Executive Summary

1. Introduction

The Central and East Rand mining areas have been extensively mined since 1886 to depths of up to 3 500 m below surface. During the long history of mining these areas have been dewatered to allow mining operations to continue unhindered by water ingress. Up to the 1950's, each mine was responsible for their own pumping. As some mines reached the end of their working lives and were abandoned or closed, so more and more pumping was left to the remaining mines, until most of the pumping was conducted from one mine in a particular area. Because pumping from these points kept all the related mines dry, some operations were able to mine without pumping. Thus those mines that continued to pump were granted state assistance for their pumping costs.

Until June 1991, dewatering on the East Rand was achieved from S.A. Lands and Exploration (Sallies) No. 1 Shaft, with smaller volumes pumped from Grootvlei Mines No 3 and 4 shafts. On the Central Rand dewatering has continued until the present from East Rand Proprietary Mines (ERPM) Hercules and SW vertical shafts and at Durban Roodepoort Deep (DRD) from No. 5 Shaft.

Mining in this area cannot continue indefinitely and at some time either due to economic constraints or to the ore being totally depleted, all mining will stop. At that time there will be no further reason to dewater the underground excavations and, if the results were environmentally acceptable, pumping could stop and the pumping costs would be saved, this future eventuality gave rise to this project. Thus if mining stops, and at the same time dewatering stops allowing the mine excavations to flood, what will the results be?

The objectives of the investigation were therefore:

- Investigate the rate of water-table recovery in the abandoned gold mines of the Eastern and Central Witwatersrand; upon cessation of pumping from these mines.
- Investigation into processes affecting the quality of the water in these mines and prediction of the likely water quality in fully recovered mines.
- Quantification of possible seepages from these mines upon full recovery of the water table.
- Evaluation of the overall impact on possible further deterioration of the surface water quality in the catchments.

2. Physical Description

The Central and East Rand Mining areas are two of the nine distinct gold mining areas (goldfields) that have developed in the greater Witwatersrand Basin, these are shown in Figure 1.

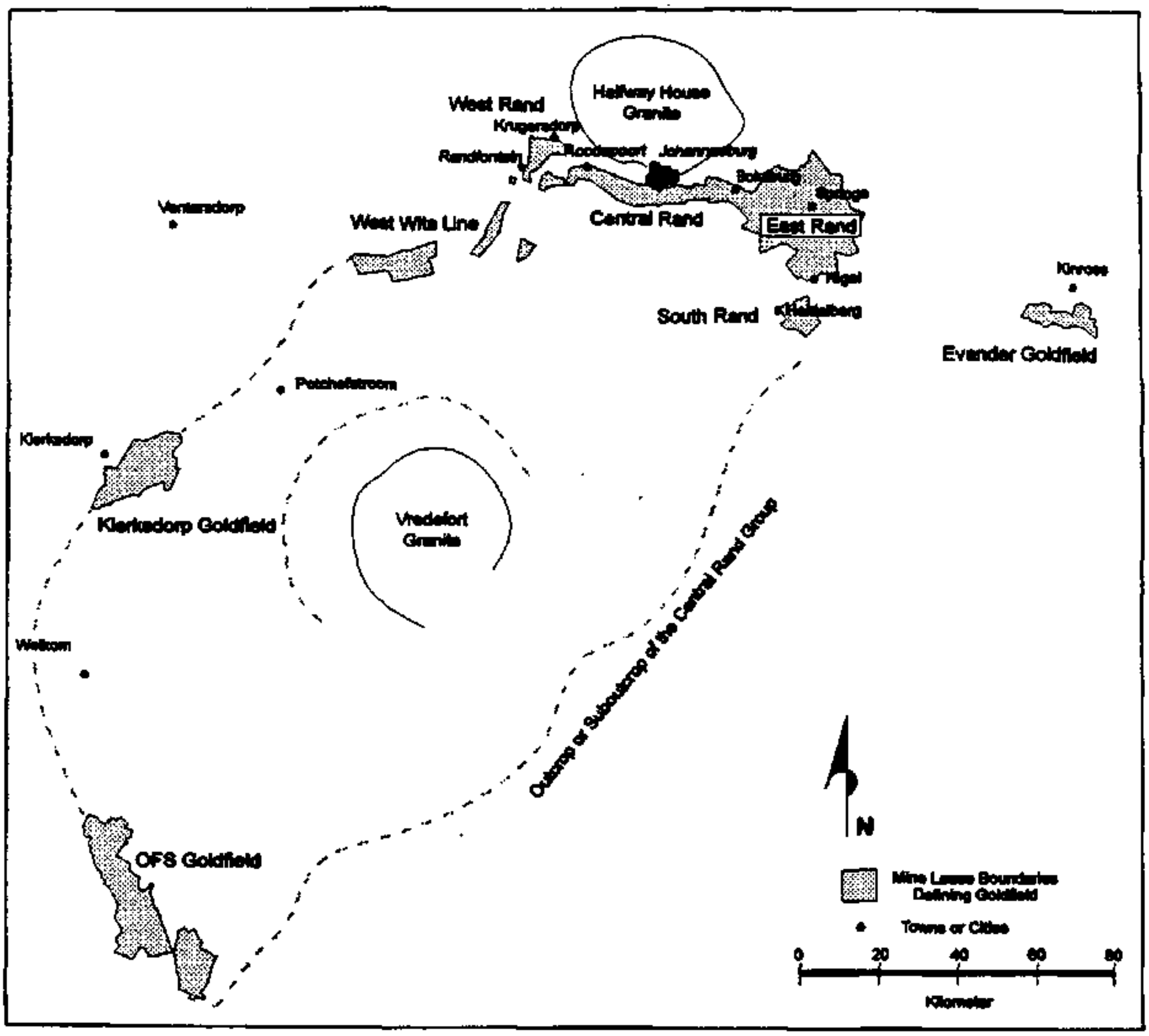

Figure 1 Map of the Witwatersrand Basin

On the Central Rand the first mines developed because the gold bearing reefs are well exposed, extensions were easily traced into the East Rand area where the reefs have a shallow basin-like structure. These reasons: early discovery and initial mining development on the Central Rand and the shallow nature of the East Rand reefs have led to both areas being mined to the limit of profitability and most of the mines are now inactive.

3. Methodology

The Investigation was conducted by studying historical records of mining development, investigating records kept by the mines and the Department of Water Affairs as well as taking stream, groundwater and mine water samples to get a picture of the conditions that prevailed at the time of investigation.

4. Recovery

There are many variables that govern water recovery in the mines. They are dependant on the history of mining, for example, such factors as ownership changes, mining techniques and level of expertise attained by the company, have a bearing on the recovery. Many of the factors differ from mining company to mining company. Mining has not stopped everywhere thus, some of the variables, such as mined out volume, are presently changing in space and time. Many of the factors that influence the underground volume cannot be determined. This means that a detailed study of some of the aspects can be very confusing and defining parameters for modelling is extremely difficult, or so full of assumptions that the model results are meaningless.

4.1. Mechanisms of Recovery

Observation of the underground inflows leads to the following classification:

Rapid Flows. These flows cascade rapidly downgradient in preferred channels, such as incline shafts, to meet the rising mine water body. There is little further degradation of this type of water, it retains its recharge identity. Some of these inflows are closely related to rainfall events as their flow increases soon after such events.

Diffuse Flows. Slow drips and trickles occur anywhere mine openings intersect water bearing geological structures. This water may move through stopes, dam up against ore heaps left in the stopes or haulages. It collects in some places forming stagnant pools. Because of its travel path this water degrades in the mine. The diffuse drips and trickles combine forming flows, collect in drains and become larger flows eventually joining the other water flowing rapidly to the deep flooded regions.

The nature of the underground flow can be related to the sources of recharge.

Four sources of recharge are active:

Direct recharge from rainfall events to outcrop and outcrop workings. This is often facilitated by the removal of topsoil over a fairly wide area in an attempt to expose the reefs. The loose material scraped off in this way is usually placed so that runoff is controlled, this prevents erosion but also forms a holding pond which encourages recharge. Direct recharge to open surface workings contributes to the rapid inflow. Direct recharge to outcrop contributes to the diffuse inflow.

Seepage recharge. Where outcrop or outcrop workings have been covered or filled seepage through the cover or fill material, which may be very permeable, takes place.

Surface water losses. Surface streams and dams may flow over outcrop or outcrop workings, or be located above mine workings and loose water to the underground openings, these contribute to the rapid flow. Many streams flow in geological structure-controlled valleys and losses via the structure to subsurface workings are possible. For example via dike or fracture zones, thus contributing to the diffuse flow.

Groundwater on the Central Rand contributes a baseflow to the recovery. On the East Rand most of the mining area is overlain by dolomites and dolomitic groundwater contributes the bulk of the inflow. Groundwater losses are predominantly via geological structures, such as dikes or fissure zones. Groundwater contributes a diffuse, continuous, steady flow to the underground workings.

On the Central Rand, Witwatersrand Supergroup sediments outcrop. A large proportion (minimum of one third) of the water entering the subsurface is derived from direct recharge, seepage recharge and surface water losses. The remaining baseflow (up to two thirds) is derived from groundwater losses. The catchment area in which the reef outcrops occur has sufficient recharge to provide the groundwater contribution without an extensive cone of dewatering around the workings being evident.

On the East Rand, Witwatersrand Supergroup sediments are covered by younger rocks over most of the area, very little outcrop occurs. Direct recharge occurs during exceptional rainfall and forms an insignificant contribution to the total recharge. Most of the recharge is derived from groundwater losses, predominantly from the Transvaal Supergroup dolomites which overly approximately one third of the investigation area. Recharge to the dolomite from within and outside the investigation area and from the swampy stream system of the Blesbok Spruit is sufficient to provide the bulk of the mine inflow. This aquifer acts as a capacitor, attenuating seasonal fluctuations in the system.

4.2. Rate of Recovery

The rate of recovery is governed by the volume of the excavations and the water inflow rate. The time of recovery can be derived from an elementary relationship:

$$\text{Time} = \frac{\text{Mined out Volume}}{\text{Inflow Rate}} \frac{D^3}{D^3 / T}$$

4.2.1. Volume of the Excavations

Variables which affect the volume of rock removed include the following:

Differential mining and mining intensity, for example, on the East Rand some areas were mined predominantly for pay shoots, this led to patchy discontinuous mined-out areas, while others areas were mined out completely.

Number of reefs mined, in the Central Rand up to six reefs were mined, predominantly in the western parts, toward the east fewer and thinner reefs were mined until on the East Rand predominantly one reef was mined.

Efficiency of scale and economics, some mines due to poor early planning closed down prematurely so that considerable volumes of mineable reef were left, while adjacent mines with perhaps better planning and more efficient management and mining techniques were able to mine to greater depths with higher extraction proportions.

Stratigraphy and structural geology were not as well appreciated by all parties in the earlier stages of mining. When mining went off-reef due to a geology related problem, if a solution was not easily found, large blocks were left unmined.

Backfilling. During active mining, waste rock was packed into haulages and stopes, this saved dump space on surface (land was expensive) and added support to the mine workings. In recent times, slimes, from the reworking of dumps, have been backfilled by gravity feeding into the underground workings.

Stope closure and collapse. This is related to various rock mechanics factors including: dip of the reef, fracture density and orientation, competency and weathering resistance of the overlying strata, depth of mining and the amount of support left or introduced. The latter, in spite of being engineered is very variable. For example, in some places rock supports were left unmined or backfilling of waste rock added support. Wooden supports or packs were placed more regularly where problems were expected, thus providing more predictable support. Originally teak supports were used, but even this hard wood has collapsed due to the humid and acid atmosphere and now offers no support.

From the above description it can be understood that determining the volume of mine excavations could never be precise. A further complication is the partial filling by water that occurs in all mining areas.

Two methods were used to estimate the mined out volume.

1. Volume = stope area × stope height

The area affected by stoping can be measured from the mine shareholder plans. The stope height could vary from 0.5 m to more than 2 m, although the accepted limit for the working height is 0.8 m. Thus volumes were calculated using stope heights of 0.5 and 0.8 m. Other mine excavations, such as haulages and crosscuts, make up approximately 15% of the volume.

2. $\text{Volume} = \dfrac{\text{Tonnage}}{\text{Density}}$

The total tonnage of rock that was milled at each of the mines has been recorded by the Chamber of Mines since it's inception in 1887. The tonnage conversion to volume was calculated using a density of 2.75, which is the value used on the mines for density related calculations.

The tonnage milled was predominantly ore, off-reef tonnage was usually not sent to the plant for milling. Thus 15% off reef development must be added.

4.2.2. Inflow Rate

Due to the diffuse, multiple source, nature of the inflows to the workings and the inaccessibility of many of the old areas, flow gauging of the incoming water was not possible.

The mines kept accurate records of the volume of water that was pumped from the workings. These records were required by the mine for engineering planning and cost accounting since pumping costs form a large proportion of the mines working costs. The records were also required by the Department of Water Affairs for the mine's water consumption permit and by the Department of Mineral and Energy Affairs to determine the pumping subsidy that was to be paid.

During periods when stable underground water levels were maintained an equilibrium existed between inflowing and pumped water volumes, since no dewatering nor storage was taking place. During such periods, the pumping record, will give the best available estimate of the rate of water inflow to the mines.

On the **East Rand** stable water levels were maintained from 1988 until pumping stopped in 1991. The pumping records for this period shows that

An average of 53 Ml/day were pumped from Sallies No. 1 shaft and 11.5 Ml/day were pumped from the Kimberley Reef at Grootvlei No. 3 and 4 shafts.

Thus, over a period of almost 3 years when the water level was maintained at 1606 mbd the average extraction from the system was **64.5** Ml/day.

On the **Central Rand** water levels have been stable in the central and eastern sections since 1977. While in the west stable water levels have been maintained since 1990. The pumping records show that:

- ERPM (Based on 12 years of data)

At Hercules shaft water collecting on ERPM is pumped to dewater the mine, thus 16.02 Ml/day is pumped, but 8.93 Ml/day of this water is service water, originating from RWB water and ice, which is used to cool the workings. Thus, 7.09 Ml/day is made on ERPM

At SW Vertical Shaft pumping maintains the water level at 1083 mbd in the central mines (CMR to Simmer and Jack), and 1170 mbd in Rose deep. These mines are defunct so no service water is added but some slime is disposed underground. Thus 16.58 Ml/day are pumped but 2.74 Ml/day slime is disposed, so 13.84 Ml/day is made in the central mines.

- DRD (Based on 2 years of data)

At DRD water is derived from the eastern neighbour Rand Leases and from DRD. Pumping maintains the water level at 2380 mbd in DRD and 1200 mbd in Rand Leases. About 18.06 Ml/day is pumped from DRD, made up of 4.74 Ml/day from Rand Leases, 10.23 Ml/day is from DRD and 3.09 Ml/day service water, thus 14.97 Ml/day is made on the western mines.

Thus almost **36** Ml/day is made daily in the Central Rand mines.

4.2.3. Predicted Recovery Times

		Mined Vol. (km^3)	Inflow Rate (m^3/day)	Time to fill (years)
	Max.	283.7		22.90
Central Rand	Min	224.5	35900	18.13
	Min (Unreliable)	84.1		6.88
	Max.	304.4		13
East Rand	Min	207.1	64500	9
	Extrapolated			14

On the East Rand the recovery has been monitored since pumping stopped in June 1991, thus the observed recovery trend could be used to help predict the times of recovery. The times given for the East Rand ignore the fact that three years of recovery are already completed, thus the times should be reduced by 3 years.

The wide range given for the Central Rand includes, area measurement from mine plans, which underestimates the area due to the scattered nature of the workings on many different reefs. In addition some mines were not measured because there are no maps available but volumes were inferred from the lease areas. Thus this volume is considered to be unreliable.

5. Discharge

5.1. Discharge Points

The mine excavations, in solid crystalline rock, introduce porosity to an otherwise impervious rock sequence. Thus the mine openings and the surrounding mining induced fracture systems form tabular, porous zones within impervious rocks. The hydraulic properties of these tabular zones will be the same as those described for confined aquifers:

- The aquifer is a permeable body which is bound above and below by impervious material, the usual example would be a fairly clean washed sand bound by clay layers.
- The aquifer has a recharge area where the rocks are exposed or unconfined.
- The water in the aquifer is under pressure, the pressure head of the supposed recharge area.
- Water will rise in a borehole drilled into such an aquifer to a level termed the piezometric* surface.
- When the ground surface is lower than the piezometric surface, a borehole drilled at such a point would be free flowing. Such boreholes are often referred to as artesian boreholes.

The *mine openings are defined as* **mine aquifers**, *because due to fracturing,* closure and water filling, they can no longer be viewed as stopes or haulages. And while they appear to have confined aquifer relationships, the characteristics have not been proven.

The mine aquifers of the Central and East Rand are partly dewatered. When all pumping stops and the mine aquifers are allowed to fill, piezometric surfaces will be definable for the aquifers. Vertical shafts which intersect the aquifer are equivalent to boreholes drilled into a confined aquifer, they can therefore be considered to be piezometers where the piezometric surface could be measured. Shafts with collar elevations lower than the piezometric surface will become discharge points, equivalent to artesian boreholes, from the mine aquifer.

The mining induced porosity is such that the mine aquifers are highly transmissive zones and once filled, water will move preferentially via the most transmissive route, following the path of least resistance. Thus even when fully recovered, the water will move through the mine aquifers without recharging the surrounding, low permeability rock. The shafts connected to the mine aquifers are therefore the potential discharge points and not geological structures such as faults or dike zones which have much lower transmissivity.

Thus identifying shafts with potential to become discharge points involves predicting what the piezometric surface would be and comparing shaft elevations

* A piezometric surface is defined as an imaginary surface representing the total head of groundwater in a confined aquifer. It is shown by the level to which water will rise in a well.

with that surface. All shafts with elevations below the predicted piezometric surface have potential to become discharge points.

Piezometric surfaces are assumed to be the elevation of the major inflows (recharge points) to the system.

5.1.1. Central Rand

Historical evidence has shown that the main inflows are occurring at the outflow from Florida Lake, in the vicinity of Village Main Reef Mines, and at the Knights and Waverley mines. The surface elevation§ of these points ranges between 1670 and 1720 m above mean sea level (mams). The measured average groundwater level in these areas is 15 m below surface, the piezometric level would be similar to, or slightly lower than, this level. Thus for identifying potential outflow shafts a level of 1660 mams has been used.

Using this level South East and Far East Vertical shafts have the greatest potential to flow, being 59 and 54 m below the proposed piezometric surface. This is some 10 to 15 m lower than the next nearest shaft, Hercules shaft. The South East Shaft is the most probable shaft based on the elevation determination used in this investigation. It is located adjacent to Cinderella Dam on a headwater stream of the Elsburg Spruit.

All the mines on the Central Rand are interconnected at some level. It would be possible to isolate DRD by plugging present connections which exist at 14 level 580 m below surface. By doing this DRD will fill up in isolation from the rest of the system and the discharge points will be either old incline shafts in the Klip River Valley or DRD No. 6 shaft. Some advantage may be derived from this approach, due to the outflow volume being shared by two catchments. The water quality at DRD may also be better than the overall quality at one outflow point.

5.1.2. East Rand

Precise locations of the inflow points, in this area, are not known, thus predicting a piezometric level for the mine aquifer is difficult. Major inflows were recorded in the vicinity of Consolidated Modderfontein and East Geduld thus if the piezometric surface is related to the type of shallow inflow observed at Cons. Modder No. 8 shaft, where the surface elevation is 1623 mams, the inflow depth is 50 m below surface then the piezometric surface would be 1573 mams.

Using this level, Nigel No. 3 shaft is 24 m below the proposed piezometric surface, this is 9 m lower than the next nearest shaft elevations. The outflow at this point is dependant on interconnectedness between Sub Nigel and Vogelstruisbult Mines. If the interconnection is blocked then Marivale 4 or 7 shafts, which are 8 and 9 m respectively below the proposed piezometric surface,

§ All surface elevations have been measured from 1: 10 000 orthophoto maps. More precise elevation surveying may be necessary to properly differentiate between points where elevations are similar.

could form outflow points. Appropriate monitoring at selected shafts will provide early warning of the state of the connection between Sub Nigel and Vogelstruisbult.

5.2. Discharge Volume

5.2.1. Central Rand

The discharge volume will be similar to the pumped volume minus service water, ice and waste disposal. This is because recharge of the surrounding secondary aquifers will be confined to areas around shafts, especially if the shaft linings have broken down, this means that there will be little reduction in volume. Thus if decanting is allowed to take place a steady state will develop with the recharge volume equal to the discharge volume. Thus some 34 Ml/day will discharge from the identified outflow shaft, made up of a groundwater baseflow of 24 Ml/day and a seasonally variable component of some 10 Ml/day.

Constructed compartmentalisation at DRD would allow 8 Ml/day to discharge at DRD and reduce the volume at South East Shaft to 26 Ml/day.

5.2.2. East Rand

The volume of water emanating at Nigel No 3 shaft will be less than the present inflow volume. This will be due to the recovery rate slowing down from the base of the dolomites (550 mbd), due to some of the inflows from the dolomites being cut off. This will particularly apply to the last 100 to 140 m of water rise.

When the water level reaches the main inflow level, estimated to be 25 to 27 m below surface at East Geduld, equilibrium will be established. At this point the outflow rate at the decant shafts will be equal to the inflow rate from the dolomites. The volume should be of a similar order of magnitude to the river flow rate before mining and effluent disposal altered the surface and groundwater flow situation in this area. This estimate assumes that the main flow in the river, prior to mining, was derived from groundwater.

The flow rate can therefore be estimated from Mellor's (1921) observations that the swamps dried up in winter, the dry period lasting for about half of the year. This means that the flow rate will be lower than the total effluent disposal to the river, which is able to keep the river flowing year round. If the total effluent disposal is 65 Ml/day from Herold (1990), then the outflow at Nigel will be less than this figure, probably half (based on the half year dry period) i.e. 33 Ml/day.

More precise estimation of the flow rate is not possible because:

- No hydraulic records were kept during mining activity
- Lack of information on groundwater conditions in the area
- The inaccessibility of the underground workings for direct observation.

6. Water Quality

6.1. Factors affecting the quality of the rising water.

One of the major factors contributing to water degradation is the reaction of water with sulphide minerals, producing the so called *Acid Rock Drainage*. The Witwatersrand Supergroup sediments contain varying proportions of sulphide minerals, the predominant sulphide being pyrite (FeS_2). In many of the gold bearing reefs this mineral may form up to three percent (by mass) of the rock.

Mining of the Witwatersrand Supergroup sediments has produced: On surface; rock piles, sand and slime dumps. Underground; backfilled rock piles and spoil heaps in stopes and haulages. These all contain pyrite which, in the broken and crushed rock, is now exposed to air and water and oxidises. Due to this oxidation the rocks and accumulations have characteristic red and yellow staining and discoloration from secondary iron oxide minerals and mineraloids. The acid content of water that passes through such accumulations increases.

Thus the reactivity of the water increases, and in its passage, it reacts with other minerals, either to generate more acid or to neutralise the existing acid. The total dissolved solids (TDS) content of the water rises. The water may be characterised by one or more of the following: Low pH, high TDS, high sulphate (SO_4) content, or high heavy metal content (particularly Fe, Mn, Ni or Co).

Due to the variable nature of the recharge sources and to the many different places where acid formation can occur, water degradation is diffuse and no one source can be identified as a major contributor to the overall degradation of the water. Surface degradation and subsurface degradation both contribute to the overall lowered water quality.

1. Surface Degradation

- Surface water through intimate interaction with mine wastes takes on a very similar identity to the water found in the mines.
- Groundwater which is affected by seepage from mine waste heaps has the same chemical identity as the water in the mines.
- Reef outcrop areas that have not been mined nor developed in any way were found to have acid water draining from them.

These water sources contribute to water flowing into the mine cavities. The mine waste heaps are often located above shallow surface workings and reef outcrop and are thus in hydraulic communication with the deep mine cavities. Seepage may be lost vertically to the mine openings or may contaminate surface water streams which flow between the mine wastes, these streams loose* water on flowing over surface workings and outcrop.

- The area is highly industrialised and densely populated thus the surface streams carry a wide variety of effluent in addition to mine waste-derived seepage, their quality can vary within tens of metres. None of the streams are in pristine condition. These streams loosing to the subsurface contribute a diffuse pollution load.

Incipient water chemistry classification work suggests that mine water is closely related to surface water types. Study of the Boron content of the different water types also shows this relationship, surface water and mine water containing high Boron while groundwater samples contain little or no boron. Boron is an element used in hard detergents and is common in waste-water streams.

2. Subsurface degradation

A proportion of the water recharging the mines arrives from a number of widely distributed small drips, trickles and seeps, most are via geological structures.

- This water has passed through different geological horizons where mineral water interactions will have caused further degradation from what may have started on surface. Water on the East Rand is buffered by dolomitic water, thus the pH drop is not as pronounced as it is on the Central Rand. Seepage recharge in this area rarely enters the mines directly, but first via the Karoo or dolomites where reactions (predominantly neutralisation in the dolomite) can change the chemistry of this source of poor quality water.

- Other Mining. On the East Rand, shallow, underground coal mining has taken place in many areas. Many of these old coal mines are flooded and contribute seepage to the gold mine workings below. The groundwater in the vicinity of such coal mines shows increased sulphates.

- In the mines these diverse flows pass through a variety of conditions, such as backfilled waste rock, loose ore in stopes and haulages that has never been removed and fine material that has collected in travelling ways. These materials are pyrite bearing, thus the flows are exposed to pyrite in many of their courses. The mines are open to air circulation and even in abandoned sections, natural air circulation, due to up-draught shafts, ensures that there is enough oxygen for oxidation of the pyrite. In addition the warm, humid, underground conditions, encourage bacterial development. Bacteria catalyse the oxidation of the pyrite increasing the rate of this acid forming reaction. Thus the water further deteriorates on its passage underground by reaction with sulphide minerals and mixing with stagnant water lying in disused mine openings.

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*The term loose is in use in the mining industry, the process is similar to seepage or percolation, the trems commonly used in geohydrology relating to vertical (steep hydraulic gradient) movement of water into the subsurface. Loose is distinct from these terms, in that, certain characteristics such as, flow rate, potential flow volumes and leaching characteristics, are very different from what may be expected under natural conditions due to the underground excavations generating channel flow conditions and dewatering creating steep hydraulic gradients for kilometres underground.

When an equilibrium is reached between inflowing and outflowing water the water level in the mines will be within the region of the deepest surface workings which penetrated the oxidised zone. In this zone pyrite had already been oxidised in antiquity. Thus with much of the subsurface flooded, anoxic conditions will prevent, or slow down, continued degradation. The non-flooded region will contain little unoxidised pyrite, thus subsurface degradation will be naturally minimised. At this stage the degradation process will predominantly be controlled by surface sources.

Surface sources are dynamic and some are being removed by recovery of the mine waste heaps, others can be controlled by legislation and policing.

> The water flowing from the dolomites has a high buffer capacity which acts against pH lowering caused by pyrite oxidation, thus pH rarely goes below 5. Sulphates and other salts in solution give the water an unacceptably high TDS, much of this is derived from surface pollution sources.

6.2. Predict quality in filled mines.

Because of the many variables governing water inflow to the mines, the large number of points where degradation can occur and the number of indeterminable factors, using a model to generate the final water quality is not possible.

The water quality in the filled mines is predicted from samples taken of dammed underground water and rising water in the mined basins. This is the best basis for prediction since conditions in these basins are similar to what they will be on full recovery. Water collecting in stagnant pools in underground workings is often isolated from the recharge water and may be degraded to a much greater extent, thus having very low pH and high TDS. Water in actively filling areas is more dynamic and has not degraded to the same extent.

The most contaminated mine water has a high density of about 1.02, this will ensure that the worst water is trapped in the deepest parts of the mine aquifer.

Water in the Kimberley Reef basin should show the maximum level of degradation that will be reached on the East Rand, since typical Kimberley Reef ore has a higher pyrite content than Main Reef ore. Thus representative samples from the Kimberley Reef basin could be used as indicators of the typical water quality that may be expected.

7. Management

Management of this system must aim to reduce the influence of mine water recovery on the natural environment.

7.1. Possible Influences of Mine Water Recovery

A number of possible influences were proposed at the beginning of this study while others have become evident from the study:

- Springs re-emerging in the Blesbok Spruit river system that will inundate low lying areas and destabilise mine waste heaps.
- Increase in subsurface instability and seismic activity.
- Recharge of local aquifers by mine water. On the East Rand, it was suggested, that such recharge would promote instability in the dolomites.
- Negative impacts on the natural environment around the discharge points.
- Water quality deterioration.
- Negative impacts on water users downstream of the discharge points.
- Water inrushes into ERPM from the filled East Rand mining basin.

7.2. Significance of the Impacts

- This study has shown that the re-emergence of springs in the Blesbok Spruit will not significantly alter the volume of water in the river.

- Mine stability will increase rather than decrease.

- Recharge of local aquifers.

  On the Central Rand the groundwater is held in secondary aquifers which are intimately associated with the mine aquifers in the reef outcrop zone only. The secondary aquifers loose water to the mine aquifers in this zone. As long as water is allowed to decant a hydraulic gradient will remain from the secondary aquifers to the mine aquifer. Thus there will be continued movement of water from the secondary aquifers into the mine aquifers. Proper monitoring of water levels to ensure that gradient reversals do not take place will be necessary to provide warning of any reversals that may occur. Aquifers may be recharged by mine water at the decant points depending on the condition of the shaft linings.

  On the East Rand the dolomitic aquifer will be recharged by mine water. This will be a problem if there is significant water movement through the dolomite since the mine water will dissolve the dolomite. Such water movement will be controlled by water level gradients in the dolomite. Understanding and evaluation of these were not part of this project, but this aspect should be evaluated as a priority.

- Surface discharge

  The most significant impact of the recovered mine water will be where it discharges into surface stream systems. On full recovery water will be discharged from the East Rand mines into the Blesbok Spruit and from the Central Rand mines into the Elsburg Spruit. Both of these streams are already affected by Acid Mine Drainage derived from seepage from mine waste heaps.

Neutralised and clarified mine water is also disposed of into the upper reaches of the Elsburg Spruit.

Large flows of poor quality mine water will have a negative impact on both of these streams, affecting both the biota and the downstream water users. Thus some form of control or purification will be necessary.

7.3. Impact Reduction

7.3.1. Removal of Surface Sources

Seepage inflows and surface water quality could improve with time due to:

- Reworking and removal of some of the mine waste heaps.
- The termination of mine water disposal when mining stops.
- Better stream management, controlling pollution inputs and stream flow in the vicinity of mine dumps.

Thus with time, and perhaps added control measures, the quality of water recharging the dolomites could improve.

Better effluent clean up which is being investigated by some of the industries on the East Rand should ensure that some of the river water has a better quality and hence losses from the river system to the mines will be of improved quality.

7.3.2. Treatment of Discharge Water

One of the options that has been proposed for control of the outflowing water has been continued pumping of mine water from shallower than mining depth. For example on the East Rand a pumping depth, from within the mine, at the base of the dolomites has been proposed. This method retains the hydraulic conditions between the mine aquifers and the surrounding shallower aquifers, the pumped volume would be the same as when mine dewatering remained active. This approach would reduce pumping costs due to the lower lift required, but pump operation and maintenance will continue indefinitely. The pumped volume would remain high and pre-pumping and post-pumping water treatment would be required. Good water will continue to be drawn into the system to be pumped out as bad water.

The discharging water whether pumped or allowed to emanate naturally will be of poor quality and some permanent treatment plant would be required to control pH (particularly the Central Rand) and remove dissolved solids from the water before discharge to a river system. This is a costly long term option. Chemical techniques to purify the outflowing water are capital intensive, require skilled personnel for operation and supervision. Such a system may have to operate indefinitely thus maintenance and upgrading will also become problems. The disposal of wastes and sludges generated by such processes will also transfer the problem to some other point.

7.3.3. Inflow Control

In many instances, reasonable quality groundwater or surface water enters the mine aquifer system where it becomes contaminated in the recharge area by reaction, mixing or further degradation in the mines. Thus inflow control must be introduced. Two forms of control are possible:

- Surface water losing sites must be controlled
- Groundwater losses must be minimised

Surface water losing sites must be positively identified, by stream gauging. The surface losses must then be minimised, where possible, by blocking surface sinks at appropriate places, and canalising streams where they flow over reef outcrop. This method is used on the West Rand to prevent pumped water from re-entering the mines.

Prevention of groundwater losses to the mines where degradation starts or continues would be a good control measure. This could be achieved by consuming groundwater in such a way that a balance is achieved between recharge and consumption which minimises the inflow to the mines. Thus reducing the volume of outflowing poor quality water. Certain precautions are required here to retain a balance so that poor quality mine water does not recharge the shallow aquifers.

For these reasons the baseflow component from groundwater must be established by monitoring and the area should be investigated hydrogeologically so that a planned groundwater development program could be used to minimise groundwater losses to the mines. This investigation has shown that groundwater quality varies in space. Optimal extraction points may be identified in poor quality groundwater areas, thus a detailed study of quality variations in the aquifers would have to be undertaken, to properly plan water use.

8. Recommended Future Work

8.1. Monitoring

The effective implementation of any of the management options require better understanding of the system. This will only be achieved by monitoring followed by further study and evaluation of the monitored data.

Monitoring and modelling of the situation would be required to note any improvement in water quality with time and to prevent contamination of presently clean groundwater due to hydraulic gradient changes.

Monitored data that is required includes

- Stream flow gauging