



# An investigation into recharge in South African underground collieries

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## Synopsis

The Mineral and Petroleum Act of 2002 states that no closure certificate may be issued to mines unless the management of potential pollution to water resources has been addressed. Continuous recharge into the abandoned collieries occurs, and it is important for collieries that close down to plan their future management strategy accordingly. Research has been initiated to determine the recharge into abandoned mines of different mining depths, methods and size. Collieries of a nature similar to these case studies can thus associate with the recharge values obtained.

Water balances are of overriding importance in determining recharge and water loss. These vary from mine to mine. Overriding factors are the method of mining, depth of mining, and surface hydrology. High extraction methods (stooping and longwall) invariably disturb the overlying strata more than bord and pillar methods. A summary of the percentage influx to be expected for the various mining methods is as follows:

Shallow bord and pillar: 5–10% of the rainfall

Deep bord and pillar with no subsidence: 3–4 % of the rainfall

Stooping: 5–12% of the rainfall

Longwall: 6–15% of the rainfall

Rehabilitated opencast: 14–20% of the rainfall.

The actual percentages depend largely on specific circumstances.

The longwall mining value<sup>9</sup> was not covered in this investigation, but is included for reference purposes.

Keywords: Coalmines, underground, recharge, mining methods

## Introduction

Coalmining has been ongoing in the Mpumalanga province of South Africa since 1870 (Figure 1). Initially, all the mines were in the shallower areas around the town of Witbank. Bord and pillar mining was used throughout. This is an underground coal extraction procedure, through which coal pillars of sufficient size and frequency are left in the mine to keep the roof of the mine from collapsing. With the aid of research conducted by the Chamber of Mines<sup>14</sup>, pillars were designed on a scientific basis. Pillars before this date were known to have collapsed, sometimes with catastrophic consequences.

Once the economically mineable coal has been removed, mines close down and are left

to fill up with water. Most of this water will eventually decant and/or seep into the adjacent strata and environment, thus polluting aquifers and rivers.

In underground mines, the following water sources could be encountered:

- ▶ Water encountered in the seam as mining commences. This is fairly low, except where fractures, or fissures as they are known within the mining industry, are encountered
- ▶ Recharge through the roof lithologies. The magnitude of this varies, depending on mining-induced fracturing of the overlying sediments
- ▶ Direct recharge, where cracks from the collapse of mining areas, usually due to high extraction mining, run through to the higher-yielding transmissive aquifers closer to surface
- ▶ Regional groundwater flow, which will usually occur along the coal horizon, due to its higher hydraulic conductivity compared to the surrounding sediments
- ▶ Influx through the floor lithologies. This can play an important role in areas where the floor is transmissive, but where the mining floor is close to the Dwyka, as where the No. 1 Seam or No. 2 Seam are mined, such influxes are negligible.

These are schematically presented in Figure 2.

In the 1970s, large-scale opencast mining became a reality in the Mpumalanga coalfields. Many mines include up to four of the five coal-seams that are extracted by dragline methods. Coal produced per operating opencast mine is in the range of 4–12 Mtpa<sup>9</sup>. For each ton of coal extracted, some eight tons of rock, on average, is removed and replaced as spoil.

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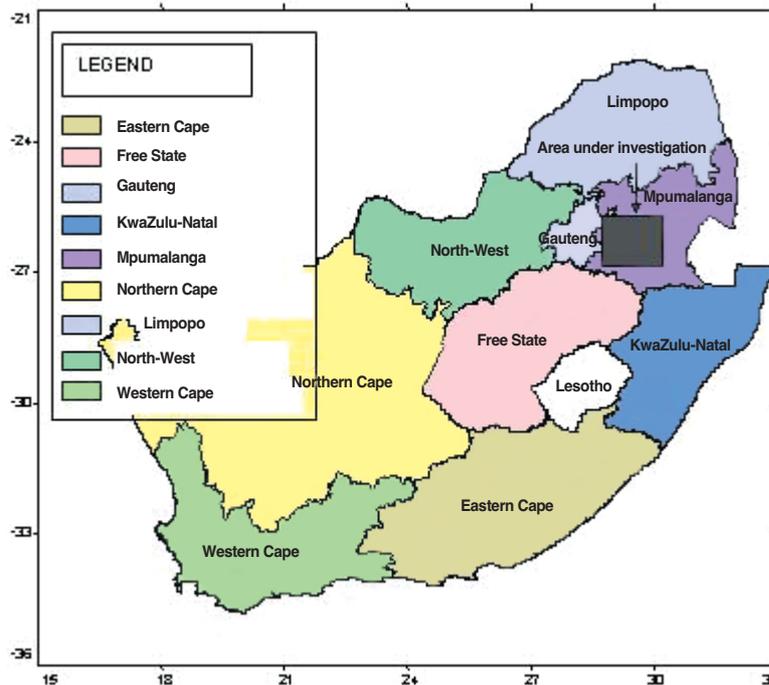


Figure 1—Map of South Africa

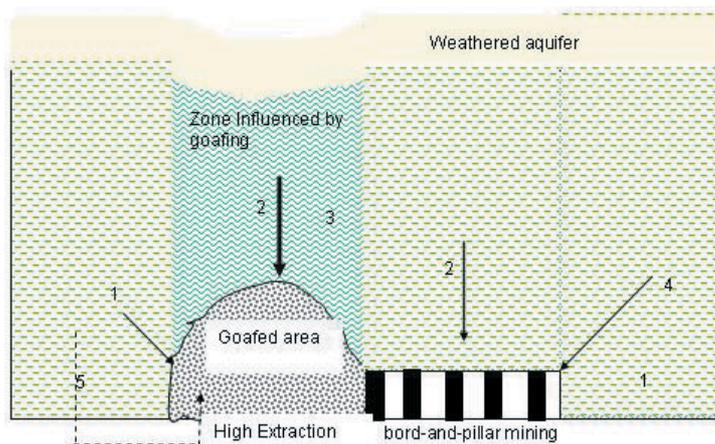


Figure 2—Schematic representation of influxes of water (numbers refer to sources of water; thickness of line indicates relative magnitude).

This:

- Increases the hydraulic conductivity of the medium
- Enhances recharge, and about 20% of the rainfall ends up in the opencast pits.

In order to make mining possible, excess water is pumped from the collieries, discharged under permit conditions, or desalinated. Georgius Agricola, in his monumental work *De Re Metallica* written in 1556, noted that excessive ingress of water was one of the three main reasons (together with failure of reserves and bad air) for the abandonment of mines<sup>15</sup>. A few desalination plants, using spiral reverse osmosis (SRO), are presently in operation or in the planning phase. This pertains particularly to the south, where the sodium concentration in the mine water is high. Projections of future volumes of water to decant/seep from the mines have been made by Grobbelaar *et al.*<sup>5</sup>. In total, about 360 M<sup>3</sup>/d will eventually decant/seep from all the

mines combined. On a catchment basis, this amounts to (in M<sup>3</sup>/d):

This demonstrates the anticipated future scale of water that will decant into the various catchments.

Influx of water into collieries will eventually lead to filling up, and to the shallower collieries and opencast mines decanting onto the surface. Some seepage into the weathered zone will also occur. Seepage directions follow the topographic gradient and seepage water surfaces at the nearest streams.

Table 1  
Total future water seepage into catchment areas (M<sup>3</sup>/d)

Wilge/Klip	Olifants	Klein Olifants	Vaal	Komati
23	170	45	120	2

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The South African Minerals Act of 1991 was the first act that forced all mining operations towards sustainable land management rather than just addressing the aesthetic issues. The Act states that the mine remains the property of the owner until a closure certificate is issued.

The law allows authorities to gain insight into to, and control mining activities that could adversely affect the water environment. Since the implementation of the Minerals Act of 1991, the number of closure certificates has dwindled to a point where very few are issued. This is a major concern, since astronomical sums of money are involved either way. The South African Mineral and Petroleum Act of 2002 replaced this law. This act states that no closure certificate may be issued unless the management of potential pollution to water resources has been addressed. Rehabilitation must be part of mine pre-planning mine. The implications of Section 19 of the National Water Act (1998), that the mine will be held responsible for its impact on water resources, even after formal closure and the receipt of a certificate from the Department of Minerals and Energy, remains the basis for long-term water management with a risk-based approach.

It is thus important to be aware of the exact recharge into the abandoned collieries in order to determine the underground water volumes and decant rates (if any) over time. With funding from the Water Research Commission of South Africa, and in consultation with Anglo Coal and Ingwe Coal, five collieries different size, depth, mining methods, mining heights and surface structures, e.g. streams and dams, were selected to determine the average recharge values. (Table II)

The localities of the selected collieries with respect to the rest of coal mining in Mpumalanga are shown in Figure 3.

### Methodology

An analytical approach was followed and is based on an underground water balance. Water balances are of overriding importance in determining areas of recharge, water loss and reaction rates. These vary from mine to mine. Important

factors are the method of mining, depth of mining, and the surface hydrology. High extraction methods invariably disturb the overlying strata more than bord and pillar methods.

The investigation was conducted over a number of years (since 1997 at TNC) and time series data of water levels were gathered at regular intervals. The recharge into the collieries was calculated by measuring water levels in the mining void over time. From this, and with the aid of stage curves that take the floor contours, mining height and the void space (determined from the method of mining and pillar size) into account (Figure 7), the increase or decrease of the underground water volumes could be calculated over time:

$$I - O + Re = \Delta S$$

Where :

*I* = Inflow into mining cavity

*O* = Outflow from mining cavity

*Re* = Recharge into mine

$\Delta S$  = Change of volume water in mining cavity

Colliery	Characteristics	Mining method
Minnaar	Small underground mine; compartments; artificial recharge; mine water irrigation	Bord-and-pillar
Ermelo	Large underground mine, partially stooped; in the process of filling up with water; flushing option considered	Bord-and-pillar stooping
TNC	Complex arrangement of underground and opencast mining; partially filled with water; water quality management is possible through mixing	Bord-and-pillar stooping opencast
New Largo	Underground mine with very little subsidence; water balance calculations and seepage losses	Bord-and-pillar Limited stooping
Schoongezicht	Underground mine; currently decanting; water and salt balance studies	Bord-and-pillar opencast

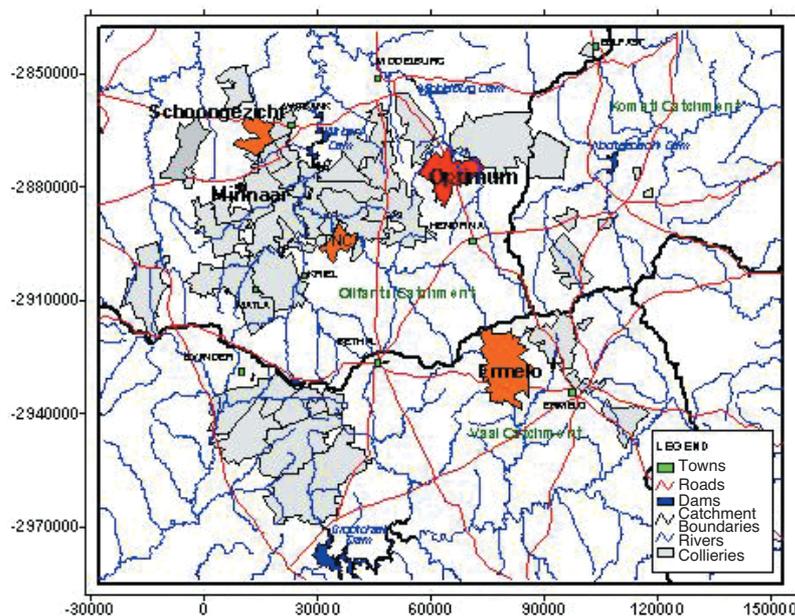


Figure 3—Mine lease areas for collieries in Mpumalanga

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The assumption was that the lateral inflow played a minor role in the mines and that the volumes gained in the collieries are mostly due to vertical influx. Recharge is thus expressed as a percentage of the rainfall. As far as mine water is concerned, complexities that arose from the mining are:

- ▶ Mining is often so shallow that it enters into the weathered zone. Pillars are unstable and collapse
- ▶ Groundwater flow is possible in the weathered zone, irrespective of whether or not pillars have collapsed
- ▶ As a guideline, it has generally been accepted earlier that between 1 and 3% of the rainfall above bord-and-pillar mining in Karoo formations infiltrate into the mines<sup>1,2</sup>. In areas where pillars have extensively collapsed, percentages are higher.

The coal-seams deepen to the south and the potential impact of coalmining on surface water and groundwater should, in theory, be less. This is, however, not the case, because much of the coal extraction in the southern mines occurs through underground high extraction methods. As far as mine water is concerned, complexities that arise from mining are that cracks develop in the overlying strata, and rock that is generally impermeable to water flow, becomes a conduit for surface water and groundwater from overlying aquifers to enter into the mine workings.

From the recharge, the water level rises over time, and subsequently decant times can be forecast.

However, not all mines will decant. The vertical influx into the mine plays a dominant role in filling the mine due to the disturbance of the strata above the coal resulting from the mining processes. If the mine is filled, lateral influx and outflux through the barriers will virtually cancel out each other, and influx will be determined by the vertical K-value of the strata above the coal if no preferred pathways were created due to mining. The rising water level in the mining cavity reduces the amount of inflow due to the decrease in the gradient as the piezometric level from the mine approaches the water level. The water level in the mine will continue to rise until a dynamic equilibrium is achieved between inflow and outflow. Contrary to earlier beliefs, this will result in the groundwater system returning to natural conditions, and thus moving horizontally along the weathered zone if this level is higher than the piezometric level from the mine. Not all mines will therefore decant, especially in the case of deeper mines

Opencast mines decant or seep at nearly the same rate as recharge. A combination of stage curves and topographic maps indicates the volumes and position of the decant.

Shallow underground mines also decant, usually at the same rate as recharge. This usually happens at the lowest man-made conduits, e.g. shafts and adits.

## Geology

The succession consists of pre-Karoo rocks overlain by Dwyka Formation tillite, followed by Ecca Group sediments, of which the Vryheid Formation is the coal-bearing horizon. The Dwyka Formation consists of tillite, siltstone and sometimes a thin shale development. The upper portion of

the Dwyka sediments may have been reworked, in which case carbonaceous shale and even inclusions of coal may be found. The Dwyka sediments are underlain by a variety of rock types, although Bushveld felsite is the most likely rock type at TNC. The Ecca sediments mainly consist of sandstone, shale, interbedded siltstone, mudstone and coal of varying thickness. The total thickness of the Karoo sediments ranges from 15–160 m.

Dolerite intrusions in the form of dykes and sills are present over the entire Mpumalanga coalfield. These sills displace the seams and cause structural complications. The devolatilization of the coal, caused by the sills, is a more serious problem. Dolerite sills often outcrop on surface.

All the collieries, except Ermelo Colliery, lie in the Springs-Witbank Coalfield and are flanked by the Highveld and Ermelo coalfields. The coalfield extends over a distance of approximately 180 km from the Brakpan/Springs area in the west to Belfast in the east, and about 40 km in a north-south direction<sup>12</sup>. It is currently the most important coalfield in the country. Post-Karoo erosion has removed large parts of the stratigraphic column, including substantial volumes of coal over wide areas. A maximum of 120 m of Karoo strata have been preserved in this coalfield. The coal-seams are discontinuous over prominent paleotopographic highs. The five classical coal-seams of the Witbank Coalfield, numbered from the bottom as Nos. 1 to 5, are contained within a 70 m succession<sup>3,12</sup>.

Ermelo Colliery lies in the Ermelo Coalfield (formerly the Eastern Transvaal Coalfield) and is flanked by the Highveld, Witbank, Klip River and Utrecht coalfields. The stratigraphy of the Ermelo Coalfield is typical of the coal-bearing margins of the Karoo Basin. It contains five major coal-seams. These seams are labelled from E at the base to A at the top of the formation<sup>4,13</sup>.

## Regional geohydrological background

Two distinct and superimposed groundwater systems are present in the Witbank and Highveld coalfields, as described by Hodgson and Grobbelaar<sup>8</sup>. They are the upper weathered aquifer and the system in the fractured rock below.

### *The weathered groundwater system*

The top 5–15 m consists of soil and weathered rock. The upper aquifer is associated with this weathered horizon. In places, a thick dolerite sill is present close to surface. In boreholes, water may often be found at this horizon. This aquifer is recharged by rainfall.

Rainfall that infiltrates into the weathered rock reaches impermeable layers of solid rock underneath the weathered zone. Movement of groundwater on top of the solid rock is lateral and in the direction of the surface slope. This water reappears on surface at fountains, where the flow paths are obstructed by barriers such as dolerite dykes, paleo-topographic highs in the bedrock, or where the surface topography cuts into the groundwater level at streams. It is suggested that less than 60% of the water recharged to the weathered zone eventually emanates in streams<sup>9</sup>. The rest of the water is evapotranspired or drained by some other means.

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The weathered zone is generally low yielding (range 100–500  $\ell/h$ ) because of its insignificant thickness. Few farmers therefore tap this water by boreholes. The excellent quality of the water is attributed to many years of dynamic groundwater flow through the weathered sediments. Leachable salts in this zone have been washed from the system long ago, and it is only the slow decomposition of clay particles that presently releases some salt into the water<sup>9</sup>.

### The fractured groundwater system

The grains in the fresh rock below the weathered zone are too well cemented to allow any significant water flow. Most groundwater movement therefore occurs along secondary structures such as fractures, cracks and joints in the rock. These structures are best developed in sandstone, hence the better water-yielding properties of the latter rock type. Dolerite sills and dykes are generally impermeable to water movement, except in the weathered state.

In terms of water quality, the fractured aquifer always contains higher salt loads than the upper weathered aquifer. The higher salt concentrations are attributed to a longer contact time between the water and rock.

An important aspect of groundwater occurrence and flow is the layered nature of the rock. It is possible, in theory, for mining to drain water from deep layers, not affecting shallow groundwater resources. This makes an evaluation of the current impact on groundwater reserves very difficult. Additional subsidence may occur, which would have a further impact on groundwater reserves.

### Case studies

#### Minnaar Colliery

The mined area constitutes 235 ha. Bord and pillar methods

were used, and the abstraction rate was 65%. The average mining height was 3 m. The mine consists of four separate main areas (A—35 ha, C—47 ha, E—74 ha and F—75 ha), as illustrated in Figure 4, and two small areas (B and D). All these mined areas are interconnected by narrow mining panels developed through poor ground conditions. Seals have been installed in these narrow panels.

Figure 5 shows the underground floor contours. The depth of mining ranges from 13 to 78 m below surface. The shallowest mining is in the south and west. Dips are generally to the east.

The surface area above the mine is used for agriculture, with both summer and winter crops being harvested. Two 40 ha centre pivots have been in operation for fourteen years, utilizing water from a surface run-off dam, supplemented by water extracted through BH9 in Area F. A 40 ha centre pivot (Pivot 3) has been in operation since 2002, extracting water from BH4 in Area C.

Mine water levels are different for each of the four main compartments (Figure 6). This is because of the different recharge rates due to surface activities such as subsidence, and abstraction for irrigation from two of the compartments, and because the ventilation seals between the compartments are still intact.

From the water level of BH9, it is clear that the irrigation has a significant influence on compartment F. Normally this compartment will be recharged artificially from a borehole in the surface water run-off dam, but because of lower than normal rainfall since 2001, the water level in the dam is too low for recharge through the borehole.

#### Block A

Block A is an isolated, sealed-off area still in the process of filling up. The water levels of the boreholes in this

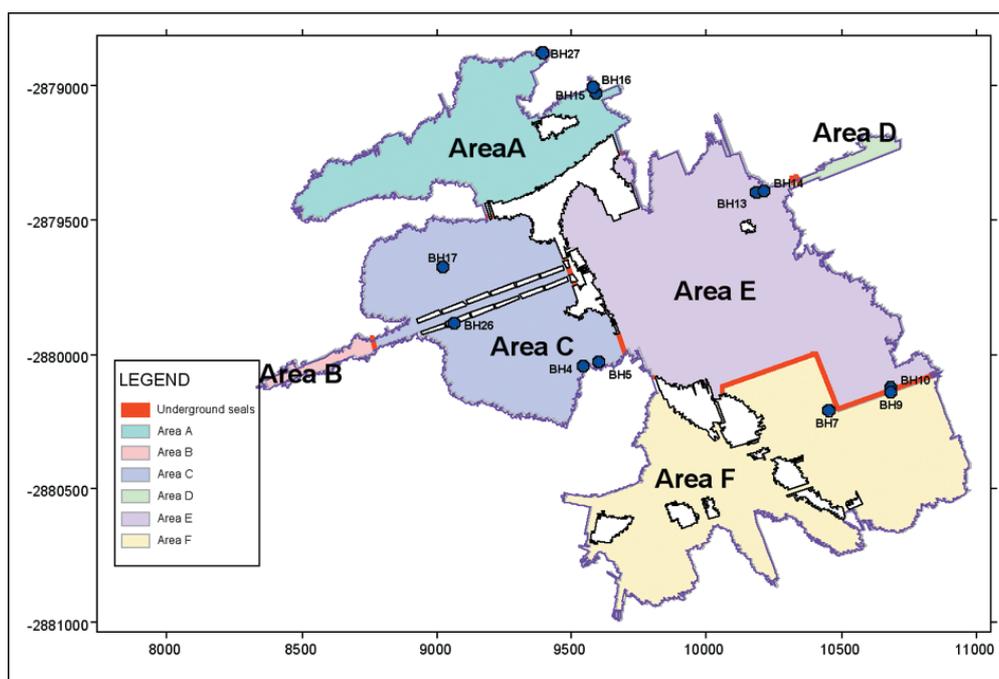


Figure 4—Outline of Minnaar Colliery and monitoring borehole positions

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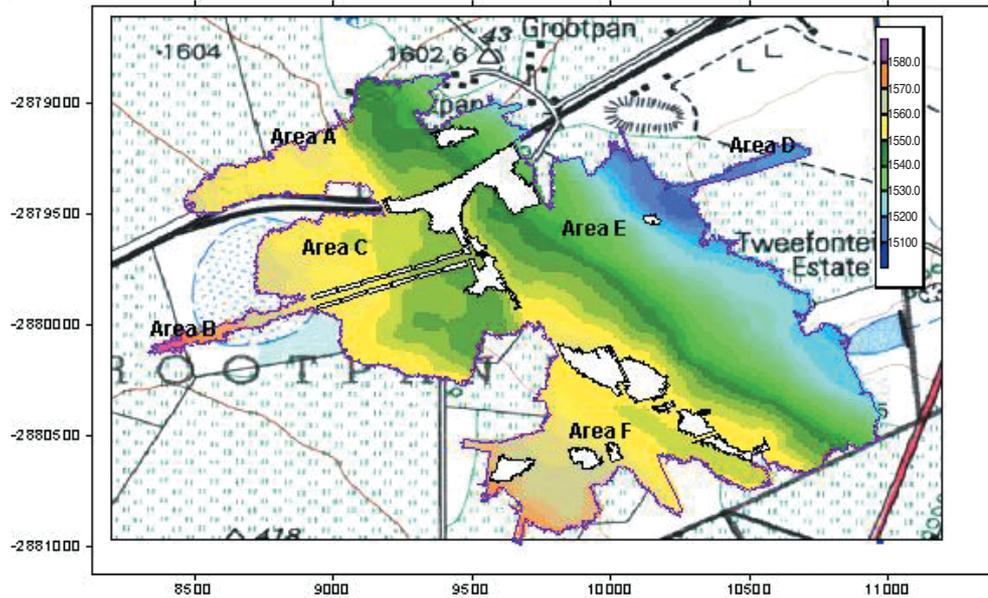


Figure 5—Floor contours at Minnaar Colliery

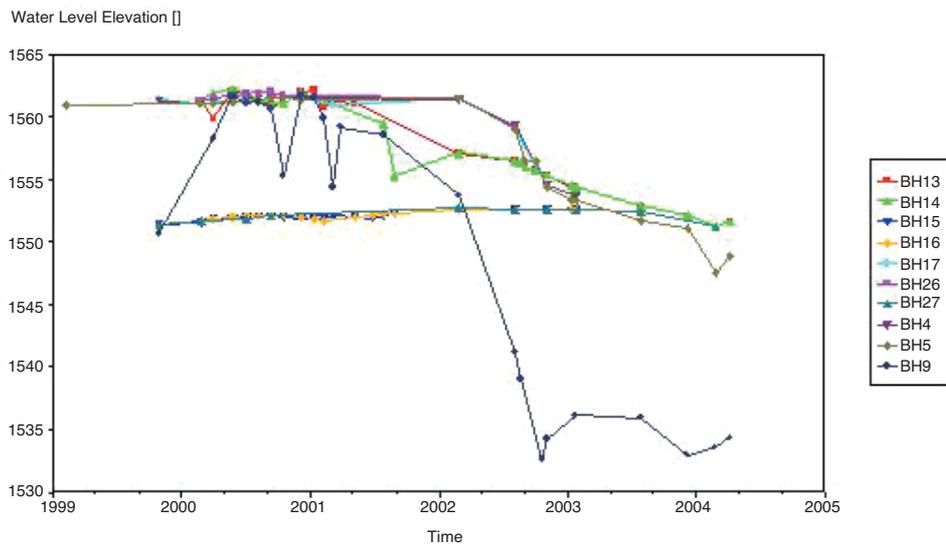


Figure 6—Water levels at Minnaar

compartment (BH's 15, 16 and 27) are not being influenced by abstraction, as is the case in the other main compartments. There seems to be very little interaction with adjacent areas, as the water levels are completely different from those of Block C and Block E. This suggests that the seals are still intact. Block A will thus be used in this paper for recharge calculations as no external activities, e.g. irrigation or subsidence, have an influence on recharge this area. The water levels used for calculations in this area, the volumes determined from stage curves (Figure 7) and water balance calculations are shown in Table III. (All water levels are mean average above sea level.)

The area is situated on a topographic high, probably with little lateral influx. This suggests that the influx into Area A is mainly due to vertical influx, translating into a vertical K value of  $1.02E-4$  (the ease with which the water moves

vertically through the strata). The vertical K value is calculated by:

Total recharge/area/time

The influx, expressed as a percentage of the rainfall, is 4.24%, and is determined as follows:

Total recharge/(area\*total rainfall)\*100

Conclusion: the value of 4–5% is a good indicator for relatively deep mines ( $\pm 80$  m), with fractured rock aquifers, little dolerite intrusion and no surface subsidence.

### Block C

The water levels in Block C (BH's 4,5,17 and 26) were static until extraction from a newly installed pump in BH4 commenced in July 2002. Since then, there has been a steady decline in the water level for this area.

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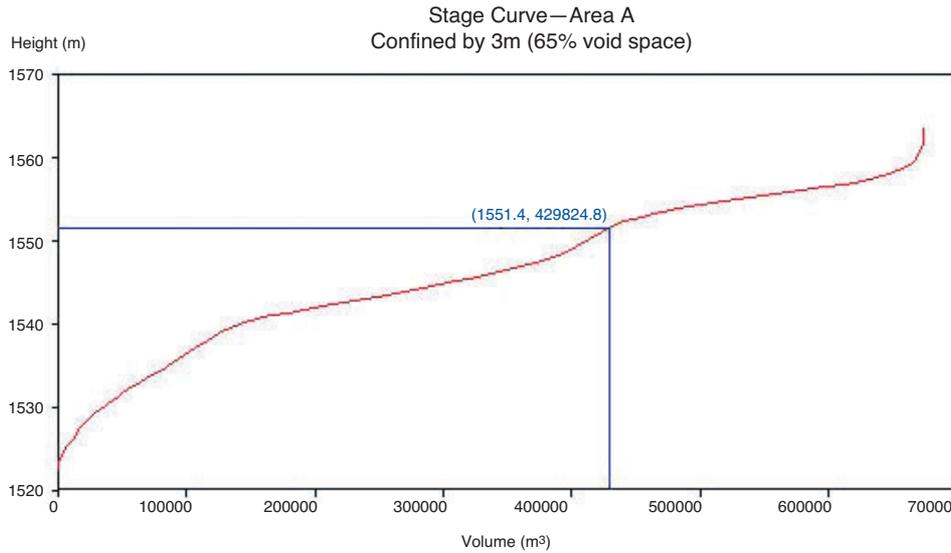


Figure 7—Stage curve for Area A on 28/10/1999

Area size (ha)	34.7
Water level (28/10/1999)	1551.43
Water volume in m <sup>3</sup> (28/10/1999)	429 825
Water level (4/11/2002)	1 552.63
Water volume in m <sup>3</sup> (4/11/2002)	449 515
Days	1 102
Water volume gain (m <sup>3</sup> )	19 690
Rainfall (m)	2.655
Outflux distance (m)	78
Lateral outflux (m <sup>3</sup> )	12 976
Extraction (m <sup>3</sup> )	6 402
Total influx (m <sup>3</sup> )	39 069
Recharge %	4.24

The water level was 1561.43 mamsl before pumping commenced, indicating a total volume of 903 594 m<sup>3</sup> for Area C. Because the mine was closed in the early 1970's, the recharge into this block is in the order of 30 000 m<sup>3</sup> per annum. This translates to a recharge of 9.15%, which is rather high, and possibly due to:

- ▶ The mine being relatively shallow (35 m) in this area. The surface in the vicinity of BH's 4 and 5 is a low-lying area, which will result in higher recharge

Subsidence in the area

Conclusion: this value of 9% is a good indicator for relatively shallow areas ( $\pm 30$ – $40$  m), with some degree of surface subsidence.

Note: The water levels for Areas E and F were influenced by abstraction, and will not be included in this study.

## Ermelo Colliery

The colliery ceased production in April 1997, and the surface area has been rehabilitated. Two mining methods were employed at Ermelo Colliery. Primary development occurred through the bord and pillar method. This was followed by secondary extraction (Figure 8), mainly stooeping<sup>10</sup>. The mining statistics are provided in Table IV.

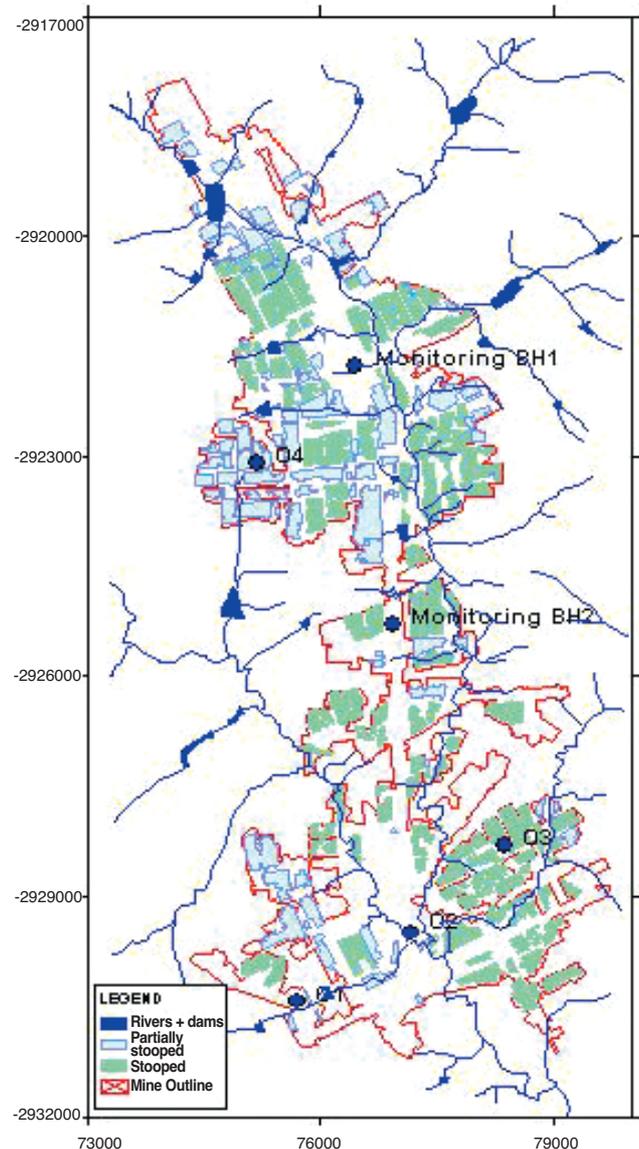


Figure 8—Stoooped and partially stoooped panels at Ermelo Colliery

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Considerable difficulty has been experienced in measuring water levels in mine boreholes because of the significant depth of the mine, water falling down the boreholes from groundwater sources above the mine, or

methane rising through boreholes where the mine is not flooded to its roof. Nevertheless, reasonably accurate water levels were obtained and the data have been plotted in Figure 9.

Four boreholes in the mine serve as observation boreholes. In addition, two other old mine boreholes are also available. Each borehole monitors an area in the mine that was not hydraulically interconnected during the early stages of flooding because of natural barriers due to undulations in the coal floor (Figure 10). Despite the undulations, the coal floor features a general dip to the south.

The deepest areas are in the south-west and in an isolated area in the east, where the coal floor has been displaced through the intrusion of a dolerite sill. The latter areas are interconnected with the northern portion of the

*Table II*

**Mining statistics relating to Ermelo Colliery**

Description	Value
Area mined (ha)	2 680
Area stooped (ha)	790
Area partially stooped (ha)	514
Volume mined (m <sup>3</sup> )	41 867 000
Average mining height (m)	2.14
Average extraction rate (%)	73
Mining depth below surface (m)	80–185
Pillar Width (m)	9–15

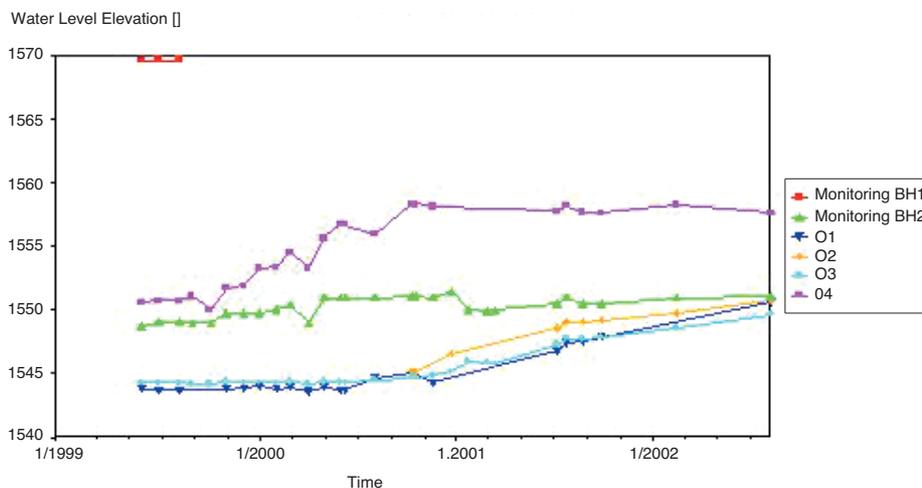


Figure 9—Water levels at Ermelo Colliery

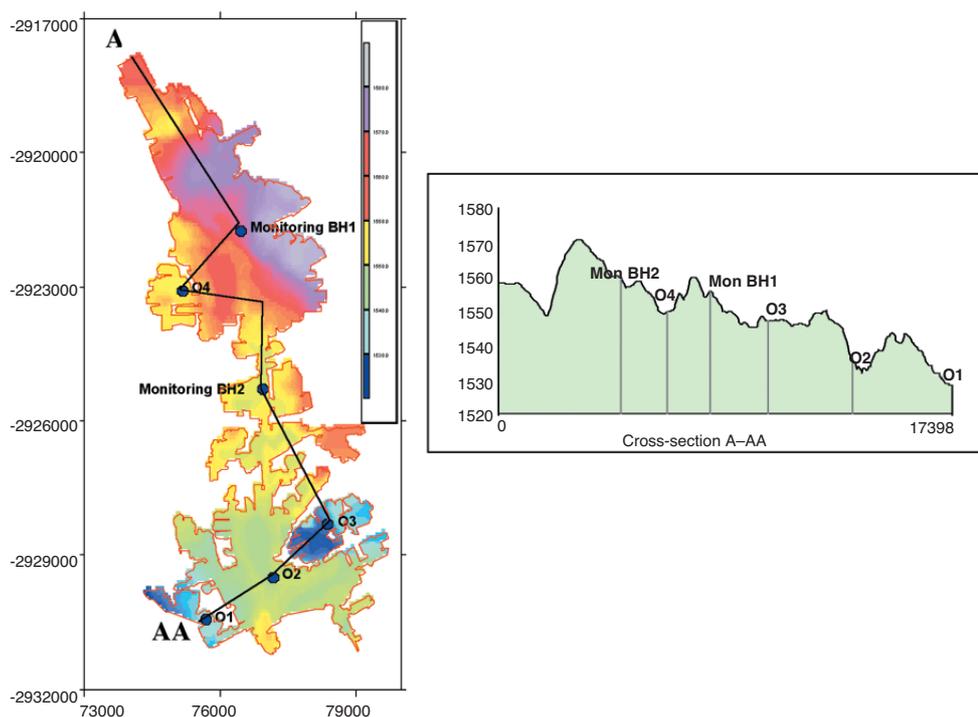


Figure 10—Map of the coal floor contours, localities of monitoring boreholes and a north-south cross-section of the coal floor

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mine through a large, rather flat area. Here, many undulations in the coal floor are present. Significant amounts of water were retained within the undulations, before allowing the flow of water to the south. Further north, the coal floor dips steeply from the south-east to the north-west. In this area, local smaller depressions are also present. It is anticipated that the depression storage amounts to about 15% of the mine volume.

### Conceptual model

Initial influx occurred in all the compartments due to normal recharge. The exceptionally high rainfall during late 1999 and early 2000 resulted in a sharp rise in the water levels of Borehole O4. The streams above the high extraction areas in the northern compartments were in flood, enhancing recharge, and the unrealistic value of 52% was calculated for Area B. As the northern compartments filled, water spilled over into the deeper southern compartments. Since 2002, the water levels of Areas C, D and F equalized as it backfilled, and the water levels of these areas are now rising at the same rate. A conceptual model of how the colliery filled over time is illustrated in Figure 11.

Water balance calculations have been done for three periods:

- 8/06/1999–24/10/2000—It appears that recharge occurred mainly in the northern compartments. The exceptionally high rainfall since December 1999

resulted in a sharp rise in the water levels of Borehole O4. The streams above the stooped areas were in flood, enhancing recharge. During this period there were very few increases in the water levels of the boreholes in the southern parts of the mine

- 5/01/2000–28/02/2002—The water level rise of the boreholes in the southern areas resulted from water spilling over undulations of the coal floor in the northern Areas A and B, causing the water levels of the northern areas to stabilize. During this period the water level of monitoring BH2 in Area C dropped. This is most likely the result of an underground seal that collapsed
- 1/03/2002–22/08/2002—During this period the water levels of Areas C, D and F equalized. The water levels of these areas will now rise at the same rate.

The results of the water balance calculations are shown in Table VI. The volumes were determined from stage curves.

It appears that, due to the nature of the floor contours, Area A overflows into Area B, resulting in an influx of 52% into the latter, with no gain in Area A.

As illustrated in Figure 11, water spilled over the undulations in Areas A and B, flowing down gradient towards Area D. The mining cavity in Areas E and F is already filled, with water rising only in the strata above the mine, and also backfilling into Area D. There were thus no gains in Areas A, B, E and F.

Table V

### Water balance calculations

Period 8/6/1999–24/10/2000							
Rainfall (mm)		886					
Days		504					
Area	Surface area (m <sup>2</sup> )	Water levels (mamsl)		Volumes (m <sup>3</sup> )		Rain volumes (m <sup>3</sup> )	Influx
		8/6/1999	24/10/2000	8/6/1999	24/10/2000		
Area A	3915859	1565.10	1565.10	3789235	3789235	3469451	0.0%
Area B	2409553	1550.63	1558.30	870605	3793189	5604315	52.1%
Area C	11620907	1548.70	1551.13	2216239	4376953	10296124	21.0%
Period 28/2/2002–22/8/2002							
Rainfall (mm)		109					
Days		175					
Area	Surface area (m <sup>2</sup> )	Water levels (mamsl)		Volumes (m <sup>3</sup> )		Rain volumes (m <sup>3</sup> )	Influx
		1/3/2002	22/8/2002	1/3/2002	22/8/2002		
Area A	3915859	1565.10	1565.10	3789235	3789235	426829	0.0%
Area B	2409553	1557.80	1557.80	3793189	3793189	262641	0.0%
Area C	11620907	1550.89	1550.97	4226638	4279248	1266679	4.2%
Area D	8192120	1549.90	1550.81	12146008	12320081	892941	19.5%
Area E	1389411	1548.58	1549.65	1895931	1895931	151446	0.0%
Area F	869266	1549.31	1550.89	1341714	1341714	94750	0.0%
Period 5/1/2001–28/2/2002							
Rainfall (mm)		682					
Days		420					
Area	Surface area (m <sup>2</sup> )	Water levels (mamsl)		Volumes (m <sup>3</sup> )		Rain volumes (m <sup>3</sup> )	Influx
		5/1/2001	28/2/2002	5/1/2001	28/2/2002		
Area A	3915859	1565.10	1565.10	3789235	3789235	2670616	0.0%
Area B	2409553	1558.83	1557.80	3793189	3793189	1643315	0.0%
Area C	11620907	1551.39	1550.89	4554755	4226638	7925459	-4.2%
Area D	8192120	1546.68	1549.90	10762252	12146008	5587026	24.8%
Area E	1389411	1545.10	1548.58	1895931	1895931	947578	0.0%
Area F	869266	1544.60	1549.31	1341713	1341713	592839	0.0%

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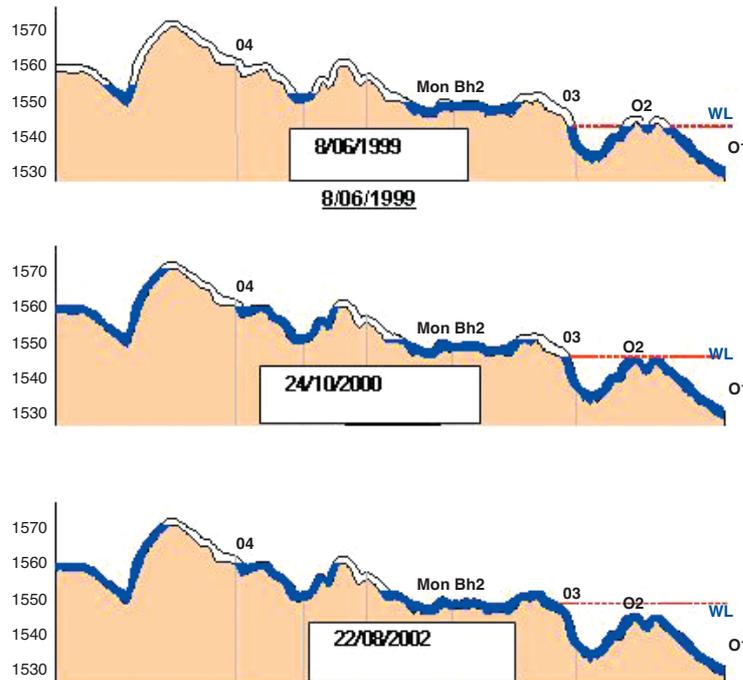


Figure 11—Conceptual model of Ermelo Colliery filling up over time

Table VI  
Influxes into Ermelo Colliery

Period	Total Influx (m <sup>3</sup> )	Daily Influx (m <sup>3</sup> )
8/6/1999–24/10/2000	5 083 300	10 086
5/1/2001–28/2/2002	1 055 640	2 500
28/2/2002–22/8/2002	226 680	1 300

The negative value for Area C during the last period is probably because of the collapse of a seal, resulting in water spilling into Area D, increasing the influx into this area. During this period Area D filled, and then the water started to backfill into Area C, as illustrated Figure 11. This resulted in the influx in Area D being smaller than in the previous period. When added to the influx into Area C, it is virtually the same as the 24.8% of the middle period.

The influx into Area D and C in the middle and last periods indicates a recharge of 5.5–7% of the rainfall when calculated over the entire mine, and the influx into Areas B and C indicates a recharge of more than 20% for the high rainfall first period. Table VI lists the influx volumes into the mine for the different periods.

## Conclusion

This information is significant, demonstrating the importance of considering not only average values. Particularly in water treatment plants or in water holding facilities, spare capacities must be available if extreme rainfall events are to be managed. Recharge rates are highly variable, depending on the mining method. The influx into Area D and C in the middle and last periods indicates a recharge of 5.5–7% of the rainfall when calculated over the entire mine. However,

recharge in stooped areas can range from 5% to above 20% (as calculated) of the annual rainfall, depending on the amount of annual rainfall.

## TNC (Transvaal Navigational Colliery)

The TNC investigation is an ideal example of mine water associated with a complex mine layout, which has been mined by different methodologies and interacts with surface water sources. The Olifants River runs through the middle of the mine lease area (Figure 12).

Mining methods have been by bord and pillar extraction, followed by stooping in 21% of the underground. Much of these stooped areas are in topographically low-lying areas. The central portion of the TNC coal-seam floor has a basin structure, with its lowest point underneath the TNC Village. The coal floor rises in all directions away from this point to attain a maximum elevation in the south-east. The other areas at TNC are separated from the main Welstand Block through dolerite displacements. Because of the basin structure, mining depth varied from 6 m to 101 m (Figure 13). The total mined underground area was 1 824 ha, of which 387 ha was stooped. Because of the shallowness of the coal-seam at places, 253 ha was mined by means of opencast mining.

Conditions differ in the various mined areas and only the Welstand-TNC Block (by far the largest and still in the process of filling up) will be discussed. It has been mined by bord and pillar methods, with subsequent stooping in less than 10% of the area. During 2000 the Olifants River burst its banks and the water levels rose dramatically, as can be seen in Figure 14. The positions of the monitoring boreholes, spread over the whole area, are illustrated in Figure 15. The water volumes during January 2002 and January 2003 (the period on which recharge calculations were based) were determined using stage curves.

## An investigation into recharge in South African underground collieries

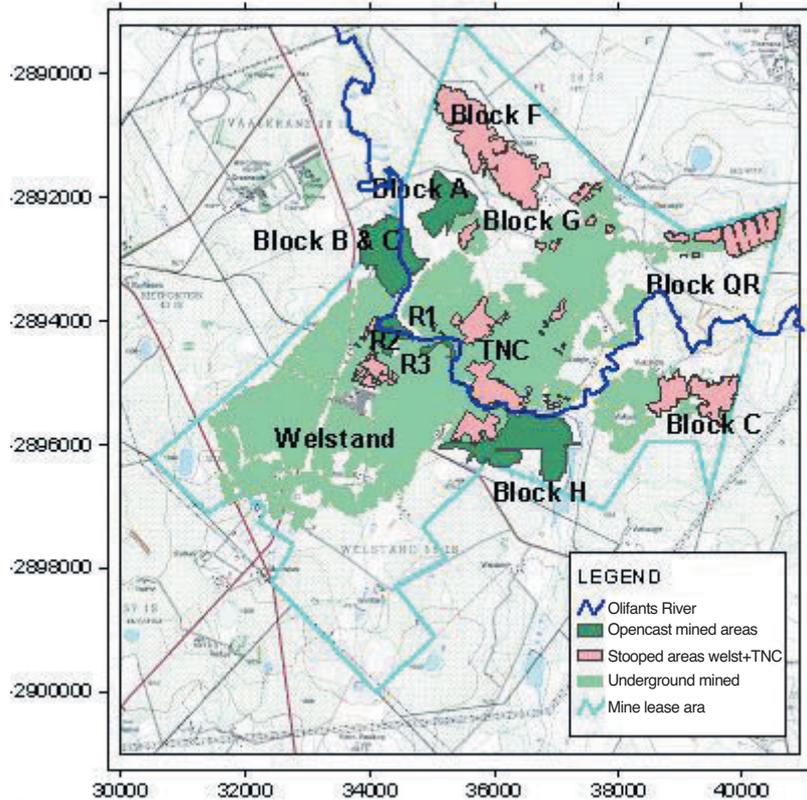


Figure 12—Map of TNC

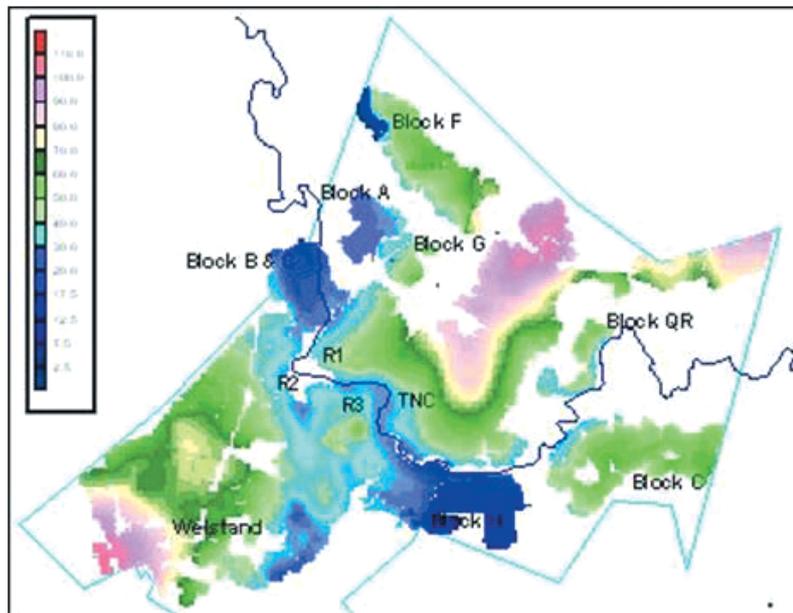


Figure 13—Depth of mining below surface at TNC

Lateral flux into the mining cavity plays an important role in the filling process. This is because the Welstand-TNC area is situated on both sides of the river, and due to the steepness of the terrain next to the river, the groundwater flow increases. To determine the lateral influx into the mine, the gradient value was based on slope measurements, and the transmissivity value of 0.3 m<sup>2</sup>/d was calculated from packer tests done for conductivity<sup>9</sup>.

Since the flood of 2000, the water level of the Welstand-TNC Block rose by less than a metre. The volume gained for 2002, excluding the lateral influx, indicates a gain of 53 000 m<sup>3</sup>. This is 5% of the annual rainfall.

### Conclusion

The TNC investigation is an ideal example of mine water associated with a complex mine layout. Mining occurred by

# An investigation into recharge in South African underground collieries

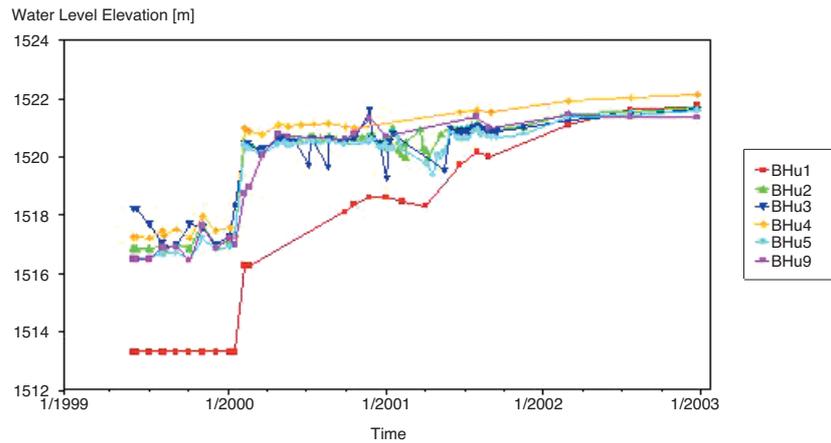


Figure 14—Water levels for Welstand-TNC

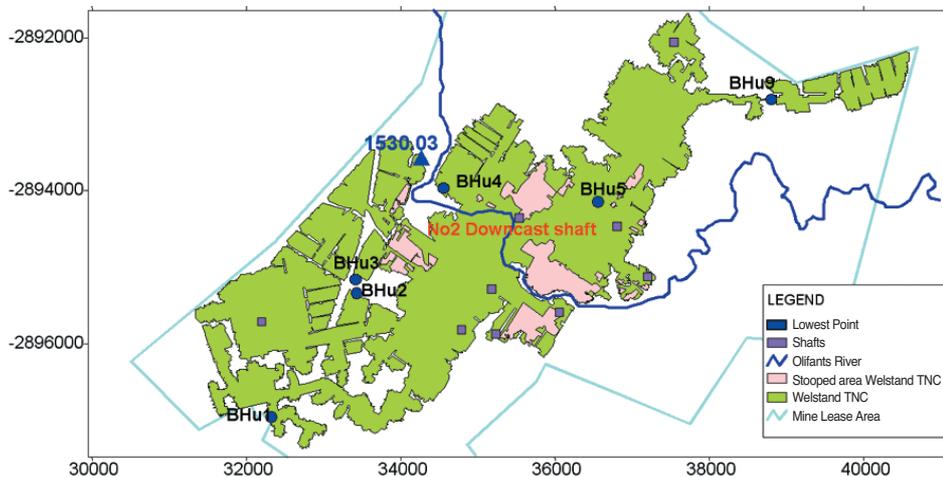


Figure 15—The Welstand-TNC Block, indicating the position of the boreholes

different methodologies, interacting with surface water sources. The mine is in the process of filling up with water. Only when decanting commences can current predictions of volumes and qualities be verified. Nevertheless, valuable information has been gained from geohydrological investigations at the mine. A recharge of 5% of the rainfall was determined for a mine with varying depth and some surface disturbance due to stooeping. A high degree of confidence is attached to these calculations and it is unlikely that significant changes in the understanding of the system will result from future monitoring.

### New Largo

New Largo lies on a topographical high, with water draining to both sides in the direction of the Klipfontein and Saalklap Streams. A large pan (33 ha) is located in the northern half of the mine above the area where the No. 2 Seam has also been mined. New Largo ceased production in 1989. Mining methods included bord and pillar extraction in both the No. 4 Seam and the No. 2 Seam. The No. 2 Seam was mainly mined in the north (Figure 16). Stooeping of the No. 4 Seam was done on an experimental basis along the western fringe of the mine. Due to subsidence, this practice was stopped and

the subsided area rehabilitated. Depth of mining for the No. 4 Seam ranges from 10 m to 30 m below the surface. The No. 2 Seam lies some 15 m below the No. 4 Seam, with no outcrops visible in the area.

During the past 11 years, the water level in the mine has risen by more than 10 m (Figure 17). This rise has been gradual and about 8 Mm<sup>3</sup> has entered into the mine in this time. This amounts to a daily average of 2 000 m<sup>3</sup>. During this time, some water losses from the mine also occurred in the form of pumpage and possible seepage from outcrop areas. Water pumped from the mine was discharged into a surface pan. From this pan, a maximum evaporation rate of 870 m<sup>3</sup>/d is possible, which could be added to the average water gain in the mine in order to calculate the influx rate. In reality, this amount is expected to be lower, because the pan was not always full and surface run-off into the pan was not diverted.

Expressed as a percentage of the rainfall for the area, the total mine water influx therefore amounts to about 8%. This is a feasible amount and falls at the high end of the suggested recharge to the mine by Hodgson<sup>7</sup>. The recharge to the mine constitutes two components, namely infiltration and regional flow towards the mine. Experience in the coal

# An investigation into recharge in South African underground collieries

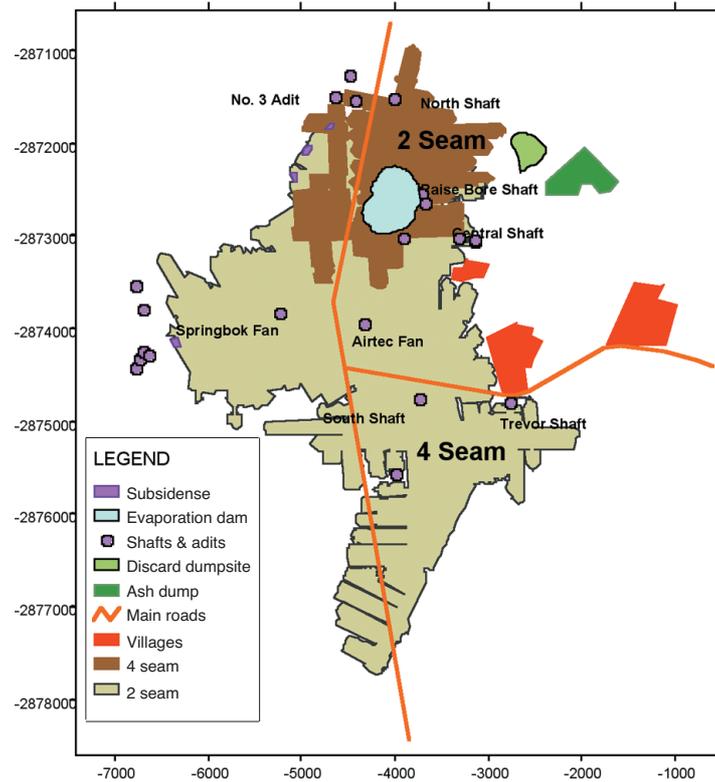


Figure 16—Map of New Largo, illustrating the No. 2 and 4 Seams

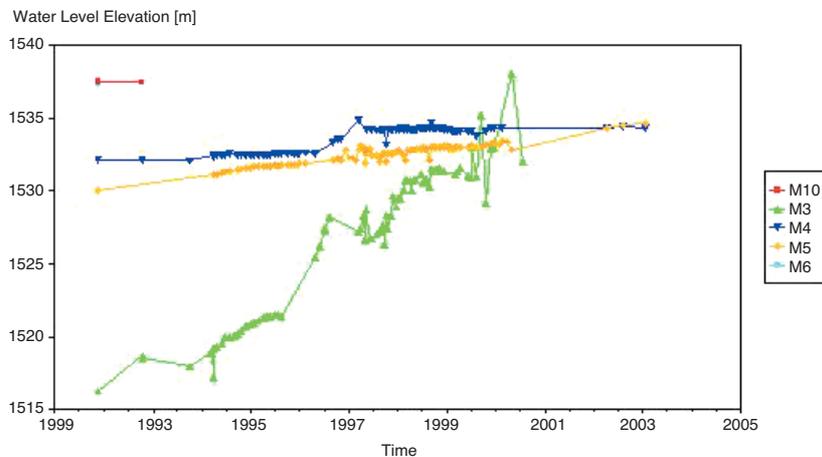


Figure 17—Water levels at New Largo

industry has shown that the regional influx of groundwater usually contributes a smaller proportion of the mine water than vertical seepage. This is because of the generally low hydraulic character of the coal-seam. Under shallow mining conditions, the likelihood that significant amounts of groundwater would be intersected is greater. A likely split would be 30% groundwater and 70% infiltration. This would reduce the amount of mine water derived from direct rainfall to about 5%. This is still high compared to the generally accepted 3% recharge of rainfall on Karoo sediments<sup>1,2</sup>

It should, however, be remembered that portions of the underground workings did undergo stooping and that higher recharge rates are possible here.

### Schoongezicht

Schoongezicht Colliery ceased production more than 20 years ago. It is a shallow mine of 8–50 m deep. Mining was by the bord and pillar method, with the No. 1 Seam being the most dominant. The No. 2 Seam, and the No 4 Seam to a lesser degree, were mined. Part of the No. 4 Seam was mined by opencast methods (Figure 18).

The structural failure of shallow pillars near Dam 1 resulted in an opening where decant occurs. Water decants into Dam 1 at an average rate of 944 m<sup>3</sup> per day (obtained from recorded pumping figures, as water from this dam is pumped daily to Dam 3) plus evaporation, which is 55 000 m<sup>3</sup> annually, based on an evaporation of 1.2 m.

# An investigation into recharge in South African underground collieries

The recharge calculations are provided in Table VII. At a below average rainfall of 550 mm for 2002, this results in a recharge rate of 7%. Under normal rainfall conditions of 684 mm, the recharge will amount to 5.5%. This seems like a

contradiction, but is based on an average decant rate equal to the pumping rate; therefore the lower rainfall years will indicate higher recharge rates.

### Conclusion

This is important information that can be used for calculating water volumes from the shallow mines in the Witbank area. Some of these mines have collapsed to a greater extent than Schoongezicht Colliery and a higher recharge percentage will be applicable. The latter could be as high as 10% or even greater under extreme rainfall events, as seen from the study of Ermelo Mine. For a start, 5–7% recharge is a good average value. Other shallow areas of possible higher recharge should be investigated separately.

### Discussion on decant

Underground collieries will decant if the hydrological conditions are favourable. Water will recharge over the whole mine. When the mine fills, fractures caused by the mining operation will serve as conduits where water will be forced out as a result of hydrological differences, usually at the lowest interconnections between the surface and the mine. Mining structures such as shafts and adits will also provide the opportunity for water to decant. The major distinction between flooded and unflooded mines is the method and location of the discharge.

### Unflooded collieries

Unflooded mines discharge at the lowest elevation in the mine connected to the surface.

- At Schoongezicht, the 2 Seam and 4 Seam are very close to each other, and are connected by boreholes and fractures. Water from the upper seam decants at a hole caused by structural failure. This hole is at the same elevation as the low lying area, and the water flows into a dam (Figure 19). The 2 Seam is at a lower elevation than the surface and will stay filled
- Figure 20 illustrates a scenario, not investigated in this study, where a single seam was mined, and because of an outcrop, fracture or adit, the mine will also decant before it is flooded

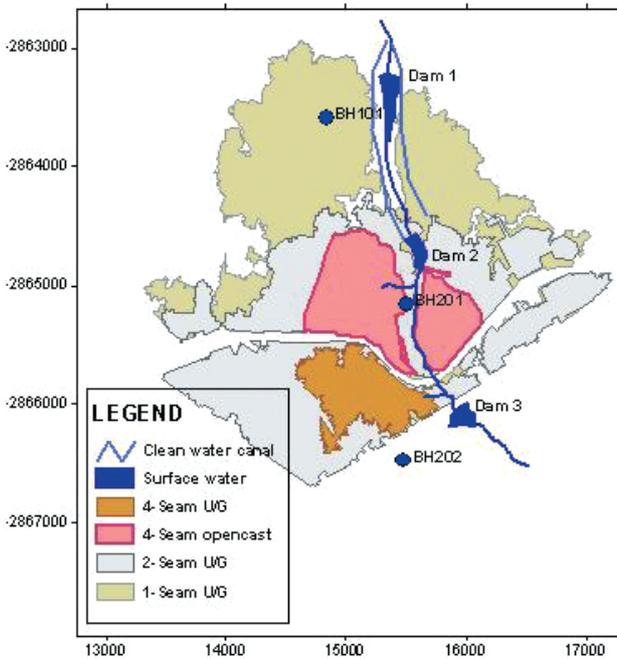


Figure 18—Map of Schoongezicht

Area (ha)	1 040
Rainfall (m)	0.55
Total water from rainfall (m <sup>3</sup> )	5 72 0000
Daily discharge (m <sup>3</sup> )	9 44
Annual discharge (m <sup>3</sup> )	344 560
Lateral influx into mine cavities (m <sup>3</sup> )	13 742
Dam area (ha)	4.6
Evaporation from dam (m)	
Annual evaporation volume (m <sup>3</sup> )	55 200
Recharge %	6.75

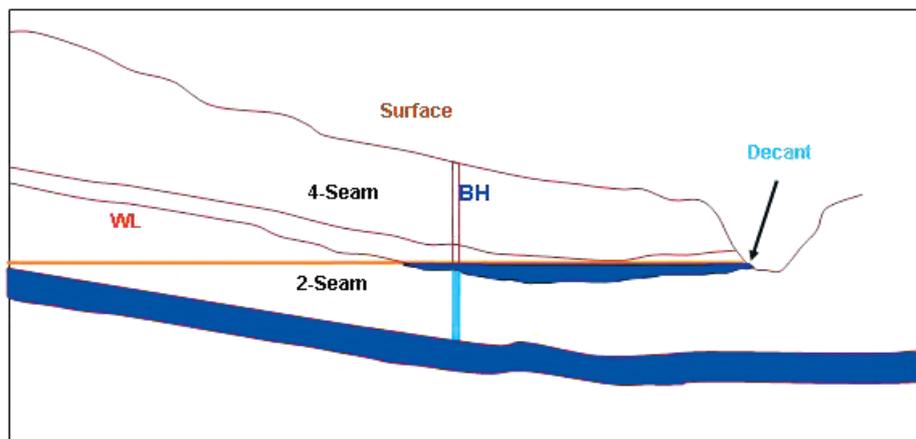


Figure 19—Decant illustration of Schoongezicht (unflooded mine with two seams mined)

# An investigation into recharge in South African underground collieries

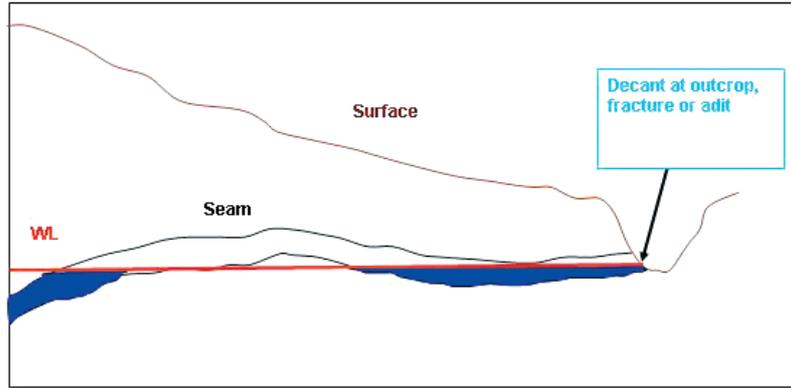


Figure 20—Decant illustration of an unflooded mine, with one seam mined

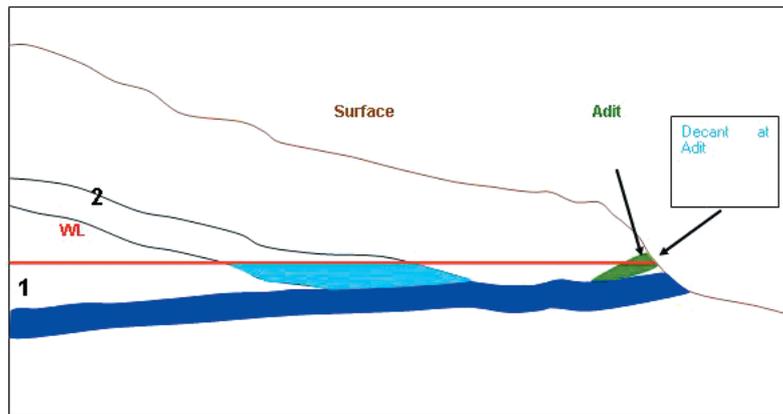


Figure 21—An illustration of an area where the position of the seam in a shallow mine determines if the mine will flood or not

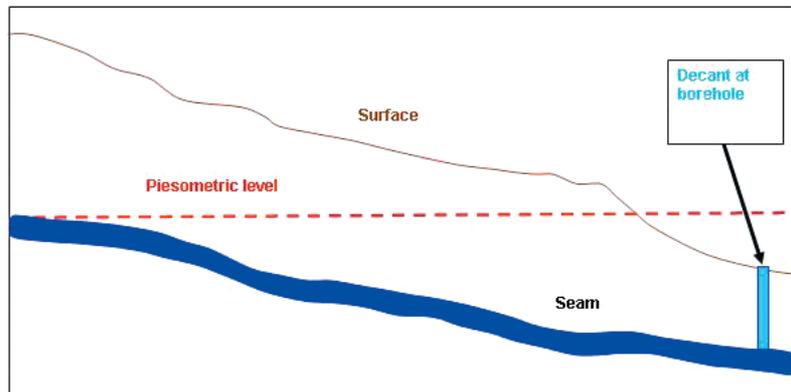


Figure 22—An illustration of a case where the seam elevation in one area of the mine is higher than the surface elevation in another area

- The position of the seam in a shallow underground mine will determine if a mine floods at the adit. The illustration in Figure 21 shows two different positions for the seam. In Position 1, the whole seam will flood, as the adit is higher than the entire seam. It will start to decant only when the water level in the aquifer reaches the elevation of the adit. In Position 2, the adit is higher than only parts of the seam, and the mine will decant before it is totally flooded. In the latter scenario the mine will fill up only to where the illustration in Figure 21 is filled with the lighter blue colour.

### Flooded collieries

Flooded mines discharge through conduits like fractures and shafts at the lowest elevation at which the mine meets the surface, which may be far above the lowest elevation of the mine.

- At Minnaar Colliery the elevation of the seam at one side of the colliery is higher than the surface elevation at another part of the mine, as illustrated in Figure 22. If the underground sections are not sealed off, a piezometric level is created over the entire mine, as

# An investigation into recharge in South African underground collieries

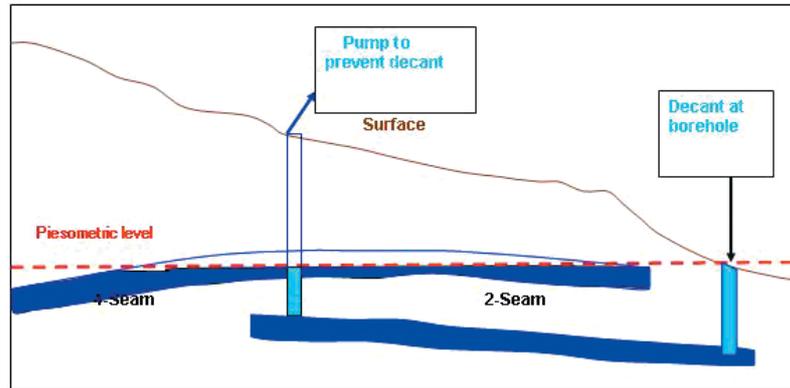


Figure 23—An illustration showing where one seam decants because of piezometric pressure created by water in a seam above

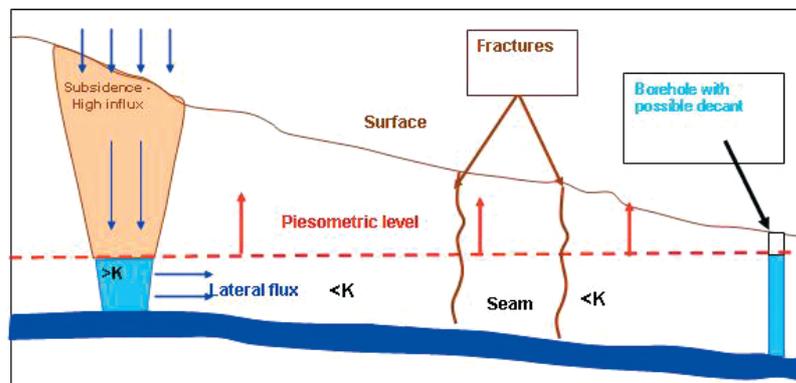


Figure 24—Illustration of case where different permeability conditions prevail above a colliery

illustrated in the diagram. The piezometric pressure created will cause decant from the seam through a conduit, e.g. a borehole or fracture at the lowest connection to the surface

- At New Largo a unique situation occurs where the 2 Seam decants if the 4 Seam, which is connected to the 2 Seam through a borehole, fills up, as illustrated in Figure 23. The piezometric pressure created by the water in the 4 Seam forces the water out at a borehole whose collar elevation is lower than the piezometric level created at the 4 Seam. A ridge in the coal floor results in parts of the cavity of the 4 Seam not filling up. It is thus possible that different oxidation scenarios can prevail for the different seams in this colliery.
- At the deep underground collieries, e.g. Ermelo Colliery, fractures caused by subsidence result in areas of different permeability. These can range from vast areas to single fractures. The permeability in the areas (>K) will be higher than the surrounding strata (<K). Influx of water along these areas will occur more quickly than through the surrounding strata. When the mining cavity is filled, water will rise more rapidly in the areas of higher permeability. This is illustrated by the lighter blue colour in Figure 24. A piezometric level will be created in the higher permeability areas. If the influx into the high permeability areas is higher than the lateral flux along the strata, the piezometric level

will keep rising. Decant will then eventually occur at boreholes or fractures with surface elevations lower than the piezometric level.

## Conclusions and recommendations

The five collieries for this investigation have been selected with specific intent. Each has specific merit for being included in this investigation. Collieries must use a combination of the conditions described and adapt it to their own unique situation.

Water balances are of overriding importance in determining recharge and water loss. These vary from mine to mine. Overriding factors are the method of mining, depth of mining, and the surface hydrology, and these factors dictate the end result in terms of water influx. High extraction methods (stooping and longwall) invariably disturb the overlying strata more than bord and pillar methods. The actual percentages depend greatly on the specific circumstances. A summary of the percentage influx to be expected for the various mining methods is as follows:

- *Shallow bord and pillar*—5–10% of the rainfall
- *Deep bord and pillar with no subsidence*—3–4% of the rainfall
- *Stooping*—5–12% of the rainfall, or even as high as 20% in some abnormal cases
- *Longwall*—6–15% of the rainfall
- *Rehabilitated opencast*—14–20% of the rainfall.

## An investigation into recharge in South African underground collieries

(The longwall mining value and rehabilitated opencast mining<sup>9</sup> were not covered in this investigation, but are included for reference purposes.)

Lateral water movement along the coal-seams, and water influx that moves vertically downwards into the mines determines recharge into mines. Typically, the rising water level in the mining cavity reduces the amount of inflow due to the decrease in the gradient, but does not eliminate it completely. This is true both for vertical infiltration through the overburden and horizontal leakage that may occur through the barrier pillars. Despite nominal barrier leakage, the water level in the mine will continue to rise until a dynamic equilibrium is achieved between inflow and outflow. Despite the reduction in flow, surface discharge or seepage into shallow weathered strata is a likely result. Once a mine is flooded, inflow will thus not cease.

A flow chart of the influx into the collieries is included in (Figure 25) summarizes the recharge values in the investigation.

There are several factors that need to be considered about recharge in the mining industry:

- The major factors that control mine hydrology and govern recharge into abandoned coal mines include the geometry of the mine, the extent of collapse and subsidence resulting from the type of mining, the extent of fracturing caused by the mining methods, the general nature of overburden, discharge elevation, coal

barriers and whether the coal-seams outcrop. Of significant additional risk is the undermining of streams and surface water bodies by high extraction methods. The sequence of mining and interlinking of underground workings are also important when considering the eventual flooding of mine workings. A general rule is that groundwater infiltration decreases as the thickness of the overburden increases, and that hydraulic conductivity decreases an order of magnitude for every 30 metres increase in depth. Hence the shallow portions of the mine dominate the inflow to the mine, as illustrated at Minnaar Colliery

- Water management problems often result because of a lack of storage space after about 20–30 years of mining. In areas of high underground extraction, problems may arise earlier. Mine scheduling, commencing with mining in low-lying areas and retreating to higher coal seam elevations can solve this problem. This is an important water control strategy. New mines or new development in a mine should be planned so that natural compartments are created in which excess water can be stored while mining continues in other areas
- All five mines in this study will eventually fill with water. Thereafter, seepage of mine water into the weathered strata will commence. The rate of seepage is controlled by the hydraulic conductivity of the strata. If

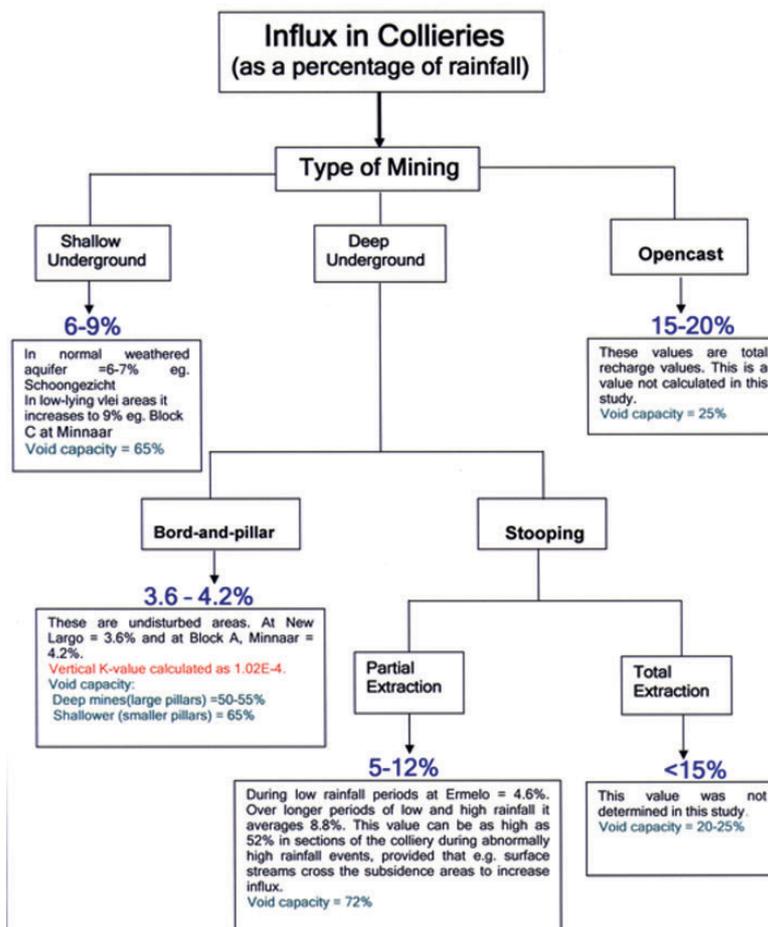


Figure 25—Flow chart of the influx into the collieries

# An investigation into recharge in South African underground collieries

the hydraulic conductivities of these strata are too low to transmit significant volumes of mine water, recharge rates to the mines will exceed seepage rates, and excess water will eventually decant onto the surface

- ▶ This investigation stresses the importance of providing for the likelihood of decanting water from collieries. Pathways along which decanting can take place are numerous, e.g. shafts, subsidence areas and boreholes. Numerous prospect boreholes are typically drilled during the life of the mine, and these should be sealed by grouting. Collapsed surface areas must be rehabilitated to channel the run-off away from these areas. Cracks should be destroyed by ploughing across them.
- ▶ Many of the larger collieries extend over several catchments. Through proper planning, the interconnection of collieries may be considered to channel mine water to specific points for treatment or utilization, rather than having numerous small uncontrolled seepages or decants into streams. It has been demonstrated in previous research that excess mine water can be channelled over vast distances through underground workings, to emanate in areas where better control of the excess water is possible<sup>6</sup>.

To put the influx figures in this study into context with other areas in the world, they were compared with figures described by Younger *et al.* in *Mine Water*<sup>15</sup>. According to this, the term 'water make' may be defined as the total volume of water entering workings over a specific period of time. In most cases the water make corresponds closely to inflows of natural waters, and depends greatly on mining type and depth, as well as seasonal variations in rainfall. In Europe, much pioneering work was done by Saul on the influx of water into mines. This profoundly influenced the thinking of many generations of mining engineers worldwide to the present day. One of Saul's major conclusions was that, in previously unmined coal measures, the main source of water will be from the overlying sandstones; the future water make of a new deep mine can be expected to be between 20% and 40% of the mean annual rainfall<sup>11</sup>.

*Table VIII*  
**Water makes around the world**

Mining area	Water make (m <sup>3</sup> /d/km <sup>2</sup> )
Durham, England	0.3
Dysart-Leven, Scotland	0.6
Jharia, India	0.3
Lower Silesian, Czech Republic	0.2
Ruhr, Germany	0.2
Polkemmet, Scotland	0.1
Upper Silesian, Poland	0.4

*Table IX*  
**Water make in South African collieries**

Colliery	Influx %	Water make (m <sup>3</sup> /d/km <sup>2</sup> )
Schoongezicht	6-9	0.08-0.11
New Largo & Minnaar	3.6-4.2	0.07
Ermelo*	5-12	0.09-0.22

Younger *et al.*<sup>15</sup> state that there is a remarkable compatibility in the rock sequences of coal mining areas worldwide, and suggest an international similarity for water makes in deep coal mines around the world (Table VIII).

This study showed lower influx volumes for the South African collieries investigated, compared to those described by Younger *et al.*<sup>15</sup>. However, Ermelo Colliery showed that recharge rates are highly variable, depending on the mining method (Table IX), and in areas where subsidence occurs, water make values in the same order as those described by Younger can be obtained.

\*Influx values as high as 20% were measured in some areas during specific periods, indicating a water make volume of 0.37 m<sup>3</sup>/d/km<sup>2</sup>.

## Acknowledgements

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Ingwe Coal and AngloCoal, for supplying information.

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