Areas	Placer Dome WAJV	711	Y	2001	EMPR being amended
Roodepoort	Durban Roodepoort Deep Ltd	DRD	169	N		Ceased operation
Westonaria	Libanon Gold Mine	Gold Fields Ltd	367	Y	1996	***
Springs	Grootvlei Proprietary Mines Ltd	Petra Mining Ltd	254	Y	1999	###
Oberholzer	West Wits Operations-Western Deep Level	Anglogold	713	N		Ceased operation
Oberholzer	Driefontein Consolidated	Gold Fields Ltd	172	Y	1996	EMPR being amended
Westonaria	Kloof Gold Mine (Ventersdpost)	Gold Fields Ltd	344	Y	1996	***
Krugersdorp	West Witwatersrand GM Co Ltd	DRD	416	N		
Benoni	Consolidated Modderfontein Mines 1979 Ltd	Petra Mining Ltd	1148	Y	2000	###
Benoni	Gravelotte Mines Ltd	Salene Mining (Pty) Ltd	1369	Y	1999	
Westonaria	Leeudoorn Mine	Gold Fields Ltd	1809	Y	1996	
Nigel	Nigel Gold mining Co-ltd	Petra Mining Ltd	2937	Y	1999	###
Randfontein	Randfontein operations	Harmony Gold Mining Co.	528	Y	1997	
Boksburg	Enderbrooke-ERPM	Enderbrooke Investments (Pty)	176	Y	1996	To submit new EMPR 2001
Oberholzer	Blyvooruitzicht Section	DRD ltd	54	Y	2000	

*** *Libanon/Kloof and Ventersdpost now operating as one : Kloof Gold mining Co.*

Nigel/Grootvlei and Consol Modd - now operated as single mine (Petmin) but each has own EMPR

^^^ *Deelkraal and Elandsrand -bought by Harmony (to submit a new EMPR)*

Province /District	Mine	Owner	MB #	Approved EMPR Y/N	Year	Comments
Free State						
Welkom	Free State Operations + HJ Joel	Anglogold	1829	Y	2001	EMPR awaiting approval
Ventersburg	Harmony FS Operations	HGMC	261			
	Harmony Original			N		To submit new EMPR 2001
	Saaiplaas-Masimong			N		To submit new EMPR 2001
	Brandt Shaft			Y	1999	EMPR awaiting approval
	Unisel			Y	1995	
Odendaalsrus	Target Division-Loraine Gold Mine	Avgold	370	Y	1998/9	
Welkom	President Steyn Gold Mine	PSGM Ltd	511	N		
Welkom	St Helena Gold Mine	Gold Fields Ltd	611	Y	1997	
Theunissen	Oryx mine	Gold Fields Ltd	2307	Y	1999	
Theunissen	Beatrix Mine	Gold Fields Ltd	1178	Y	1997	
Welkom	ARM	ARM		Y	2000	To submit new EMPR 2001
Mpumalanga						
Barberton	New Consort Gold Mine	Avgold	180	Y	1998	
Barberton	Fairview Gold Mine	Avgold	36	N		
Highveld Ridge	Evander Operations	Harmony Gold Mining Co Ltd	333	N		Consold. To submit new EMPR
	Kinross			Y	1996	
	Winkelhaak			Y	1994	
	Lesley					
	Brachen					Applied for closure
Barberton	Sheba gold Mine	Avgold	179	N		
Barberton	Agnes gold Mine	Cluff Mining (SA)Pty Ltd	181	Y	2000	
Barberton	Makonjwaan Imperial Mining Co (Lily mine)	Simmer and Jack Mines Ltd	1443	Y	2000	
Pilgrims Rest	Tvl Gold Mining Estates Ltd	TGME		Y	2001	Draft awaiting approval
KZN						
Simdlangentsha	Klipwal Gold-Bosveld Mines Pty Ltd	Matt Trading (pty) Ltd	63	Y	1999	

A2: LIST OF DEFUNCT GOLD MINES
(AS RECEIVED FROM CHAMBER OF MINES OF SOUTH AFRICA)

Area	Mine	From	Till	Comments (a)
EAST RAND	Nigel	Sep 1888	Aug 1956	Ceased production January 1918; restarted July 1934
	Van Ryn Estates	Mar 1892	Aug 1948	
	New Kleinfontein	May 1894	Mar 1967	
	ERPM	Sep 1894	Aug 1999	
	New Modderfontein	May 1896	Mar 1952	
	Geduld	Nov 1908	Apr 1966	
	Sub Nigel	Dec 1909	Dec 1971	
	Cinderella Cons	Jun 1910	Jul 1913	
	Brakpan	Jun 1911	Apr 1964	
	Modderfontein B	Nov 1911	Sep 1956	
	Van Ryn Deep	Aug 1913	Nov 1945	
	Govt GM Areas	Oct 1914	Sep 1962	
	Modderfontein Deep Levels	Jan 1915	Mar 1951	
	Springs Mines	Jan 1917	Sep 1962	
	Modderfontein East	Apr 1920	Jan 1962	
	New State Areas	Jun 1923	Feb 1954	
	West Springs	Jul 1924	Jul 1948	
	East Geduld	Jul 1931	Oct 1970	
	Daggafontein	Jan 1932	Oct 1967	
	Vogelstruisbult	Jun 1936	Feb 1968	
	SA Land	Jun 1938	Dec 1976	
	Grootvlei	Sep 1938	Jun 1997	Merged with Harmony
	Van Dyk Cons	Dec 1938	Nov 1967	
	East Daggafontein	Jun 1939	Nov 1976	
	Witwatersrand Nigel	Jun 1940	Apr 1985	
	Vlakfontein	Jan 1942	Nov 1977	
	Spaarwater	Nov 1947	Aug 1969	
	Welgedacht	Jan 1948	Jul 1956	
CENTRAL RAND	Jubilee	Sep 1887	Jan 1912	
	Salisbury	Sep 1887	Feb 1912	
	Jumpers	Oct 1887	Dec 1910	
	City & Suburban	Nov 1887	Apr 1920	
	Wolhuter	Dec 1887	May 1929	
	Langlaagte Estate	Jan 1888	Dec 1946	
	Robinson	Jan 1888	Jun 1926	
	Meyer and Charlton	Feb 1888	Jul 1932	
	Roodepoort United Main Reef	Feb 1888	Jul 1922	
	Durban Roodepoort	Apr 1888	Dec 1918	
	Simmer and Jack	Sep 1888	Apr 1964	
	May Cons	Jan 1889	Aug 1917	
	New Primrose	Jan 1889	Jun 1928	
	Witwatersrand	Jan 1889	Nov 1953	
	Princess Estate	Feb 1890	Jun 1920	
	Glencairn	Nov 1890	Dec 1918	
	Treasury	Dec 1891	Jan 1911	
	Village Main Reef	Jan 1892	Oct 1920	
	New Rietfontein	June 1892	Dec 1915	
	New Heriot	Nov 1892	Jun 1920	
	Ginsburg	Mar 1894	Jun 1919	

	Geldenhuis Deep	Nov 1895	May 1947	
	Nourse Mines	Jan 1896	Dec 1948	
	Bonanza	Aug 1896	Mar 1908	
	Vogelstruis Estate	Dec 1896	Sep 1918	
	Crown Mines	Aug 1897	Mar 1977	
	Rose Deep	Oct 1897	Jan 1965	
	Cons Main Reef	Jan 1898	Aug 1975	
	Robinson Deep	Apr 1898	Mar 1966	
	New Unified	Nov 1898	Jun 1923	
	New Goch	Jan 1899	Nov 1923	
	Aurora West United	Feb 1899	Nov 1927	
	Ferreira Deep	Mar 1902	May 1929	
	Knight's Deep	Aug 1902	Sep 1920	
	Witwatersrand Deep	Nov 1902	Sep 1944	
	Village Deep	Feb 1905	Jan 1930	
	Jupiter	Oct 1908	Aug 1920	
	Simmer Deep	Oct 1908	Aug 1920	
	Knight Central	Feb 1909	Jun 1923	
	Bantjies Cons	Sep 1910	Jan 1920	
	City Deep	Dec 1910	Nov 1976	
	Jumpers-cum-Treasury	Jan 1911	Jun 1913	
	Rietfontein Cons	Apr 1935	Jan 1967	
	Rand Leases	Apr 1936	Jun 1971	
	Marievale	Nov 1939	Oct 1993	
WEST RAND	Champ d'Or	Jul 1893	Dec 1911	
	Luipaards Vlei	Feb 1898	Mar 1970	
	French Rand	Oct 1898	Feb 1910	
	Lancaster West	Jun 1899	Jun 1913	
	West Rand Cons	Sep 1908	Aug 1992	
	Randfontein	Jun 1924	Mar 1967	
	East Champ d'Or	Jun 1936	Oct 1964	
	Randfontein Estates	Jan 1974	Dec 1999	Merged to form Evander Mines
FAR WEST RAND	Venterspost	Oct 1939	Jan 1992	From 1 July 1992 merged with Kloof (Libanon)
	Blyvooruitzicht	Feb 1942	Sep 1997	Merged with Durban Deep
	Libanon	Mar 1949	Jun 1992	From 1 July 1992 merged with Kloof (Libanon)
	Doornfontein	Nov 1953	Nov	Merged with Blyvooruitzicht
	1995Elsburg	Dec 1968	Jun 1974	
	Deelkraal	Jan 1980	Jun 1997	Sold to Harmony
EVANDER	Bracken	Aug 1962	Oct 1993	
	Winkelhaak	Dec 1958	Jun 1996	Merged to form Evander Mines
	Leslie	Oct 1962	Jun 1996	Merged to form Evander Mines
	Kinross	Jan 1968	Jun 1996	Merged to form Evander Mines
KOSH	Western Reefs	Jun 1941	Sep 1971	
	Stilfontein	Jul 1952	Sep 1995	
	Ellaton	Jan 1954	Feb 1963	
	Hartebeesfontein	Jul 1955	Aug 1999	
	Buffelsfontein	Jan 1957	Sep 1997	Merged with Durban Deep
	Zandpan	Jul 1964	Jun 1972	
FREE STATE	Welkom	Nov 1951	Jul 1981	From 1 July 1981 merged with Western Holdings
	Freddies North	Jul 1953	May 1954	
	Freddies South	Jul 1953	May 1954	
	Western Holdings	Jul 1953	Jul 1981	From 1986 merged with Free State Cons (North Region)
	Freddies Cons	Jun 1954	Dec 1976	From 1986 merged with Free State Cons (North Region)

	Virginia	Oct 1954	Dec 1972	
	President Steyn(4)	Apr 1954	Dec 1985	
	President Brand j	Aug 1954	Dec 1985	From 1986 merged with Free State Cons (South Region)
	Loraine	May 1955	Jun 1999	
	Free State Geduld h i	Jan 1956	Dec 1985	From 1986 merged with Free State Cons (North Region)
	Merriespruit	Mar 1956	Oct 1956	
	Free State Saaiplaas h j	Jan 1961	Jul 1981	From 1986 merged with Free State Cons (South Region)
	Anglo American OFS Jnt MetallurgProd Scm	1977	Oct 1988	
	Unisel(c)	Oct 1979	Mar 1996	
	Western Holdings i	Jul 1981	Dec 1985	From 1986 merged with Free State Cons (North Region)
	St Helena (Beisa Sect)	Jan 1982	Oct 1984	
	Free State Cons (North Region) m	Jan 1986	Mar 1993	April 1993 merged to form Free State Cons Gold Mines Ltd
	Free State Cons (South Region) m	Jan 1986	Mar 1993	April 1993 merged to form Free State Cons Gold Mines Ltd

APPENDIX B

RELATIONSHIP BETWEEN GEOHYDROLOGY AND SURFACE HYDROLOGY

Relationship between geohydrological gold mining units and quaternary surface catchments

Area	Geo-hydrological Unit	Mine	Situated in Quartenary Catchment	Tertiary Catchment Name	Adjacent Quartenary Catchment	Tertiary Catchment Name	Transfer confirmed
KOSH	KOSH	Stilfontein, Hartebeestfontein & Buffelsfontein	C24A	Schoonspruit			
KOSH	KOSH	Vaal River Operations & ARM	C24H	Schoonspruit	C24B	Schoonspruit	
Free State	Odendaalsrus sub basin	Target, Jeanette, Tshepong & PS north	C25	Makwassie-spruit			
Free State	Welkom sub basin	PS south, St Helena, P Brand, Unicel, Matjhabeng, Banbanani & ARM	C43B	Vet	C42J	Vet	
Free State	Virginia sub basin	Harmony original, Old Virginia, Old Saaiplaas, Old Erfdeel, Old Merriespruit	C42J	Vet			
Free State	Oryx	Oryx	C42L	Vet	C42K	Vet	
Free State	Theunissen sub basin	Joel & Beatrix	C42K	Vet			
WW Line	Western sub basin	Deelkraal, Driefontein, Blyvooruitzicht, Western Deeps & Elandsrand	C23E	Mooi	C23J	Mooi	
WW Line	Central sub basin	Kloof	C22J	Klip (Rietspruit)	C23D	Mooi	Yes. Situated in Rietspruit catchment but gets water from and discharges to Mooi River catchment
WW Line	Central sub basin	Venterspost, Libanon	C23D	Mooi			
WW Line	Eastern sub basin	Placer Dome	C22H	Klip (Rietspruit)			
WW Line	Eastern sub basin	Harmony Cooke	C23D	Mooi			
Barberton	Barberton	New Consort	X23B	Krokodil	X23G	Krokodil	
	Barberton	Sheba	X23G	Krokodil			
	Barberton	Fairview, Agnes	X23F	Krokodil			
Evander	Evander	Winkelhaak, Bracken, Leslie & Kinross	C12D	Waterval	B11D		
West Rand	West Rand	Randfontein Operations & West Wits	A21D	Upper-Krokodil	C23D	Mooi	
Central Rand	DRD and Rand Leases	DRD, 5A shaft & Rand Leases	C22A	Klip			
	Central	CMR, Crown, Rose Deep & City Deep	C22A&B	Klip			
	ERPM	ERPM	C22B	Klip			
East Rand	East Rand	Grootvlei & Modderfontein	C21D	Suikerbosrand			
	East Rand	Nigel	C21E	Suikerbosrand			
Pilgrims Rest	Pilgrims Rest	Tvl Gold Mining Estate	B60a	Blyde			