Investigation of water decant from underground collieries in Mpumalanga

by

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THESIS

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1. Introduction

1.1. Background Information

South Africa is a country blessed with an abundance of minerals. Coal, which is the main source of energy in South Africa, is one of these abundant minerals. In 1997, 68% of the energy consumption of Southern Africa was coal-based (Energy Information Administration,2000).

In South Africa coal recourses are contained in 19 coalfields (Erasmus *et al.*, 1981). The most important coalfields in the Mpumalanga Province are the Springs-Witbank Coalfield and the Highveld (Eastern Transvaal) Coalfield. A map of the coalfields in South Africa is shown in Figure 1-1.

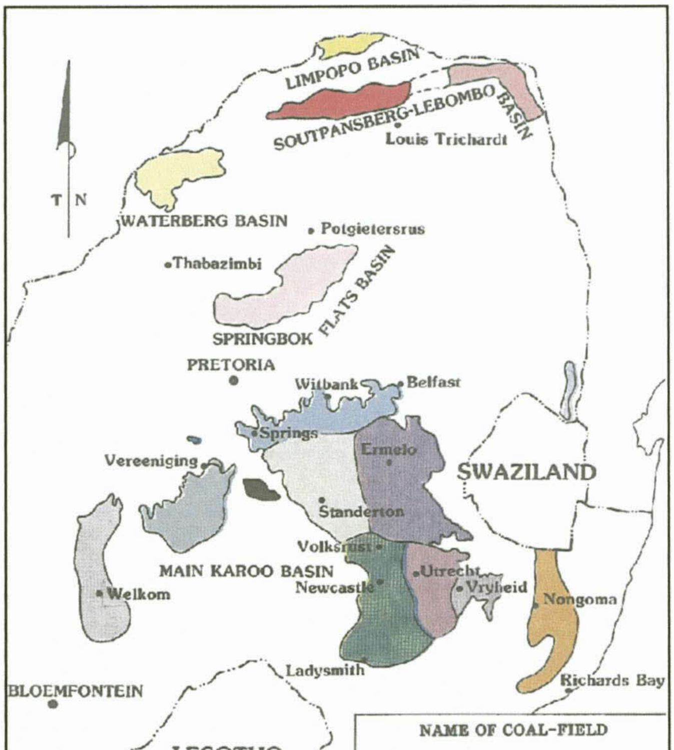


Figure 1-1. The South African Coalfields, after Erasmus et al. (1981).

Deterioration in the mine water quality results from coal mining. Sulphuric acid is formed as a result of oxidation reactions in the mines. Because South Africa is a water-scarce country, a significant impact on the environment has been forecasted, as far back as 1983 (Funke, 1983).

1.2. The problem of mine closure

Once the economically mineable coal has been removed, mines close down and are left to fill up with water. Most of them will eventually decant and/or seep into the adjacent strata and environment, thus polluting aquifers and rivers.

The Minerals Act 1991 was the first act that forced all mining operations towards sustainable land management and not just beautifying disturbances. The Minerals Act, 1991: Act 50 of 1991 stated that the mine remained the property of the owner until a closure certificate had been issued. The law allowed authorities to gain insight into, and control mining activities that could adversely affect the water environment. This law was substituted by the Mineral and Petroleum Act of 2002. This act states that no closure certificate may be issued unless the management of potential pollution to water resources has been addressed.

Since the implementation of the Minerals Act of 1991, the number of closure certificates dwindled to a point where very few are issued. This is a major concern since astronomical sums of money are involved either way. At a WISA Mine Closure Conference (2002), various speakers expressed their views on the subject:

- Van Zyl of Anglo Coal said that the greatest challenge to the industry is to obtain closure. Closure liabilities should be turned into opportunities and involve communities, including the previously disadvantaged.
- Cochrane of the Department of Minerals and Energy (DME) said that the act should force all mining operations towards sustainable rehabilitation programs, and not just the beautification of the surface. Rehabilitation, including underground rehabilitation, must be part of the pre-planning of the mines.
- Schwab of the Department of Water Affairs and Forestry (DWAF) stated that a useful heritage must be left behind for future generations. Mines must prove that their objectives are reached with rehabilitation in mind before closure certificates will be issued. The rehabilitation must be sustainable and the area left behind must present minimal risks for the community. DWAF`s mandate lies in the National Water Act, 1998 (Act 36 of 1998), as summarised in the preamble to Part 4:

Part 4 deals with pollution prevention, and in particular the situation where pollution of a water resource occurs or might occur as a result of activities on land. The person who owns, controls occupies or use the land in question is responsible for taking measures to prevent pollution of the water resources. If these measures are not taken, the catchment management agency concerned *may itself do whatever is necessary to prevent pollution or to remedy its effects, and to recover all reasonable costs from the persons responsible for the pollution.*

Section 19, regulation 9(1) and (2) are aimed at the protection of the water resources and states:

1. *Any person in control of a mine must at either temporary or permanent cessation of operations ensure that all pollution control measures have been designed, modified, constructed and maintained so as to comply with these regulations.*
2. *Any person in control of a mine or activity must ensure that the in-stream and riparian habitat of any water resource, which may have been affected or altered by the mine or activity, is remedied as to comply with these regulations.*

Schwab concluded that the way forward from DWAF`s perspective is thus strongly dependent on the changes in legislation and the guidance requirements of the mining industry. A holistic approach should be taken over the life cycle of a mine. Integrated mine water management should address all the life cycle phases from the scoping or feasibility phase through to closure and the long-term residual water resource impacts after mine closure. The current view that mine closure is unachievable needs to be addressed through policy guidance.

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 with a certificate from DME was achieved, remains the basis for long-term water management with a risk based approach.

1.3. Scope of Investigation

The following are the aims of this investigation:

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

Each case study described in this report deals with a specific situation in the coal industry. The descriptions and data presented in this report are meant for the industry and authorities to:

- Learn from past practices and experiences.
- Select from these the most viable solutions.
- Implement relevant strategies at existing mines with the purpose of standardisation in the industry.

Very little work along these lines has been done in the past. Much of the previous work has been confidential within the mining groups. Examples of past work are that by Grobbelaar *et al.* (2000) at TNC; Hodgson and Grobbelaar (2000) at Minnaar Colliery; Hodgson and Grobbelaar (1999) at Ermelo Colliery; and Hodgson (1992) at New Largo Colliery. These studies were intended to gain an understanding of geohydrological impacts by individual collieries and not as directives to aid other collieries in their operational and closing down planning.

1.4. Approach to the Research

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

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
Kromdraai	Underground mine currently being reworked by opencast methods; impact of change in mining method.	Bord-and-pillar Secondary opencast

The localities of the selected collieries with respect to the rest of coal mining in Mpumalanga are shown in Figure 1-2.

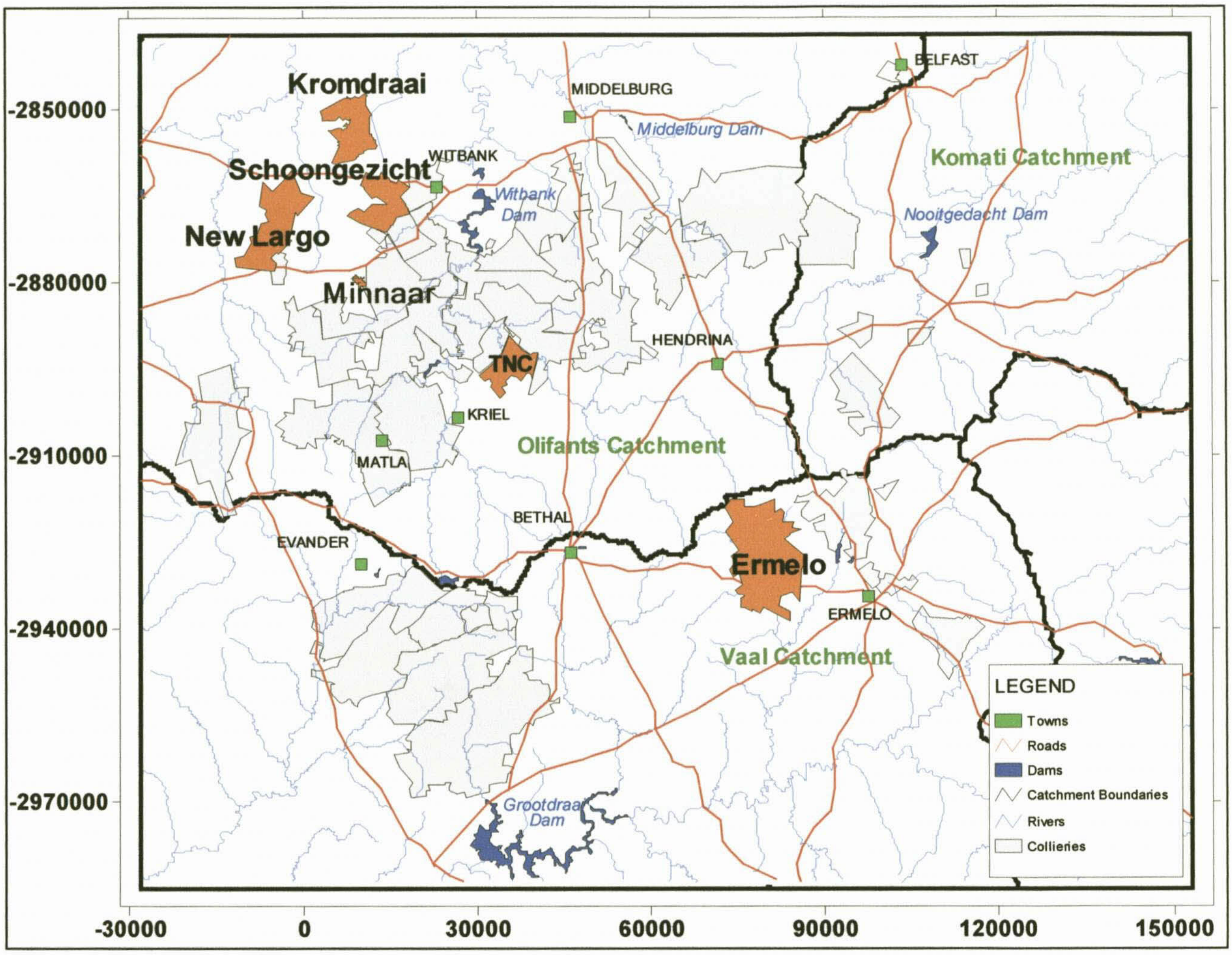


Figure 1-2. Mine lease areas for collieries in Mpumalanga. (The investigated mines are highlighted in red).

1.5. Structure of the Report

The crux of this report consists of the six chapters that describe the case history investigations. These chapters may be read in isolation, depending on the interests of the individuals. It may however be difficult, to understand the potential impact of all actions without scanning the full report. To locate relevant information with ease, the following table is included.

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

These are not the only issues of interest or significance discussed in this report. It is recommended that the reader scan through the six chapters for other points of interest that may be applicable to his/her specific situation. It is the intention that these six case histories provide the groundwork on which much of the planning for future development and closure scenarios should be based.

The databases developed during this investigation have been made available to the relevant mining houses. This information is also available, with the WISH software package for data processing, upon request from the Institute for Groundwater Studies (IGS), at the Internet URL www.WISH.co.za. Only through using this report and data will the possibilities for water management at each of the mines become apparent. A request has been made to the two mining companies involved that they continue with monitoring and submit information for updating to the IGS.

2 Water in Mpumalanga Collieries

2.1 Introduction

Coal mining has been ongoing in the Mpumalanga Area since 1870. Initially, all the mines were in the shallower areas around 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 (Wagner,1980), pillars were designed on a scientific basis. Pillars before this date were known to have collapsed, sometimes with catastrophic consequences. As far as mine water is concerned, complexities that arose from this 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.
- Areas of collapse aggravate the influx of water and oxygen to the mine workings, resulting in an increase in oxidation rates, sometimes leading to spontaneous combustion of coal left in the mines.
- As a guideline, it has generally been accepted that between 1 - 3% of the rainfall above bord-and-pillar mining infiltrate into these mines. In areas where extensive collapse of the pillars has occurred, percentages can be higher.
- Much of the base potential has been leached from the top 30 m of the sediments due to circulating groundwater. Mining in this zone has a high probability of uncontrollable acid production. This is confirmed by water draining from shallow mines west of Witbank, for instance.

During the 1970's, wide-scale expansion lead to the development of mega mine structures south of the existing coalfields. Almost all of these developments were associated with power generation (Eskom) or the utilisation of the coal by the chemical industry (Sasol). The coal seams deepen to the south and the potential impact of coal mining 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 is done through underground high extraction methods. As far as mine water is concerned, complexities that arise from this mining are:

- Cracks develop in the overlying strata, and rock that is generally impermeable to water flow, become conduits for groundwater from overlying aquifers and surface water to enter into the mine workings.
- The influx of water into such areas is regulated by many factors. Historically, influxes of 6 - 11% of the annual rainfall have been observed (Hodgson and Krantz, 1998).

- The water qualities in these mines follow characteristic trends that are the consequence of successive actions and reactions, such as the mechanical release of sodium from the coal; chemical oxidation of sulphide; neutralisation of the acid, first by bicarbonate rich connate water and later by dolomitic lime in the coal and rock. Another not yet observed reaction is the diminishing of acid production and equilibrium adjustment through illite abundance. All stages are characterised by high salinities, except for the very last stage.
- After 20 years of operation, all of these mines are still in the early stages of this chemical evolutionary process.

In the 1970's, large-scale opencast mining became a reality in the Mpumalanga Coalfields. Many mines have come into existence up where up to four of the five coal seams are extracted by dragline methods. Coal produced per operating opencast mine is in the range of 4 - 12 Mt/a (Hodgson and Krantz, 1998). For each ton of coal extracted, some eight tons of rock, on average, is removed and replaced as spoil. This:

- Increases the hydraulic conductivity of the medium.
- Enhances recharge and about 20% of the rainfall ends up in the opencast pits.
- Causes oxygen ingress due to thermal gradients that develop in the spoil.
- Results in water quality deterioration of the pit water at an average sulphate production rate of 5 - 10 kg/ha of spoil, per day at sulphate concentrations of between 1 000 - 2 000 mg/L (Hodgson and Krantz, 1998).

In order to mine, excess water is pumped from the collieries, discharged under permit conditions, or desalinated. Several desalination plants using spiral reverse osmosis (SRO) or electro dialysis (EDR) are presently in operation, particularly in the south where the sodium concentration in the mine water is high. Projections for future volumes of water to decant from the mines have been made by Grobbelaar *et al.* (2000). In total, about 360 ML/d will decant from all the mines in combination. On a catchment basis, it relates to the following (ML/d):

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

This demonstrates the anticipated scale of the water decanting from the mines. Influx of water into collieries will inevitably lead to them filling up and decanting onto the surface. Some seepage into the weathered zone will also occur, but due to the relatively low hydraulic conductivity of the weathered strata, the seepage component will be relatively small. Seepage directions follow the topographic gradient and seepage water surfaces at the nearest streams.

2.2 Risk Factors

The impact risk of coal mining on water resources has been described by Hodgson *et al.* (2001). They used a two-tiered classification system, one relating the mine water and the other relating to the aquifer. For mine water risk assessment, aspects considered are the acidity of the water; area to be mined; rock type; mining method; mine status; salinity and toxicity of the water. For the mine/aquifer risk assessment, aspects considered are the dewatering rate of the mine; mining relative to the aquifer; interconnectivity between the mine and the aquifer; surface topography; rainfall; access for water to and from the mine and the development potential of the aquifer. This work has led to the classification of all the collieries in the Mpumalanga area by calculating risk factors and depicting these by means of a GIS system.

The conclusion is that the mining method is one of the dominating factors in controlling the pollution potential for a colliery. Hodgson *et al.* (2001) subsequently pointed out that through advanced planning much can be done to minimise the impact on the mine water during and after mining. They specifically developed software to assist in the scheduling of underground sections to minimise the impact of excess water during the mining phase. Examples are included in their work regarding how underground high extraction could, for instance, be rescheduled to accommodate the influx of water during the life of the mine and how to best utilise the natural alkalinity of the mine water for neutralising acid mine water.

Previous work (Hodgson and Krantz, 1998; Grobbelaar *et al.* 2000; Hodgson *et al.* 2001) has stressed time and again that the time scale in which things are likely to happen should not be ignored. The time for the collieries to fill with water is relatively short. The rise in water levels in opencast mining is in the order of 1 m per annum and depending on the pit geometry, decanting usually occurs within 10 years after mining has ceased. Depending on the recharge coefficient, underground mining could take longer. Many of the operating underground mines are already 20 - 40% filled with water. Often at closure, only small areas of these mines still have to be filled by water influx. Decanting on a massive scale is therefore predicted within the next 40 years.

Water that will decant will be saline. Previous work has stressed that chemical reactions in mines will not stop once decanting occurs. Most of the mines can only partially be flooded before decanting will occur. Oxidation reactions will continue in unflooded areas, and under acid conditions even in flooded areas. In sodium-rich areas such as the southern mine, dissolution will continue, rendering the water useless for general purposes outside the mine itself.

Over the past 20 years, the Institute for Groundwater Studies has done a vast amount of work in the collieries of South Africa. More than 95% of the collieries have been investigated. Despite all this work, very little response towards standardisation of methodologies has been stimulated within the industry, and very little guidance has been forthcoming from the government to this effect. It is the opinion of the authors that a point of sufficient understanding has been reached of the water situation in the coal mining industry to tackle most of the current problems on a unified front. Where past results have been summarised in reports to the Water Research Commission, what may still be required is the detailed description of a number of case histories. This will enable the industry and the government to judge the status of knowledge for themselves and to evaluate specific problems by examining the case histories.

3 Minnaar Colliery

3.1 Introduction

Minnaar Colliery is an underground mine located in the Mpumalanga Province between the towns of Ogies and Witbank. It forms part of the Witbank Coalfield (Erasmus *et al.*, 1981, Figure 1-1) and lies in the Olifants Catchment. Tweefontein Colliery borders it to the east. To the west, but some distance away, lies Ogies Colliery, an old, defunct mine. The N12 road runs north of the mine. Figure 3-1 shows the topography of the area at Minnaar Colliery.

The surface area of the mine has been rehabilitated and the only evidence of past mining activities is the rehabilitated discard dump, northeast of the mine. A number of 600 mm borehole casings protrude from the surface above the mine (Figure 3-2 and Figure 3-3). Surface subsidence has occurred at two localities in the south and one in the west. These have been rehabilitated and no evidence of current surface subsidence is present. The rehabilitated coal discard dump is not considered in this report. Farming activities continue unhindered in the area and for the past nine years, water from the mine has been utilised for irrigation.

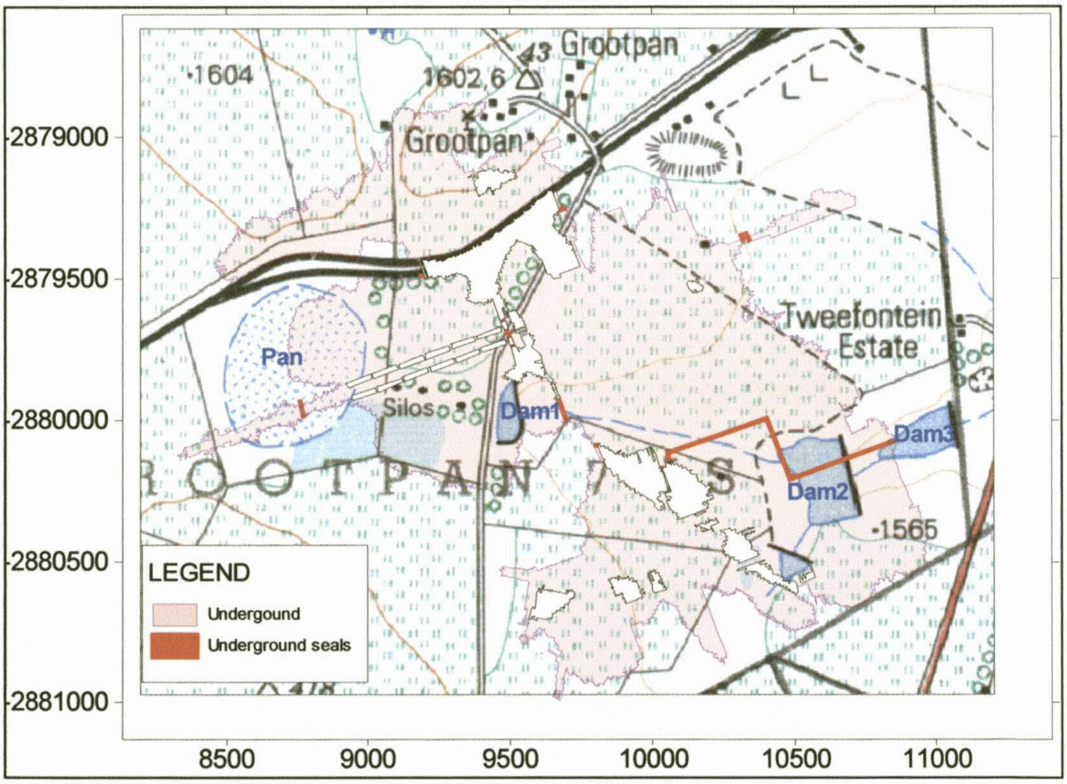


Figure 3-1. Topographic map, also showing the outline of the mine and underground seals.

Figure 3-2. Rehabilitated discard dump.

Figure 3-3. Example of a remaining borehole casing at Minnaar Colliery.

3.2 Surface Hydrology

Minnaar Colliery lies in the Olifants Catchment. The run-off area for Minnaar Colliery comprises 590 ha. The northern border of the mine lies on a water divide. From here, surface drainage is mainly southeast into Dam 2, as can be seen on the photograph in Figure 3-4 and the map in Figure 3-5. In the northwest of the area, surface run-off is in the direction of the pan.

The mean annual rainfall for the area is 698 mm (SA Weather Service - Rainfall station: Ogies No. 478093). A time-series plot for the rainfall is included in Figure 3-6. The mean annual evaporation for the area is 1 600 mm and the mean annual run-off is 39 mm (Midgley *et al.*, 1990). This translates to a mean annual run-off volume of 230 000 m^3 for this catchment.

Boreholes BH6 and BH7 are located in Dam 2. During the rainfall season, water from the dam drains through the boreholes into the mine. The mine water is used by the farmer for irrigation.

Figure 3-4. Photograph to illustrate the topographic high in the north and the slope towards the dam. Borehole BH7 is situated in the dam.

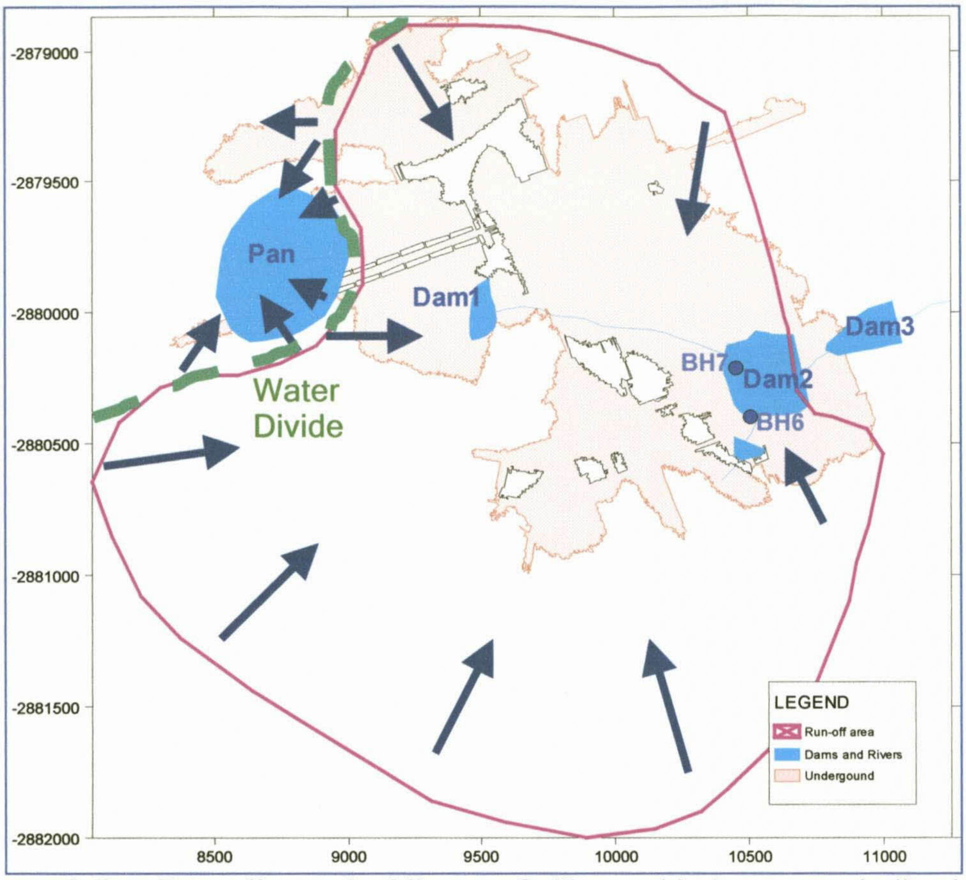


Figure 3-5. Run-off area for Minnaar Colliery, with the arrows indicating the run-off directions.

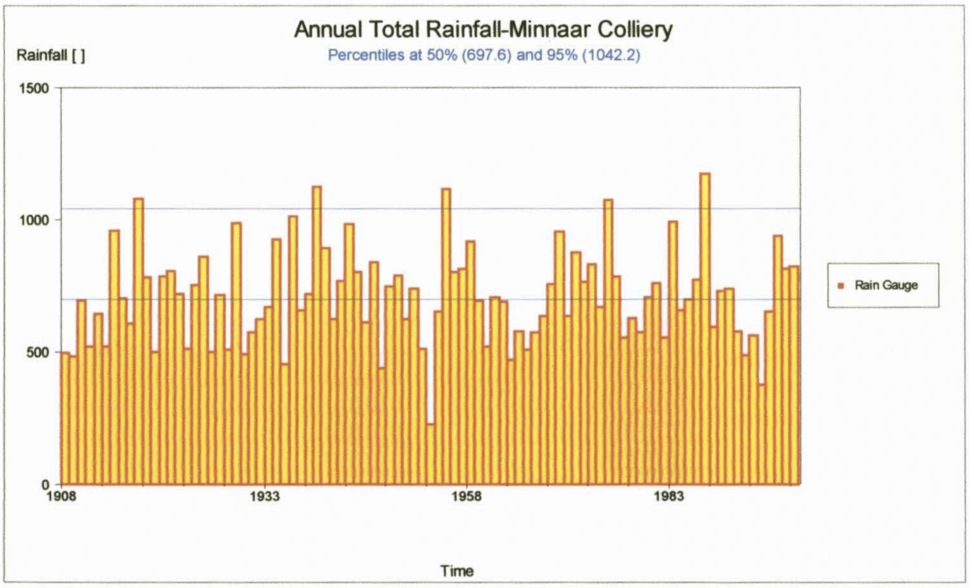


Figure 3-6. Annual rainfall for Ogies, also showing the 50 and 95 percentiles.

3.3 Geology

Minnaar Colliery lies in the Springs-Witbank Coalfield and is 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 (Smith and Whittaker, 1986). 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 No.`s 1 to 5, are contained within a 70 m succession (Smith and Whittaker, 1986; Cairncross, 2002). Dykes are ubiquitous throughout the area, with the most prominent of them all the Ogies Dyke, which has been traced on surface over a strike length of approximately 100 km (Figure 3-7). The main strike of this dyke is west to east. North of the Ogies Dyke, smaller dykes are generally less common than in the south. The northern dykes are commonly 0,5 to 1 m thick, whereas south of the Ogies Dyke, dykes are up to 5 m thick.

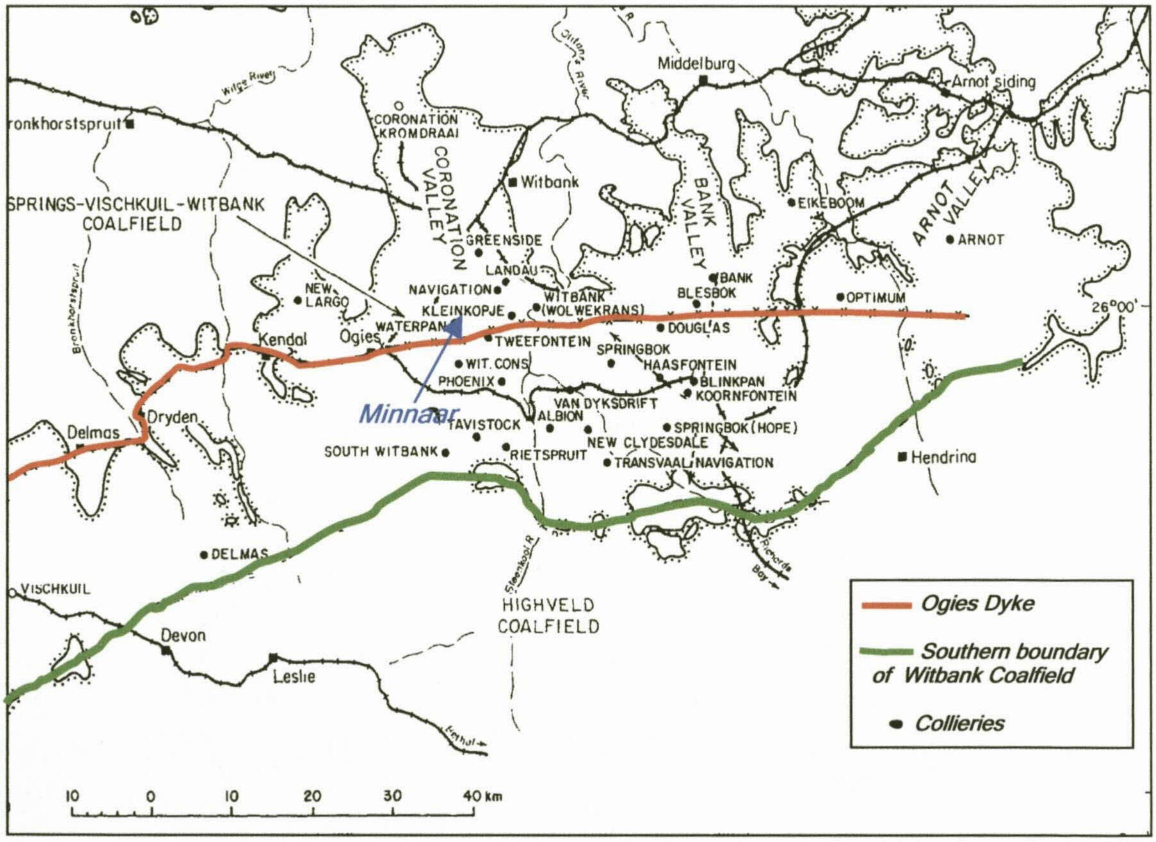


Figure 3-7. Locality plan of Springs-Witbank Coalfield, also showing the Ogies dyke (after Smith and Whittaker).

No information is available on the local geology for Minnaar Colliery, but the general geology for the Ogies Area is indicated in Figure 3-8. From the regular dip of the floor (Figure 3-10) it seems that dolerite intrusions did not play a major role.

The Ogies Dyke, with its associate areas, has a burnt zone of up to 300 m wide within which the coal has been burnt or devolatilised. Elsewhere, dykes have burnt zones of less than 10 m wide.

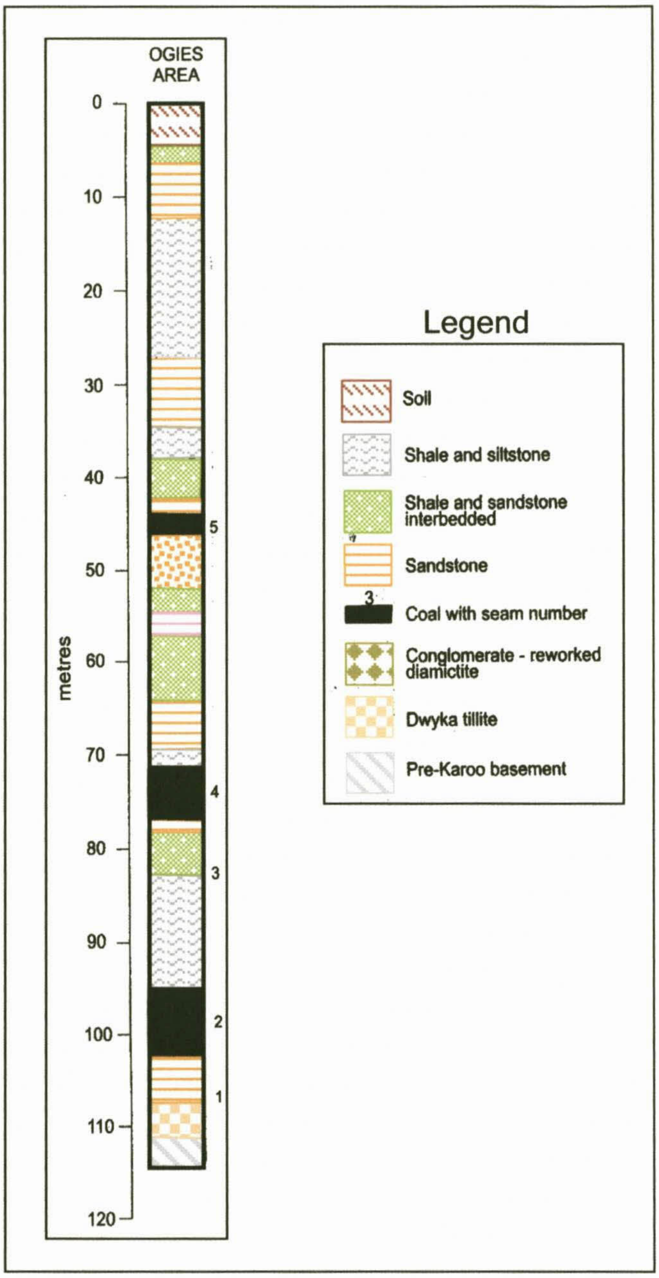


Figure 3-8. Stratigraphy of the Ogies area (simplified after Smith and Whittaker, 1986).

3.4 Geohydrology

3.4.1 The weathered groundwater system

From other investigations in this area (Hodgson and Krantz, 1998) it is known that the depth of natural weathering extends up to 10 m below the surface. The upper aquifer is associated with this weathered horizon. This aquifer is recharged by rainfall. The percentage recharge to this aquifer is estimated to be in the order of 1 - 3% of the annual rainfall, based on work in other parts of the country by Kirchner *et al.* (1991) and Bredenkamp *et al.* (1995).

Seepage of groundwater from the weathered aquifer into the mine workings should therefore be possible in mining areas that coincide with blue colours in Figure 3-11, with a gradual decrease in groundwater influx towards the deeper areas.

3.4.2 The fractured groundwater system

The grains in the fresh rock below the weathered zone are very well cemented and allow little significant flow of water. Most groundwater movement is therefore along secondary structures, such as fractures, cracks and joints in the rock. These structures are best developed in the 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.

3.5 Mining

The area mined constitutes 235 ha (Figure 3-1). Bord-and-pillar methods were used. The mine consists of four separate main areas (A, C, E and F) as illustrated in Figure 3-9, and two small areas (B and D). These are linked by narrow development in which seals have been installed.

Statistics on Minnaar Colliery are as follows:

Description	Value
Total area mined (ha)	235
Area A (ha)	35
Area B (ha)	2
Area C (ha)	47
Area D (ha)	2
Area E (ha)	74
Area F (ha)	75
Total area included but not mined (ha)	21
Volume mined (Mm^3)	4.76
Average mining height (m)	3
Average extraction rate(%)	0.65
Mining depth below surface (m)	12 - 77

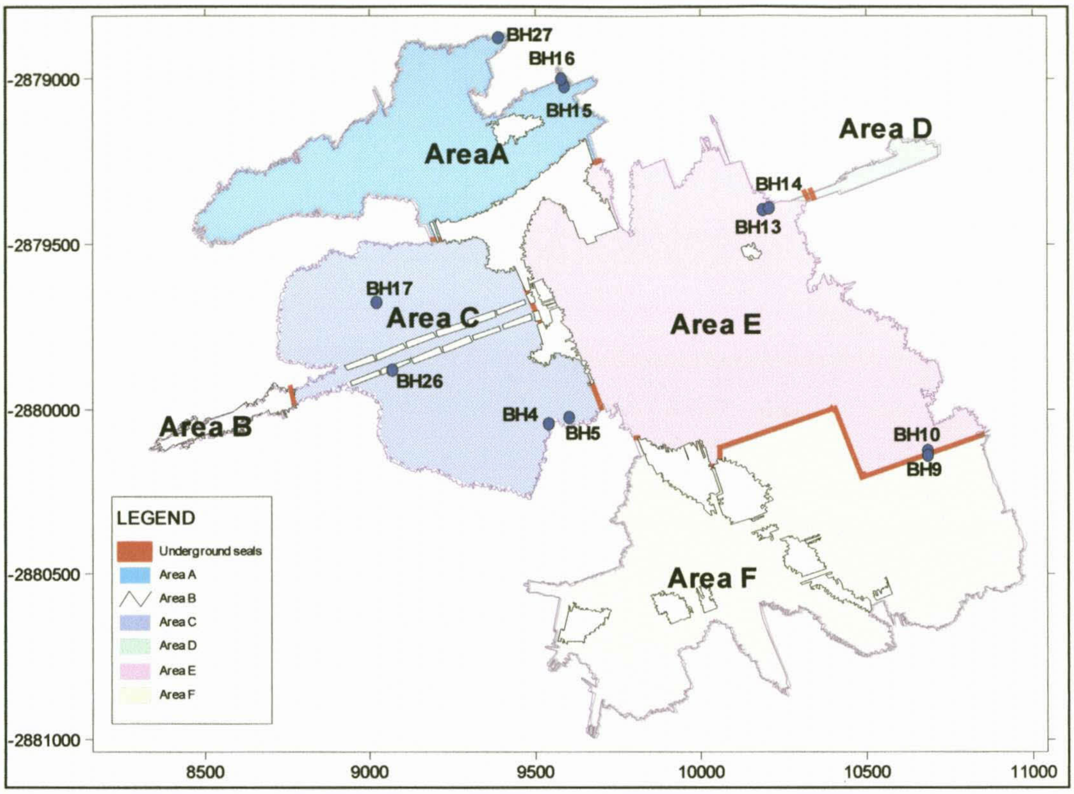


Figure 3-9. Map indicating the underground areas at Minnaar Colliery, including monitoring boreholes.

Figure 3-10 shows the underground floor contours and Figure 3-11 the depth of mining. Information on the mine extremities and floor contours for Minnaar Colliery has been obtained from SEF (Strategic Energy Fund). This information was generated during the early 1970`s, when Minnaar Colliery was considered for possible crude oil storage. The casings left on surface, are relics of this venture.

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. If this information is compared with Figure 3-8, it is possible that the No. 4 Seam was mined at Minnaar Colliery. Information from Tweefontein Colliery shows its No. 4 Seam mining adjacent to Minnaar. The EMPR for Tweefontein (1997), done by Wates, Meiring and Barnard indicates that the No. 4 Seam lies at an elevation of 1518 mamsl, next to Minnaar. This is at a similar level to other No. 4 Seam mining east of Minnaar (Figure 3-10).

According to Smith and Whittaker (1986), the seam usually contains dull to dull lustrous coal. The mining horizon is generally restricted to the lower 3.5 m of a 5 m seam, because of the poor quality of the upper section. Bad roof conditions are usully present, especially if the normal shale roof is exposed. This also seems true for Minnaar Colliery, as 3 m of the coal seam was mined, according to the SEF.

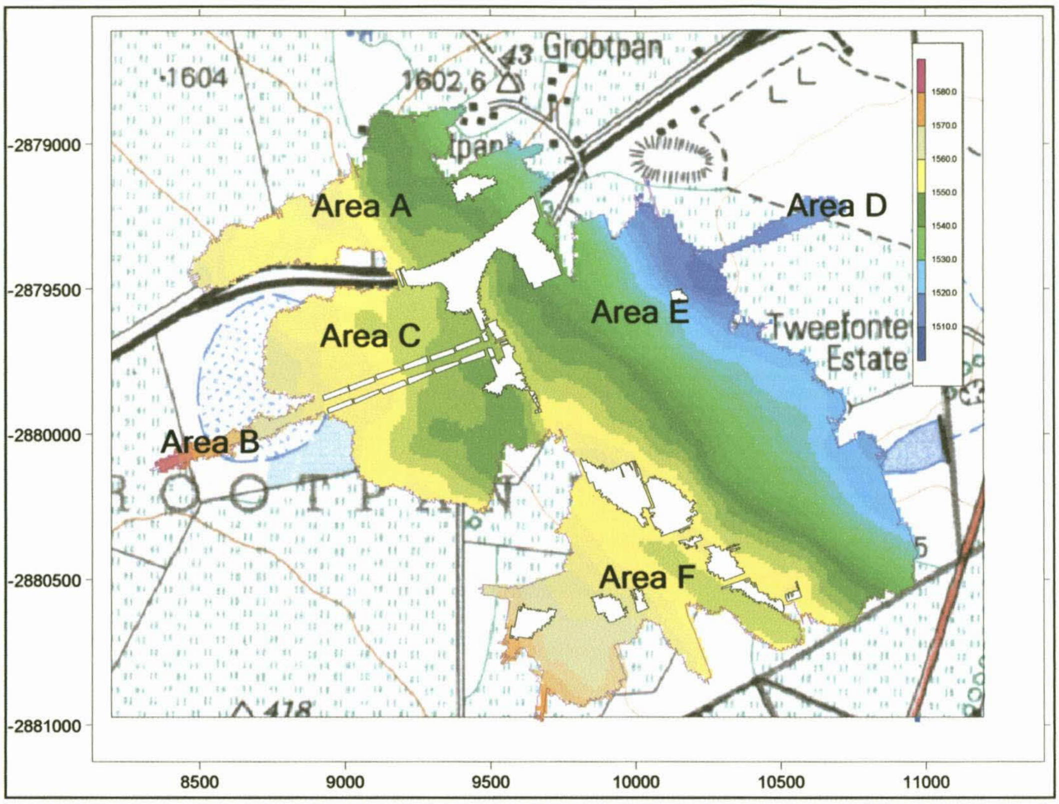


Figure 3-10. Floor contours at Minnaar Colliery.

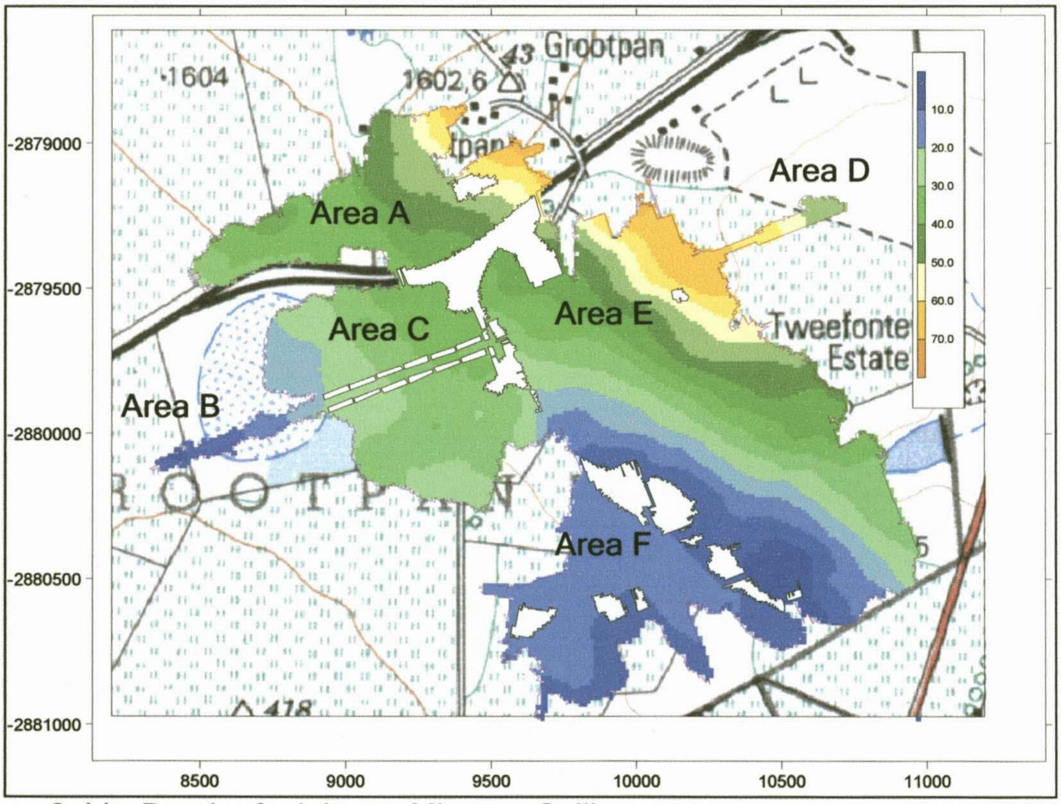


Figure 3-11. Depth of mining at Minnaar Colliery.

3.6 Water Balance

The surface area above the mine is used for agriculture, with both summer- and winter crops being harvested. Two 40 ha center pivots have been in operation for nine years, utilising water from Dam 2, supplemented by water extracted through BH9 in Area F. A new 40 ha center pivot (Pivot 3) has been in operation since 2002, extracting water from BH4 in Area C. One of the two older pivots (Figure 3-12) also extracted water from Area C during the winter of 2002.

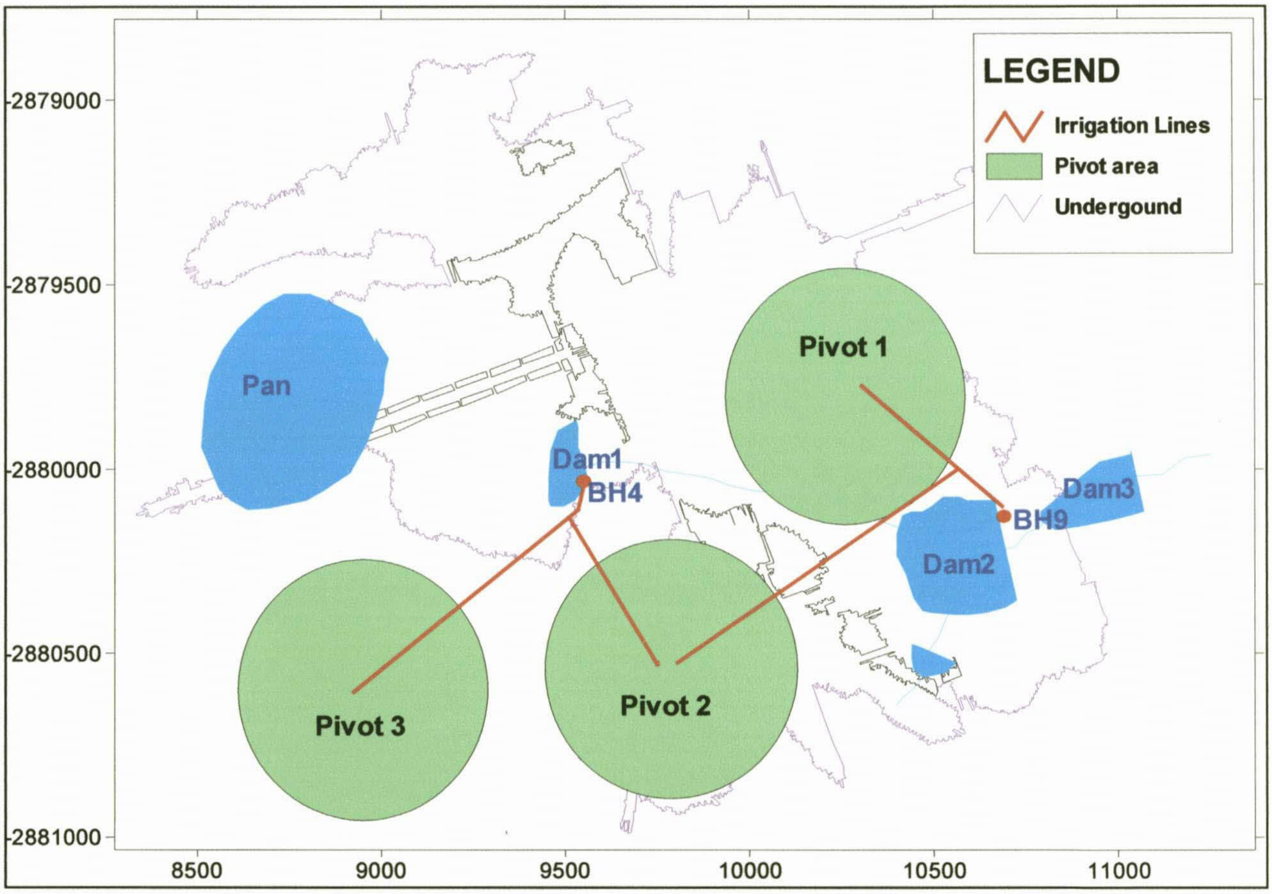


Figure 3-12. The position of the center pivots in relation to the outline of Minnaar Colliery.

Mine water levels are different for each of the four main compartments. Short-term water balances have been calculated for the different areas to investigate this phenomenon. Figure 3-9, Figure 3-13, Table 3-1 and Table 3-2, together with the floor contours in Figure 3-10 serve as background to this calculation.

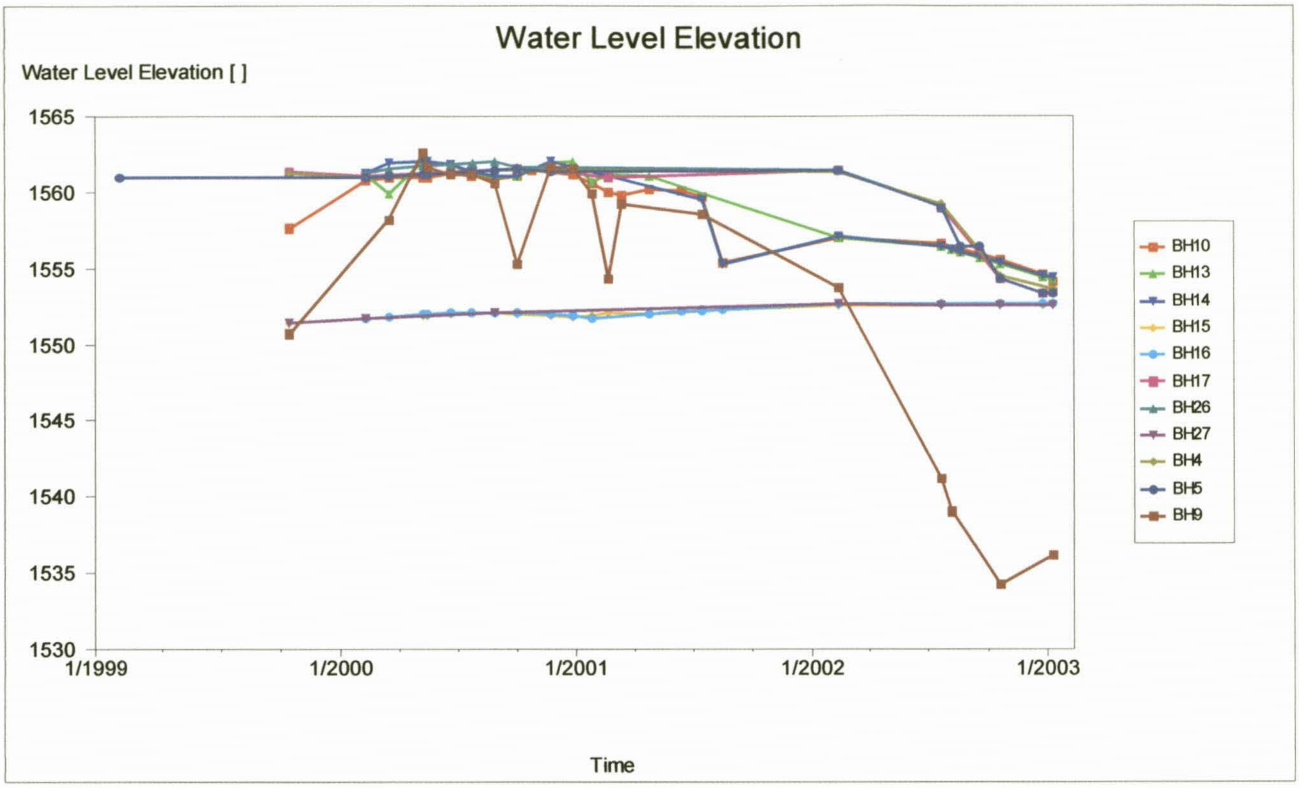


Figure 3-13. Water-elevation graph for Minnaar Colliery.

Month	1999	2000	2001	2002
Jan	140	240	53	77
Feb	5	160	96	31
March	9	125	51	0
April	23	67	12	11
May	0	27	75	28
June	3	0	37	0
July	0	0	0	0
Aug	0	0	0	0
Sept	23	19	18	11
Oct	37	131	49	20
Nov	474	123	84	89
Dec	330	193	106	114

Table 3-1: Rainfall values (mm/month) for Ogies District.

Table 3-2: Input data for Minnaar Colliery.

Input data	Value
Mined area (ha)	235
Internal unmined area (ha)	21
Mine perimeter (m)	10 000
Compartments E/F (ha)	150
Perimeter E/F (m)	6 000
Pivot area (ha)	123
Dam area (ha)	5.43
Catchment area (ha)	590
Average rainfall (mm/a)	700
Surface run-off from virgin ground	5.6%
Surface run-off from pivots	2%
Hydraulic groundwater gradient towards mine	5%
Lateral hydraulic conductivity of strata (m/d)	0.1
Coal thickness (m)	3
Coal extraction rate	65%

3.6.1 Area A

Block A is an isolated sealed-off area and is still in the process of filling up (BH`s 15, 16 and 27). Water from BH27 is utilised for irrigation of the garden. The water levels used for calculations in this area, and the volumes determined from stage curves (of which Figure 3-14 is an example) are shown in Table 3-3.

Table 3-3: Water levels and volumes for Area A.

Area A	Area size (ha)	WL (28/10/1999)	WL (4/11/2002)
	34.7	1551.43	1552.63
Water volume (m^3)		429825	449515

The water balance calculations are summarised in Table 3-4.

Table 3-4: Water balance calculations Area A.

Days	1102
Water volume gain (m^3)	19 690
Rainfall (m)	2.655
Outflux distance (m)	785
Lateral outflux (m^3)	12 976
Extraction (m^3)	6402
Total influx (m^3)	39 069
Recharge %	4.24
Vertical K-value	1.02E-4

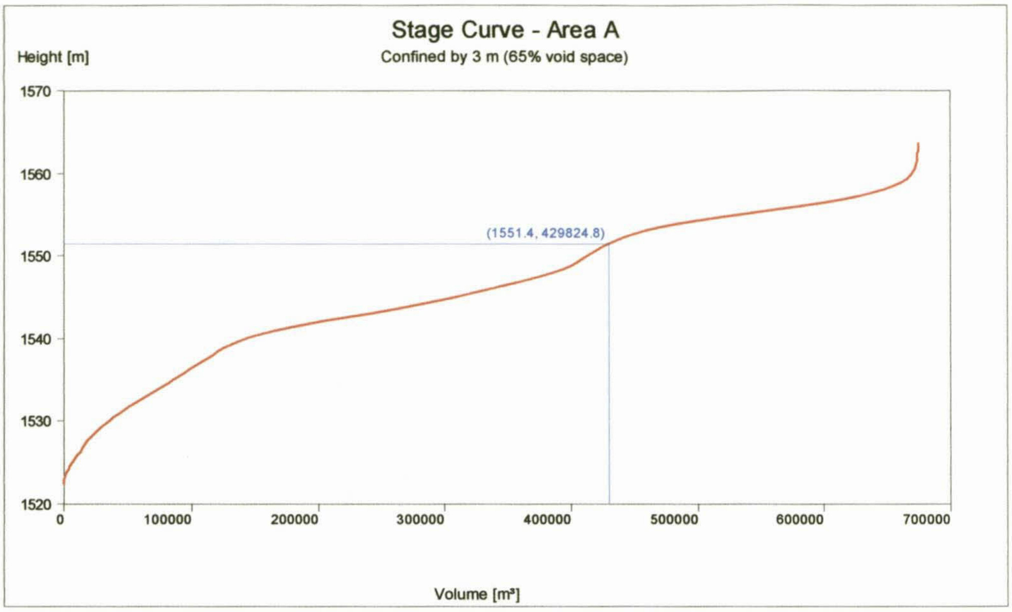


Figure 3-14. Stage Curve for Area A at 28/10/1999.

As can be seen from Figure 3-15, there is no real correlation between rainfall and the rise in the water level. Extraction did not play any significant role, as the extraction from BH27 is relatively uniform trough the year (according to the gardener of the farm that extracts the water). The area is situated on a topographic high, probably with little lateral influx into this area. This suggests that the influx into Area A is dominantly due to vertical influx, translating into a vertical K-value of 1.02E-4.

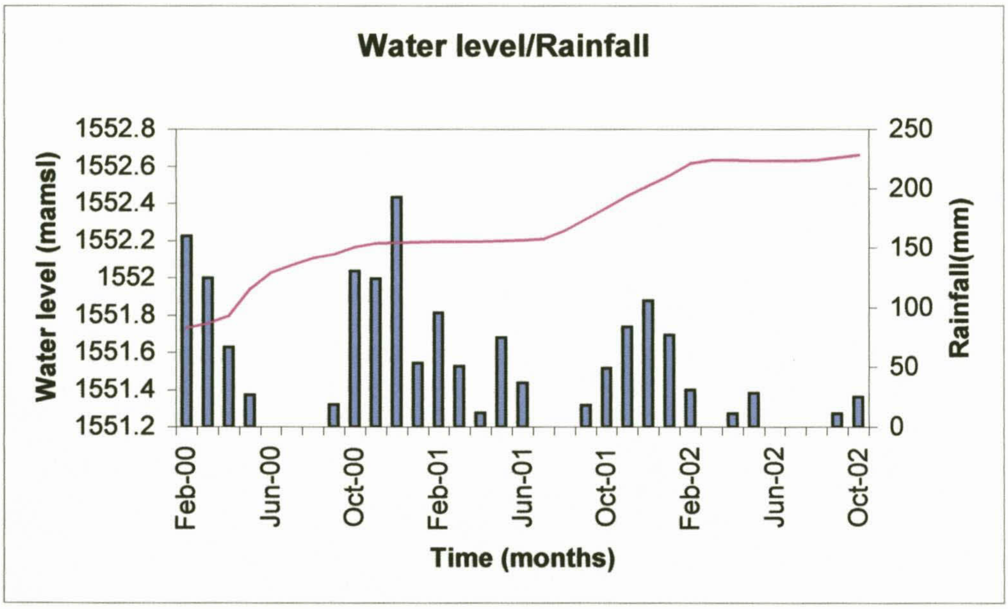


Figure 3-15. Rainfall against water level.

There seems to be very little interaction with adjacent areas, as the water levels are completely different from that of Block C and Block E. This suggests that the seals are intact. No information is available of the type of seals installed.

The lowest surface elevation above Block A is at 1 590 mamsl, as can be seen in Figure 3-16. This is much higher than the current water level of 1 552.63 mamsl. It is concluded that all of Area A can be flooded. Once this block has been flooded, the level in the mine will equalise with that in the surrounding aquifer. No decanting will therefore occur from this site. Seepage through the seals is, however, a possibility because a head difference of more than 20 m could finally establish from north to south. At this pressure difference, the seals are bound to leak or as a worst-case scenario, collapse. A collapse of the seals will not have a severe impact on the other areas, since the volume of water in Area A above the decant level in Areas C and E, is small.

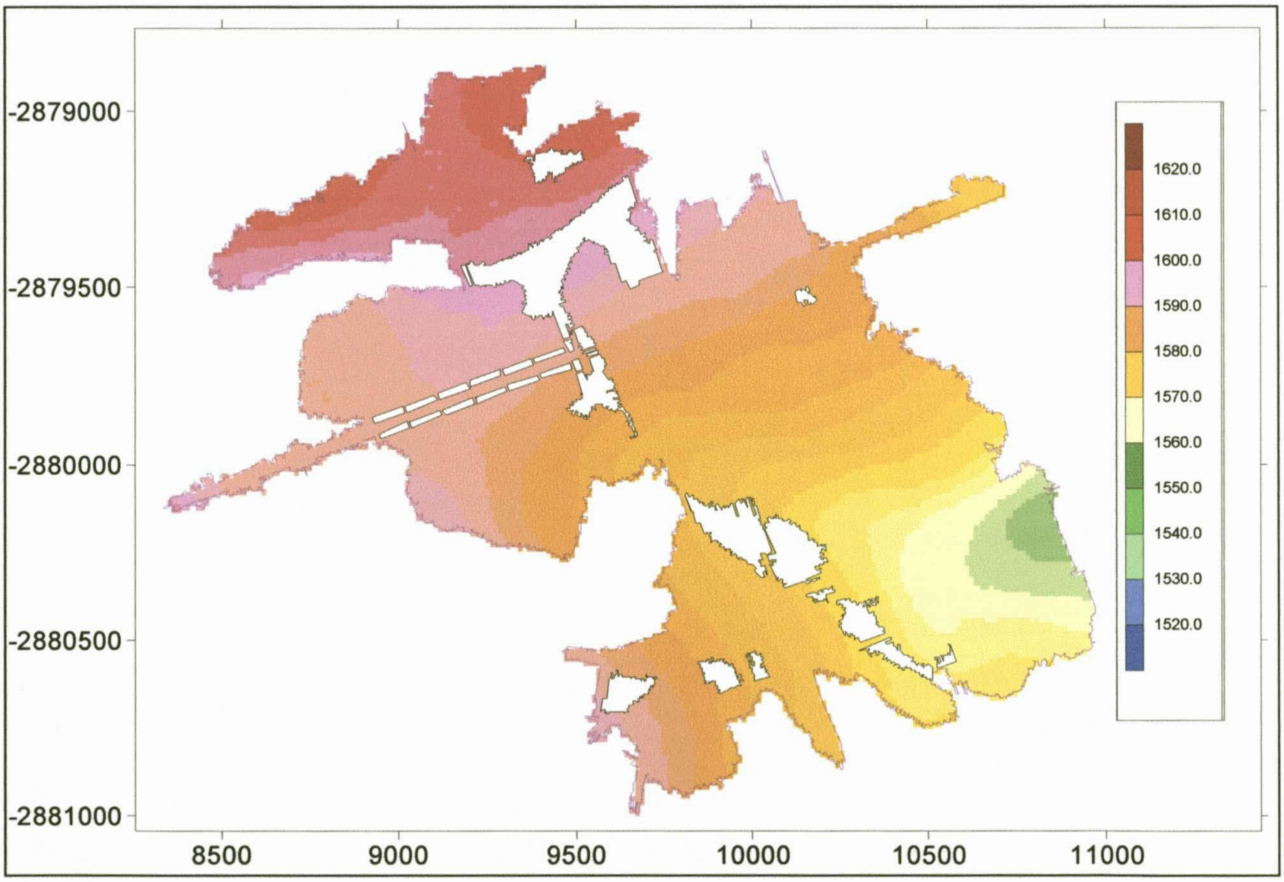


Figure 3-16. Surface contours for Minnaar Colliery.

3.6.2 Area 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 (Figure 3-13 and Table 3-5). Since then, there was a steady decline in the water level for this area.

A water budget has been calculated for the period 5/08/2002 to 4/11/2002, since this is the period of certainty on pumping statistics. The water volumes at different dates in this period, as determined from stage curves, are summarised in Table 3-5.

Table 3-5: Table with water levels and related volumes for Area C.

Date	Water level (mamsl)	Volume (m^3)
1/3/2002	1561.43	902597
5/8/2002	1559.02	869450
3/10/2002	1556.46	808112
4/11/2002	1554.35	679360

The total volume for Area C is 903 594 m^3. Because the mine was closed down in the early 1970`s, the recharge into this block is therefore in the order of 30 000 m^3 per annum. This translates into a recharge of 9%, 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 and this will result in higher recharge.
- Subsidence in the area.
- Water in Dam 1 (Figure 3-6), which may seep down the casing of BH4.
- Seepage from the pan into the mine.

According to the farmer, he applied approximately 35 mm per week from the mine onto the 40 ha crop of corn. According to the stage curve calculations, the drop in water volume was 190 000 m^3 over 13 weeks. These two data sets confirm each other.

From this it is clear that recharge is not sufficient to irrigate a maize crop for the required 11 weeks annually. With a recharge of 30 000 m^3, and extraction of 160 000 m^3, a shortfall of 130 000 m^3 will result annually. This implies that within 7 years, the compartment will run dry. Action should be taken to prevent this.

Table 3-6 serves as a summary for these calculations.

Table 3-6: Statistics and calculations for Area C.

Area (ha)	46.85
Maximum water level	1561.53
Maximum water volume (m^3)	903 594
Pivot area (ha)	40
Irrigation (mm/week)	36-37
Period of calculations (weeks)	13
Real weekly extraction (m^3)	14 622
Total extraction for 13 weeks (m^3)	190 090
Recharge annually (m^3)	±30 000
Recharge %	9.15

3.6.3 Areas E and F

In December 2000 these compartments were at their highest overall volume. Extraction from BH9 in Area F is the cause of the fluctuations in the water levels (Figure 3-13). Water levels dropped during the dry periods when high extraction occurred, followed by the rise in water levels because of recharge through BH7 in the dam during run-off events. (Figure 3-17 shows a photograph of BH7, situated in the dam). The effect of rainfall and extraction on the water levels is illustrated in Figure 3-18. Rainfall was below average for 2001 and 2002 and extensive extraction from the mine was necessary for crop production. (No detailed water-level information is available for the period 7/2001 to 8/2002, to show whether a recovery occurred during the rainfall period of November 2001 to January 2002. Since then, run-off into the dam was zero, with no recharge into Area F).

Extensive abstraction resulted in a drop of more than 24 m in the water level since March 2001. The extensive drop in the water level since 2001 contrary to the previous years is because two crops were irrigated during these years.

The water level in Area E (BH`s 10, 13 and 14) shows a slow decline of 6.25 m since the start of 2001, with a rise of 1.6 m during the rainfall season. The general drop in the water level of Area E during the extraction period is probably due to seepage through the seal into Area F.

A water budget has been calculated for the period 26/03/2001 to 30/10/2002. This is a period of constant decline in the water level of Area F. The water levels and volumes for Areas E and F are shown in Table 3-7, as determined from stage curves.

Figure 3-17. Locality of BH7 in Dam 2.

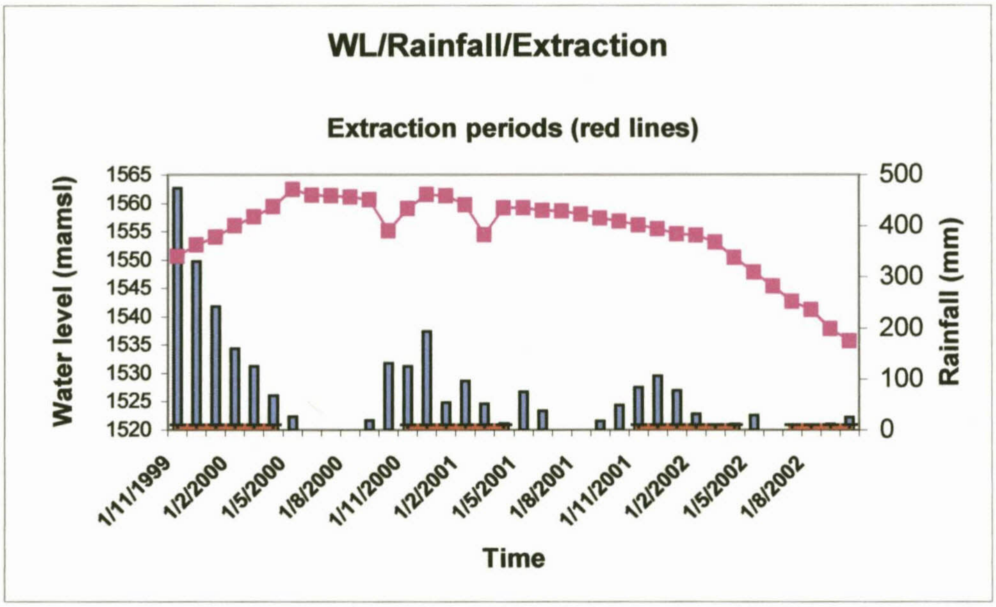


Figure 3-18. Relationship between water level and rainfall events in Area F.

Table 3-7: Water levels and volumes for Areas E and F.

Date	Area F Water level (mamsl)	Area F Volume (m^3)	Area E Water level (mamsl)	Area E Volume (m^3)
26/03/2001	1559.12	1165889	1561.15	1427417
30/10/2002	1534.01	178471.6	1555.36	1402609

Water was applied to different crops at different lengths of time at Pivots 1 and 2 (Figure 3-12). These data are summarised in Table 3-8:

Table 3-8: Summary of irrigation.

Crop type	Date	Area (ha)	Irrigation length (weeks)	Real irrigation (weeks)	Volume water (m^3)
Maize	Summer 2001	80	11	9	252 000
Wheat	Winter 2001	80	20	20	560 000
Wheat	Winter 2002	40	20	20	280 000

The irrigation duration, based on data from the farmer, is from the first application until the crops ripened. The intensity of irrigation was regulated according to crop requirements. Table 3-9 provides a summary of water balance calculations for Area F, including all the relevant data.

Table 3-9: Summary of water balance calculations for Area F.

Area (ha)	75.33
Time (days)	583
Rainfall (mm)	567
Run-off	5.60%
Recharge	4.2%
Dam area (ha)	5.43
Catchment area (ha)	590
Evaporation annually (m)	1.6
Surface run-off from pivots	2%
Weekly irrigation (mm)	35
Hydraulic groundwater gradient towards mine	5%
Lateral hydraulic conductivity of strata (m/d)	0.01
Length of outflux from Area F (m)	3220
Total water loss 26/03/2001-30/10/2002 (ΔS)	987 417
Water gains (m^3):	
Recharge	17 512
Run-off	187 337
Seepage from Area E	24 772
Run-off from irrigation	21 840
Water losses (m^3):	
Irrigation	1092 000
Evaporation from Dam2	107 982
Lateral outflux	28 159
Uncertainties in parameters	10 737

The water balance is calculated as follows:

ΔS = Irrigation + evaporation + lateral outflux - recharge - run-off - seepage from Area E - run-off from irrigation

Where ΔS = the loss of water in Area F from 26/03/2001 till 30/10/2002 i.e. 987417 m^3.

3.6.4 Decant

The surface contours with the lowest elevation above the mine workings is at 1 555 mamsl (Figure 3-16). This lies just below Dam 2. Decant will however be through borehole BH9 (1 561.61 mamsl), which is the lowest elevation at which the mine is connected to the surface. The total void capacity of the mine is 4,76 Mm^3, while the water holding capacity of the mine at the decant level is some 4,48 Mm^3 (Figure 3-20). At this level, 94% of the mine will be flooded.

During high rainfall events the compartment of Area F will again fill up, and decant, as in the past.

A photograph of the decant point at BH9, below Dam 2, is shown in Figure 3-19. BH10 is on the left and BH9 on the right hand side of the photograph. Dam 3 lies in the background.

Figure 3-19. Decant point at BH9.

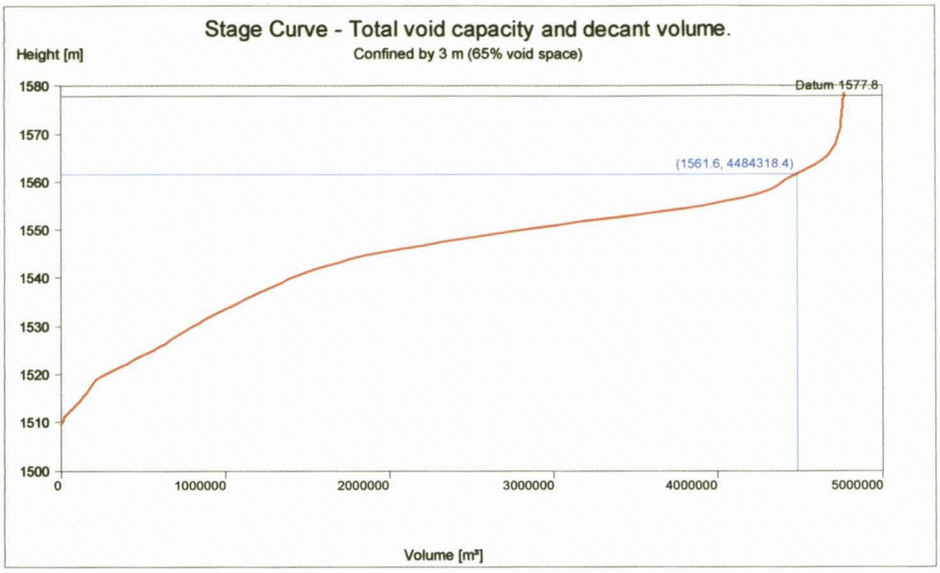


Figure 3-20. Stage curve for the decant volume at 1561.61 mamsl.

3.6.5 Conceptualisation

Figure 3-21 indicates the localities of W-E sections selected for each area. Conceptual models, to demonstrate the water levels for the four different areas discussed, are included in Figure 3-22. The sections on the left-hand side show the position of the water levels on 26/03/2001 and those on the right-hand side for 30/10/202. The water elevations are indicated in blue.

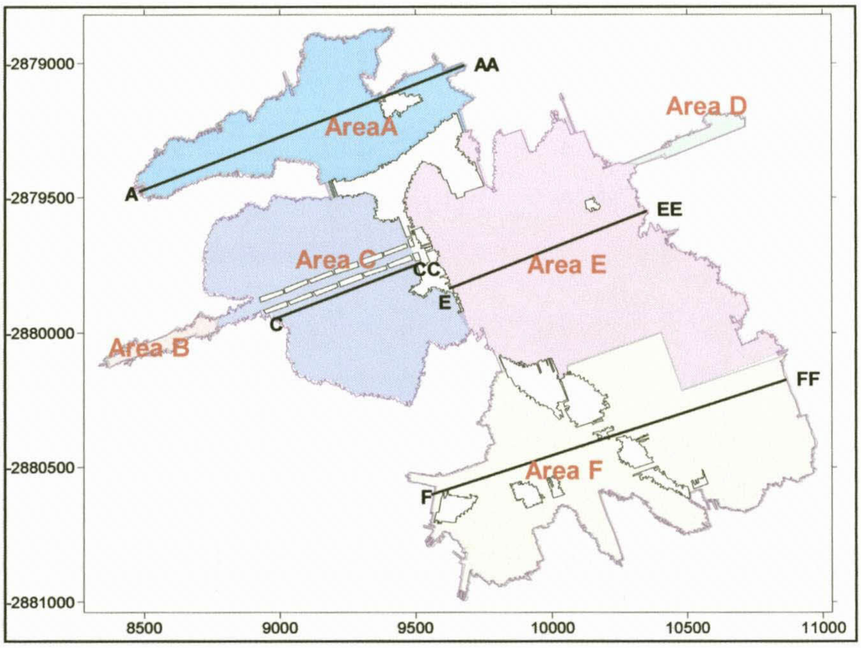


Figure 3-21. Illustration of the sections through the different areas.

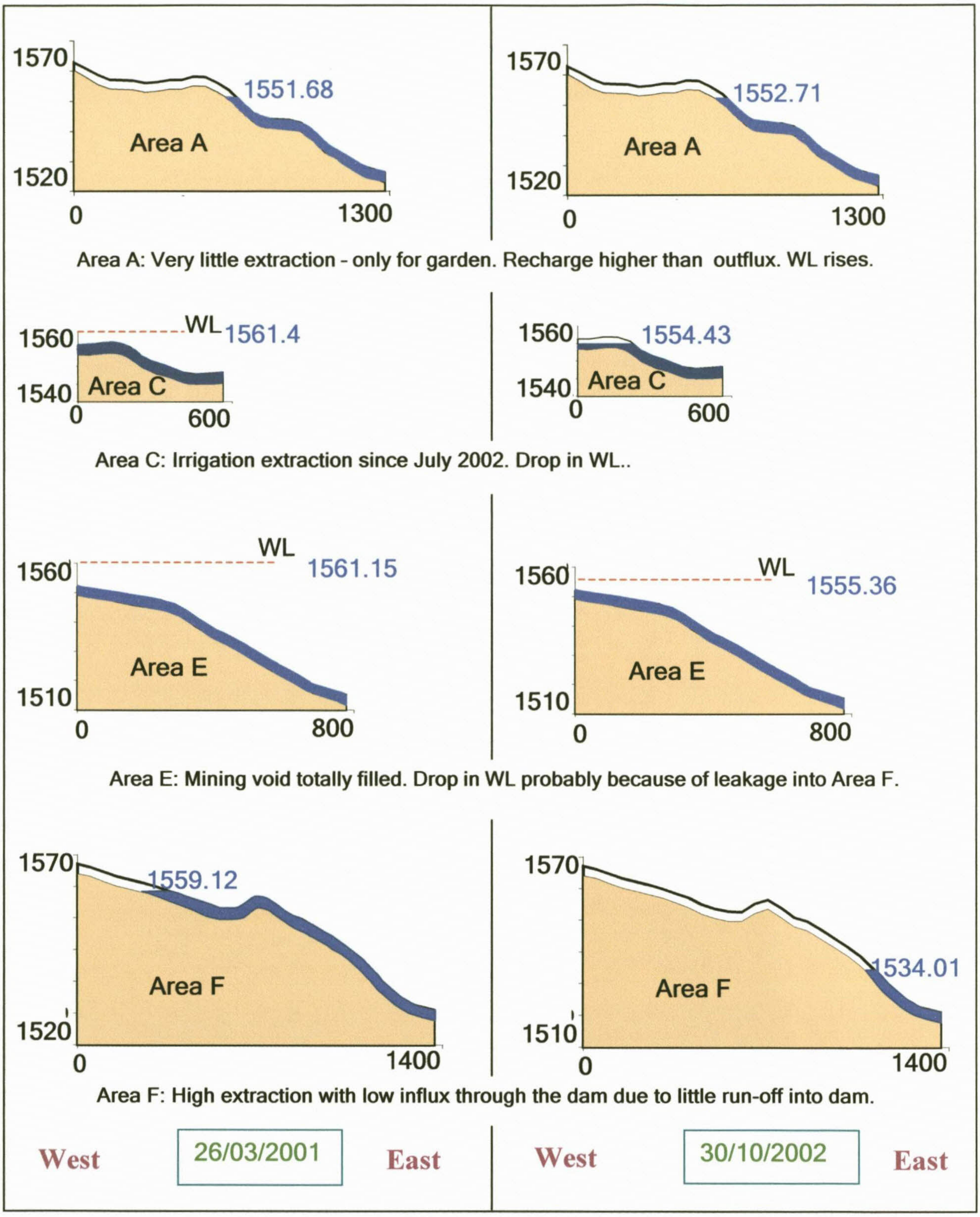


Figure 3-22. Conceptual models of the water levels in Minnaar Colliery for 26/03/2001 and 30/10/202. (Section lengths (m) are shown on the X-axes).

3.7 Water Quality

3.7.1 Mine chemistry in general

The mine-water quality has been profiled on three occasions (Feb 2000, Feb 2002 and Aug 2002), using a multi-parameter probe. Multi-parameter logs allow measurement of the water quality column without disturbing the water in the boreholes. Probing was done in all the boreholes, but only one borehole from each area is shown in Figure 3-23 to Figure 3-26, as they are representative for each area. The sharp contrast between groundwater and mine-water qualities can been seen in most graphs.

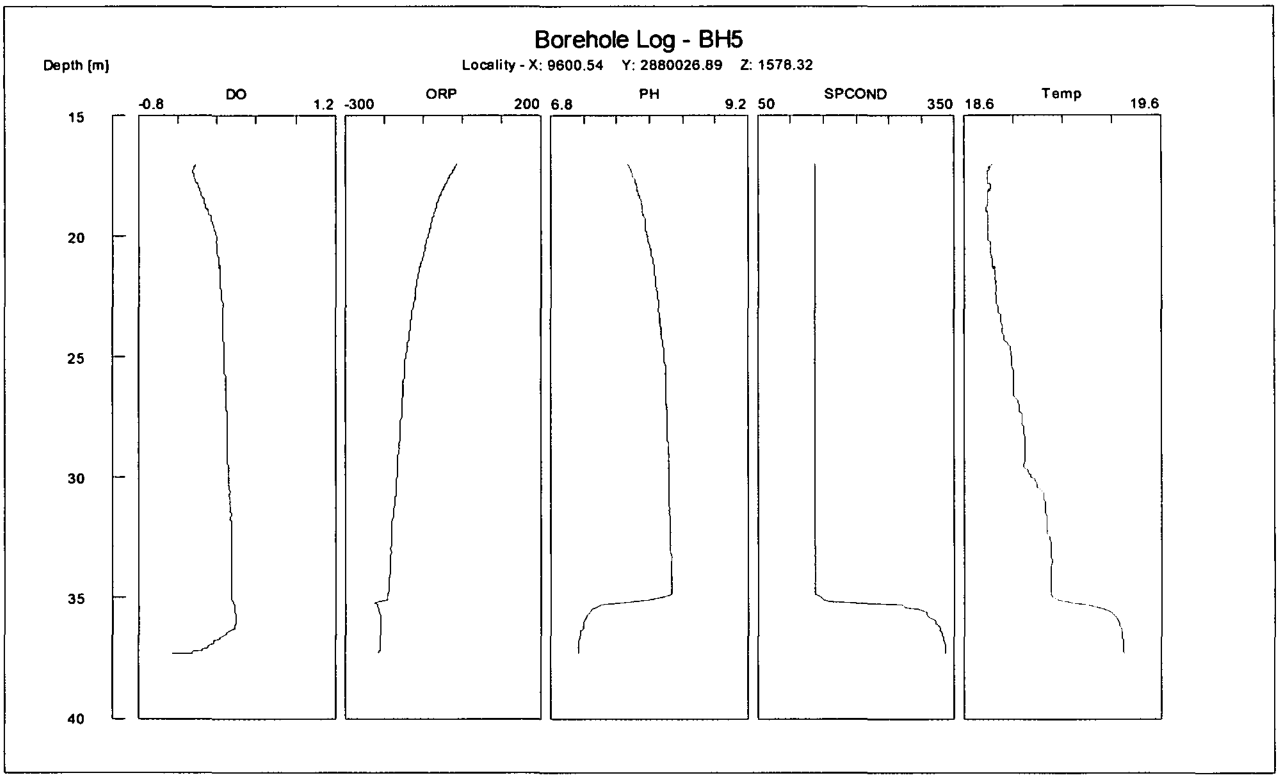


Figure 3-23. Multi-parameter chemical plots for Borehole BH5 (Area C).

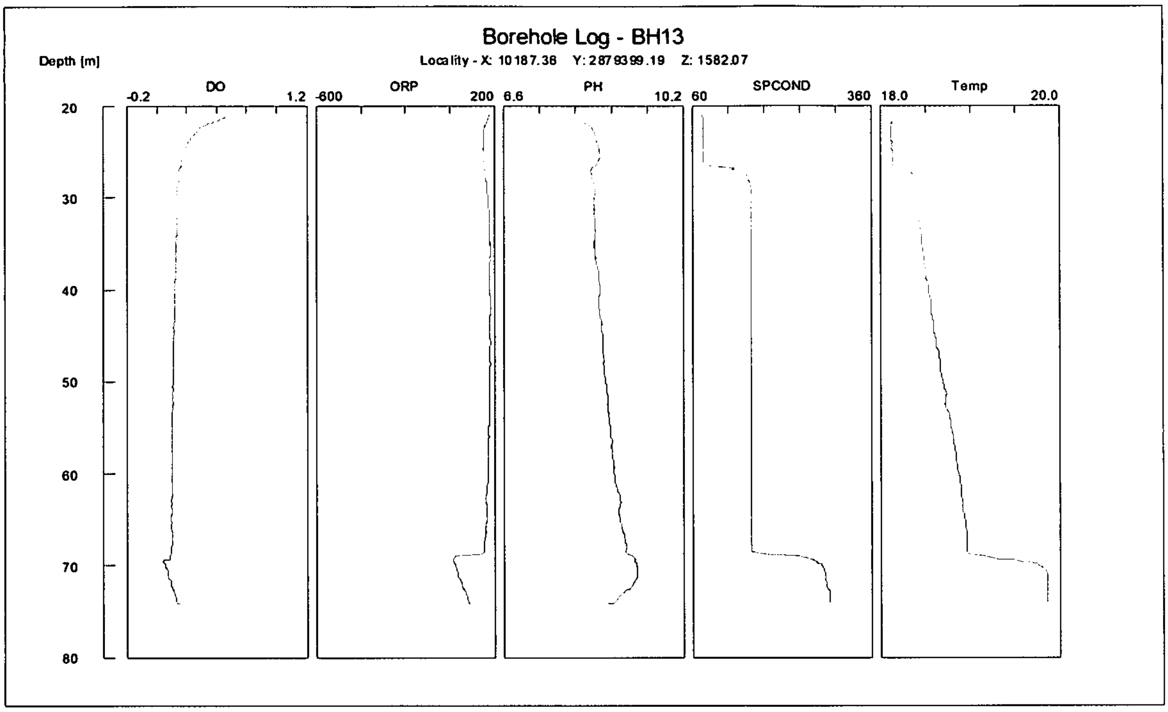


Figure 3-24. Multi-parameter chemical plots for Borehole BH13 (Area E).

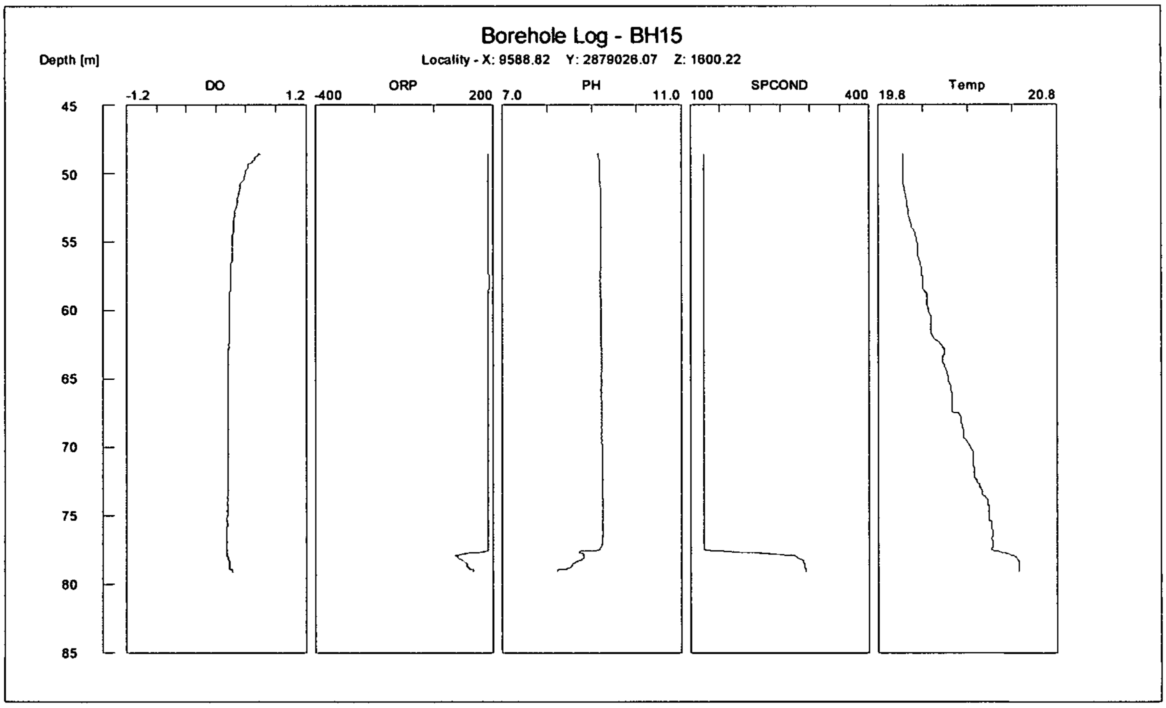


Figure 3-25. Multi-parameter chemical plots for Borehole BH15 (Area A).

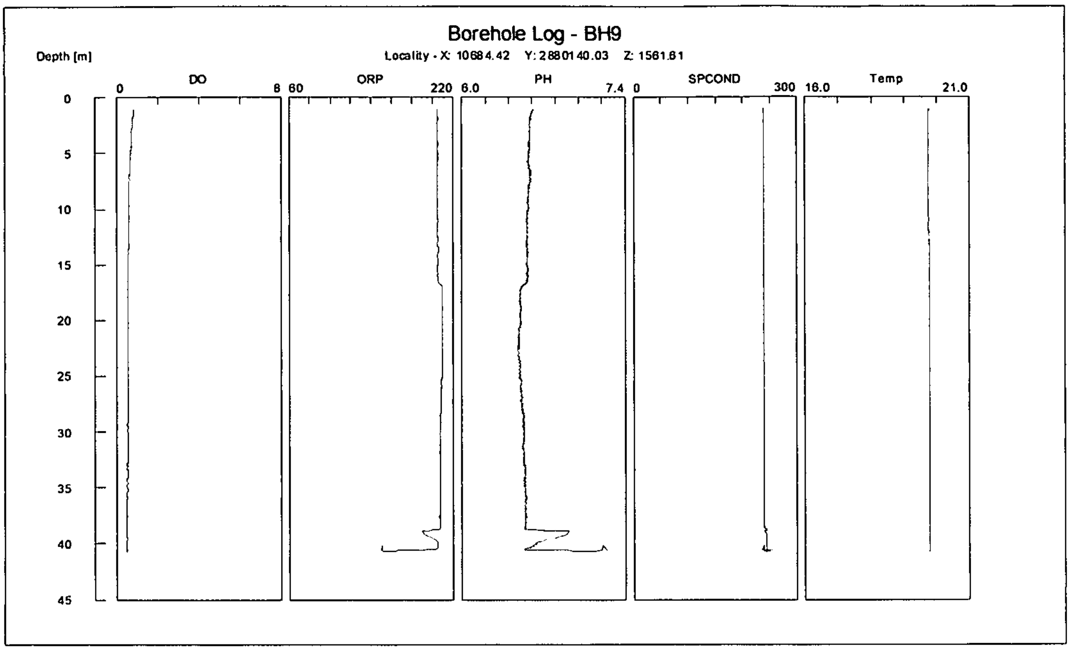


Figure 3-26. Multi-parameter chemical plots for BH9 (Area F).

The following are general characteristics of the mine water as determined by multi-parameter probing:

- The pH of the mine water generally has an alkaline character. At the lowest levels (6,5 pH), buffering by dolomitic lime in the sediments takes place (Hodgson and Grobbelaar, 2000; Usher, 2003). Oxidation of pyrite is probably minimal because of the flooded state of the mine and the near neutral character of the water pH.
- The electrical conductivity values in the mine range from 230 - 340 mS/m. This sharply contrasts with the natural groundwater higher up.
- The redox potential on the mine level is oxidising, but the oxygen concentrations at the coal seam horizon are low (0 - 0.5 mg/L). This, together with the flooded state of the mine, should limit pyrite oxidation to the extent that future sulphate generation should be insignificant.
- Temperatures of the water in the mine are only slightly elevated. This suggests that mild oxidising conditions could be present in some areas of the mine.

Following the water quality profiling of the boreholes, sampling has been done approximately 1.5 metres from the bottom of the mine.

The results of the chemical analyses are listed in Table 3-10. These results correlate well with the values measured during probing. The spatial variability of constituents in the mine water is remarkably small. This is ascribed to the high turnover and dynamic circulation of water in the mine. The low pH of BH15 and BH16 are the exceptions, but the probe readings (Figure 3-25) were similar to those in the rest of the boreholes. Previous analysis, and also that of BH27, which is in the same compartment, suggests that it is a local phenomenon.

At the slightly alkaline pH of the mine water, heavy metals are not present in significant concentrations, except for manganese.

Table 3-10: Chemical analysis (in mg/L) for Minnaar Colliery on 5/08/2002.

SiteName	MALK	PAlk	EC	pH	Ca	Cl	Mg	NO3	K	Na	SO4
BH13	213	0	335	7.04	596	10.4	98	0.00	7.2	39	1681
BH14	211	0	332	6.97	585	10.7	97	0.07	6.8	39	1669
BH15	18	0	190	5.84	317	8.39	79	0.05	6.3	34	1154
BH16	3.7	0	274	5.35	413	7.38	113	0.10	8.4	36	1516
BH17	212	0	287	6.93	487	6.62	80	0.00	5.8	31	1386
BH26	239	0	297	7.79	536	6.54	78	0.06	5.7	30	1409
BH27	239	0	329	6.93	566	7.62	100	0.01	7.0	41	1578
BH5	194	0	323	6.42	657	7.86	88	0.02	7.8	35	1707
BH9	69	0	50.9	6.77	82	6.2	12	2.51	3.3	10	198
Dam 1	176	0	252	7.59	426	32	72	0.12	17.2	34	1226
Dam 2	65	0	36.6	7.68	52	7.31	8	0.95	3.9	11	106
Dam 3	119	0	78.4	7.21	120	24.13	27	0.12	9.8	29	304
Grootpan	1005	47	274	8.91	25	158.0	36	0.17	15.2	581	131

SiteName	Fe	Al	Sb	As	Ba	Be	Br	Cd	Cr	Co	Cu
BH13	0.051	0.016	<0.006	<0.01	0.015	-0.001	0.00	<0.001	<0.006	<0.005	0.002
BH14	0.033	0.002	<0.006	<0.01	0.009	-0.001	0.04	<0.001	<0.006	<0.005	0.001
BH15	0.594	<0.006	<0.006	<0.01	0.017	-0.001	0.09	<0.001	<0.006	<0.005	0.002
BH16	2.653	0.013	<0.006	<0.01	0.009	-0.001	0.00	<0.001	<0.006	<0.005	0.004
BH17	0.055	0.012	<0.006	<0.01	0.010	-0.001	0.27	<0.001	<0.006	<0.005	0.003
BH26	0.028	0.016	<0.006	<0.01	0.015	-0.001	0.02	<0.001	<0.006	<0.005	0.003
BH27	0.165	0.010	<0.006	<0.01	0.010	-0.001	0.03	<0.001	<0.006	<0.005	0.002
BH5	0.391	0.020	<0.006	<0.01	0.010	-0.001	0.00	<0.001	<0.006	<0.005	0.002
BH9	0.015	0.017	<0.006	<0.01	0.080	-0.001	0.09	<0.001	<0.006	<0.005	0.001
Dam 1	0.023	0.031	<0.006	<0.01	0.122	-0.001	0.17	<0.001	<0.006	<0.005	0.004
Dam 2	0.034	0.065	<0.006	<0.01	0.093	-0.001	0.14	<0.001	<0.006	<0.005	0.004
Dam 3	0.021	0.023	<0.006	<0.01	0.089	-0.001	0.28	<0.001	<0.006	<0.005	0.004
Grootpan	0.225	0.262	<0.006	<0.01	0.056	-0.001	0.84	<0.001	<0.006	<0.005	0.005

SiteName	F	Pb	Li	Mn	Mo	Ni	Se	Sr	V	Zn	SAR
BH13	0.18	<0.015	0.020	2.003	<0.002	<0.01	<0.006	4.618	<0.01	0.010	0.276
BH14	0.18	<0.015	0.021	1.919	<0.002	<0.01	<0.006	4.644	<0.01	0.024	0.279
BH15	0.06	<0.015	0.019	1.671	<0.002	<0.01	<0.006	4.473	<0.01	0.018	0.315
BH16	0.00	<0.015	0.025	1.756	<0.002	<0.01	<0.006	4.454	<0.01	0.006	0.285
BH17	0.09	<0.015	0.028	1.833	<0.002	<0.01	<0.006	4.062	<0.01	0.019	0.243
BH26	0.16	<0.015	0.026	1.548	<0.002	<0.01	<0.006	4.529	<0.01	0.022	0.224
BH27	0.20	<0.015	0.022	1.448	<0.002	<0.01	<0.006	6.064	<0.01	0.008	0.296
BH5	0.14	<0.015	0.034	1.989	<0.002	<0.01	<0.006	4.653	<0.01	0.013	0.242
BH9	0.13	<0.015	0.005	0.149	<0.002	<0.01	<0.006	0.627	<0.01	0.009	0.190
Dam 1	0.33	<0.015	0.012	1.034	<0.002	<0.01	<0.006	3.350	<0.01	0.008	0.285
Dam 2	0.17	<0.015	0.000	0.031	<0.002	<0.01	<0.006	0.355	<0.01	0.035	0.257
Dam 3	0.41	<0.015	-0.001	0.014	<0.002	<0.01	<0.006	0.906	<0.01	0.009	0.439
Grootpan	2.83	<0.015	0.002	0.077	<0.002	<0.01	<0.006	0.277	<0.01	0.007	12.274

A graph, showing the relationship between EC and SO_4 for water in the mining cavity, is provided in Figure 3-27. This graph is based on values from field measurements since October 1999, and shows a relationship of 92% between the EC and SO_4 values. This excludes the cleaner water of BH9, which is due to unnatural recharge (See Section 3.7.5.1 for more detail on water quality in Area F). It indicates that the SO_4 value can be estimated fairly accurately from an EC value measured in the field, by multiplying the value with 5.6. As stated, this applies only for the water in the mining cavity, and not for decant water. Mixing will change its composition, resulting in a less linear relation.

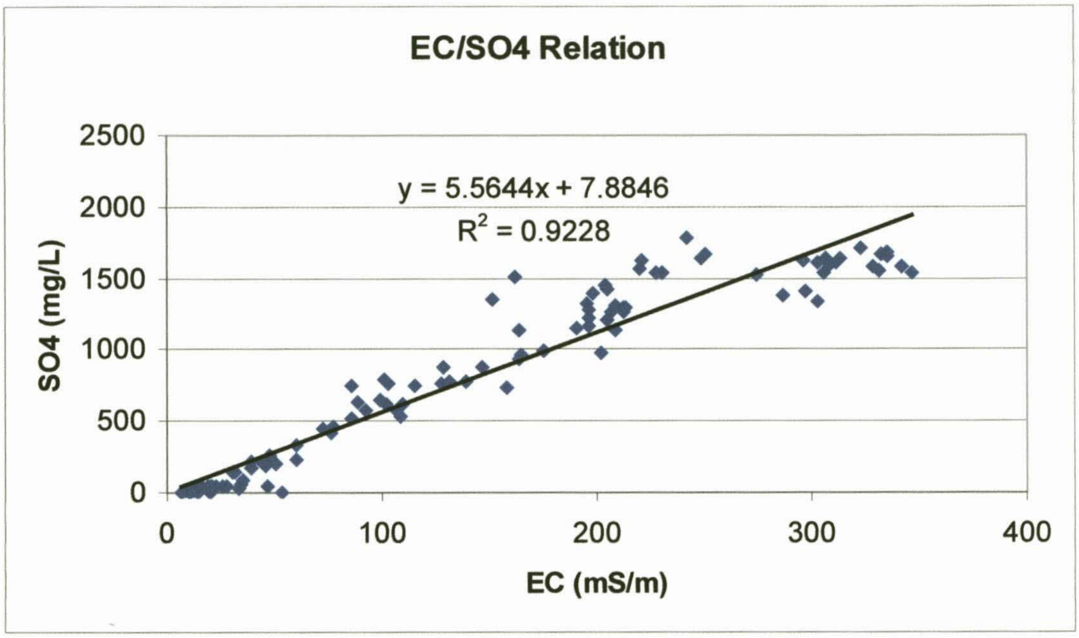


Figure 3-27. Relationship between EC and SO_4.

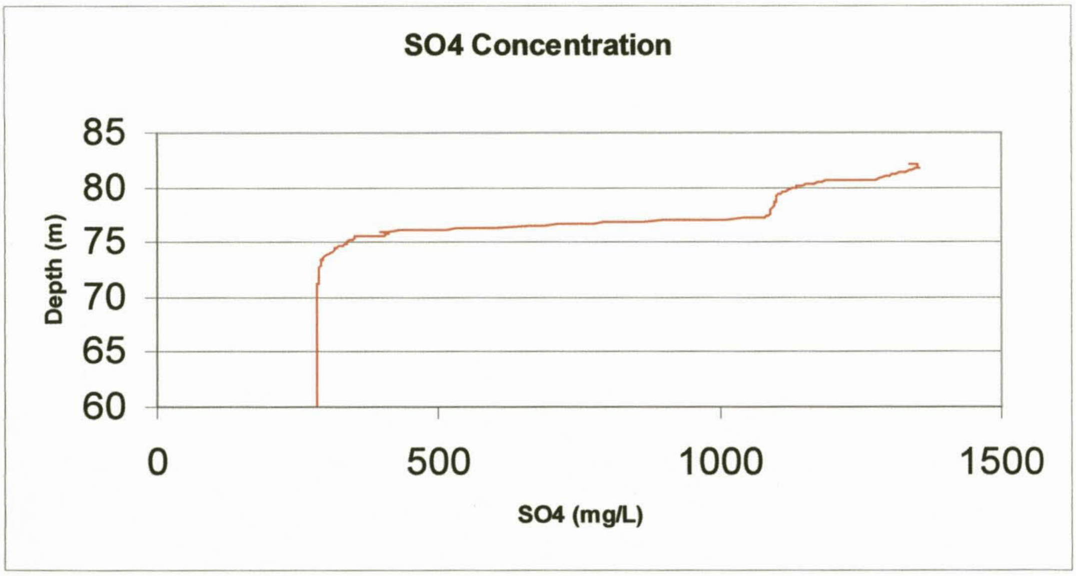


Figure 3-28. Sulphate concentration plotted against depth in BH16 in August 2002.

This formula may be used with limited accuracy to determine the SO_4 concentration for the water at a specific depth in a borehole, after probing with the multi-parameter probe has been done. As an example the August 2002 SO_4-concentration for BH16 in Figure 3-25 is calculated and illustrated in Figure 3-28. The mining cavity is between 79 m and 82 m. Sulphate is already increasing to a value of 284 mg/L from 73 m, which is not true. This can be ascribed to inaccuracies in the equation at low concentrations of sulphate.

Minnaar Colliery is in the unique situation in that the different compartments are recharged and exploited, separately. This should impact differently on the water chemistry in the different areas. The main areas will therefore be discussed separately.

3.7.2 Area A

This compartment is recharged normally, with no external sources of water, or abnormally high recharge through subsided areas. The chemistry is that which should be expected, with variations due to sampling errors or local phenomena (Figure 3-29). The water quality does not deteriorate over time because oxygen was excluded from the mine cavity after it filled up. No acidity problem is foreseen (Figure 3-30).

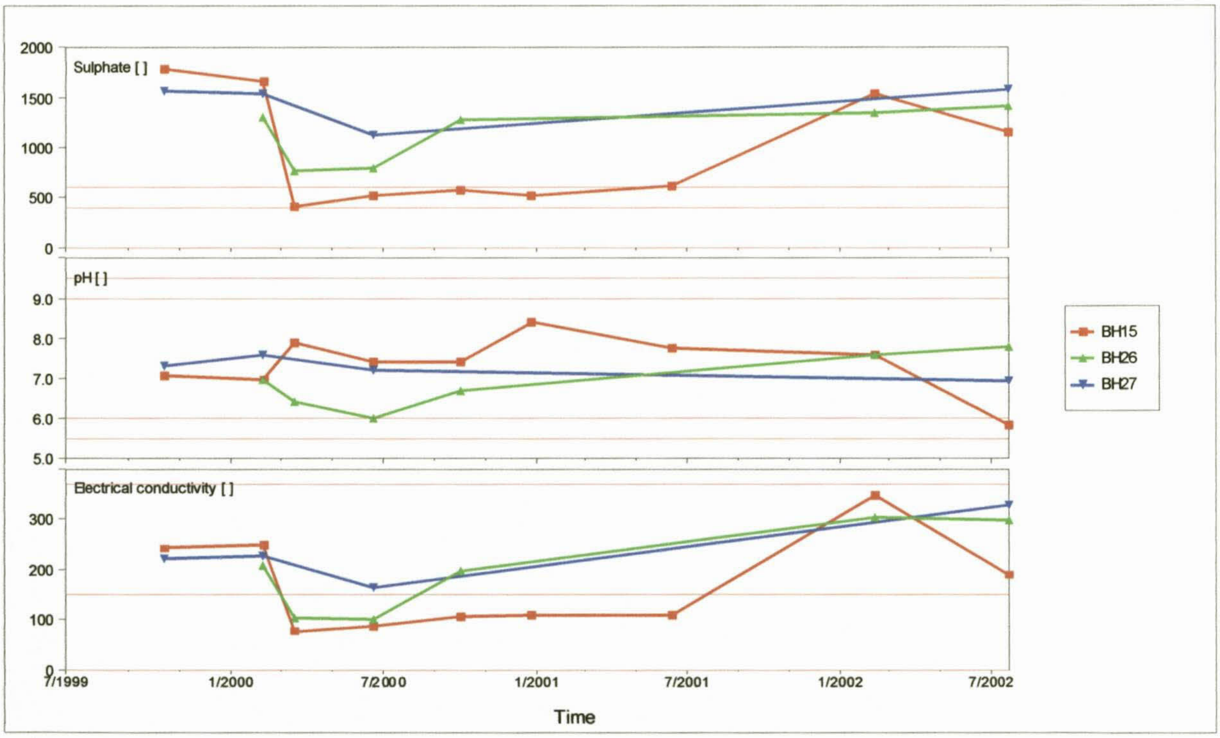


Figure 3-29. Chemistry of water in Area A (mg/L).

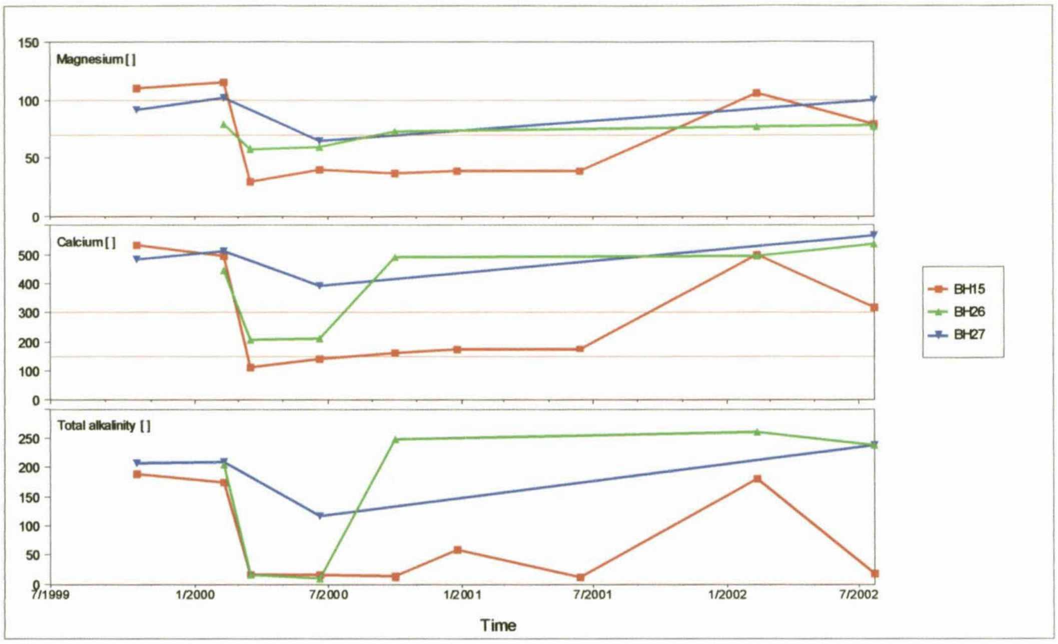


Figure 3-30. Concentration of alkalinity, calcium and magnesium in Area A (mg/L).

Table 3-11 shows the SO_4-generating calculations for different periods. The average SO_4 per day since the mine closed down some 30 years ago is 1.24 kg. As the mine filled up, oxygen availability diminished and the sulphate generation rate decreased. For the period from 24/10/1999 the SO_4 generated daily is only 0.54 kg. A graph to simulate the SO_4 dilution over time, based on recharge into this compartment, is shown in Figure 3-31. This graph suggests that concentrations could drop by 50% in the next 50 years.

Table 3-11: Sulphate-generating calculations for different periods in Area A.

Area (ha)	34.7
SO4 (mg/L)	1 050
1.Total period (years)	30
Total influx (m³)	449 515
Total SO4 (kg)	471 991
Daily SO4 (kg/ha)	1.24
2.Period 28/10/1999-4/11/2002(days)	1102
Total influx (m³)	19 690
Daily influx (m³)	18
Total SO4 (kg)	20 675
Annual influx (m³)	6 522
Daily SO4 (kg/ha)	0.54

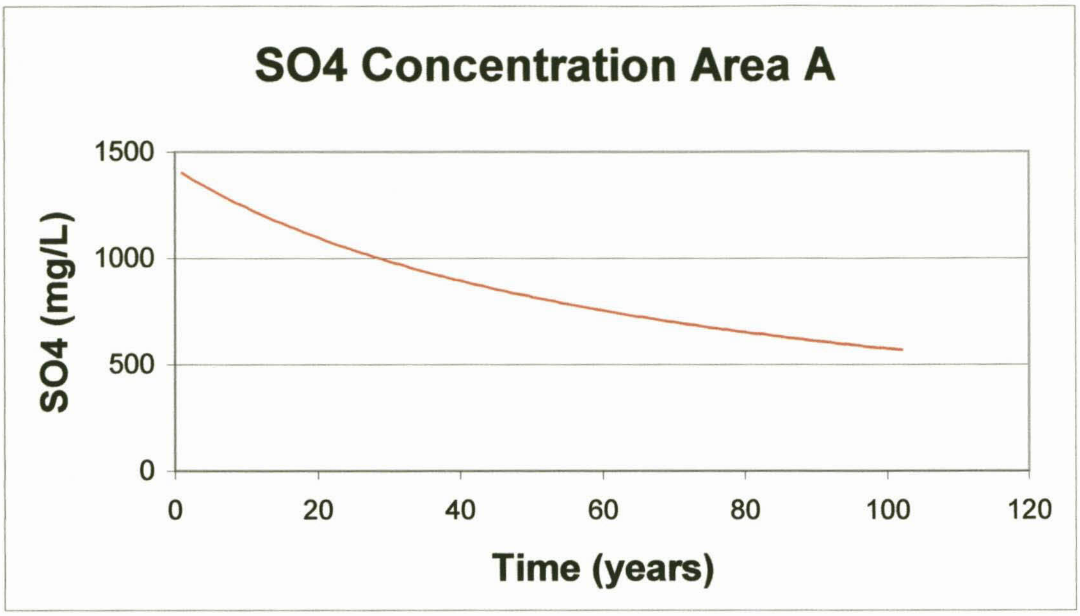


Figure 3-31. Simulated SO4 concentration for Area A, based on recharge and dilution (done in Excel).

3.7.3 Area C

A statistical analysis of water qualities in Area C is provided in Figure 3-32.

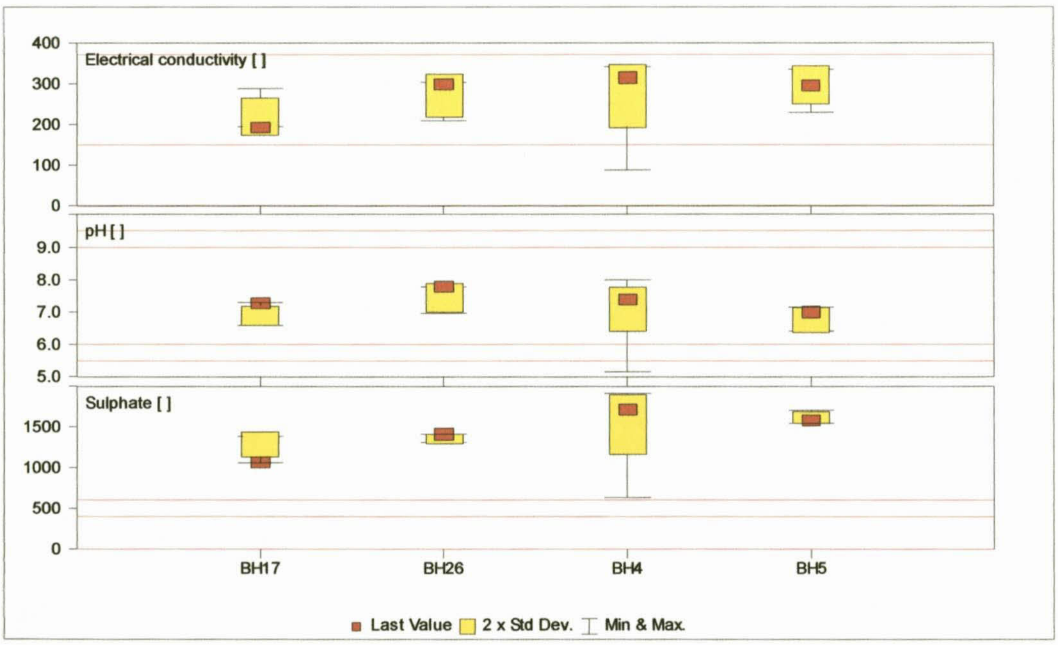


Figure 3-32. Box and whisker plot of the water quality in Area C(mg/L).

Table 3-12 shows the SO_4-generating calculations for this area. The average SO_4 per day since the mine closed down approximately 30 years ago is 2.03 kg. Future sulphate generation will depend on the rate of irrigation and subsequent recharge into this compartment.

Table 3-12: Sulphate-generating calculations for Area C.

Area (ha)	46.85
Total years	30
Total water (m³)	903 594
Annual influx (m³)	30 000
Daily influx (m³)	82.19
SO4 (mg/L)	1150
Total SO4(kg)	1 039 133
Daily SO4(kg/ha)	2.03

Since March 2002, water has been extracted from this area with virtually no recharge because of the low rainfall. The water level dropped, resulting in the increase of oxygen availability. The water pumped from the compartment has been sampled regularly since September. No deterioration in quality has been observed to date (Figure 3-33).

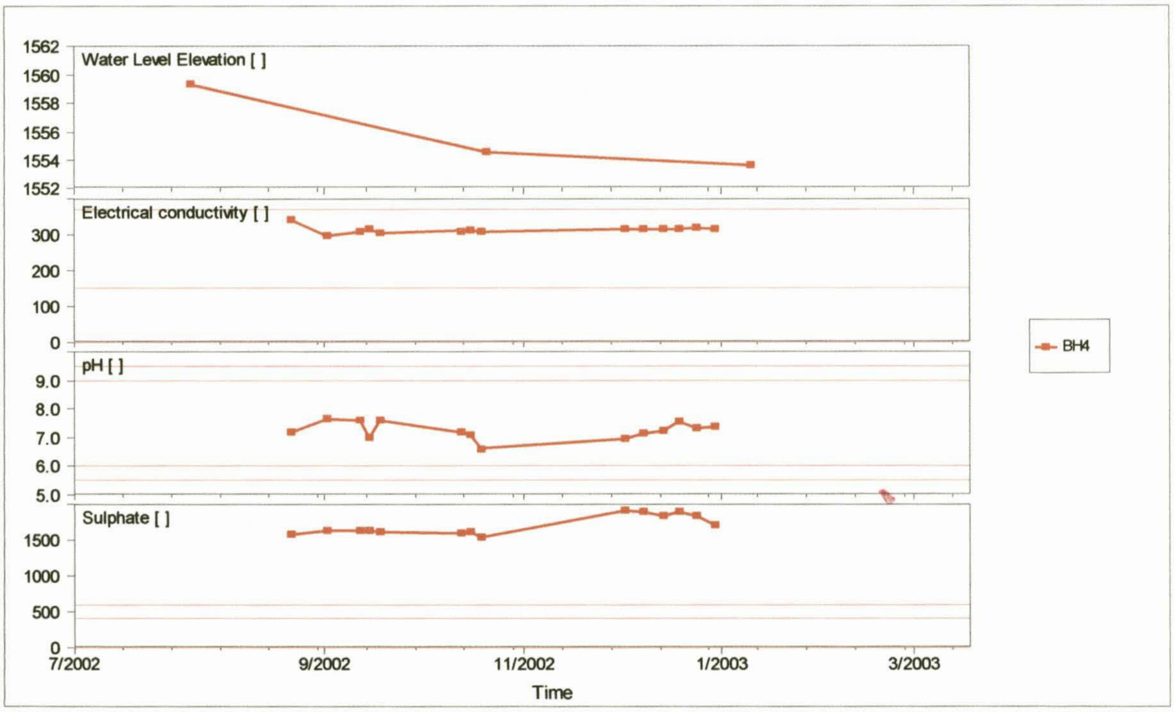


Figure 3-33. Chemistry of mine water in BH4 against drop in water level (mg/L)

Figure 3-34 provides further insight into the water chemistry of the water in Area C.

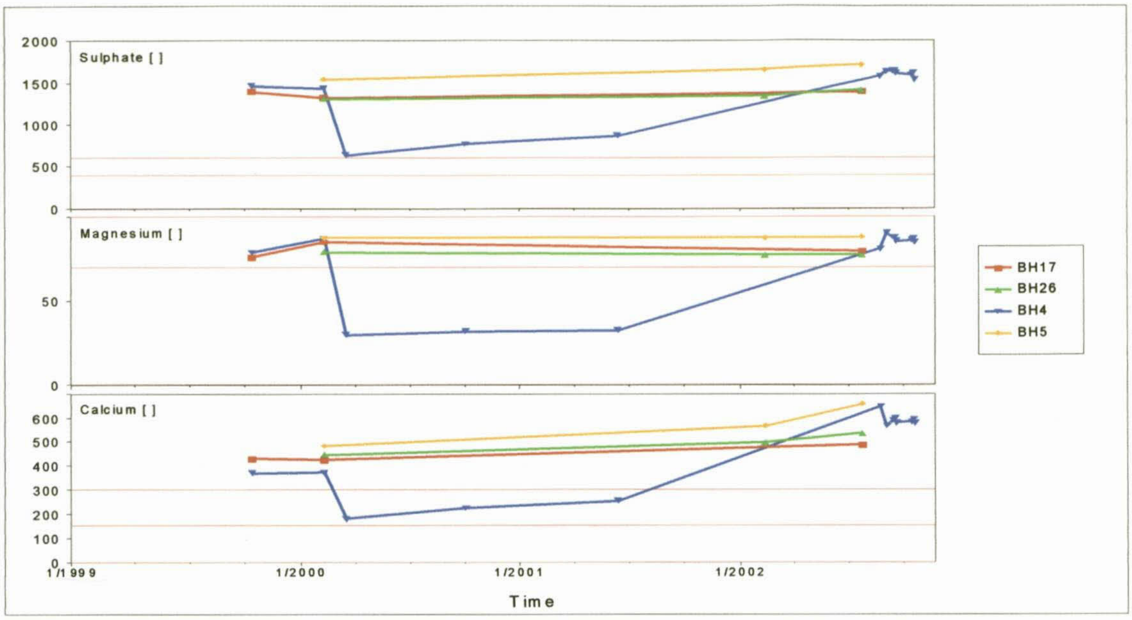


Figure 3-34. Line graph of calcium, magnesium and sulphate from Area C (mg/L).

Calculation of the saturation index of gypsum in these waters reveal slightly saturated indices (Table 3-13).

Table 3-13. Saturation index values for Areas A and C.

BH Number	Date	Saturation Index for Gypsum
BH27	23/02/2000	0.16
BH5	26/02/2002	0.22

Because of possible gypsum precipitation in the underground workings, a true sulphate generation rate can not be calculated.

3.7.4 Area E

This compartment is recharged by natural influx, with leakage to Area F. The chemistry of the water in this compartment is graphed in Figure 3-35. The water quality does not deteriorate over time, because oxygen was excluded from the mine cavity. No acidity problem is foreseen, since the buffering potential is sufficient (Figure 3-36).

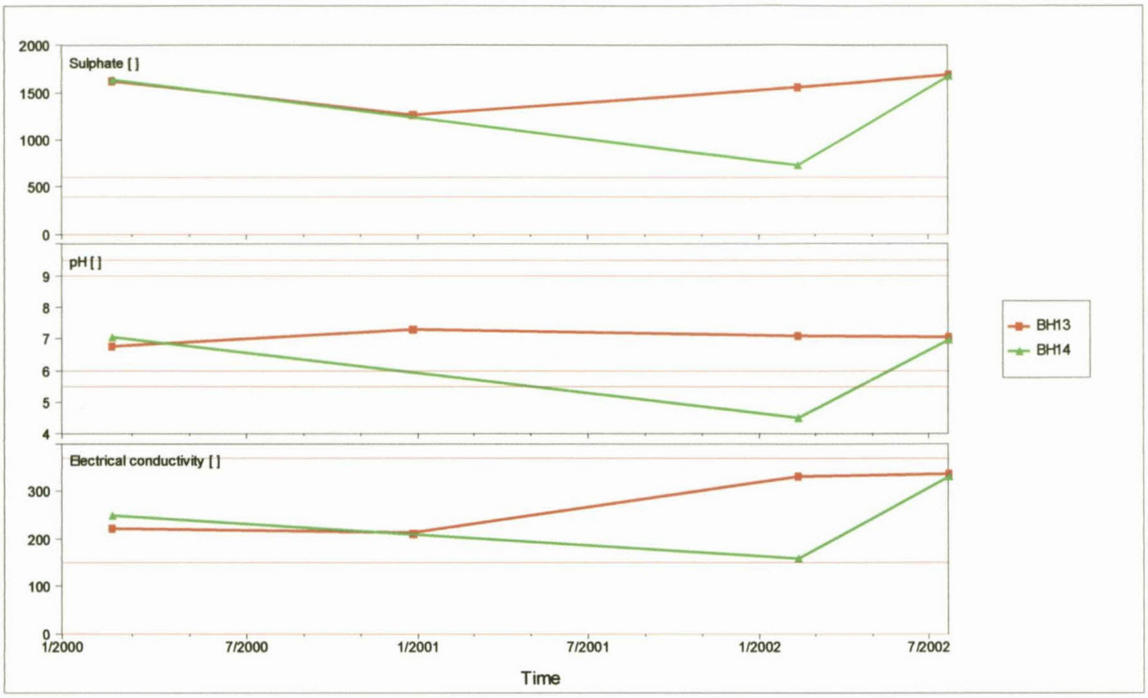


Figure 3-35. Chemistry of the water in Area E (mg/L).

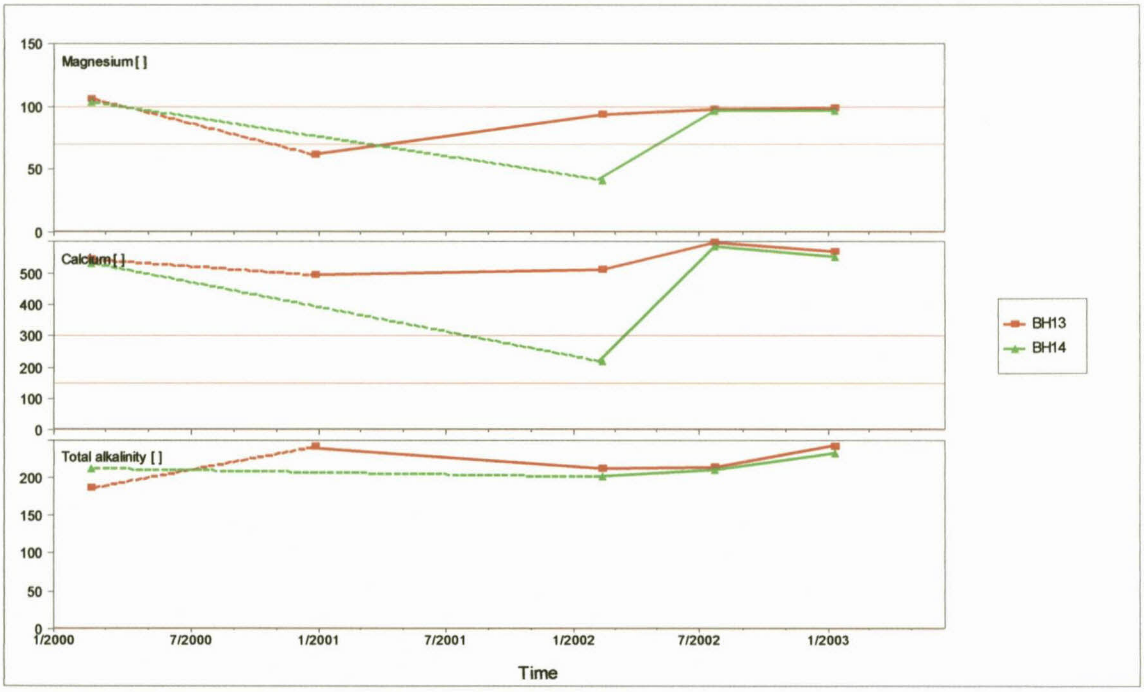


Figure 3-36. Alkalinity, calcium and magnesium concentrations in Area E (mg/L).

The daily sulphate generation in this area is 2.7 kg/ha/day over a period of 30 years. This is in line with that for the other compartments.

3.7.5 Area F

Area F is recharged through Dam 2 and continuous flushing of the underground water occurs because of water abstraction for irrigation. As a result, the water quality in this area is much better than in the other areas. The significant variation in values, with sulphate concentrations between 100 - 700 mg/L for instance (Figure 3-37), is ascribed to dilution from recharged surface water.

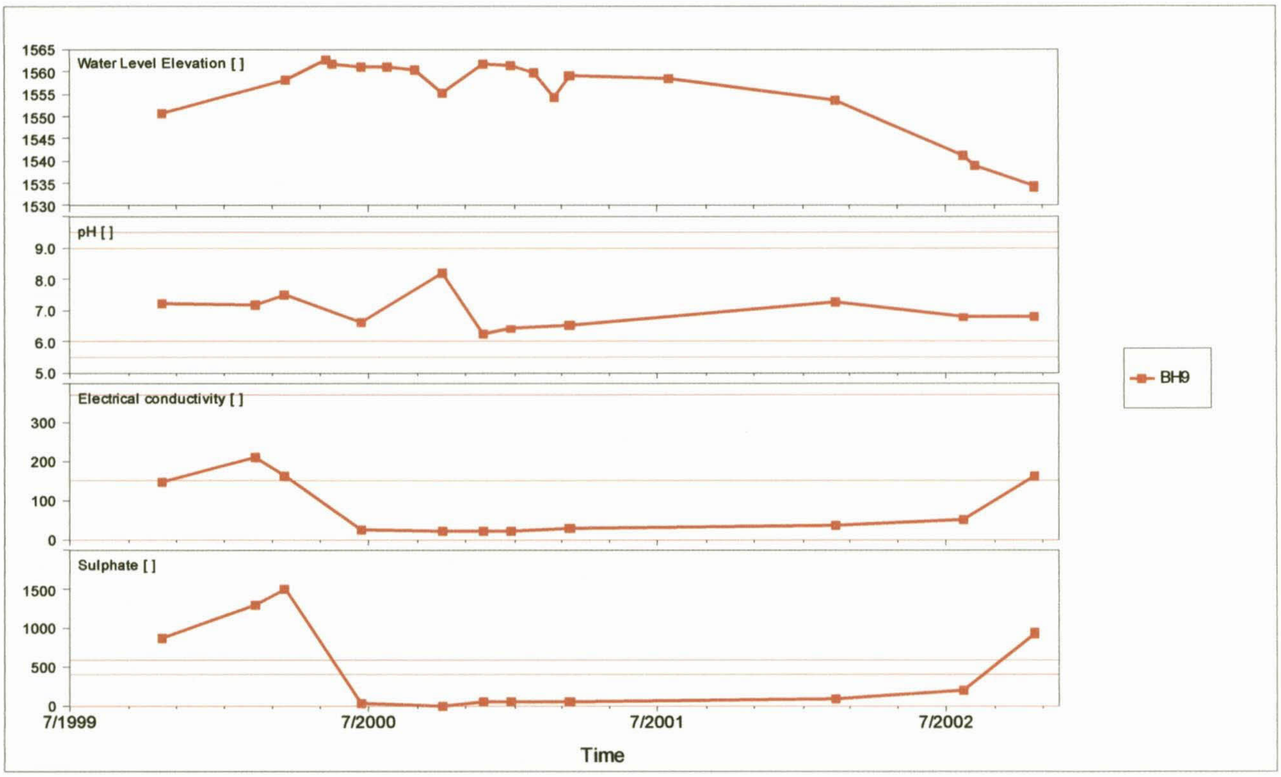


Figure 3-37. Water quality in Area F compared with the drop in the water level (mg/L).

3.7.5.1 Modelling Area F:

A mass transport simulation was done using Modflow (PMWin) to determine the influence of recharge through the borehole in the dam and irrigation on the mine water quality.

The values used are based on averages over the last nine years until February 2002, thus ignoring any deterioration in water quality since then. To simplify the model, it was assumed that from March until May, because the crops are ripe, only recharge occurs. From June until September, not being the rainy season, only water abstraction occurs. From October until February both recharge and extraction for the maize crop occurs. After discussions with the farmer, the rates were estimated as follows (Table 3-14):

Table 3-14: Statistics on recharge and extraction

Period	Days	Extraction (m^3/d)	Recharge (m^3/d)
March-May	90		800
June-Sept	120	1684	
Oct-Feb	150	1684	800

Table 3-15 shows the values used for the model. Dilution of the salt load is expressed as a percentage, because an initial concentration of 100 was used for the mine water and 0 for the recharge.

Table 3-15: Statistics on Area F model.

	Area F
Hydraulic conductivity	10 000 m/d
Specific Storage	0.65
Porosity	0.65
Water level gradient	0.000029
Recharge	0.00008 m/d
Horizontal transverse dispersivity	0.1 m
Vertical transverse dispersivity	0.1 m
Longitudinal dispersivity	2 m
Initial concentration of water in mine	100
Initial concentration of recharge water	0

The model was run for 9 years, with recharge from Dam 2 through BH7, and extraction from BH9. Recharge from rainfall was calculated at 4% of an average 750 mm/year.

Figure 3-38 illustrates the dilution of the water over time, with a definite cone of cleaner water developing from BH7 towards BH9. This explains the better water quality of Area F at the sample point at BH9, compared with other areas in Minnaar Colliery. For the rest of the water in Area F, the dilution is mostly due to recharge from rainfall.

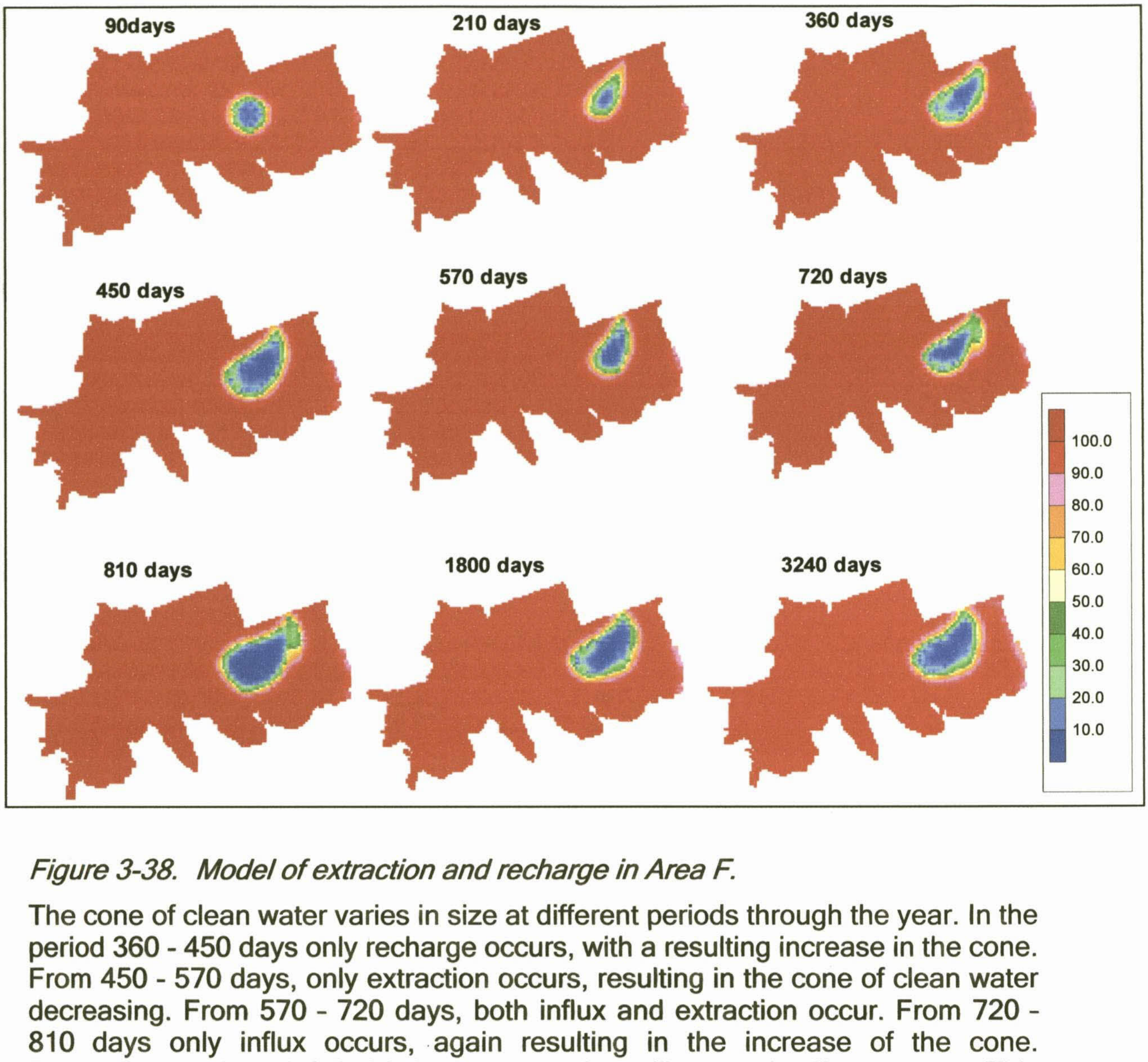


Figure 3-38. Model of extraction and recharge in Area F.

The cone of clean water varies in size at different periods through the year. In the period 360 - 450 days only recharge occurs, with a resulting increase in the cone. From 450 - 570 days, only extraction occurs, resulting in the cone of clean water decreasing. From 570 - 720 days, both influx and extraction occur. From 720 - 810 days only influx occurs, again resulting in the increase of the cone. Depending on the rainfall, this is a process that will repeat itself every year. This will ensure that the quality of water for irrigation will always be fair.

3.7.6 Irrigation

In order to determine the effect of irrigation with mine water on the soil, sampling has been done on two traverses at Pivot 1, and on a traverse on the land outside the pivot area, up-gradient from the pivot, as illustrated in Figure 3-39.

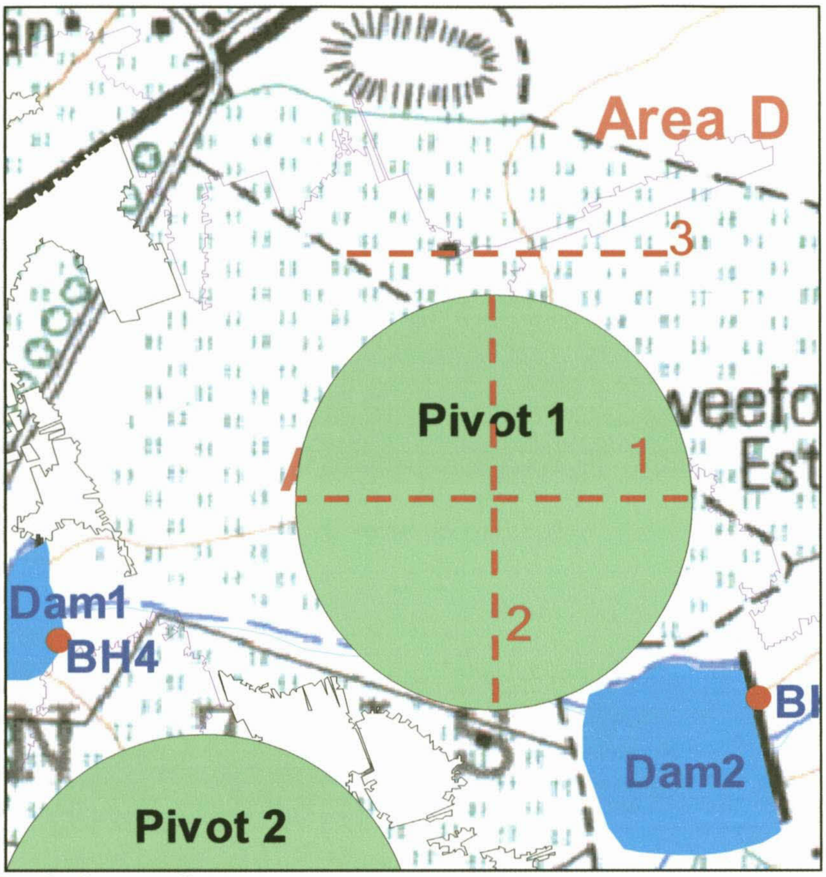


Figure 3-39. Soil sampling traverses.

Soil sampling was done at two different depths, i.e. 30 cm and 60 cm on all three traverses, using an auger. Ten samples, taken at both depths on each traverse, were mixed into one, resulting in six analyses. The results of the composite soil samples are as follows:

Table 3-16: Analyses of the soil composition.

Sample Number	%Clay	%Fine silt	%Coarse silt	%Coarse sand	%Medium sand	%Fine sand	% Very fine sand
1- 30 cm	22	1	2	7.82	15.92	31.74	18.8
2- 30 cm	19	4	3	9.34	15.86	30.30	16.52
1- 60 cm	25	1	2	7.90	13.62	24.50	17.88
2- 60 cm	26	2	1	8.66	14.88	31.18	15.10
3- 30 cm	17	3	2	8.48	19.38	36.92	14.94
3- 60 cm	19	1	2	9.04	17.76	36.66	14.44

The chemical composition of soil is shown in Table 3-17.

Table 3-17: Chemical analyses of the soil samples.

Sample Number	EC (mS/m)	pH	Ca (mg/kg)	Mg (mg/kg)	K (mg/kg)	Na (mg/kg)
1- 30 cm	76	5.41	294	113	98	31
2- 30 cm	100	5.57	428	89	148	52
1- 60 cm	50	5.21	134	81	75	37
2- 60 cm	57	6.14	214	97	83	31
3- 30 cm	27	5.57	281	113	83	26
3- 60 cm	25	5.48	160	105	53	31
Sample Number	P (mg/kg)	Zn (mg/kg)	Cl (mg/kg)	NO3(N) (mg/kg)	SO4 (mg/kg)	SAR
1- 30 cm	9.62	1.98	166	281	528	0.3
2- 30 cm	9.31	1.62	233	314	1027	0.7
1- 60 cm	1.24	0.4	150	114	473	0.3
2- 60 cm	1.23	0.38	157	184	358	0.3
3- 30 cm	2.17	1.24	88	58	155	0.2
3- 60 cm	2.48	0.73	79	56	148	0.4

From the chemical analyses it is clear that there is a build up of salts in the top layer of the pivot land if compared with the background sample outside the pivot.

3.8 Surface Water Quality

Figure 3-5 indicates the position of the surface water bodies, i.e. the pan and the three dams. The water quality in these structures is shown in Figure 3-40.

The surface water chemistry shows two polluted areas, namely the pan and Dam1.

- The chemistry of the water in the pan is different from that of the mine water, having high sodium content. This is due to evaporation, and is exaggerated in the last sample due to the very dry conditions, with zero influx into the pan.
- The pollution in Dam 1 is from mine water pumped into this dam.
- The water quality in Dam 2 is excellent. This dam derives its water from run-off and from water pumped from the mine. This mine water is, as has been discussed, not representative of the rest of the mine and does not affect the surface water quality.
- Dam 3 is currently of good quality since no decanting has recently occurred.

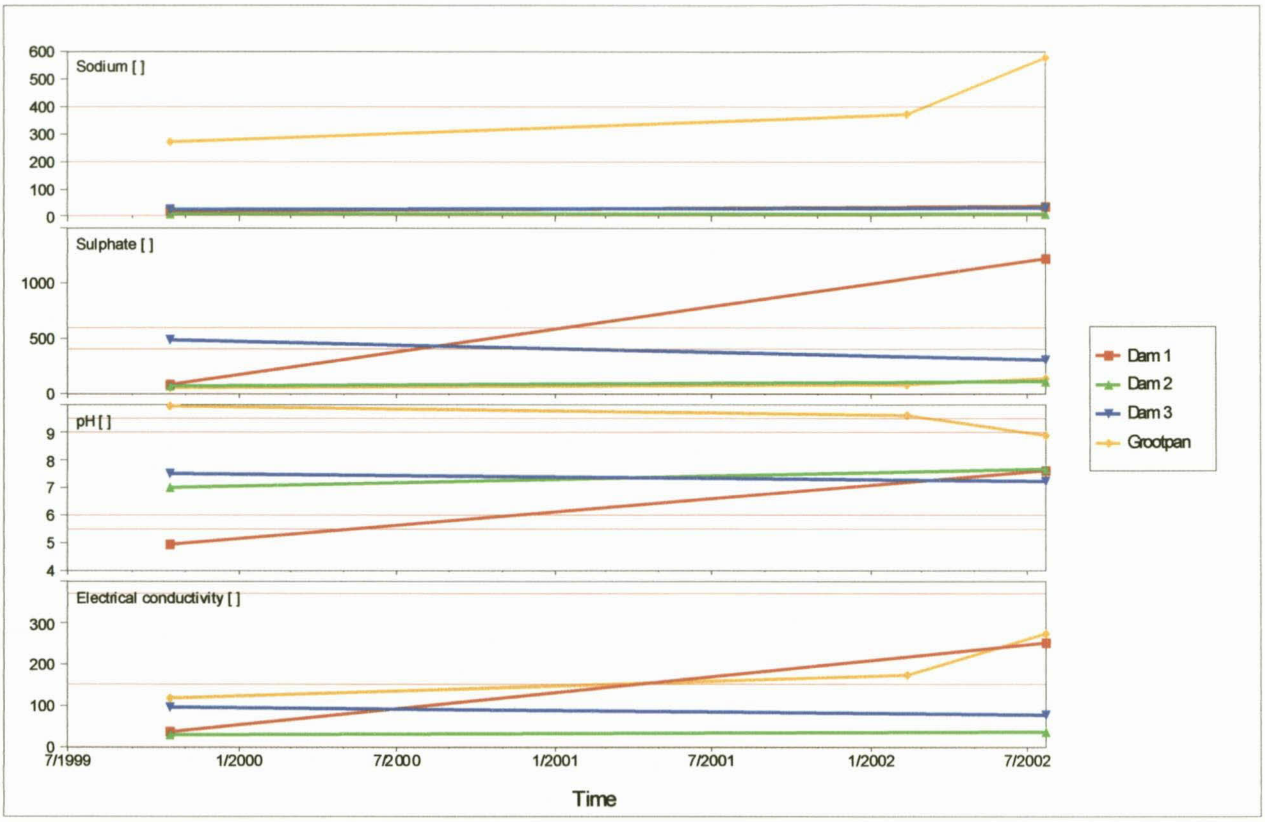


Figure 3-40. Chemistry graphs of surface structures at Minnaar Colliery (mg/L).

3.9 Conclusions

The ideal mine-water management option is already in place for Minnaar Colliery. Excess water is utilised for irrigation and the mine water is simultaneously flushed. Care should, however, be exercised not to over utilise the source, as a permanent drop in the water level can result in an influx of oxygen and subsequent oxidisation of pyrite.

Past water management practices at Minnaar Colliery should be taken cognisance of by other collieries and the authorities. It represents one of the few instances where suitable water management at a colliery came about unwittingly. Many other collieries exist where similar ventures could be initiated for the benefit of the environment and productive use of the mine water.

4 Ermelo Colliery

4.1 Introduction

Ermelo Colliery is an underground colliery in the Mpumalanga Province between the towns of Ermelo and Bethal. It forms part of the Ermelo Coalfield (Erasmus *et al.,* 1981, Figure 1-1) and lies in the upper region of the Vaal Catchment (Figure 1-2). The N17 road runs south of the mine. Figure 4-1 shows a topographic map of the area with the mine outline.

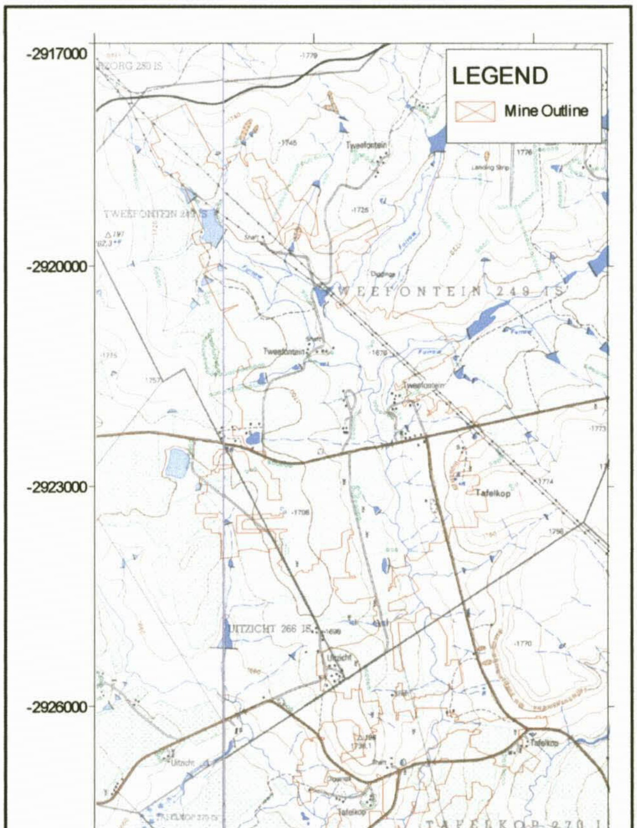


Figure 4-1. Topographic map also showing the outline of the mined area.

The colliery ceased with production in April 1997. The surface area has been rehabilitated and the only evidence of past mining activities are a few office buildings, the rehabilitated discard dump next to the N17 and a tower on one of the monitoring boreholes, for gas release from the underground workings (Figure 4-2 to Figure 4-4). Farming activities continue unhindered in the area.

Figure 4-2. Aerial photograph of Ermelo Colliery coal processing area after rehabilitation (Photo: Chris Naudé - Ingwe Coal).

Figure 4-3. Rehabilitated discard dump with N17 road in forefront and mine buildings in the background (Photo: Chris Naudé - Ingwe Coal).

Figure 4-4. Gas release tower at Monitoring BH1.

4.2 Surface Hydrology

The average annual rainfall for the area is 680 mm (SA Weather Service). Figure 4-5 shows a graph of the available rainfall for Ermelo Town.

The northern border of Ermelo Colliery lies on the water divide between the Vaal- and the Olifants Catchments. The catchment run-off area, which comprises 23 000 hectares, is shown in Figure 4-6. Surface drainage is to the south. Three streams cross the area and join at the farm Tafelkop to form the Brakspruit. With a run-off value of 8 - 9% (Midgley *et al.*, 1990), this translates to a mean annual volume of 15,5 Mm^3 for the catchment.

Run-off from the coal discard dump is controlled by spiral contour drains (Figure 4-3). The spiral contours start on the top and spirals down the slope until it reaches the natural ground elevation at the foot of the dump. From here, run-off is channelled through drains into the natural streams.

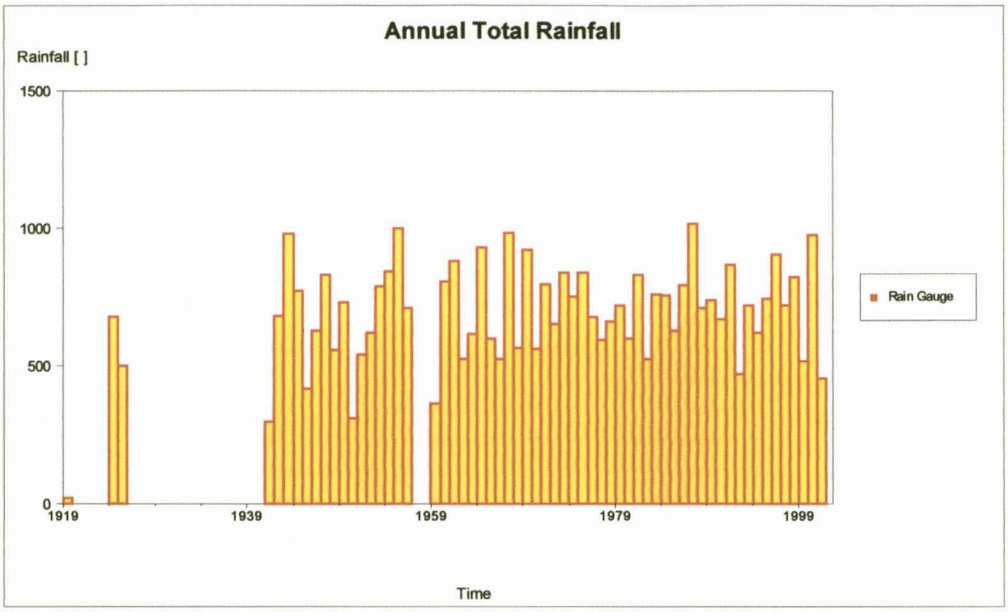


Figure 4-5. Average annual rainfall for Ermelo.

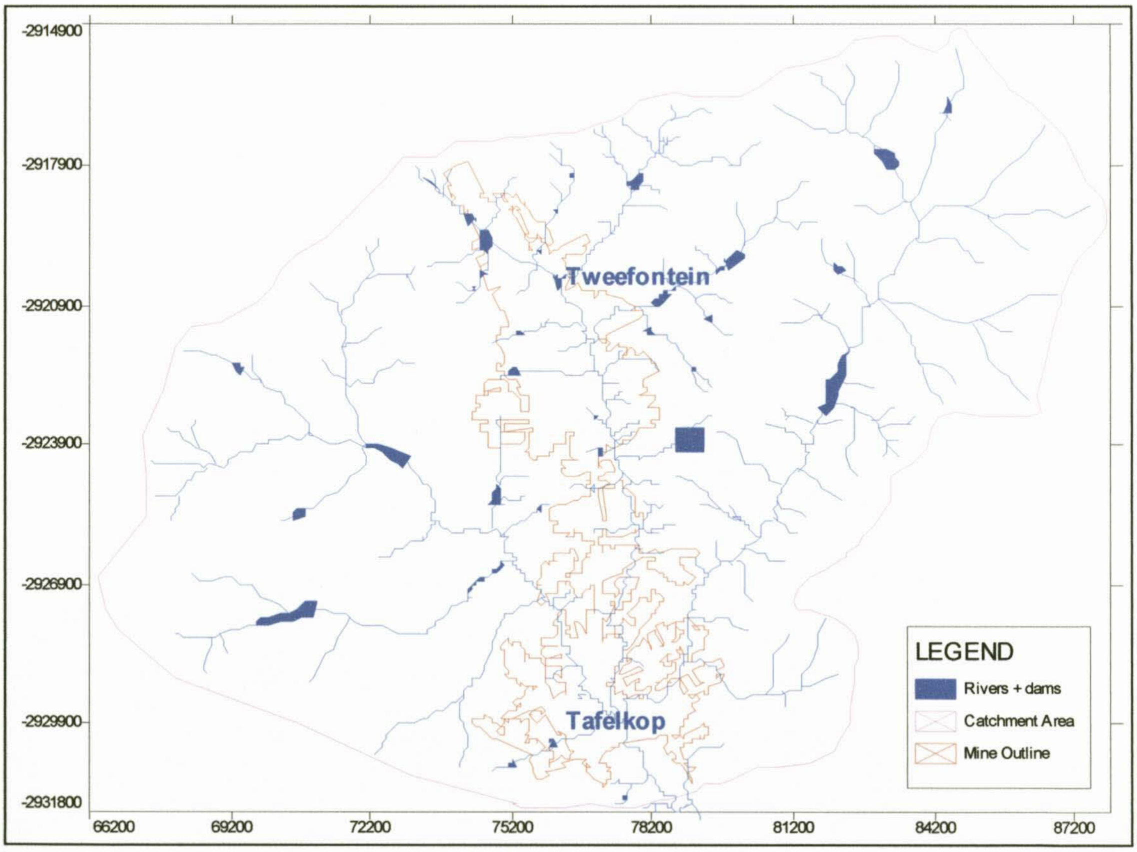


Figure 4-6. Catchment run-off area for Ermelo Colliery.

4.3 Geology

Ermelo Colliery lies in the Ermelo Coalfield (formerly the Eastern Transvaal Coal field) and is flanked by the Highveld, Witbank, Klip River and Utrecht Coalfields.

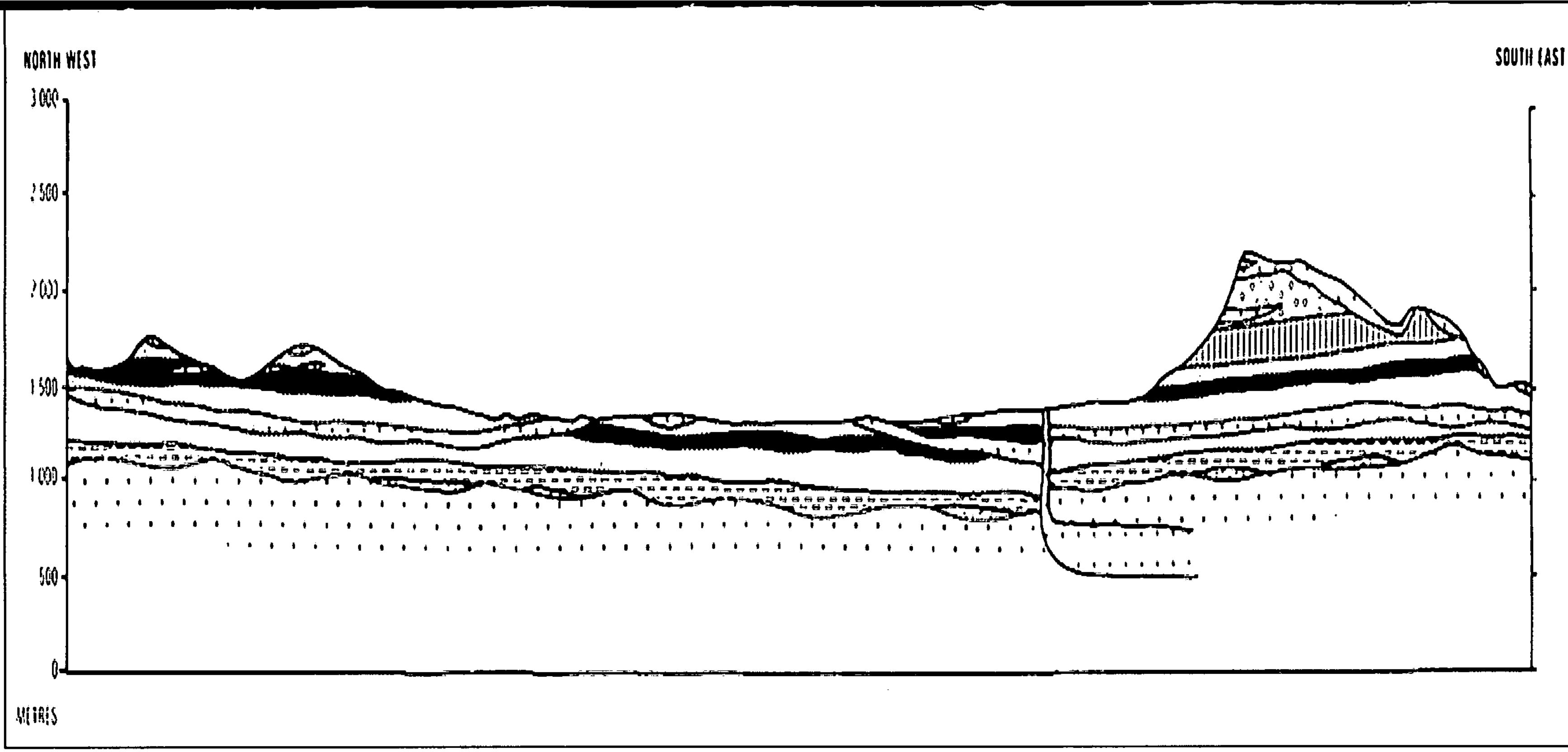
The statigraphy of the Ermelo Coalfield is typical of the coal-bearing margins of the Karoo Basin. The succession consists of pre-Karoo rocks overlain by Dwyka Formation diamictites, followed by the Ecca Group sediments, of which the Vryheid Formation is the coal-bearing horizon (Figure 4-7). The latter is present over the whole area and consists mainly of sandstone, shale and coal of varying thickness. It contains five major coal seams. These seams are named from E at the base, to A at the top of the formation (Greenshields, 1986; Snyman, 1998). Figure 4-8 illustrates the stratigraphy of the Ermelo Coalfields.

The C Seam is the most complex of the coal seams, as it is split into several plies by partings of various thicknesses. These seam splits have led to miscorrelation at places. At Ermelo Colliery the C Upper Seam was mined, which was locally known as the C Lower Seam through miscorrelation (Jordaan, 1986). The calorific value of the coal was 27.8 MJ/kg. Table 4-1 depicts the properties for crushed coal mined at Ermelo Colliery.

Table 4-1: Properties of crushed coal at Ermelo Colliery (Anhaeusser et al., 1986).

Properties	%
Moisture content	3.4
Ash	12.7
Volatile matter	31.4
Fixed carbon	52.5
Sulphur Content	1.0

Dolerite intrusions in the form of dykes and sills are present over the entire coalfield. Eight major sills have been identified. These sills displace the seams and cause structural complications. More serious is the devolatilisation of the coal, caused by the sills. Dolerite sills often outcrop on surface at the mine. The depth of the coal seam ranges from 80 - 185 m at Ermelo Colliery.



Dolerite
Beaufort Group
Volksrus Formation
Vryheid Formation, including coal layer — Ecca Group
Pietermaritzburg Formation
Dwyka
Pre Karoo Basement

Figure 4-7. Idealised section through the Ermelo Coalfields (Anhaeusser et al., 1986).

Figure 4-8 (a). Geological log of borehole O1.

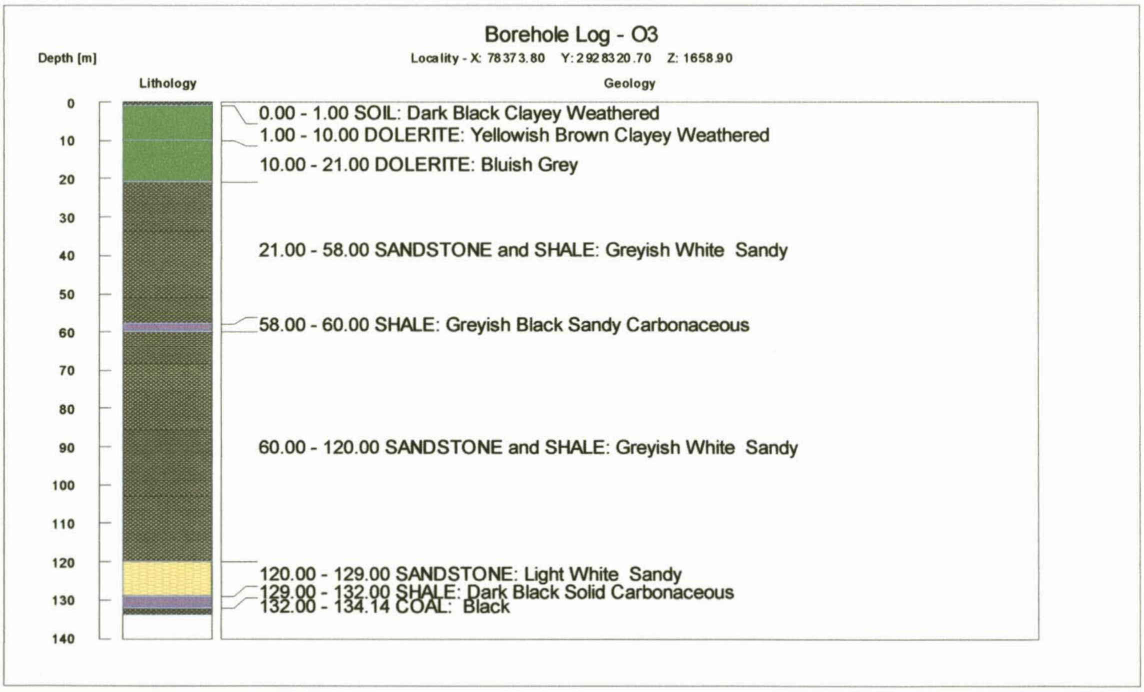


Figure 4.8(b). Geological log of borehole O3.

4.4 Regional geohydrological background

Two distinct and superimposed groundwater systems are present in the Ermelo area, as described by Hodgson and Grobbelaar (1999). They are the upper weathered aquifer and the system in the fractured rock below.

4.4.1 The weathered groundwater system

The top 5 - 15 m in the Ermelo area 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 (Hodgson and Krantz, 1998). The rest of the water is evapotranspirated or drained by some other means.

The weathered zone is generally low yielding (range 100 - 500 L/h) because of its insignificant thickness. Few farmers therefore tap this water by borehole. 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 (Hodgson and Krantz, 1998).

4.4.2 The fractured groundwater system

The grains in the fresh rock below the weathered zone are too well cemented to allow any significant flow of water. All groundwater movement is therefore 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 the rock.

An important aspect of groundwater occurrence and flow in the Ermelo area is the layered nature of the rock. It is possible, in theory, that mining could drain water from deep layers, not impacting upon 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.

4.5 Mining

Two mining methods have been employed at Ermelo Colliery. Primary development was done by the bord-and-pillar method. This was followed by secondary extraction, mainly stooping. Approximately 790 ha of the pillars have been stooped which relates to 29% of the total mined area, and 514 ha (19%), have been partially stooped (Latilla *et al.,* 1998). Stooping has been done in irregular patterns, as shown in Figure 4-9. The stooped panels, digitized from the mining maps of Ermelo Mines, are illustrated in Figure 4-10. Statistics relating to the colliery are shown in Table 4-2.

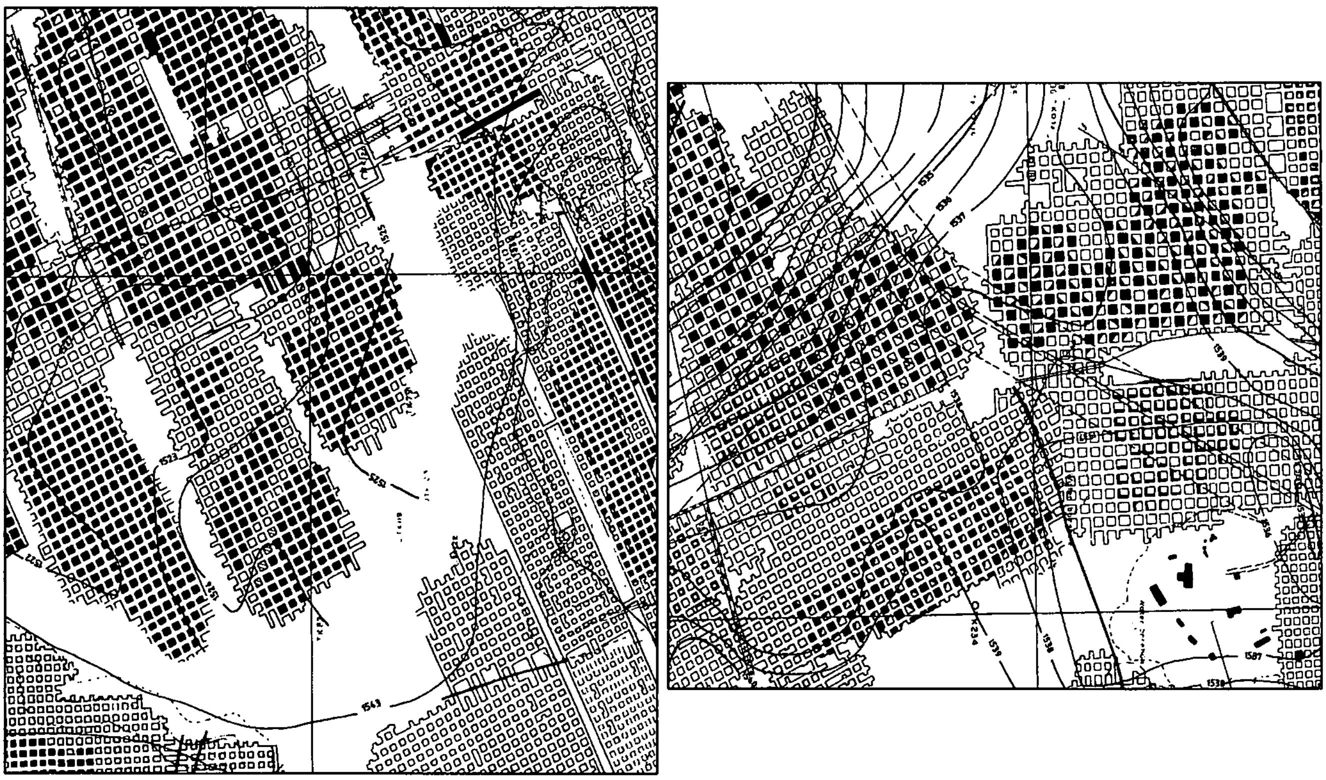


Figure 4-9. Examples of bord-and-pillar mining at Ermelo Colliery, with high extraction pillars coloured in dark (Scale: 1mm = 10.2m).

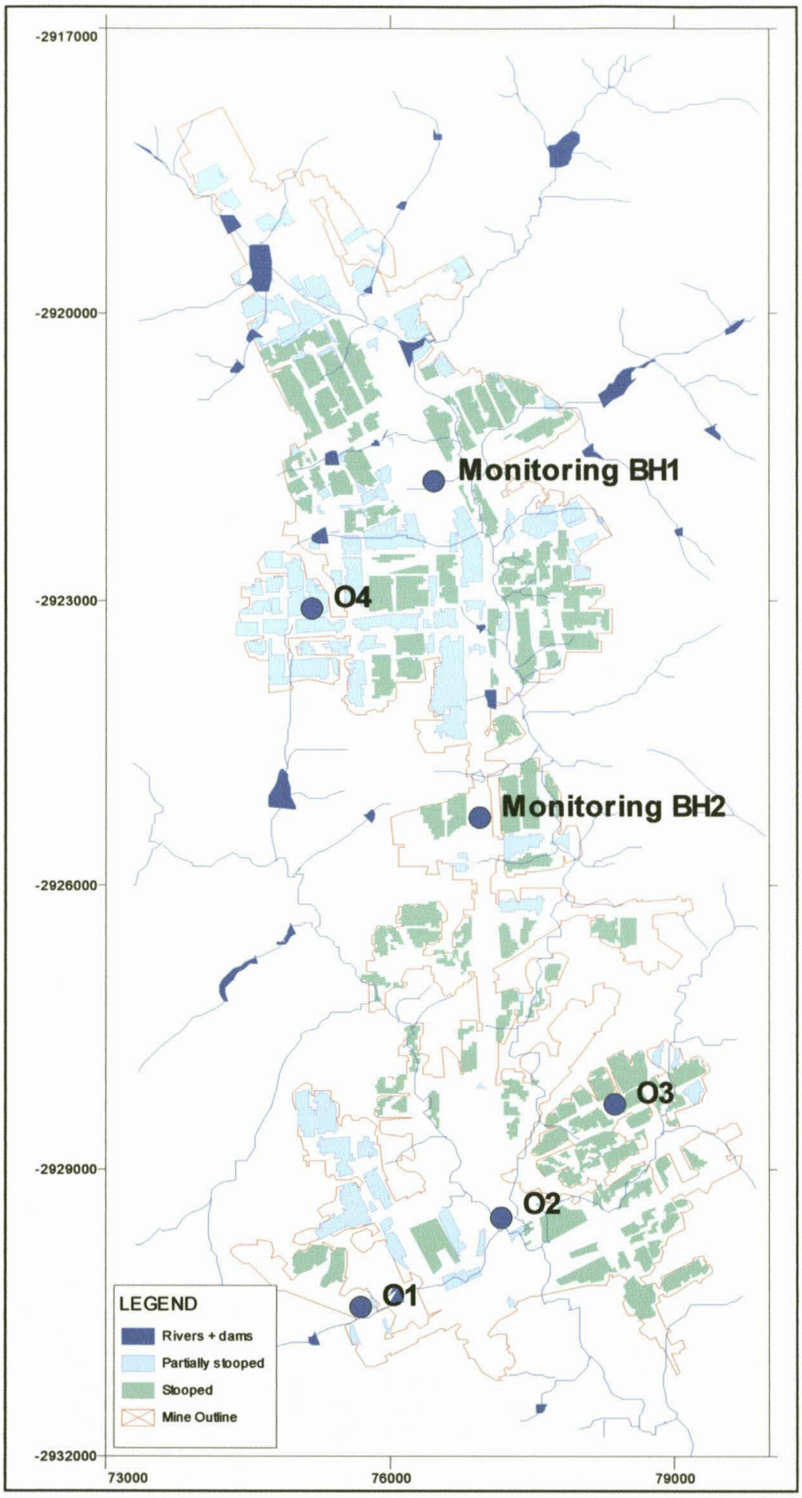


Figure 4-10. Classification of stooped and partially stooped panels at Ermelo Colliery, also showing the rivers in the area.

Table 4-2: Mining statistics relating to Ermelo Colliery.

Description	Value	
Area mined (ha)		2 680
Area stooped (ha)	714*	790**
Area partially stooped (ha)	369*	514**
Tons mined (t)		62 800 500
Volume mined (m^3)		41 867 000
Average mining height (m)		2.14
Average extraction rate (%)		0.73
Mining depth below surface (m)		80 - 185
Pillar Width (m)		9.66 - 15.66**

* Digitized from mining maps of Ermelo Mines Services (PTY) Ltd (1:5000).
** Report on Stability of Pillars - J.W. Latilla

4.5.1 Bord-and-pillar

This method is used in flat tabular deposits where it is required to prevent subsidence (collapse) of mined-out areas from affecting the surface (Figure 4-11). However, the long-term stability of pillars in the Mpumalanga Coalfields is sometimes questioned. The gradual chemical decay of the pillars, because of pyrite oxidation and accompanying carbonate dissolution, could result in future collapses.

First bords (streets) are driven, leaving supporting coal between. This is followed by cross drives, connecting the bords. Supporting coal is left behind as rectangular pillars to support the weight of the strata overlying the coal seams. Additional support is provided through the use of roofbolts.

The disadvantage of the bord-and-pillar method is that valuable coal is left behind and only between 55% and 65% of the mineable coal is extracted. In the case of Ermelo Colliery, with an average pillar width of 12 meters and a bord width of 6.4 meters, 65% of the coal was extracted with this method.

Due to methane gas ignition problems, most secondary development at Ermelo Colliery was done by the conventional drill and blast method and not by continuous miners (Latilla *et al.*, 1998).

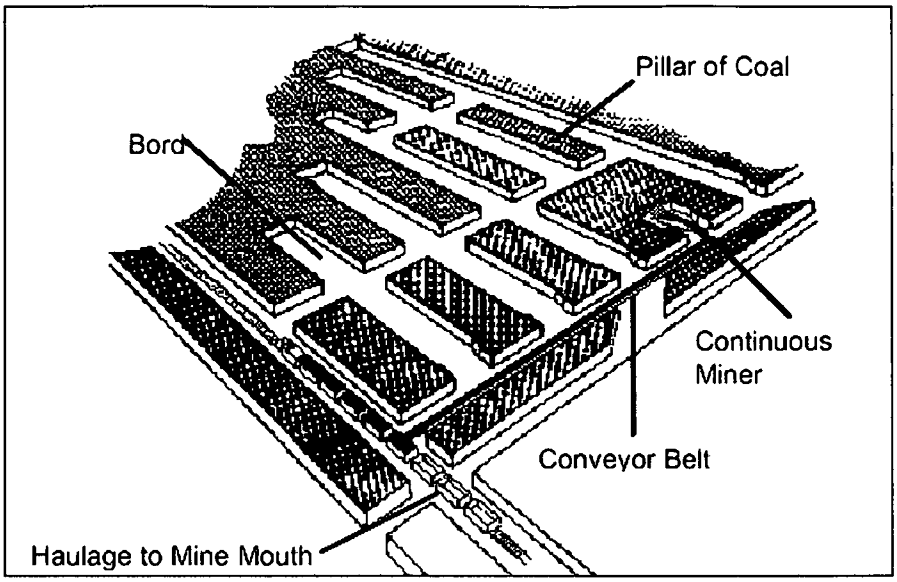


Figure 4-11. Bord and pillar mining (United Mineworkers of America, 1997).

4.5.2 High Extraction

Many forms of increased secondary extraction were practiced over the years to extract more of the coal. They were all carried out on the retreat (illustrated in Figure 4-12) and can be subdivided into four broad categories.

4.5.2.1 Stooping

With this type of mining most of every pillar in a panel will be extracted resulting in failure of the overlying strata and surface subsidence of on average 32% of the mining height (Olroyd and Latilla, 1993). Stooping enlarges the mine span, resulting in the caving of the roof strata. This has far-reaching effects on the hydrology, geohydrology and the surface.

In shale roof strata, significant movement of the strata takes place immediately after the support is removed. In sandstone strata, caving is often delayed by cantilevering of more competent sandstone layers (Wagner and Shipman, 1985). If the seam extraction is complete and if it covers large areas, as is the case with Ermelo Colliery, then the strata displacement extends to the surface and is noticeable as surface subsidence. The development of these caving zones thus extends through the water-bearing sandstone horizons and can result in significant inflow of strata water into the mine workings (Latilla *et al.*, 1998).

Shallow mining (<100 m) leads to severe disturbance of the surface, such as cracks of up to 5 cm wide, and obvious subsidence. Only deeper mining (160 m-200 m) results in less disturbance at the surface, in that cracks may be absent, although subsidence still occurs (Hodgson *et al.*, 1985). An investigation at

Somerset Mine, Pennsylvania (Barla and Boshkov, 1978) revealed that the fracture of impermeable layers inevitably leads to a drop in the water table. Geohydrological studies in the Mpumalanga Coalfields revealed similar dewatering effects. This influx is likely to continue for a lengthy period of time (Hodgson *et al.*, 1995) and could have depleted the yield of the boreholes in the area.

4.5.2.2 Chequer boarding

Every second pillar, plus a portion of the remaining pillar, is extracted. Controlled failure of the remaining pillars is expected with time. Various forms of chequer boarding were carried out depending on roof conditions and production equipment. Where continuous miners were utilised, turbo chequer boarding was carried out in areas with a competent sandstone roof. This entailed complete extraction of every second pillar plus a cut from the corner of the remaining pillar. In laminated roof areas chequer board rib extraction was practiced, this entailing 3 or 4 cuts into every second pillar and 1 or 2 into the remaining pillars. Where conventional drill and blast methods were used, various pillar slipping techniques were adopted. These included chequerboard slipping and L&U slipping. In all the chequerboard methods the remaining pillars had a width to height ratio of at least four. This was to ensure that failure of the remaining pillars occurred in a stable fashion (Latilla *et al.*, 1998).

4.5.2.3 Splitting and Quartering

Pillars are either split lengthwise or diagonally, leaving two fenders (splitting) and where the fenders themselves are also split (splitting and quartering).

4.5.2.4 Dolos mining

Cubbies of approximately 6 m by 2 m are formed on each side of every pillar in the panel.

Table 4-3: Summary of mining methods at mine closure (Latilla et al., 1998)

Mining Method	Area(ha)
Bord-and-pillar	1364
Stooping	790
Chequer bord	366
Splitting/quartering	89
Dolos	61

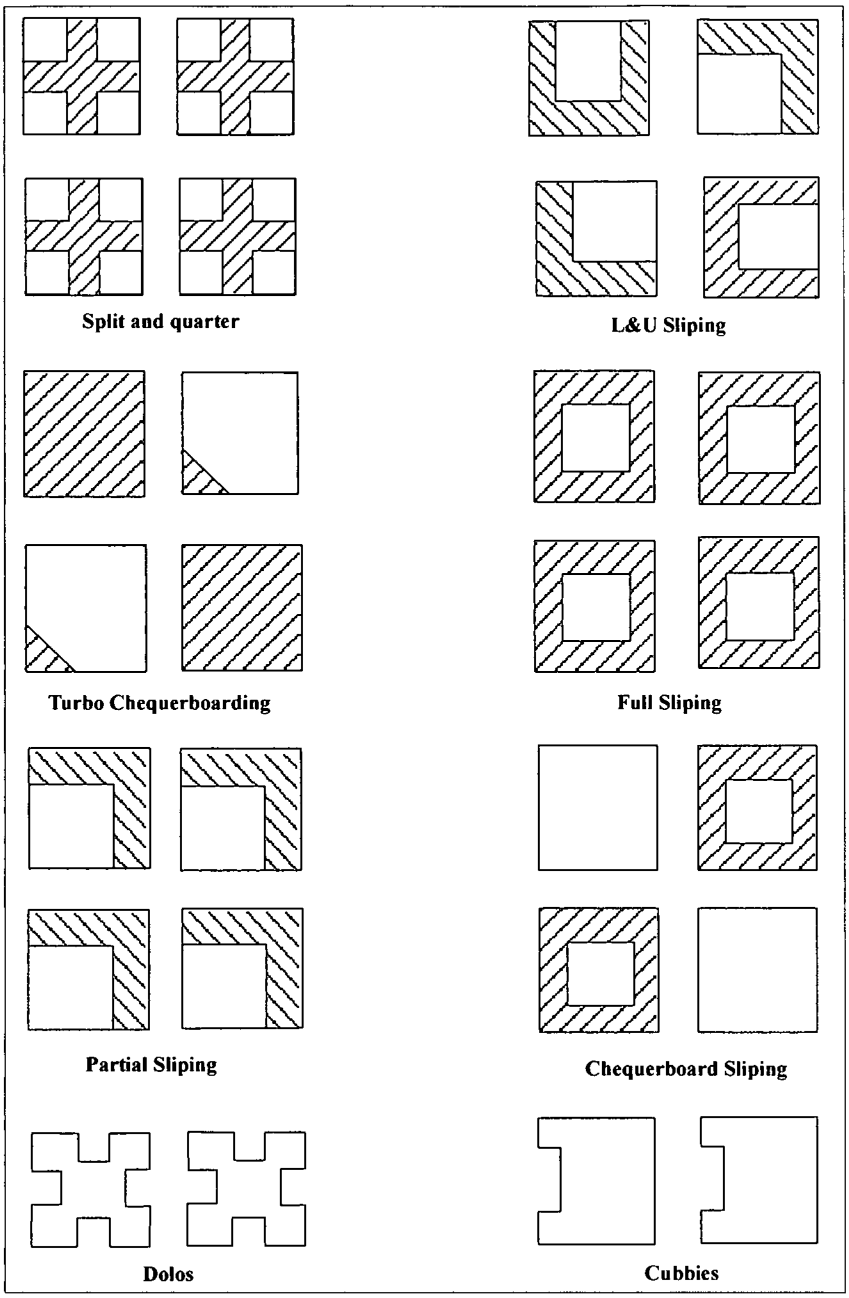


Figure 4-12. Illustration of some secondary mining methods used at Ermelo Colliery.

Experience with pillar behavior at Ermelo Colliery suggested that the coal strength of 9 to 10 MPa is considerably stronger than the industry average of 7.2 Mpa. This was used to determine the safety factor and subsequent subsidence areas for the panels (Latilla *et al.*, 1998). Where no significant thickness of dolerite (maximum 10 m) existed above the workings, the critical span was calculated using the following formula:

$$C = 2d \tan(\beta - 90°) \qquad \text{(Latilla } et\ al.\text{, 1998)}$$

In areas where dolerite sills of between 10 m and 70 m occur, and are less than 70 m deep, as is the case with Ermelo Colliery, Galvin`s critical span formula was used to determine the span required to break the dolerite and allow goafing to extend to the surface. With this formula future subsidence could be determined.

$$C = \sqrt{1165Td - 935\frac{Td^2}{Dd}} + 2TpTan(\beta - 90)$$

where C = critical span
d = cover depth
β = caving angle (taken as 120°)
Td = Thickness of the dolerite
Dd = Depth to base of dolerite
Tp = Distance between base of dolerite and seam roof (m)

The determined values are illustrated in Table 4-4.

Table 4-4: Summary of subsidence at mine closure (Latilla et al., 1998).

Extraction	Area (ha)
Secondary Extraction:	
Subsidence already occurred	496
Subsidence likely	220
Subsidence may occur	172
Bord and Pillar:	
Very low probability of failure	1337
Low probability of failure	27

At cessation of mining activities, none of the chequer borded panels was known to collapse at Ermelo Colliery. The implication is that while failure is expected at some time in the future, it is impossible to predict when this may happen.

4.6 Water Quantity

4.6.1 Current status

The coal floor is undulating but has a general dip to the south. A section line (Figure 4-13) and cross-section (Figure 4-14) demonstrate undulations in the north-south direction. Four boreholes in the mine serve observation purposes. In addition to these, two other old mine boreholes are also available.
Figure *4-15* shows the floor contours in relation to the surface. The locality of the holes in relation to the mined out-area and coal floor contours is indicated in Figure 4-16.

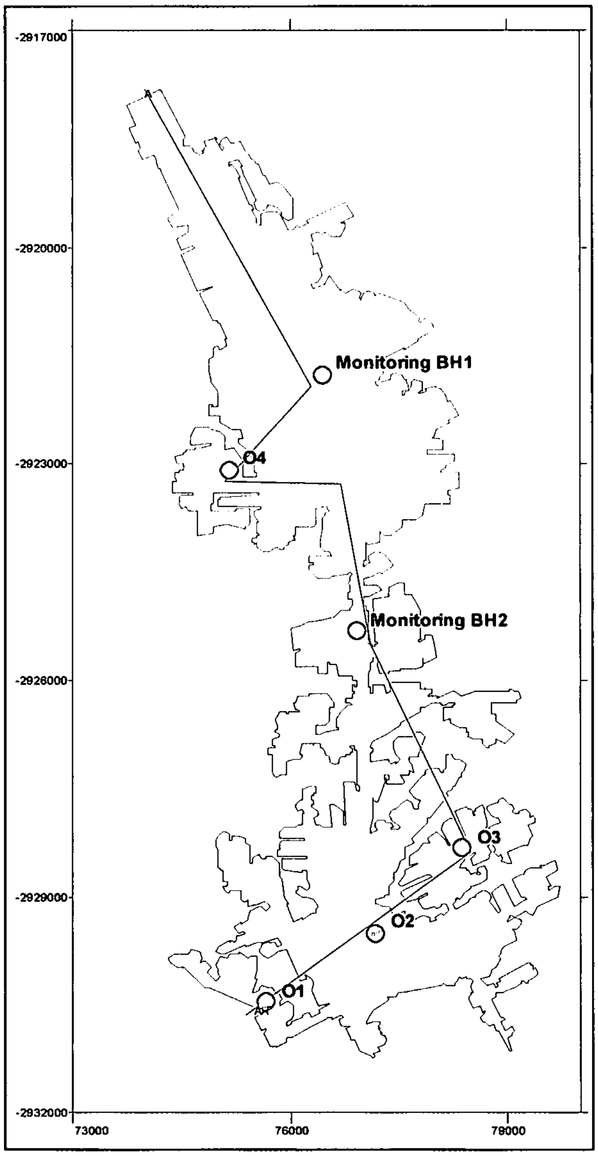


Figure 4-13. Map of Ermelo Colliery showing north - south line.

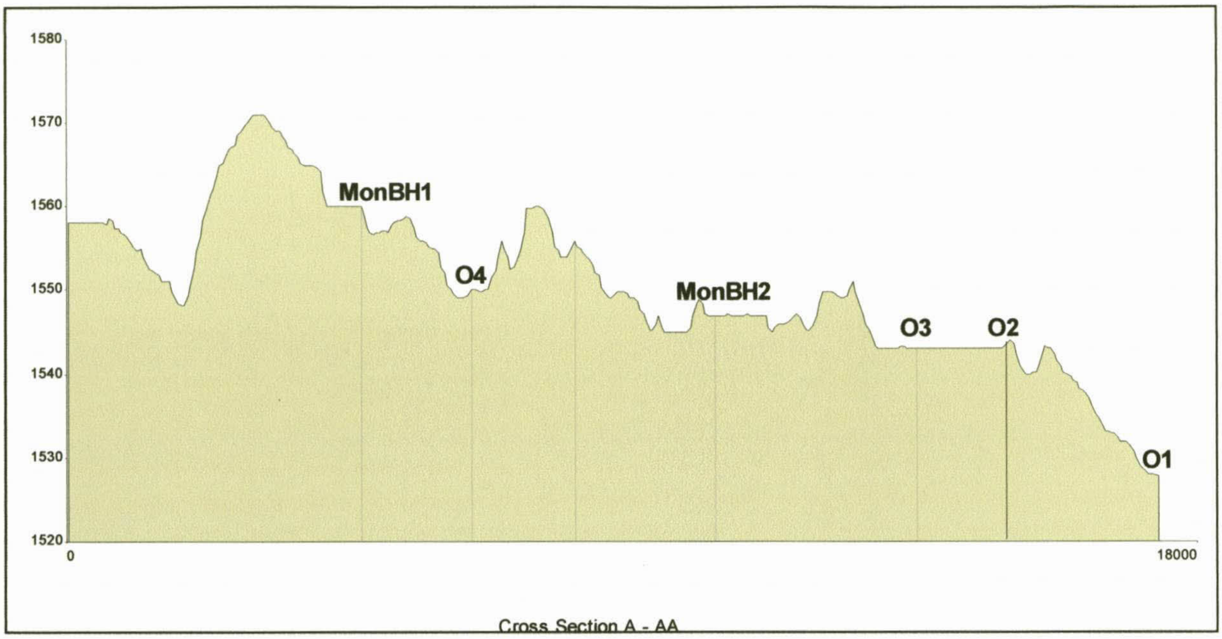


Figure 4-14. North-south cross-section of the coal floor, also showing the borehole positions.(There is no data for an unmined area between O2 and O3, resulting in the straight horisontal line).

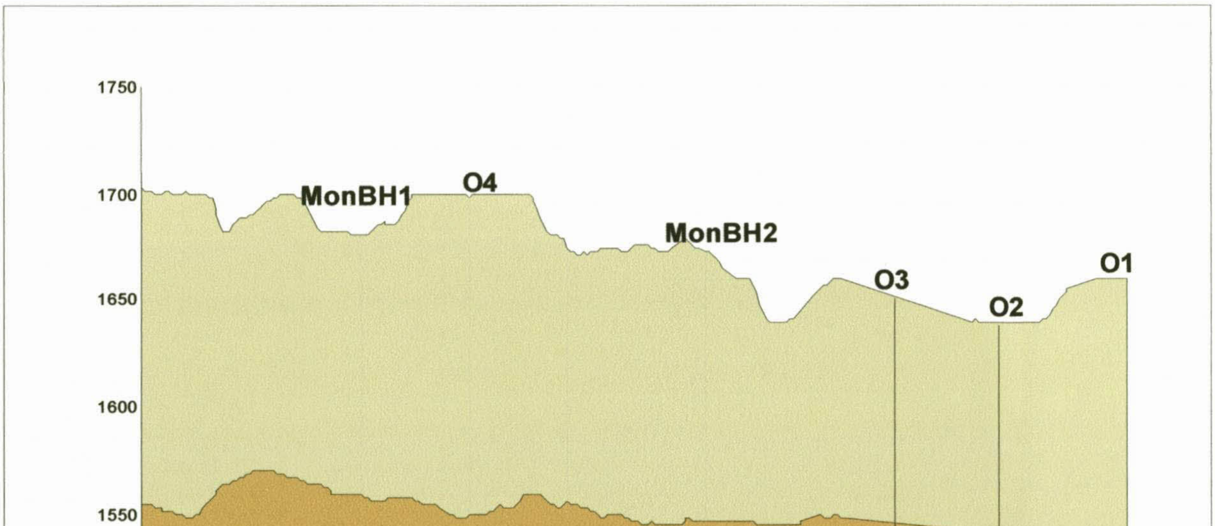


Figure 4-15. North-South section of floor contours in relation to the surface at Ermelo Colliery.

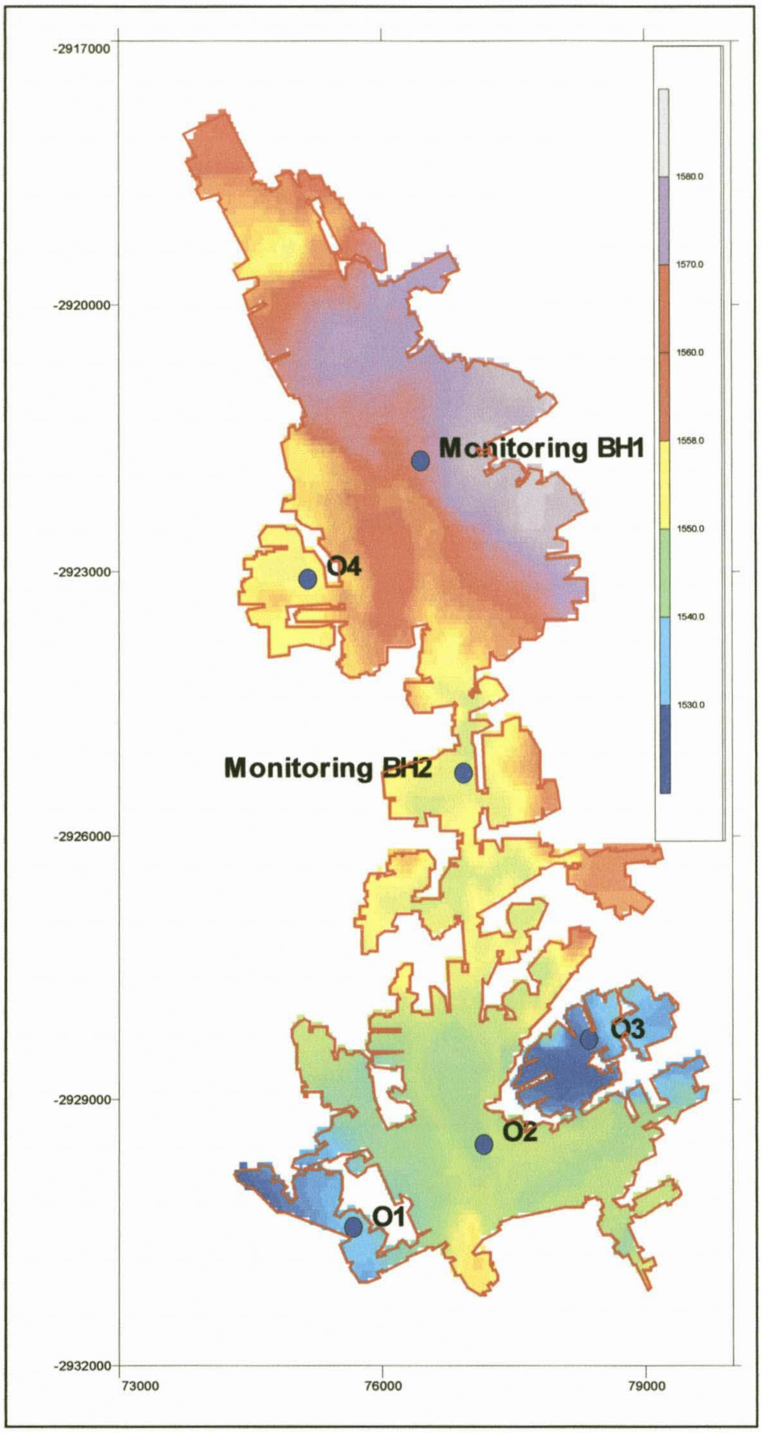


Figure 4-16. Coal floor contours and localities of monitoring boreholes.

A stage curve, showing the volume of the mined out area in relation to the elevation, is included for information in Figure 4-17. Water levels have been plotted in Figure 4-18.

4.6.2 Coal floor contours

The floor elevations range between 1 520 - 1 580 mamsl. The deepest areas are in the southwest (Figure 4-16) 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 mine through a large, rather flat area. Here, many undulations in the coal floor are present. It is anticipated that significant amounts of water will be retained within the undulations, before allowing the flow of water to the south. Further north, the coal floor dips steeply from the southeast to the northwest. In this area, local smaller depressions are also present. It is anticipated that depression storage amounts to about 15% of the mine volume.

4.6.3 Volume

The full capacity of the mine is in the order of 44 Mm^3 (Figure 4-17). To put it in perspective, this is about a tenth of the capacity of the Grootdraai Dam (360 Mm^3) (Hodgson *et al.*, 1999), into which run-off from Ermelo Colliery eventually drains. The local catchment above the mine yields about 15.5 Mm^3 per annum as discussed in Section 4.2. If all surface run-off from the catchment above the mine could be diverted into the underground workings, it would take three years' run-off to fill the colliery.

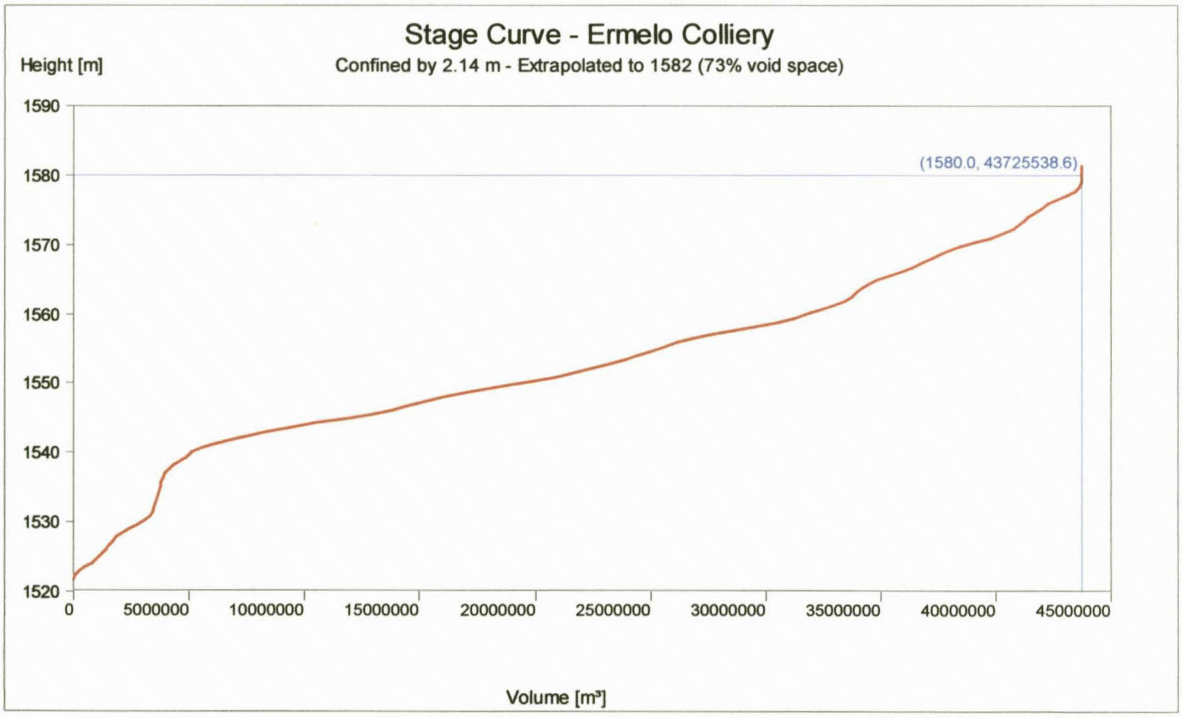


Figure 4-17. Stage curve for the underground workings at Ermelo Colliery.

4.6.4 Water levels in the monitoring boreholes

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 4-18.

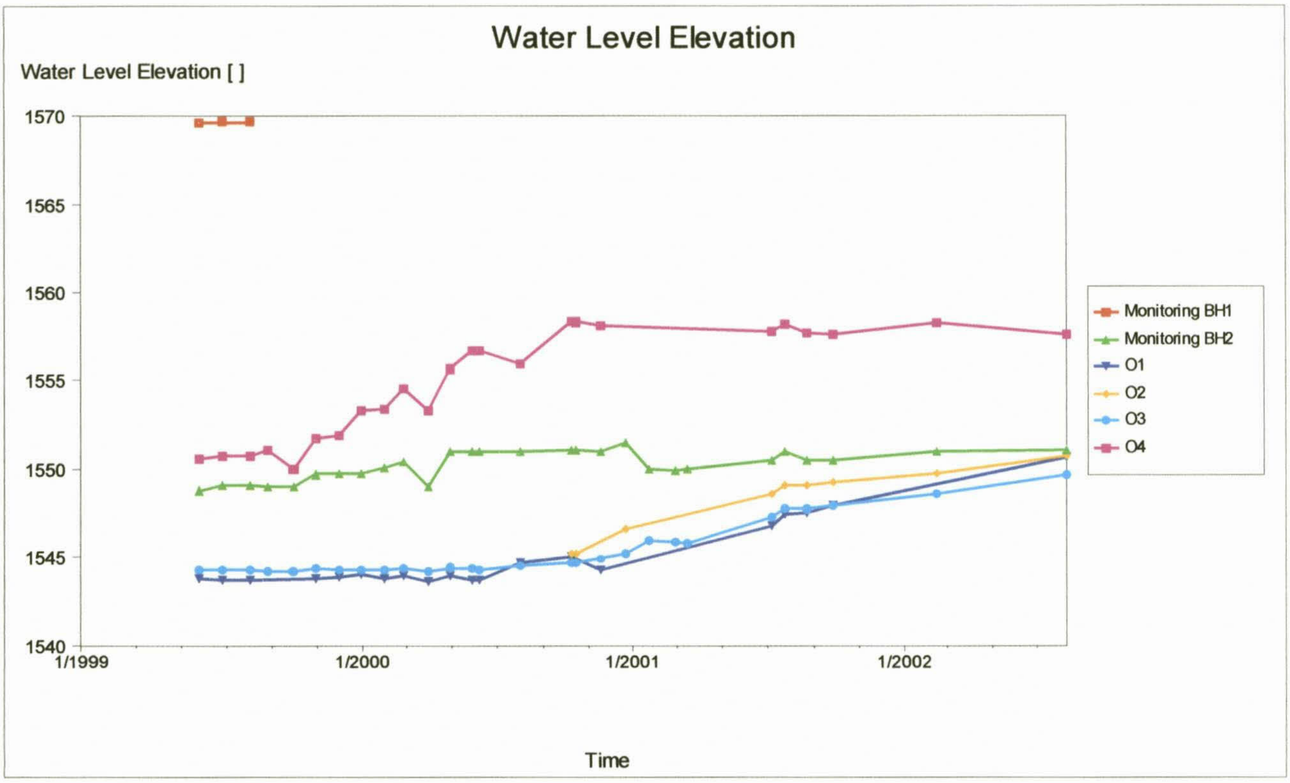


Figure 4-18. Mine-water levels.

A conceptual model (Figure 4-19) based on the water levels in Figure 4-18, was created to illustrate the filling up of the mine cavity over time. Effectively, each borehole monitors an area in the mine that was not hydraulically interconnected during the early stages of the flooding. These areas (A - F) and the borehole positions are indicated in Figure 4-20. The different areas were determined by water levels and floor contours.

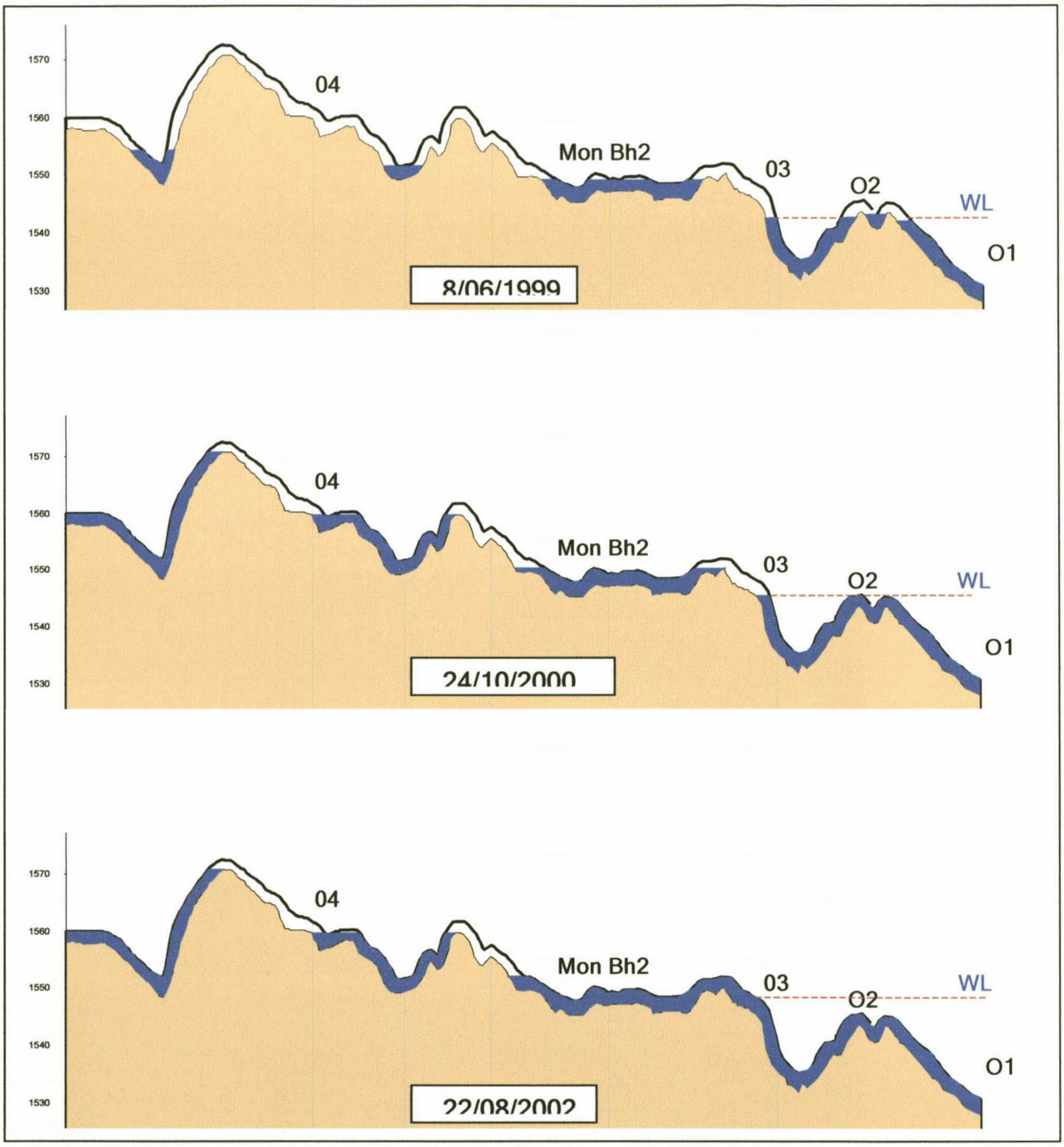


Figure 4-19. Conceptual model of the water levels at Ermelo Colliery over time.

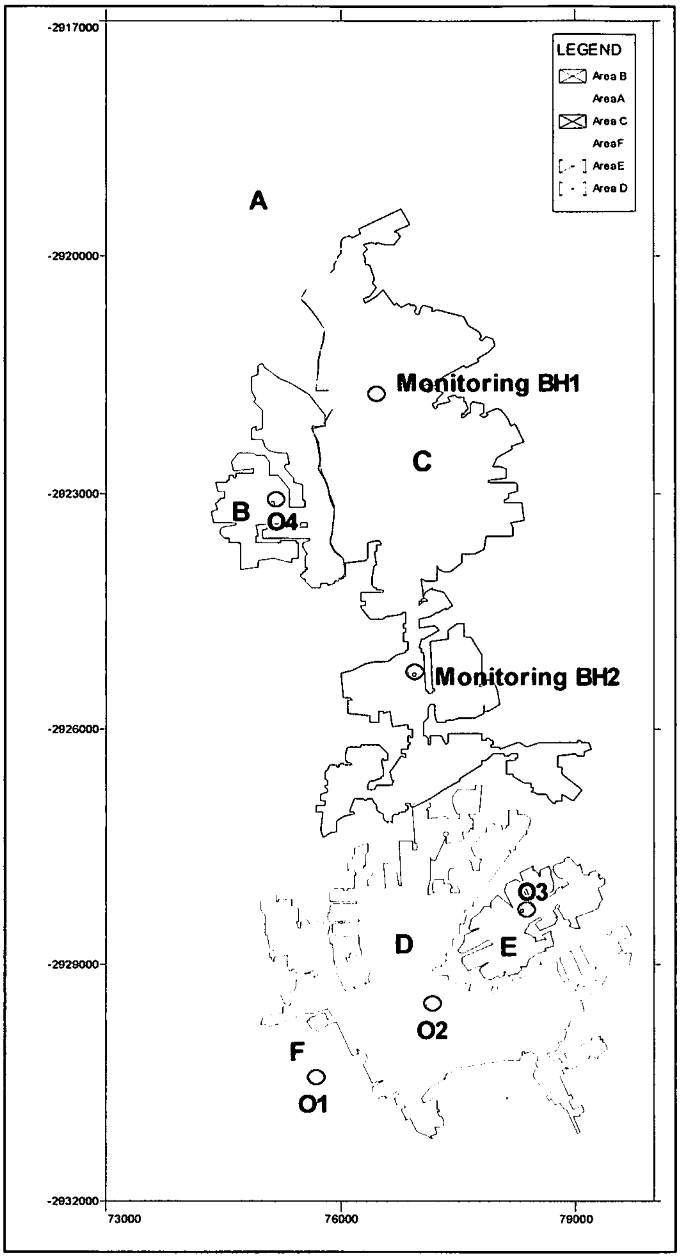


Figure 4-20. Hydraulic independent areas A- F and the position of the boreholes.

4.6.5 Water balance calculations

Water balance calculations have been done for 3 periods:

8/06/1999 - 24/10/2000: It appears that recharge was mainly in the northern compartments. The exceptionally high rainfall since December 1999 resulted in the sharp rise in water levels of borehole O4. Table 4-5 lists the rainfall for

Ermelo and Bethal. The streams above the stooped areas would have been in flood, enhancing recharge.
Table 4-6 lists the total hectares stooped for the different hydraulic areas) During this period there was no rise in the water levels of boreholes in the southern parts of the mine.

5/01/2000 - 28/02/2002: The rise in water levels of 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 stabilise. 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 equalised. The water levels of these areas will now rise at the same rate.

Table 4-5: Monthly rainfall figures for Ermelo and Bethal for the period of research.

Ermelo												
	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	April	May	Jun
1998/1999	0	0	102	66	106	253	126	4	47	12	16	6
1999/2000	0	5	0	0	0	301	180	116	56	90	20	15
2000/2001	4	4	22	146	155	167	23	44	35	49	13	2
2001/2002	0	0	21	113	70	88	118	112	56	15	6	13
2002/2003	11	28										
Bethal												
1998/1999	0	0	56	96	145	83	58	27	85	20	24	3
1999/2000	0	0	0	0	0	175	184	150	176	105	30	6
2000/2001	0	0	24	109	153	135	33	170	23	44	18	0
2001/2002	0	2	28	100	56	75	108	94	57	13	-	14

Table 4-6: Total hectares stooped in the different hydraulic areas.

Areas	Stooped (ha)	Partially Stooped (ha)	% of Area
Area A	75	0	20
Area B	40	90	54
Area C	368	115	42
Area D	130	66	24
Area E	76	0	55
Area F	13	0	15

The results of the water balance calculations are shown in Table 4-7. The volumes were determined from stage curves.

Table 4-7: Water Balance Calculations.

Period 8/6/1999 - 24/10/2000:

Rainfall (mm)	886
Days	504

Areas	Surface Area (m²)	Water Levels (mamsl)		Volumes (m³)		Rain Volumes (m³)	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%

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.

Period 5/1/2001 - 28/2/2002:

Rainfall (mm)	682
Days	420

Areas	Surface Area (m²)	Water Levels (mamsl)		Volumes (m³)		Rain Volumes (m³)	Influx
		5/1/2001	28/2/2002	5/1/2001	28/2/2002		
Area A	3915859	1565.1	1565.1	3789235	3789235	2670616	0.0%
Area B	2409553	1558.34	1557.80	3793189	3793189	1643315	0.0%
Area C	11620907	1551.39	1550.89	4554755	4226638	7925459	-4.1%
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%

As illustrated in Figure 4-19,water spilled over the undulations in Areas A and B, flowing down-gradient towards Area D. The negative value for Area C is probably because of the collapse of a seal, resulting in water to spill into Area D, increasing the influx into this area. The mining cavity in Areas E and F is already filled, with water only rising in the strata above the mine, and also backfilling into Area D. There were thus no gains in Areas A, B, E and F.

Period 28/2/2002 to 22/8/2002:

Rainfall (mm)	109
Days	175

Areas	Surface Area (m²)	Water Levels (mamsl)		Volumes (m³)		Rain Volumes (m³)	Influx
		1/3/2002	22/8/2002	1/3/2002	22/8/2002		
Area A	3915859	1565.1	1565.1	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%

During this period Area D filled, and then the water started to backfill into Area C, as illustrated in Figure 4-19. This resulted in the influx in Area D to be smaller than in the previous period. When added with 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 a recharge of more than 20% for the high rainfall first period. Table 4-8 lists the influx volumes into the mine for the different periods.

Table 4-8: Influxes into Ermelo Colliery.

Period	Total Influx (m^3)	Daily Influx (m^3)
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

4.7 Future water quantity

Currently there is 27.4 Mm^3 water in the mine, which amounts to 63% of the total volume. This is relatively fast, as water from the streams above the stooped areas resulted in high influx during the abnormal rainfall periods at the end of 1999. It is very difficult to predict how long it will take to fill up the mine, because the recharge rate varies greatly much under different rainfall conditions. It is probably safe to use 2 500 m^3/day as a reasonable average (Table 4-8), which implies that the mine will fill up in 15 years. If high rainfall periods occur, as has happened at the end of 1999, the fill-up time of the mine will decrease drastically.

Decanting from the mine is inevitable, forcing mine water out at the lowest interconnection between the mine and the surface (Figure 4-20). This is likely to be through cracks above the stooped areas in the south of the mined area.

All of the potential decanting points are located adjacent to the streambed, at surface elevations ranging from 1 624 -1 626 mamsl. At these points, the coal seam is at 1 540 mamsl, i.e. 85 m below surface. The highest elevation of the coal floor is at 1 580 mamsl. This confirms that all of the coal seam will be flooded before decanting commences.

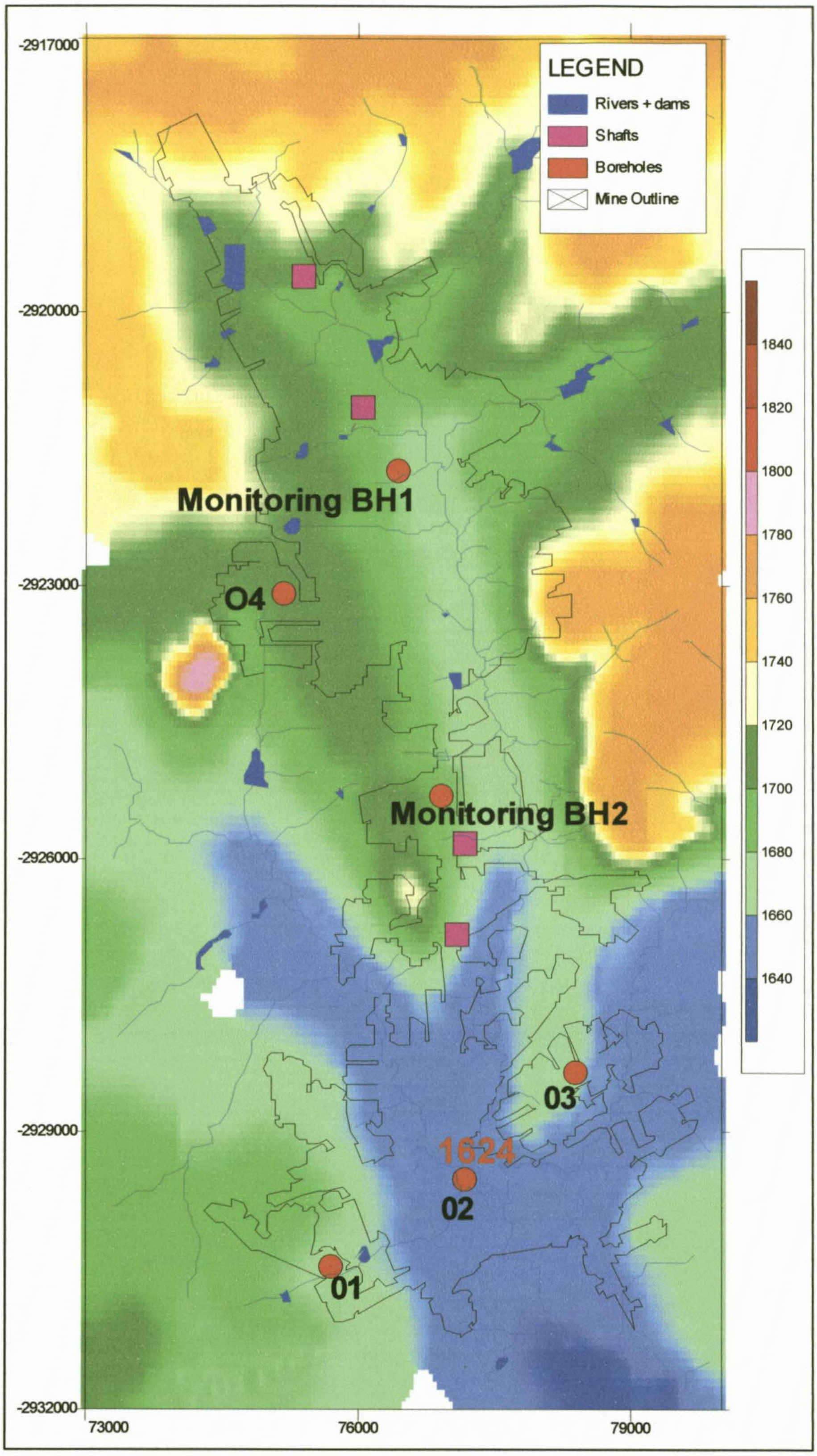


Figure 4-21. Map of the surface contours at Ermelo Colliery

4.8 Water Quality

4.8.1 Current Situation

The following includes general characteristics of the mine water as determined through multi-parameter probing (Figure 4-22):

- The pH of the water in the mine ranges between 6.8 - 8.55. This suggests that carbonate buffering of the mine water is taking place.
- The electrical conductivity values in the mine range from 70 - 850 mS/m.
- Oxygen concentrations at the coal seam horizon range from 0.07 - 1.07 mg/L.
- Temperatures of the water in the mine are not significantly elevated. This confirms that even though oxidising conditions are present, the rate of oxidation should be slow.

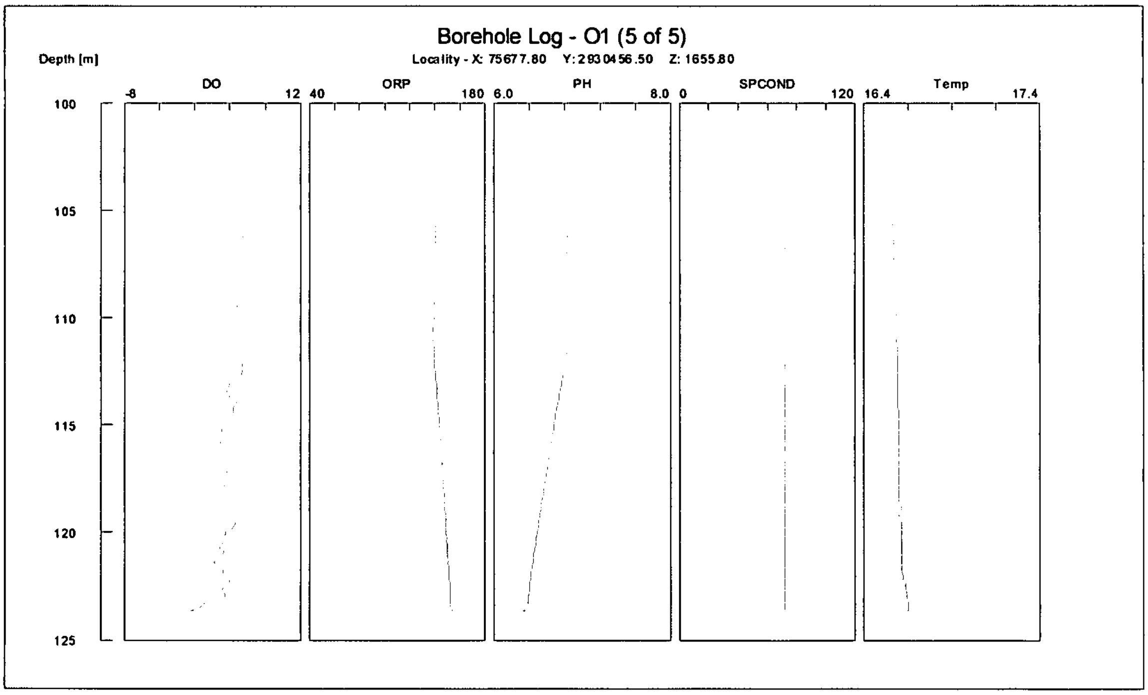


Figure 4-22(a). Borehole log BH O1.

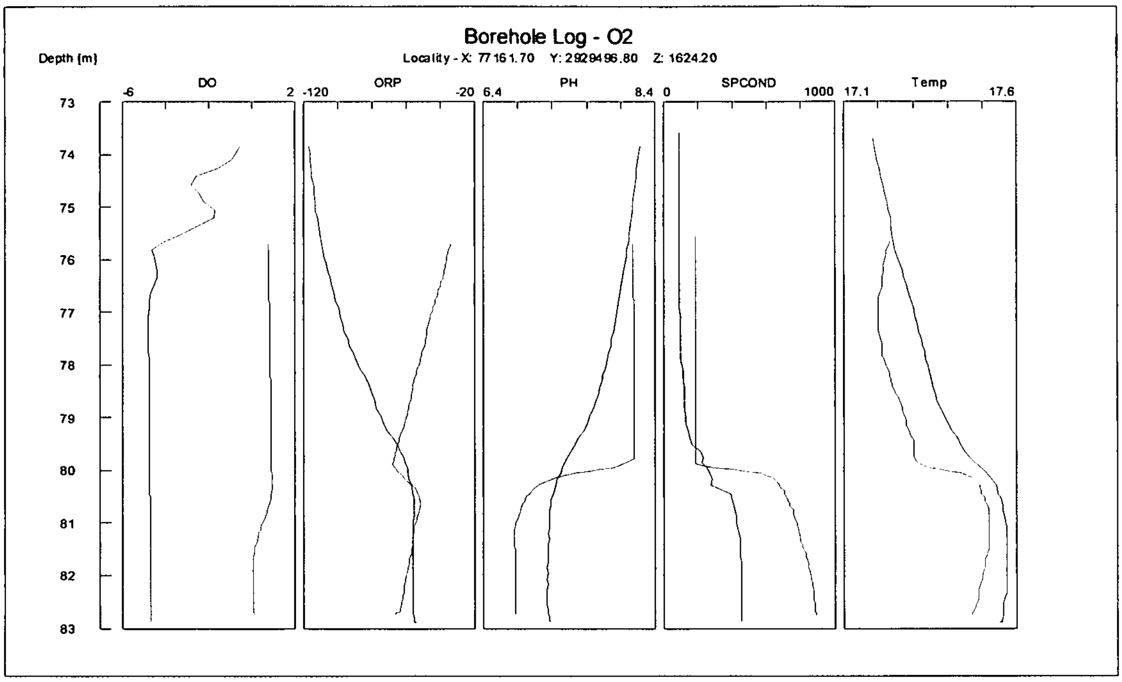


Figure 4-27(b). Borehole log BH O2.

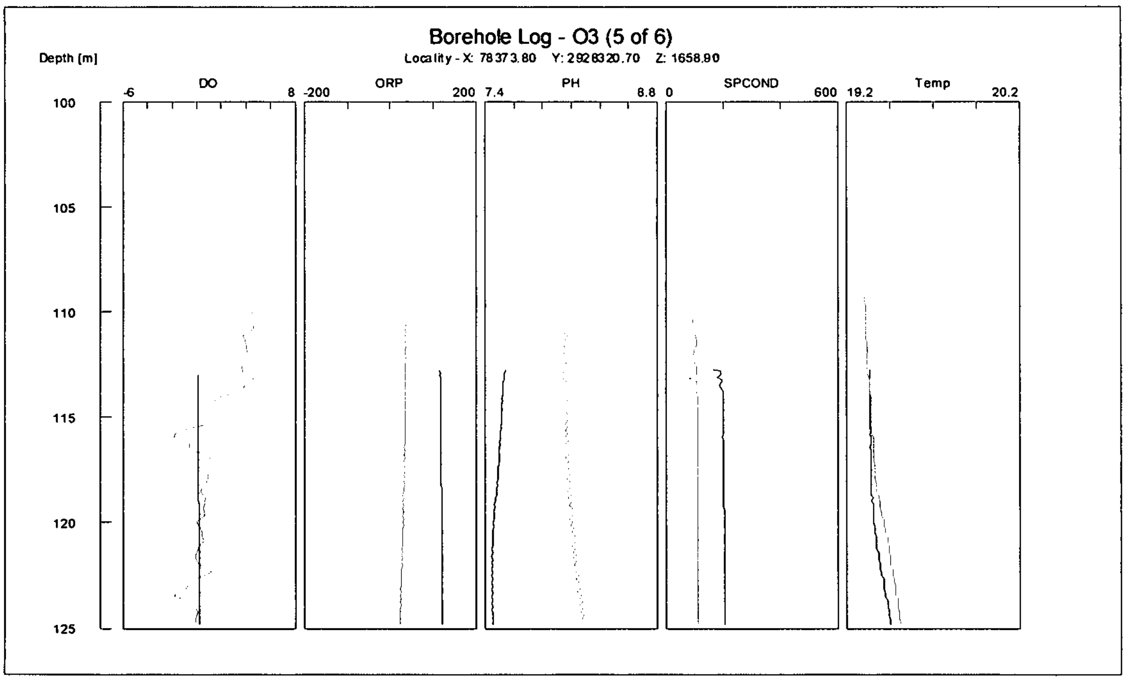


Figure 4-27(c). Borehole log BH O3.

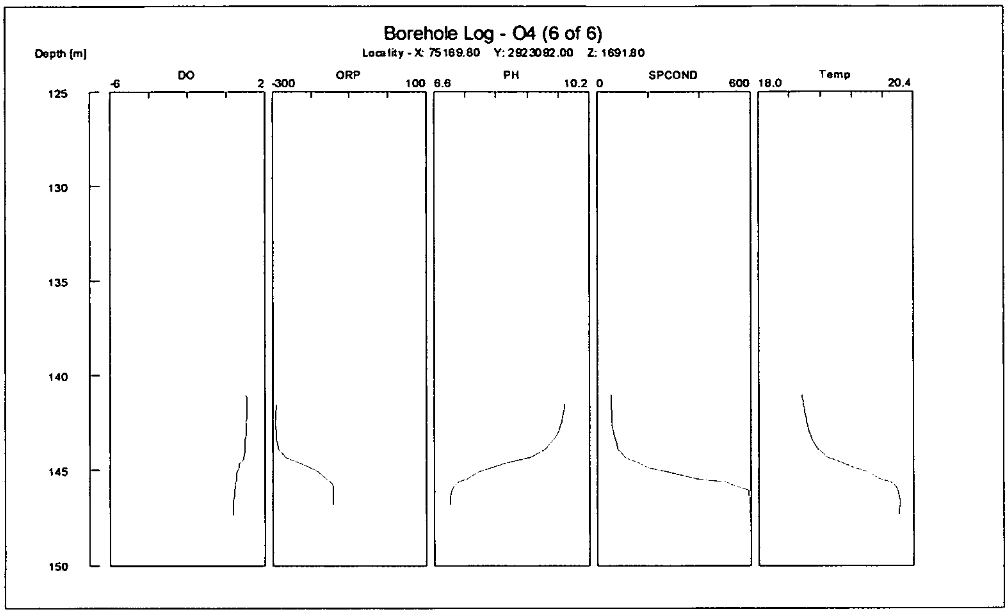


Figure 4-27(d). *Borehole log BH O4.*

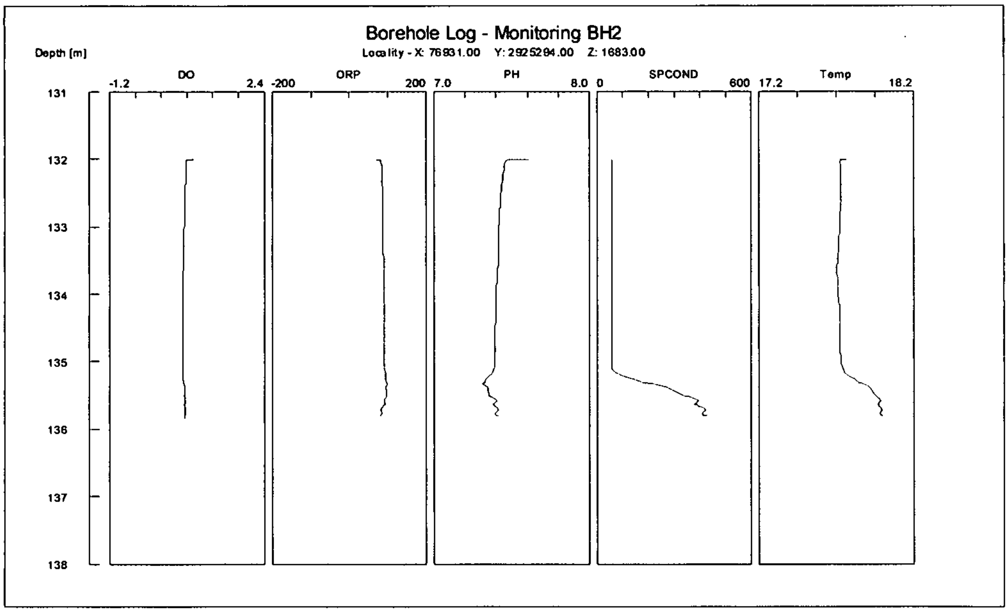


Figure 4-27(e). *Borehole log Mon BH2.*

Sampling has been done with a sophisticated pressurised depth sampler, approximately one metre from the bottom of the boreholes.

The water quality in the mine is variable. Table 4-9 lists the results for three different periods. The variable chemistry of the mine water could be attributed to dilution from groundwater entering into the monitoring boreholes and the depth at which sampling took place, making it difficult to sample at the exact horizon in the mine every time.

Table 4-9: Chemical analysis (mg/L) done at different periods of time.

SiteName	Date	MALK	PAlk	EC	pH	Ca	Cl	Mg	NO3	SO4
Monitoring BH1	2/23/1998	52	0.00	39	7.20	36	54	16	7.00	41
Monitoring BH2	2/23/1998	12	0.00	25	7.60	26	35	4	<0.05	59
O1	2/23/1998	22	0.00	371	6.10	571	46	360	<0.05	2825
O2	2/23/1998	50	0.00	38	7.00	7	79	12	0.20	54
O3	2/23/1998	480	0.00	422	8.00	724	679	347	7.20	2065
O4	2/23/1998	206	0.00	224	7.30	186	87	147	1.70	1217
Mon BH2	2/28/2002	741	0	280	8.28	75	194	23	0.26	353
O1	2/28/2002	148	0	61	7.84	65	21	37	4.32	130
O2	2/28/2002	384	1	144	8.3	42	136	12	0.17	133
O3	2/28/2002	1041	20	317	8.63	9	398	3	0.12	4
O4	2/28/2002	335	0	69	8.23	2	55	1	<0.05	23
O1	8/22/2002	146	0	76	7.13	85	34	46.9	4.27	208
O2	8/22/2002	358	0	110	8.03	26	129	7.3	0.15	49
O3	8/22/2002	205	0	116	7.65	69	151	27.0	21.69	90
O4	8/22/2002	255	0	66	7.61	2	59	0.5	0.12	15

SiteName	Date	K	Na	Si	Al	Sb	As	Ba	Be	B
Monitoring BH1	2/23/1998	2.9	15	-1.00	<0.01	<0.006	<0.01	0.00	<0.002	<0.04
Monitoring BH2	2/23/1998	1.8	8	-1.00	<0.01	<0.006	<0.01	0.00	<0.002	<0.04
O1	2/23/1998	7.2	50	-1.00	<0.01	<0.006	<0.01	0.00	<0.002	<0.04
O2	2/23/1998	3.1	66	-1.00	<0.01	<0.006	<0.01	0.00	<0.002	<0.04
O3	2/23/1998	12.0	151	-1.00	<0.01	<0.006	<0.01	0.00	<0.002	<0.04
O4	2/23/1998	4.5	230	-1.00	<0.01	<0.006	<0.01	0.00	<0.002	<0.04
Mon BH2	2/28/2002	7.6	514	-1.00	0.051	<0.006	<0.01	0.102	<0.002	0.207
O1	2/28/2002	4.0	14	-1.00	0.055	<0.006	<0.01	0.039	<0.002	<0.040
O2	2/28/2002	4.1	274	-1.00	0.052	<0.006	<0.01	0.169	<0.002	0.193
O3	2/28/2002	4.7	703	-1.00	0.058	<0.006	<0.01	0.244	<0.002	0.456
O4	2/28/2002	1.1	178	-1.00	0.070	<0.006	<0.01	0.053	<0.002	0.144
O1	8/22/2002	4.0	13	-1.00	0.009	<0.006	<0.01	0.042	<0.002	<0.04
O2	8/22/2002	3.4	223	-1.00	0.012	<0.006	<0.01	0.196	<0.002	<0.04
O3	8/22/2002	7.9	144	-1.00	0.026	<0.006	0.758	0.228	<0.002	<0.04
O4	8/22/2002	1.5	161	-1.00	0.101	<0.006	-0.010	0.044	<0.002	<0.04

SiteName	Date	Br	Cd	Cr	Co	Cu	F	Fe	Pb	Li
Monitoring BH1	2/23/1998	<0.04	<0.001	<0.010	<0.005	<0.003	0.20	0.10	<0.015	<0.005
Monitoring BH2	2/23/1998	<0.04	<0.001	<0.010	<0.005	<0.003	0.20	-0.01	<0.015	<0.005
O1	2/23/1998	<0.04	<0.001	<0.010	<0.005	<0.003	0.20	0.20	<0.015	<0.005
O2	2/23/1998	<0.04	<0.001	<0.010	<0.005	<0.003	0.20	-0.01	<0.015	<0.005
O3	2/23/1998	<0.04	<0.001	<0.010	<0.005	<0.003	0.30	0.80	<0.015	<0.005
O4	2/23/1998	<0.04	<0.001	<0.010	<0.005	<0.003	0.20	1.40	<0.015	<0.005
Monitoring BH2	2/28/2002	<0.04	<0.001	<0.010	<0.005	0.004	1.14	0.263	<0.015	0.037
O1	2/28/2002	<0.04	<0.001	<0.010	<0.005	0.005	0.04	0.008	<0.015	<0.005
O2	2/28/2002	<0.04	<0.001	<0.010	<0.005	0.003	0.71	0.023	<0.015	0.039
O3	2/28/2002	<0.04	<0.001	<0.010	<0.005	0.003	2.27	0.034	<0.015	0.049
O4	2/28/2002	<0.04	<0.001	<0.010	<0.005	0.004	0.57	0.031	<0.015	0.008
O1	8/22/2002	0.31	<0.001	0.008	<0.005	0.011	0.08	0.019	<0.015	<0.005
O2	8/22/2002	0.5	<0.001	<0.010	<0.005	0.004	0.87	0.138	<0.015	0.035
O3	8/22/2002	0.93	0.003	<0.010	<0.005	0.002	0.35	0.010	<0.015	0.014
O4	8/22/2002	0.28	<0.001	<0.010	<0.005	0.003	0.58	0.085	<0.015	0.011

SiteName	Date	Mn	Mo	Ni	Se	Sr	Sn	V	Zn	SAR
Monitoring BH1	2/23/1998	0.00	<0.004	<0.006	<0.006	0.00	-0.02	<0.010	0.00	0.521
Monitoring BH2	2/23/1998	0.40	<0.004	<0.006	<0.006	0.00	-0.02	<0.010	0.00	0.394772
O1	2/23/1998	0.70	<0.004	<0.006	<0.006	0.00	-0.02	<0.010	0.00	0.401785
O2	2/23/1998	0.00	<0.004	<0.006	<0.006	0.00	-0.02	<0.010	0.00	3.512291
O3	2/23/1998	0.00	<0.004	<0.006	<0.006	0.00	-0.02	<0.010	0.00	1.150583
O4	2/23/1998	0.60	<0.004	<0.006	<0.006	0.00	-0.02	<0.010	0.00	3.046431
Monitoring BH2	2/28/2002	0.146	<0.004	<0.006	<0.006	2.581	<0.5	<0.010	0.010	13.23773
O1	2/28/2002	0.019	0.007	<0.006	<0.006	0.253	<0.5	0.011	0.054	0.33513
O2	2/28/2002	0.124	<0.004	<0.006	<0.006	1.717	<0.5	<0.010	0.029	9.498749
O3	2/28/2002	0.031	0.005	<0.006	<0.006	0.935	<0.5	<0.010	0.023	51.2575
O4	2/28/2002	0.003	0.007	<0.006	<0.006	0.105	<0.5	<0.010	0.042	23.86671
O1	8/22/2002	0.006	0.005	<0.006	<0.006	0.282	-0.01	0.011	0.029	0.282217
O2	8/22/2002	0.040	<0.004	<0.006	<0.006	1.018	-0.01	<0.010	0.019	9.873558
O3	8/22/2002	0.006	0.012	<0.006	<0.006	0.324	-0.01	0.012	0.027	3.716779
O4	8/22/2002	0.018	0.005	<0.006	<0.006	0.075	-0.01	<0.010	0.028	24.68813

The electrical conductivity with the probe shows values of up to 850 mS/m at the bottom, while chemical analyses show values considerably lower at one metre from the bottom. This suggests that the mine water is stratified at the boreholes themselves.

Conclusions from the information in Table 4-9 are:

- The pH-levels range from 7.1 to 8.7, which is in the range where sodium carbonate from the coal buffers the water against acidification. Characteristic of the mine water is relatively high sodium and alkalinity, with variable concentrations of sulphate. Sodium and alkalinity are released from the coal in the mine during the flooding stage.
- Sulphate generation is dependent on pyrite oxidation. Oxidation is not possible in flooded areas, on condition that the mine water remains alkaline. Figure 4-23 shows the ranges of sulphate values for each of the boreholes. Dilution from groundwater influx through the boreholes could contribute to the significant spread of values.

Other results from the monitoring program are shown in Figure 4-23 to Figure 4-26.

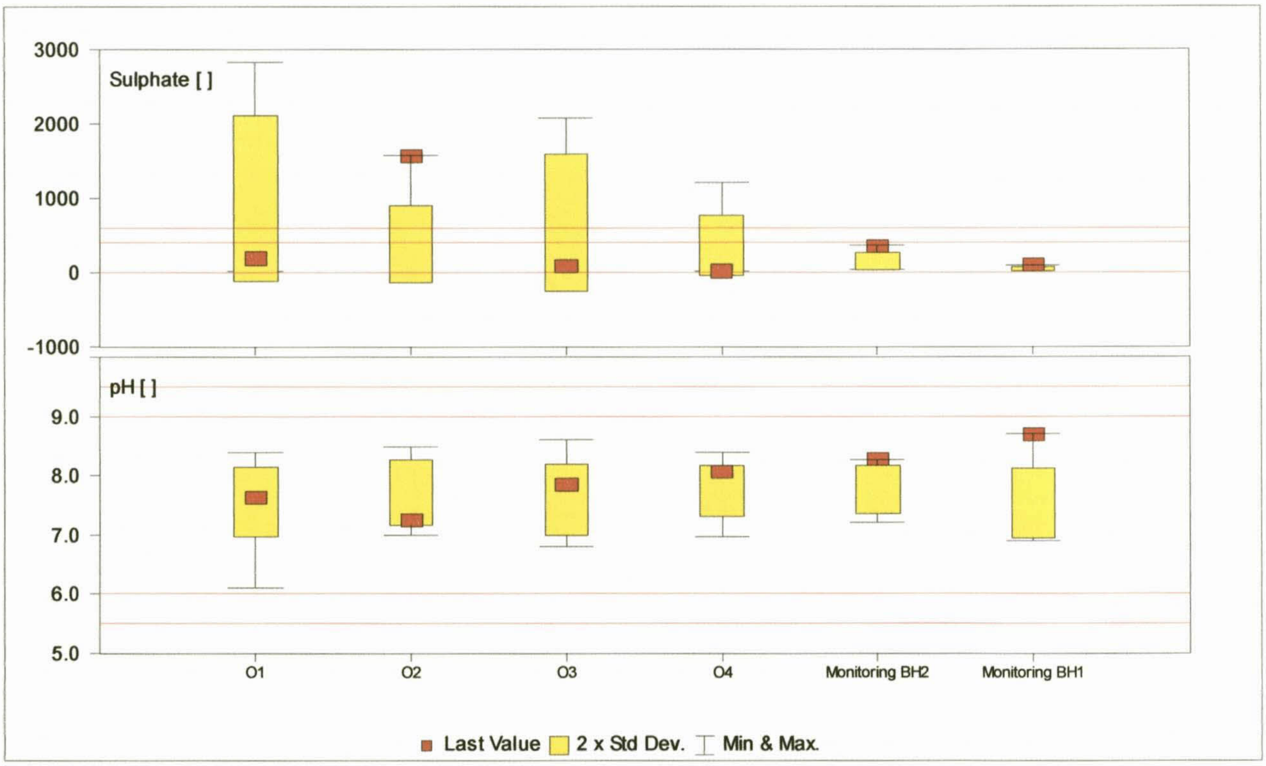


Figure 4-23. pH and sulphate statistics for Ermelo Colliery (mg/L).

Calcium and magnesium concentrations in the water are low in comparison with sodium (Figure 4-24). A significant, but dormant, base potential in the form of calcium/magnesium carbonate is expected to be present in the coal.

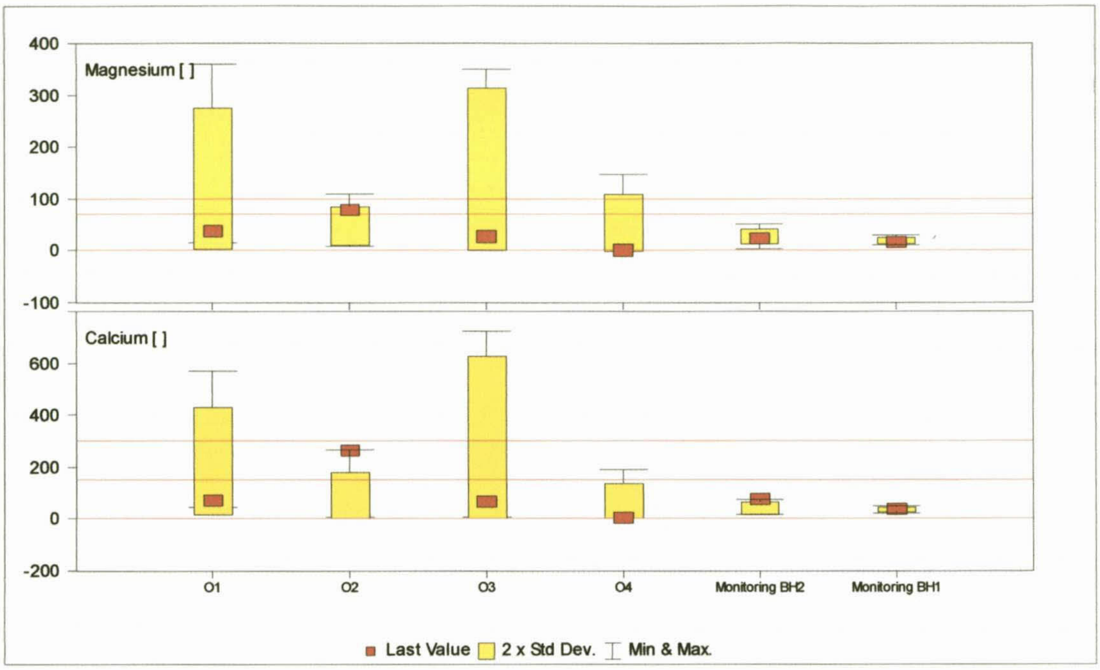


Figure 4-24. Calcium and magnesium statistics for Ermelo Colliery (mg/L).

Chloride is present in significant concentrations (Figure 4-25). This confirms that apart from sodium carbonate, sodium chloride is also a mineral to be considered when evaluating the long-term water chemistry. Sodium chloride does not impact on the pH of the mine water.

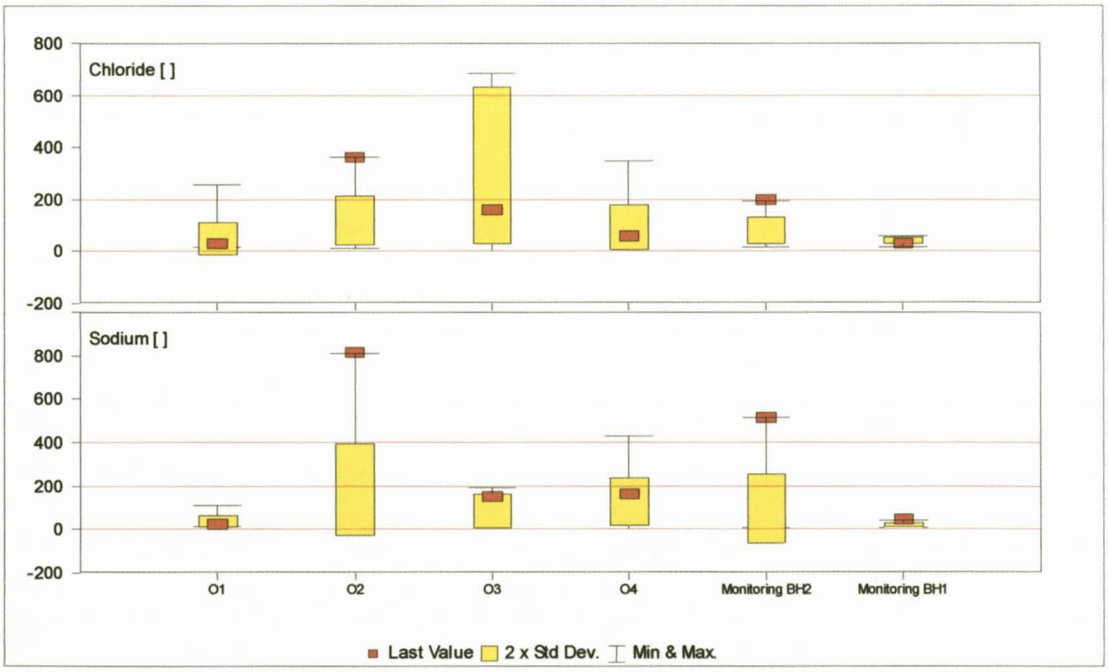


Figure 4-25. Sodium and chloride statistics for Ermelo Colliery (mg/L).

Heavy metal concentrations are low. This is ascribed to the relatively high pH-levels in the mine water. At the current pH-levels of the mine water (above 7.1), heavy metals in the water are not a problem except for manganese, which can be in solution. Iron and manganese values are shown in Figure 4-26. According to Figure 4-27 (Appelo and Postma, 1994), at a pH > 7.1, very little iron will be in solution below an Eh of -0.05 mV.

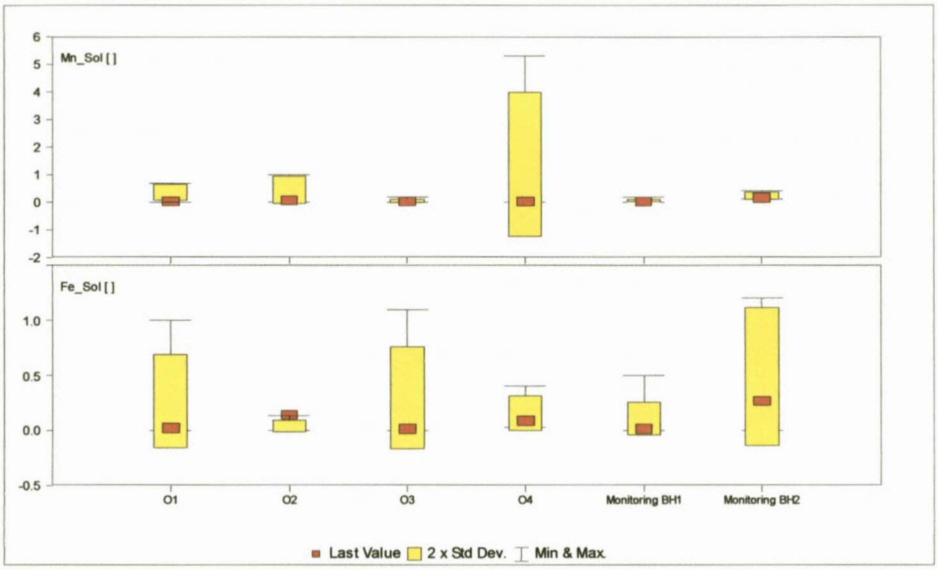


Figure 4-26. Iron and manganese statistics for Ermelo Colliery (mg/L).

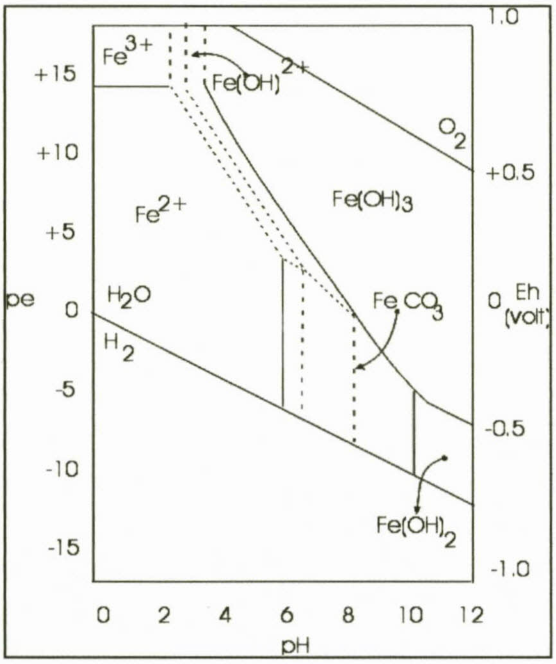


Figure 4-27. Fe stability diagram (Appelo and Postma 1994)

In Figure 4-28 the sulphate and EC concentrations, in relation to the water levels in the different compartments in the mine, are illustrated as a line graph. It is clear that just after mine closure, salt concentrations were high, due to small amounts of water, reacting with freshly exposed pyrite. Ideal oxidising conditions prevailed, generating sulphate concentrations in excess of 2000 mg/L. The drop in concentrations occurred during the 1999 summer rainfall. Boreholes O1 and Monitoring BH2 have lower values than the other boreholes due to higher recharge resulting from subsidence in the area.

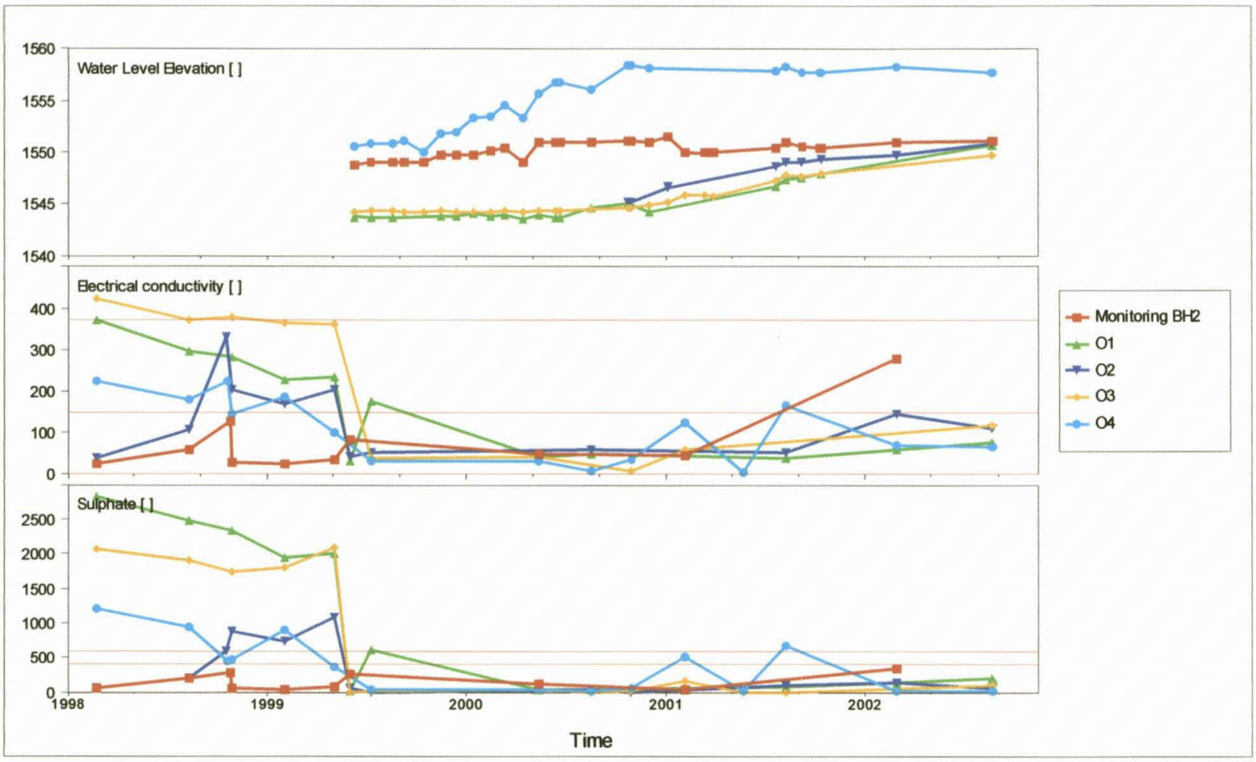


Figure 4-28. Line graph of sulphate (mg/L), EC and water levels

The increase in the salt load since February 2002 is ascribed to the lower recharge during this period, as indicated in Table 4-8. This means that the daily influx of 1 300 m³ is too slow for effective dilution, compared to 2 500 m³ during the previous year. Currently the mine generates 0.39 kg/ha SO_4/day, based on an average sulphate value of 398 mg/L as indicated in Table 4-10.

Table 4-10: Average SO_4 and EC values.

Site Name	Date	EC (mS/m)	SO_4(mg/L)
Mon BH2	5/2/01	487	3 389
Mon BH2	30/10/01	46	44
Mon BH2	28/02/02	280	353
O1	11/7/99	41	37
O1	15/05/00	48	44
O1	8/8/01	40	83
O1	28/02/02	61	130
O1	22/08/02	76	208
O2	5/2/01	172	45
O2	8/8/01	54	990
O2	28/02/02	144	103
O2	22/08/02	110	113
O3	5/2/01	60	115
O3	28/02/02	317	4
O3	22/08/02	116	90
O4	5/2/01	126	512
O4	22/05/01	6	7
O4	8/8/01	165	674
O4	28/02/02	69	23
O4	22/08/02	66	15
Mean		139	398

A graph showing the relationship between EC and SO_4 is included as Figure 4-29.

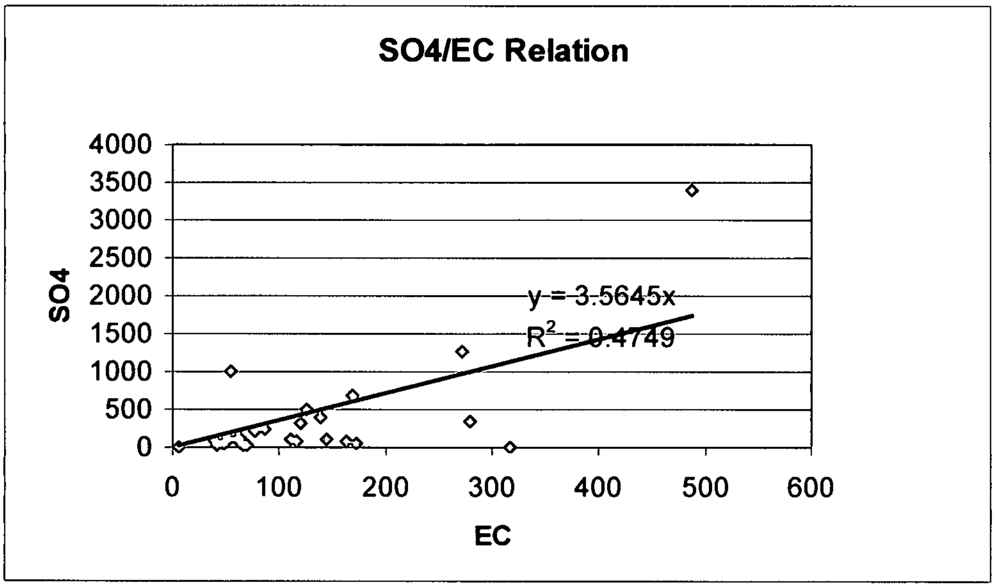


Figure 4-29. Relationship between EC and SO_4.

This graph is based on values from Table 4-10 and indicates that the SO_4 value cannot be estimated accurately from EC values. This is because of the high sodium and chloride concentrations in the water.

4.8.2 Future Quality

The cracks above the collapsed areas in the northern parts will continue to introduce fresh water. This will force lateral flow of mine water on the coal seam horizon. At the decant point, the mine water will hydraulically be forced to the surface. This mechanism will cause flushing.

The rate of flushing will depend on the rate of fresh water influx. An 8.8% influx rate was used for illustration purposes.

Figure 4-30 demonstrates the impact of fresh water recharge at selected localities. This is intended merely for demonstration purposes. The importance of this simulation is that certain pathways will leach while stagnant areas in the mine will remain at high salinity. Utilisation of water from the mine through boreholes must therefore be done in a scientific and coordinated way.

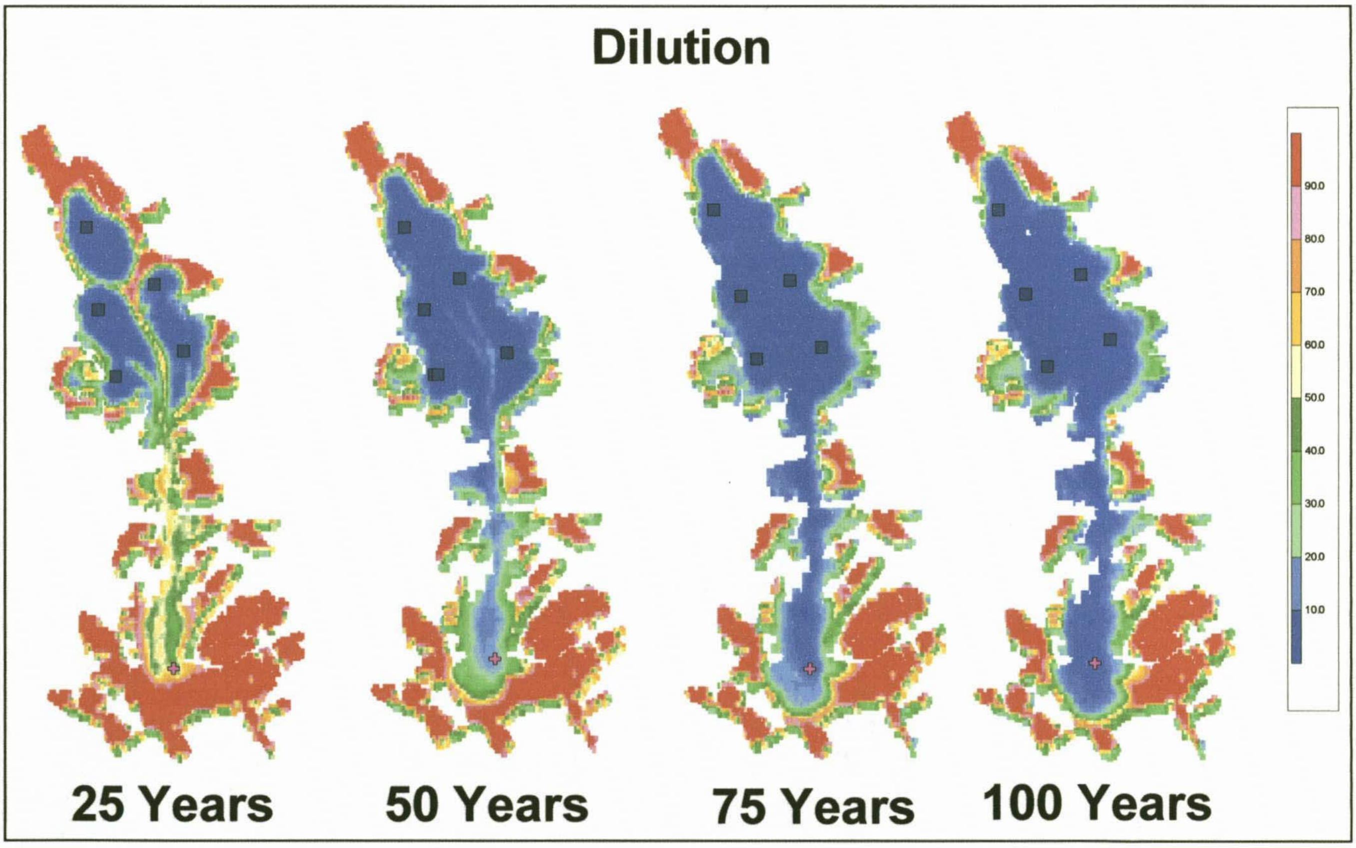


Figure 4-30. Dilution model for Ermelo Colliery.

4.9 Surface Water Quality

Water samples were taken in the Brakspruit near borehole O2 and below the tar road, downstream from the mine and the discard dump. This was to determine the effect of the mine and the discard dump on the quality of water in the stream. Figure 4-31 shows the sampling positions in the stream at Tweefontein and Mine Downstream. Table 4-11shows the results on chemical analysis done at 29 September 2002. The color-coding of the sites in Figure 4-31 illustrate the sulphate concentrations with red the highest and green the lowest values

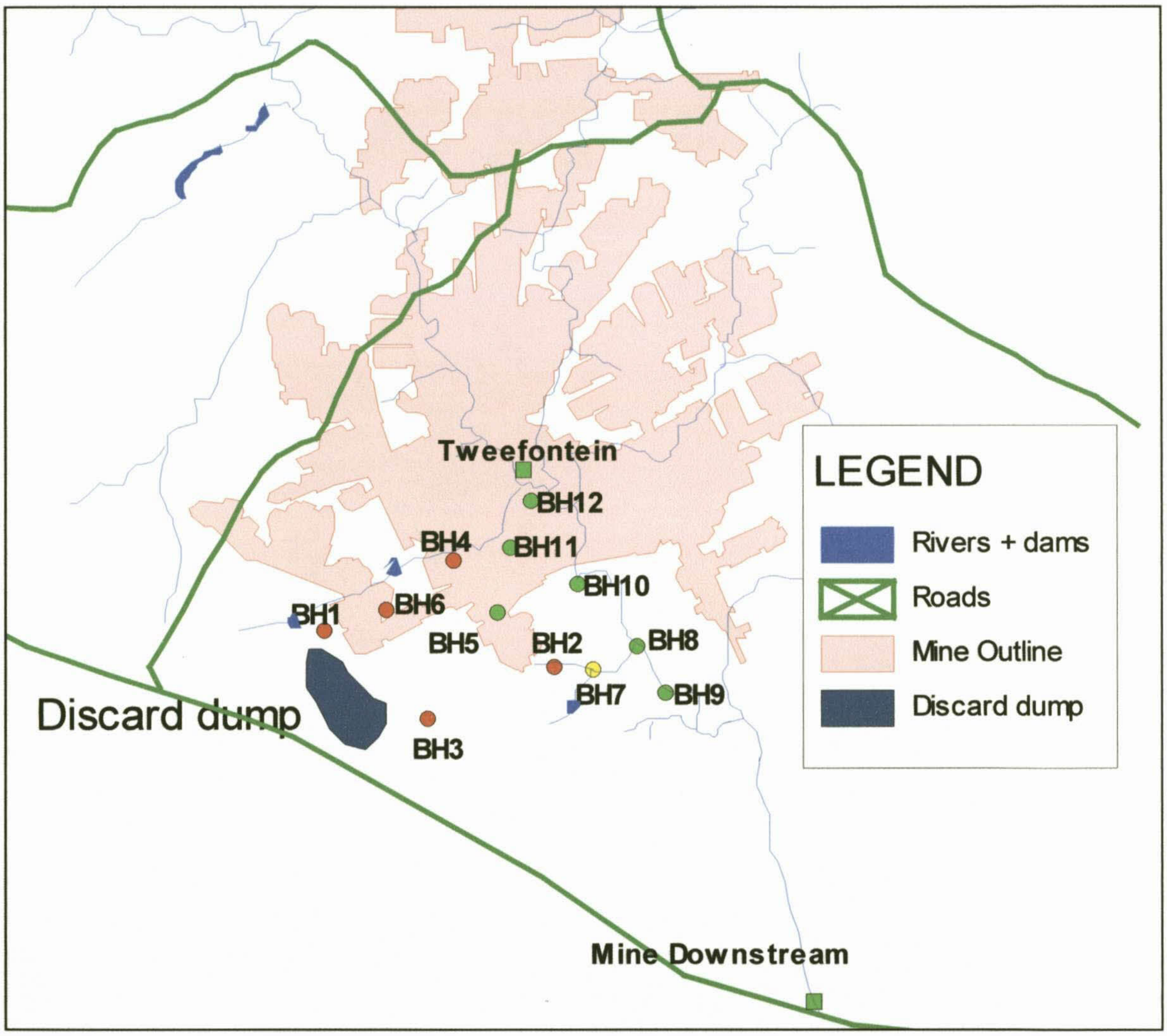


Figure 4-31. Position of sampling points in Brakspruit and boreholes below the discard dump.

Table 4-11: Results on chemical analysis of water quality of monitoring boreholes.

SiteName	pH	EC	Ca	Mg	Na	K	MALK	Cl	SO4	NO3
		mS/m	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mS/m	mg/L
BH1	7.03	478	591	278	66	6.4	213	44	2329	0
BH2	7.38	326	256	158	238	3.7	284	187	1157	0
BH3	7.06	626	759	376	62	8.5	473	537	2107	0
BH4	7.38	283	191	132	232	5.4	329	46	1045	0
BH5	6.55	29	23	10	14	1.7	36	25	28	7.54
BH6	6.84	341	337	250	26	1.1	196	208	1329	0.11
BH7	7.69	176	78	24	270	4.2	309	101	419	0
BH8	8.39	235	19	9	482	2.8	432	270	335	0
BH-9	7.89	59	27	11	109	2.4	306	18	2	0.01
BH10	7.52	49	52	15	27	1.8	127	59	23	3.68
BH11	7.31	43	40	14	39	2.2	185	13	22	1.64
BH12	8.06	69	8	2	155	1.9	252	21	69	2.15

SiteName	F	Br	Al	Fe	Mn	B	Ba	Be	Cd	Cr
	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
BH1	0.05	<0.04	0.004	0.121	0.295	<0.005	0.010	<0.001	<0.001	<0.006
BH2	0.15	<0.04	0.012	0.066	4.734	<0.005	0.048	<0.001	<0.001	<0.006
BH3	0	<0.04	0.000	0.093	0.072	<0.005	0.030	<0.001	<0.001	<0.006
BH4	0.08	0.09	0.011	0.589	0.308	<0.005	0.022	<0.001	<0.001	<0.006
BH5	0.07	0.37	0.048	0.107	0.128	<0.005	0.083	<0.001	<0.001	<0.006
BH6	0.11	<0.04	0.000	0.021	0.060	<0.005	0.026	<0.001	<0.001	<0.006
BH7	0.5	0.35	0.099	0.039	0.218	<0.005	0.056	<0.001	<0.001	<0.006
BH8	1.68	<0.04	0.365	0.349	0.089	<0.005	0.035	<0.001	<0.001	<0.006
BH-9	0.52	0.13	0.000	0.000	0.000	<0.005	0.000	<0.001	<0.001	<0.006
BH10	0.11	0.37	0.023	0.036	0.631	<0.005	0.193	<0.001	<0.001	<0.006
BH11	0.14	0.11	0.229	0.087	0.034	<0.005	0.144	<0.001	<0.001	<0.006
BH12	0.5	0.38	0.760	0.275	0.080	<0.005	0.080	<0.001	<0.001	<0.006

SiteName	Co	Cu	Pb	Li	Mo	Ni	Se	Sr	Sn	Zn
	mg/L	mg/L	mg/L	mg/L	mg/L	mS/m	mg/L	mg/L	mg/L	mg/L
BH1	<0.005	0.002	<0.015	0.002	<0.003	0.009	<0.006	1.570	<0.01	0.006
BH2	<0.005	0.001	<0.015	0.002	<0.003	0.007	<0.006	1.257	<0.01	0.008
BH3	<0.005	0.002	<0.015	0.007	<0.003	<0.006	<0.006	2.187	<0.01	0.007
BH4	<0.005	0.001	<0.015	0.008	<0.003	<0.006	<0.006	2.295	<0.01	0.006
BH5	<0.005	0.001	<0.015	0.008	<0.003	<0.006	<0.006	0.096	<0.01	0.003
BH6	<0.005	0.002	<0.015	<0.001	<0.003	0.007	<0.006	0.939	<0.01	0.005
BH7	<0.005	0.001	<0.015	0.044	<0.003	<0.006	<0.006	2.553	<0.01	0.006
BH8	<0.005	0.002	<0.015	0.034	<0.003	<0.006	<0.006	0.526	<0.01	0.003
BH-9	<0.005	0.000	<0.015	0.015	<0.003	<0.006	<0.006	0.893	<0.01	0.000
BH10	0.007	0.001	<0.015	0.010	<0.003	<0.006	<0.006	0.636	<0.01	0.007
BH11	<0.005	0.002	<0.015	0.015	<0.003	<0.006	<0.006	0.675	<0.01	0.023
BH12	<0.005	0.002	<0.015	0.016	<0.003	<0.006	<0.006	0.274	<0.01	0.013

It is clear from the water quality of the boreholes that those nearest to the discard dump (BH 1,3,4 and 6) have higher concentrations of pollution than those furthest away (BH9, 10, 11 and 12). This confirms the movement of the pollution plume from the discard dump in the direction towards the stream as shown by the modeling done by Hodgson *et al.,* (1999).

- Boreholes BH1, BH3 and BH6, which monitor water qualities at the coal discard dump are polluted, as is BH4, which is lower down in the stream running past the discard dump. High levels of sulphate, calcium and magnesium are typical of these waters.

- Boreholes BH2, BH7 and BH8 also show elevated levels of sulphate, followed by the same constituents as at the coal discard dump boreholes. In the case of BH2, this borehole monitors seepage from a pollution control dam. In the case of BH7 and BH8, these holes serve to demonstrate that pollution has progressed some distance from the original pollution sources.
- Heavy metals are currently not a problem, except for elevated values of manganese in BH2.

The effect of the polluted water on the Brakspruit is illustrated in Figure 4-32.

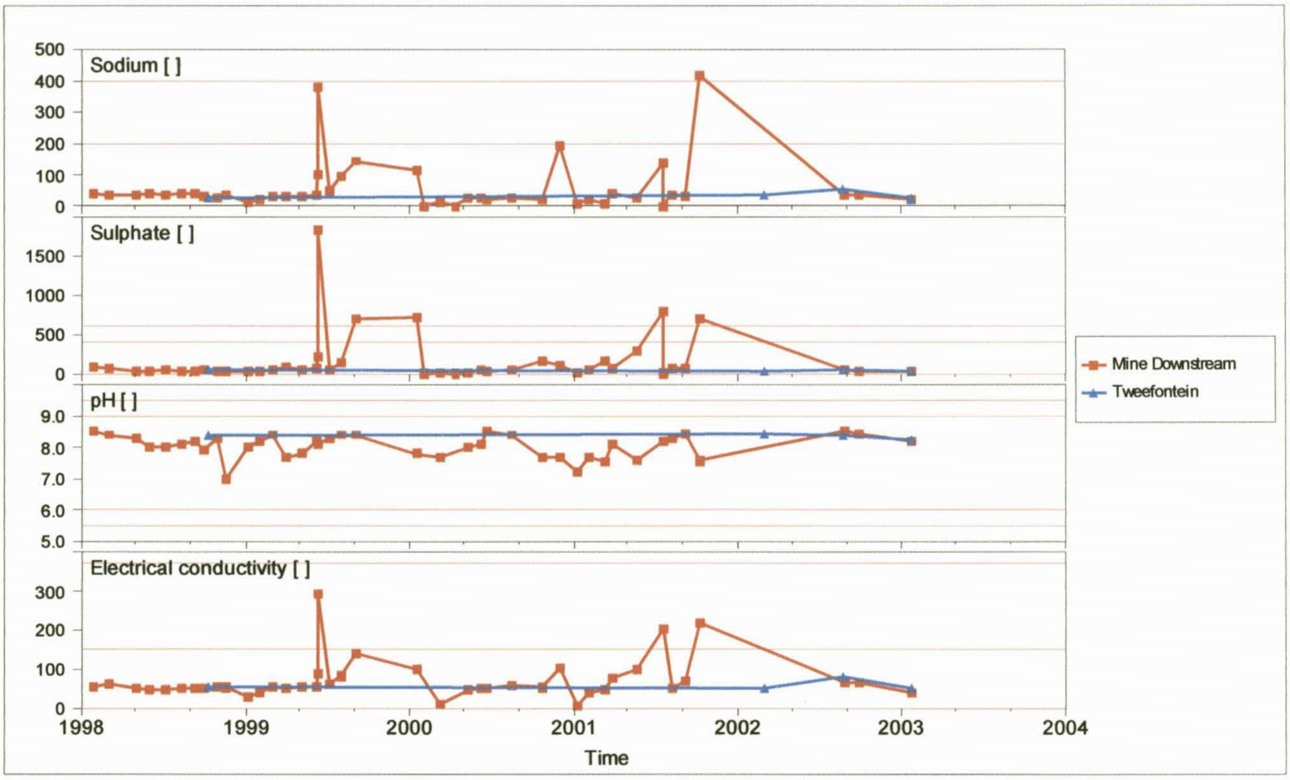


Figure 4-32. Water quality of Brakspruit above and below the discard dump.

- The water in the Brakspruit at Tweefontein sampling site is unpolluted, indicating that the mine itself currently has no effect on surface water quality.
- The water downstream is polluted, indicating that pollution from the discard dump has an effect on the stream. During the drier winter periods the salinity are higher than during summer when surface run-off dilutes the water.

4.10 Conclusions

Ermelo Colliery serves as an example of a mine where mining has ceased in recent times. This contrasts with most other mines that have been selected for this investigation.

The impact of mining methods on water influx is well illustrated in this study. Recharge rates are highly variable depending on the mining method. The average calculated for the mine is 5.5 - 7%. However, recharge in stooped areas can ranges from 1% to above 20% (as calculated) of the annual rainfall, depending on the amount of annual rainfall. This information is significant, demonstrating the importance of not designing only for average values. Particularly in water treatment plants or in water holding facilities, spare capacities must be available if extreme rainfall events are to be handled.

Also important in terms of Ermelo Colliery, is the higher than usual sodium content in the mine water. The sodium is derived from connate water in the coal and the sediments above the coal seam. Management options for the mine water that work for other collieries, such as irrigation or flushing, are not as lucrative for Ermelo Mine. Sodium is undesirable for irrigation or discharge into streams. In view of the low hydraulic conductivity of the coal left in the mine, it would take many years to flush most of the sodium from the mine. Any flushing system should take cognizance of the fact that the full salt load will be transferred into the catchment below.

After flooding of the mine, the mine water chemistry will change. Sulphate generation should diminish and so will calcium and magnesium. Sodium leaching will continue, but also at a reduced rate, because of the low rate at which sodium can be leached from the material in and around the mine excavation.

In general terms, it suffices to state that the mine will fill up with water within less than two decades, decants at rates between 1 - 10 Mm^3/d and thus, flushing will be initiated.

5 Transvaal Navigational Colliery

5.1 Introduction

The Transvaal Navigational Colliery (TNC) is located in the Mpumalanga Province between the towns of Kriel and Witbank. It forms part of the Witbank Coalfield (Erasmus *et al.,* 1981, Figure 1-1) and lies in the Olifants Catchment (Figure 1-2). Figure 5-1 shows a topographic map of the area.

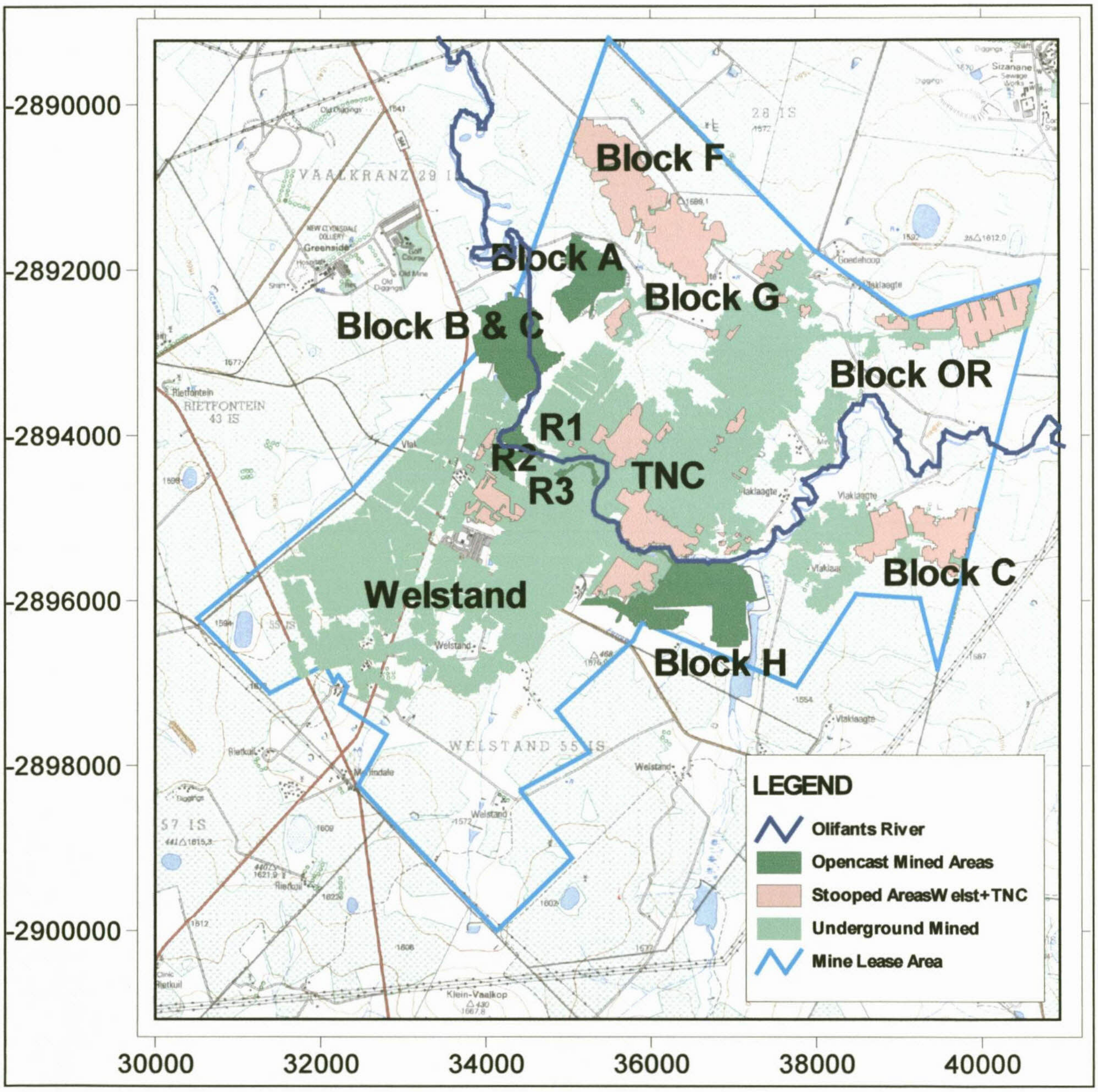


Figure 5-1. Topographic map, also showing the mining areas at TNC.

The Olifants River runs through the middle of the mine lease area. TNC ceased mining operations in 1991. The disturbed area has been rehabilitated. The only evidence of past mining is a few office buildings, a village, rehabilitated discard dump and evaporation dams (Figure 5-2 and Figure 5-3). There is no evidence of subsidence that occurred in the past. Farming activities continue unhindered in the area.

Figure 5-2. Rehabilitated coal discard dump.

Figure 5-3. Evaporation dam.

5.2 Surface Hydrology

Surface run-off on both sides of the river is in the direction of the river. Some of this water may be intercepted in surface depressions left in opencast areas. Seepage water from the discard dump flows into an evaporation dam. The flow directions are illustrated with arrows in Figure 5-4.

The average annual rainfall for the area is 687 mm (SA Weather Service). Figure 5-5 shows the rainfall for Kriel (Station 0478406A5) near TNC since 1995, with the last two years below the average. The rainfall for 2002 was 560 mm. The average regional run-off value is 36.2 mm, or 5%, for the area. Due to the steeper nature of the topography adjacent to the river, the local run-off will be higher. The mean annual evaporation for the area is 1 550 mm (Midgley *et al.*, 1990).

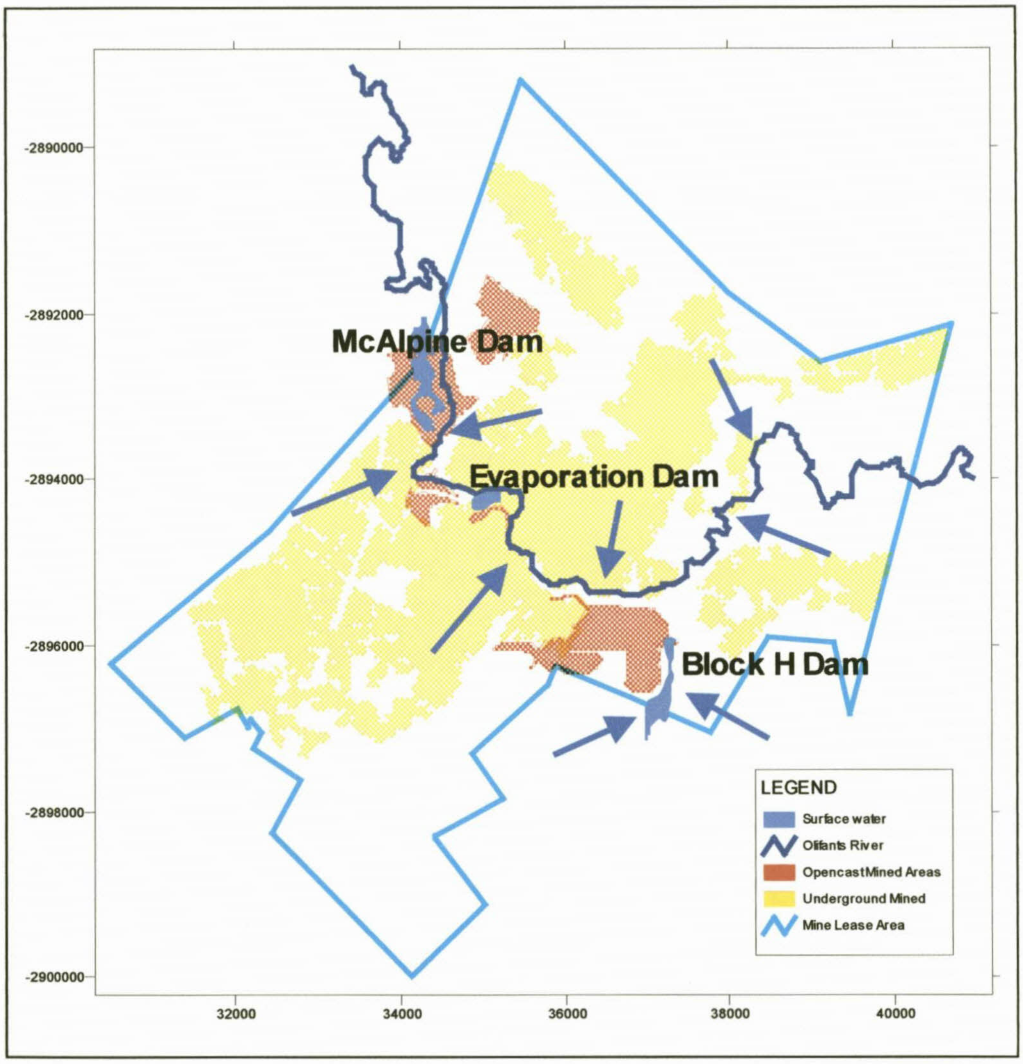


Figure 5-4. Run-off dams and directions for run-off.

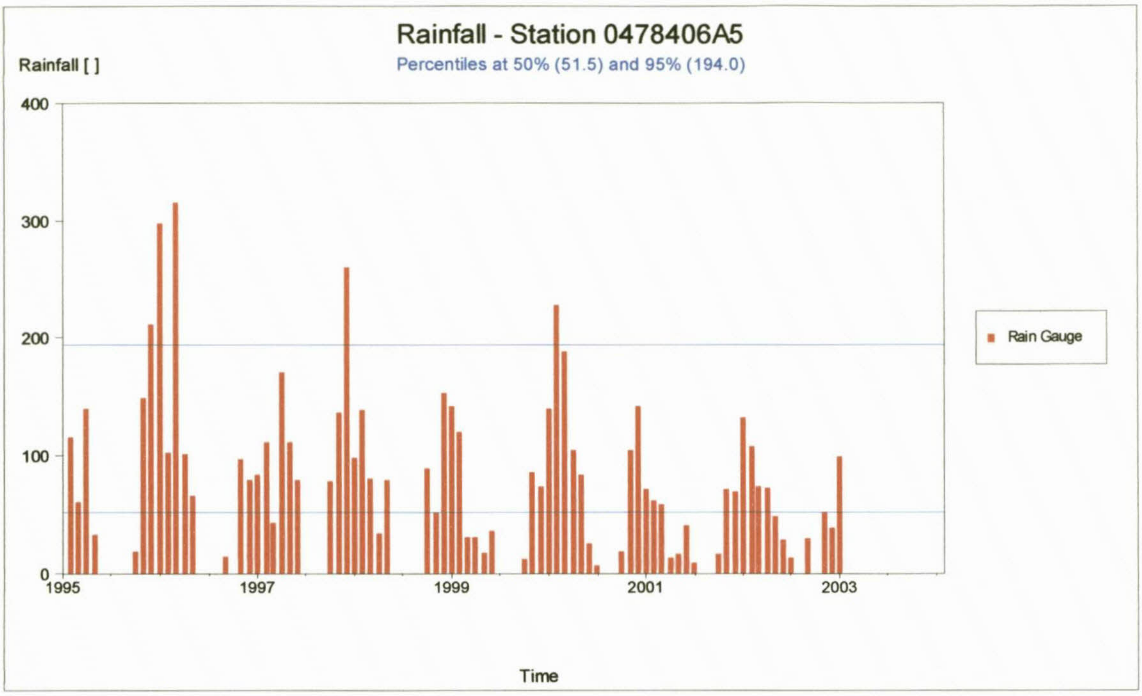


Figure 5-5. Rainfall graph for Station 0478406A5 (Kriel) near TNC.

5.3 Geology

TNC lies in the Springs-Witbank Coalfield and is flanked by the Highveld and Ermelo Coalfields.

The Karoo Sediments at TNC comprise the Ecca Group (which includes the coal seams) and Dwyka Formation. The total thickness of the Karoo Sediments at TNC ranges from 15 - 120 m.

The Ecca Sediments consist dominantly of sandstone, siltstone, shale, interbedded siltstone, mudstone and coal. Dolerite dykes and undulating sills are present. Some sills transect the coal seam, resulting in displacements of tens of metres. This is illustrated in Figure 5-6.

The Ecca Sediments overlie the Dwyka Tillite. The latter 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 at TNC, Bushveld felsite is the most likely rock type.

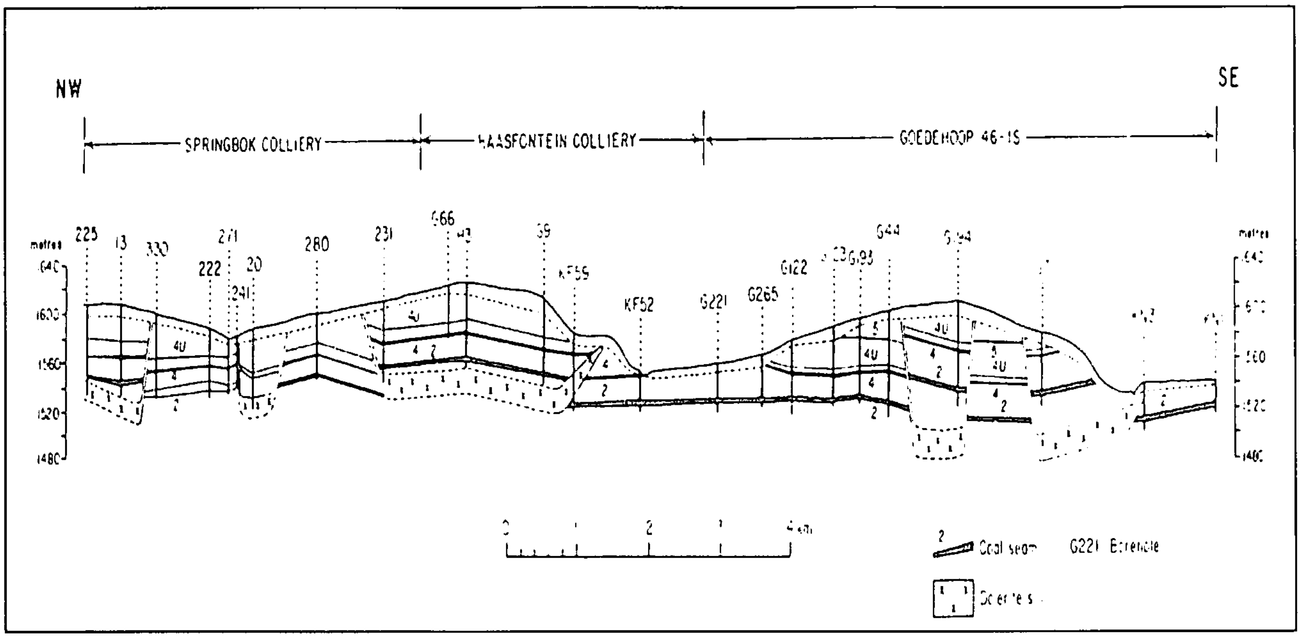


Figure 5-6. *NW-SE profile across Witbank Coalfield (from Smith and Whittaker, 1986).*

The No. 2 Coal Seam has been mined throughout the TNC area. In small areas, the No. 1 Coal Seam has also been extracted. At the entrance of the incline of Block F, about 5.5 ha of the No. 4 Coal Seam has been mined. The properties of the coal mined at TNC are summarised in Table 5-1.

Table 5-1: *Properties of crushed coal at TNC (Smith and Whittaker, 1986).*

Properties	%
Moisture content	2.5
Ash	14.6
Volatile matter	27.1
Fixed carbon	55.8
Sulphur Content	0.6

Typical geological logs for TNC are illustrated in Figure 5-7 and Figure 5-8. These two boreholes were drilled on different sides of the mine. The variability of the geology can be seen, as the logs differ completely.

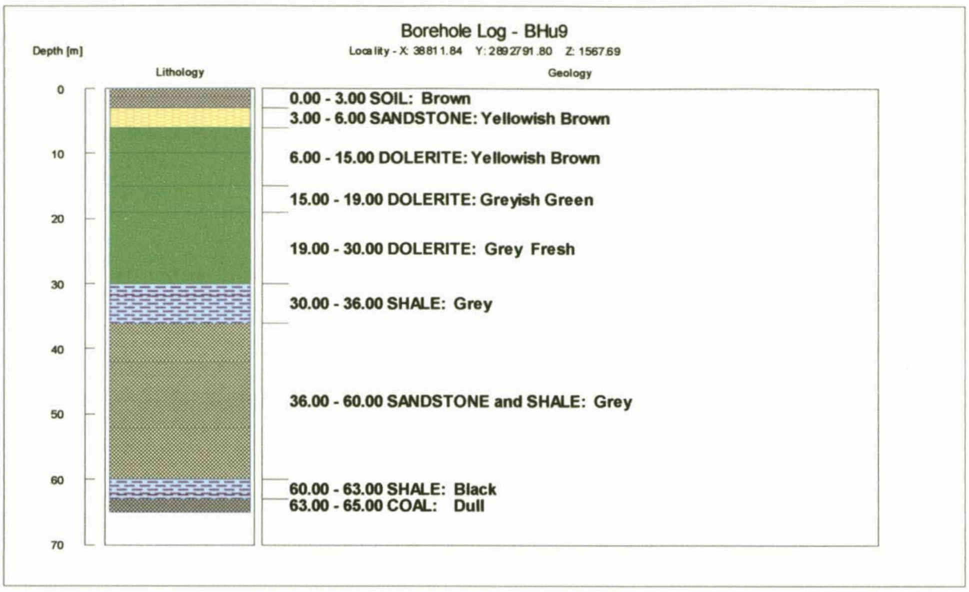


Figure 5-7. Geological log of BHu9.

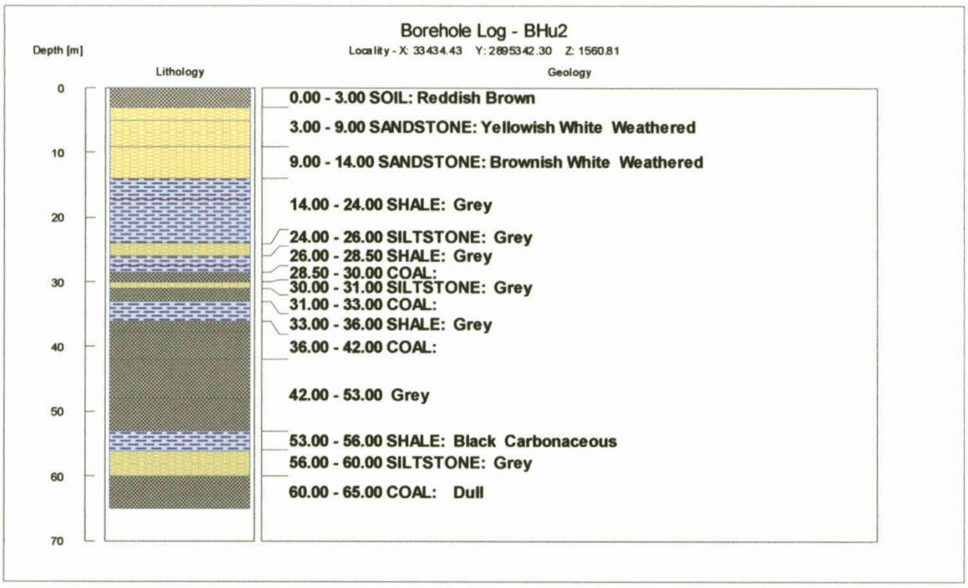


Figure 5-8. Geological log of Bhu2.

5.4 Geohydrology

Three distinct and superimposed groundwater systems are present at TNC (Grobbelaar *et al.*, 2000).

5.4.1 The weathered aquifer

The Ecca sediments are weathered to depths between 5 - 12 metres below surface throughout the TNC lease area. This can be seen in the geological logs in Figure 5-7 and Figure 5-8. The upper aquifer, which is usually perched, is associated with the weathered zone. Water is often intersected in boreholes within a few metres below surface. This aquifer is actively recharged by rainfall. Rainfall that infiltrates into the weathered rock reaches an impermeable layer of shale below the weathered zone. Movement of groundwater on top of this shale is lateral and occurs in the direction of the surface slope. Groundwater in the weathered aquifer reappears on surface at fountains, where the flow paths are obstructed by barriers such as dolerite dykes, basement highs in the bedrock, or where the surface topography cuts into the groundwater table at streams.

The aquifer within the weathered zone is low-yielding (range 50 - 500 L/h), because of its insignificant thickness. Few farmers therefore tap this aquifer by borehole (Grobbelaar *et al.*, 2000).

5.4.2 Unweathered, fractured Ecca aquifers

Pores in the unweathered Ecca sediments are too well cemented to allow groundwater flow. Groundwater movement through the fresh rock is along secondary structures, such as fractures, cracks and joints in the fresh sediments. These structures are better developed in sandstone than in shale. At depths greater than 30 m, water-bearing fractures with significant yield are few.

5.4.3 Pre-Karoo aquifers

None of the farmers at TNC tap water from the aquifer beneath the Dwyka tillite. (Grobbelaar *et al.*, 2000). The reasons for this are:

- The great depth.
- Low-yielding character of rocks below the tillite.
- Inferior water quality, with high levels of fluoride, associated with felsite.
- Low recharge characteristics for this aquifer because of the overlying impermeable Dwyka tillite.

5.5 Mining

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. Statistics on TNC mine are summarised in Table 5-2.

Table 5-2: Statistics on mining as TNC.

Mine lease area (ha)	4 567
Total mined underground (ha)	1 824
Total area stooped (ha)	387
Total area opencast mined (ha)	253
Volume mined (Mm^3)	35.35
Average mining height (m)	3
Mining depth below surface (m)	6 - 101

Figure 5-9 shows the floor contours. The central portion of the TNC coal seam floor has a basin structure, with its lowest point underneath the TNC Village. Here, the No. 2 Seam floor elevation is in the order of 1 496 mamsl. The coal floor rises in all directions away from this point to attain a maximum elevation of 1 530 in the southeast. The other areas at TNC are separated from the main block through dolerite displacements. Figure 5-10 shows the surface contours of TNC. It also indicates the position of the shafts.

The depth of mining varies from as little as 6 m in the opencast areas of Block A, Block B&C and Block H to more than 100 m in the Welstand Block. The depth of mining is shown Figure 5-11.

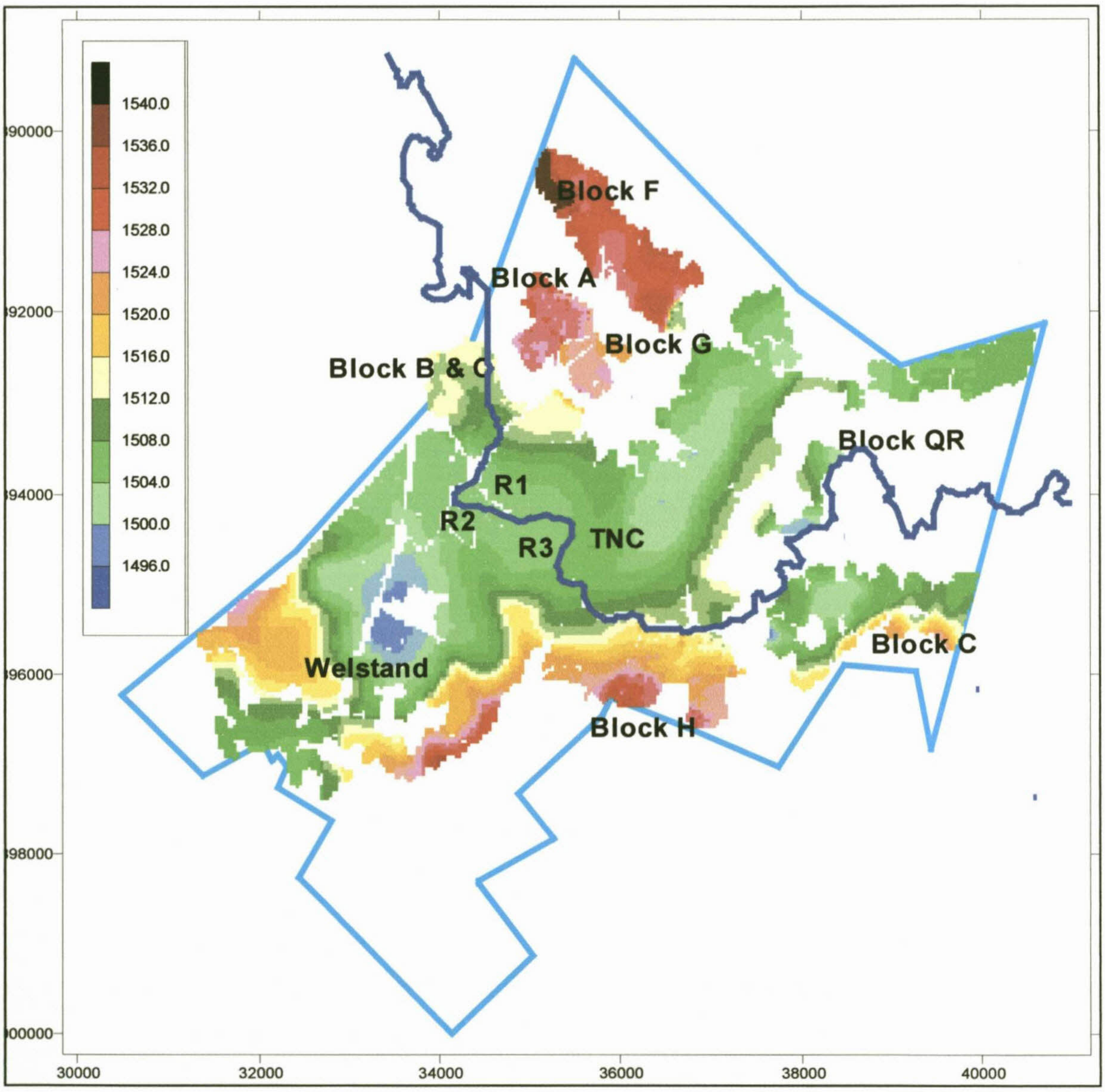


Figure 5-9. Floor contours for TNC.

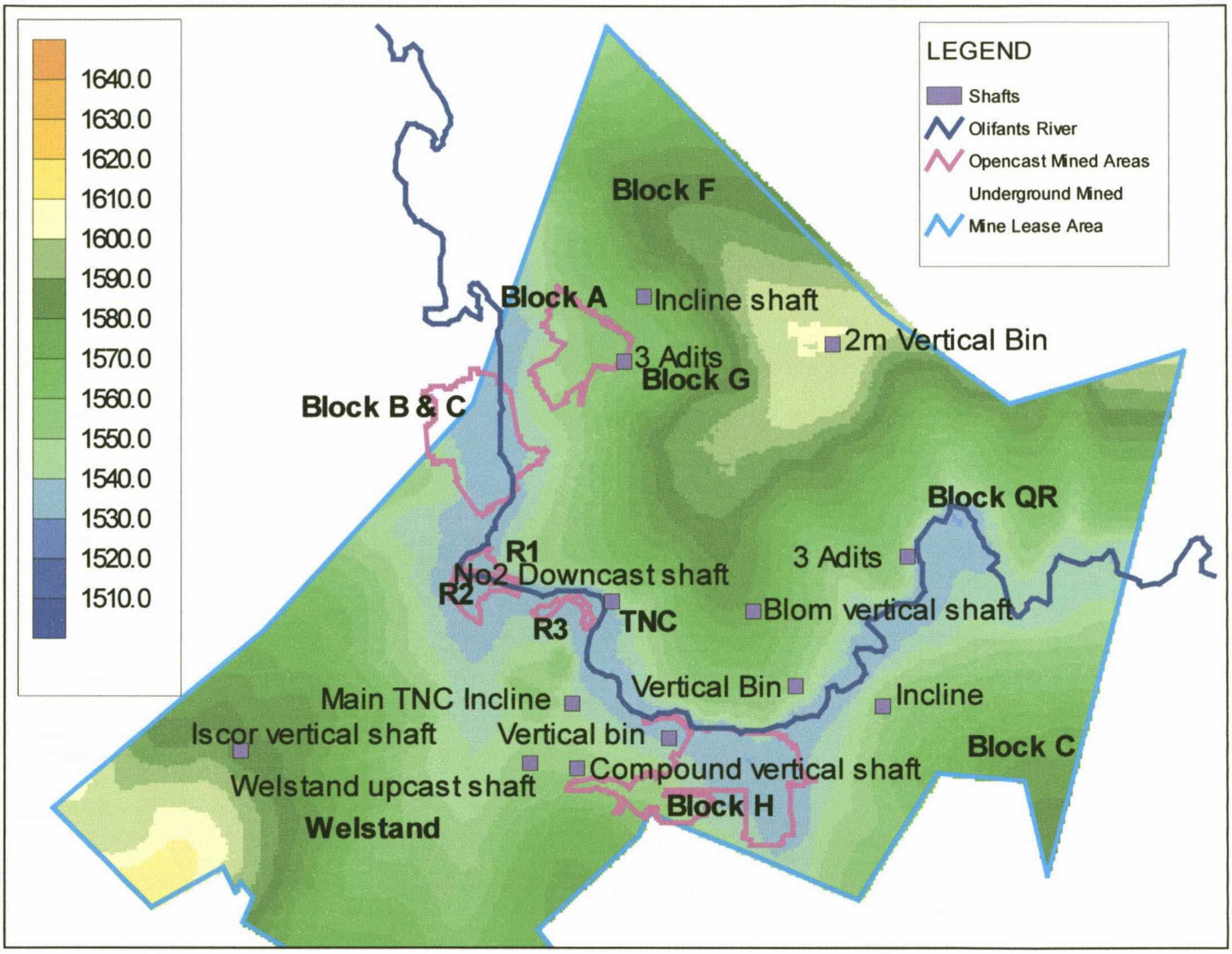


Figure 5-10. Surface contours at TNC, also indicating the position of the shafts.

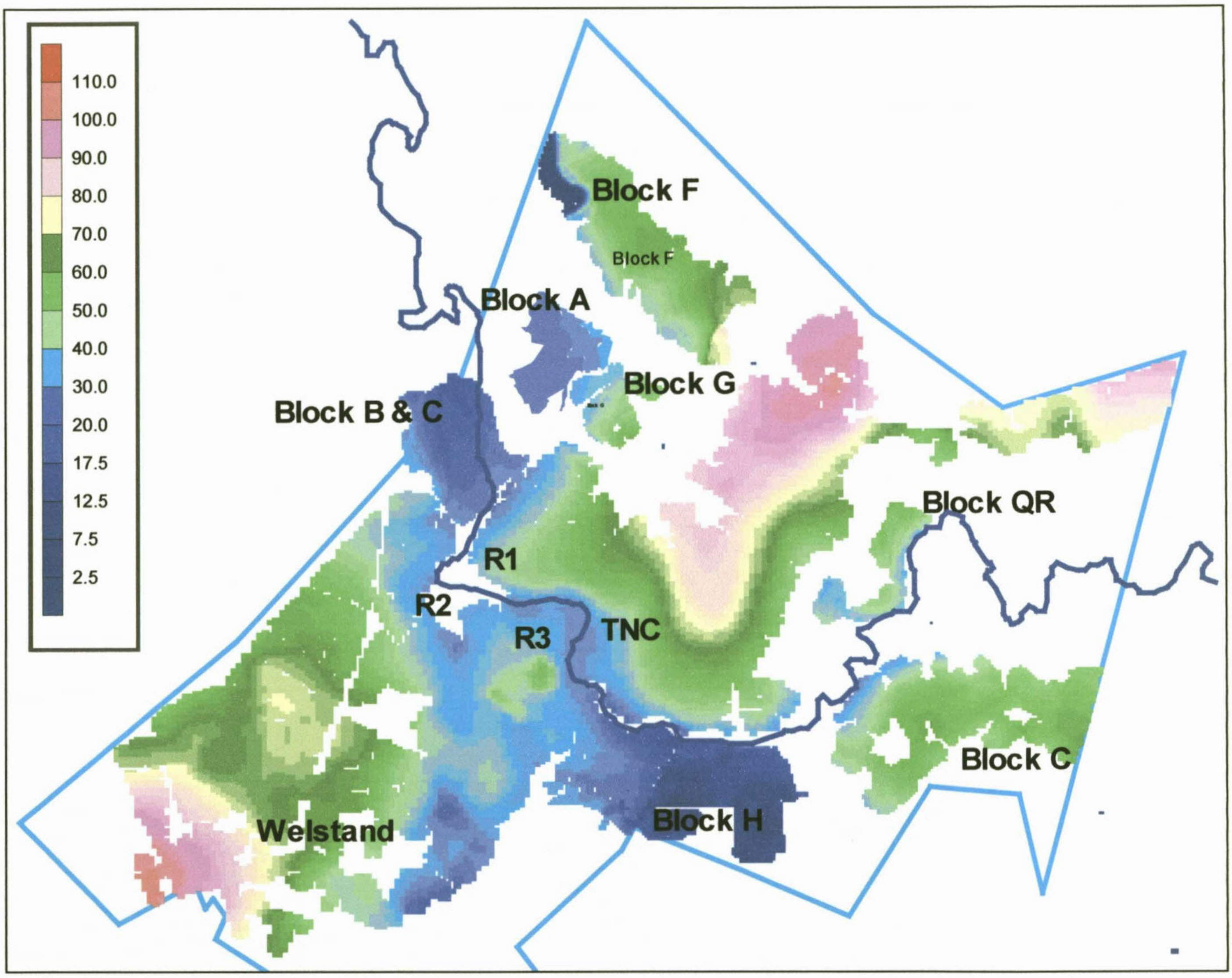


Figure 5-11. Depth of mining below surface at TNC.

5.6 Water quantities and qualities

Conditions differ in the various areas that have been mined and they will therefore be discussed separately.

5.6.1 Welstand-TNC (Underground)

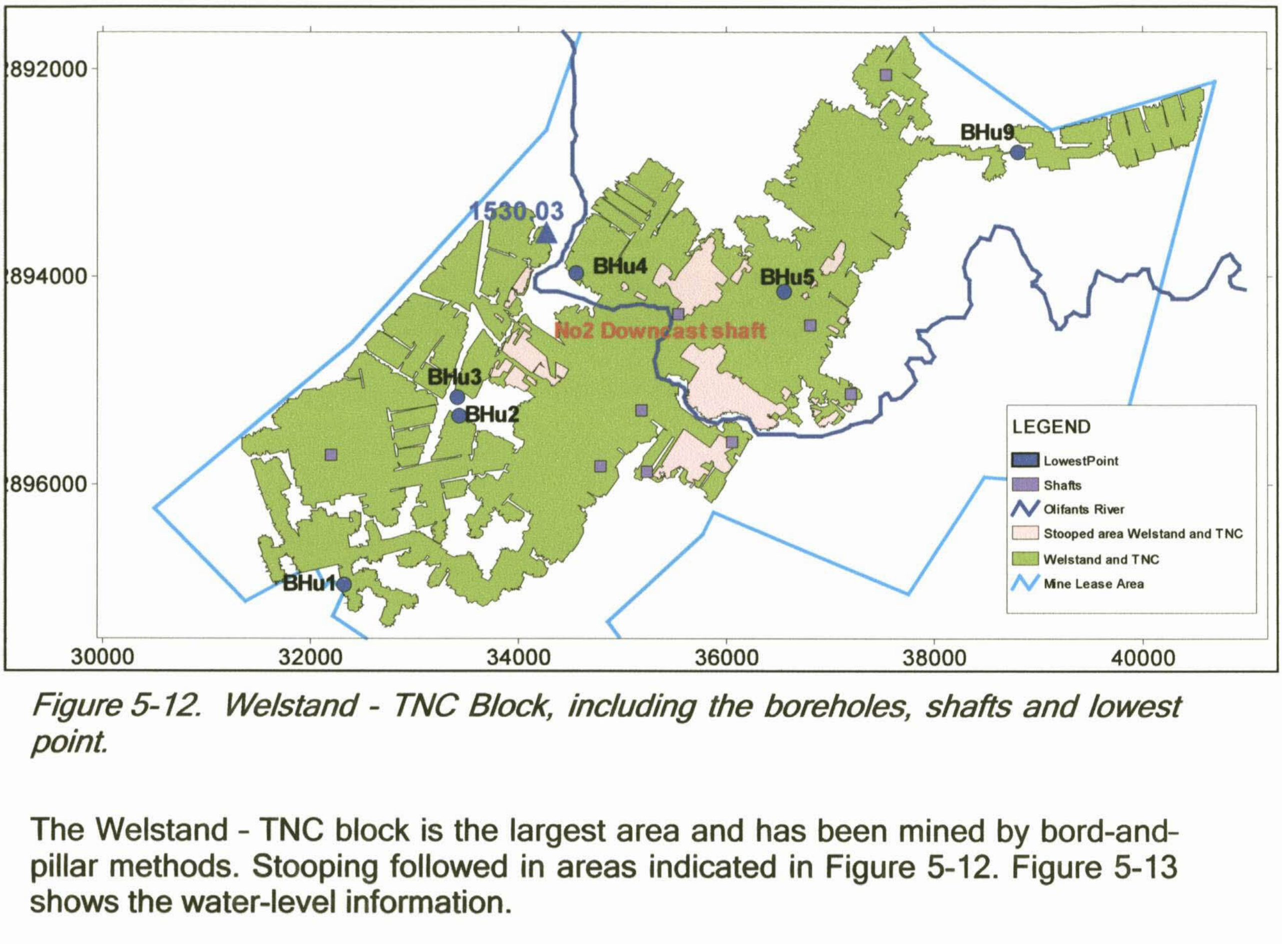


Figure 5-12. Welstand - TNC Block, including the boreholes, shafts and lowest point.

The Welstand - TNC block is the largest area and has been mined by bord-and-pillar methods. Stooping followed in areas indicated in Figure 5-12. Figure 5-13 shows the water-level information.

A summary of the statistics of the Welstand - TNC area is included in Table 5-3. The total volume of voids, the volume at decant (Figure 5-14), and the volumes during January 2002 and January 2003 were determined using stage curves. To determine the lateral influx into the mine, the gradient value was based on slope measurements, and the transmissivity value was calculated from packer tests done for conductivity (Hodgson and Krantz, 1998) and from a groundwater flow model done by van Tonder and Krantz (1997).

Table 5-3: Statistics of Welstand-TNC area.

Area Mined	1490 ha
Area Stooped	186 ha
Water level January 2002	1521.49 mamsl
Water level January 2003	1521.62 mamsl
Water volume January2002	27.405 Mm^3
Water volume January2003	27.460 Mm^3
Water volume gain	53 000 m^3
Decant elevation	1530.03 mamsl
Total volume of voids	28.95 Mm^3
Volume water at decant	28.85 Mm^3
Percentage currently flooded	95%
Percentage flooded at decant	99.6%
Lateral influx:	
Gradient	0.02
Length of influx	12400 m
Transmissivity	0.3
Groundwater influx	24 800 m^3/a
Calculated water influx	
6% Recharge over stooped areas	52 400 m^3/a
4% Recharge over bord-and-pillar areas	245 000 m^3/a
Total water influx (recharge & flux)	322 200 m^3/a

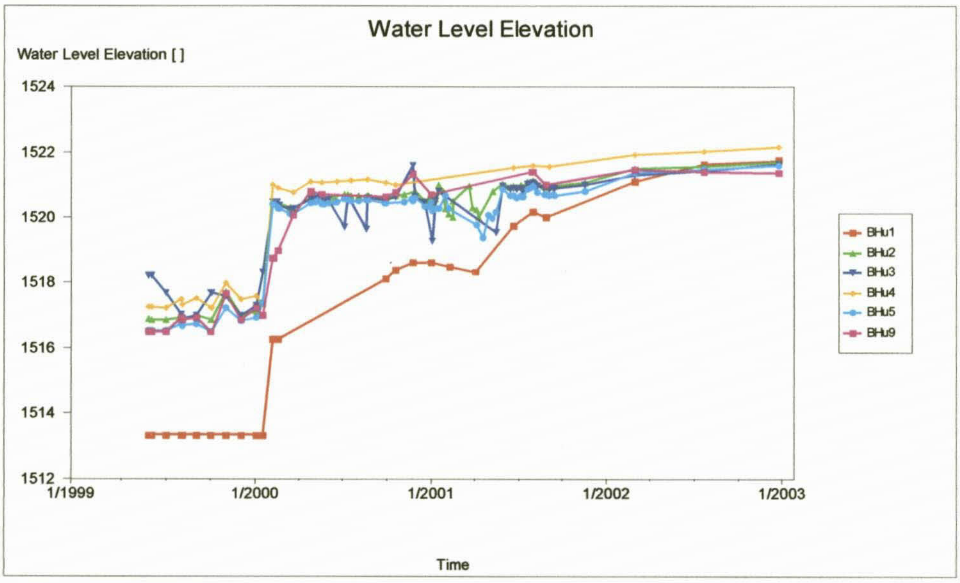


Figure 5-13. Water levels for Welstand - TNC.

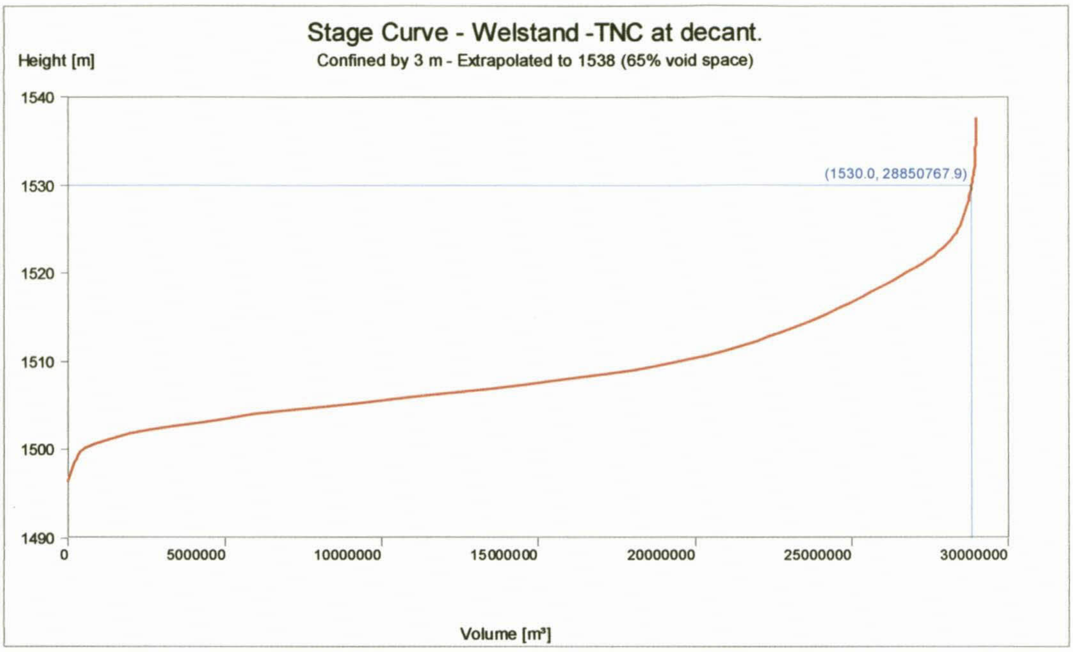


Figure 5-14. Stage curve for the Welstand Area, showing the decanting level and volume.

The following is concluded from the available information:

- The sharp rise of 3.5 m in the water level during 2000 is anomalous. It is believed by Grobbelaar *et al.,* (2000) that most of the water was derived from an inrush of Olifants River water through the Block H Opencast. This pit links with the underground workings.

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

5.6.1.1 Decant

There are two possibilities for mine water to exit from the underground workings. One is seepage towards New Clydesdale Colliery, and the other is decanting onto the surface, into the Olifants River. Currently, the mine water level at New Clydesdale Colliery is suspiciously at the same level as at TNC. This could be interpreted in a number of ways. Decant towards the Olifants River will not occur until the mine water level rises by another 8 m. For this to happen another 1,39 Mm^3 should enter into the mine. Indications are that, under natural rainfall conditions (687mm), this would take another 20 years.

5.6.1.2 Water quality

The water quality measured on 7 August 2002 and 4 October 2002 is shown in Table 5-4.

Table 5-4: Water quality for Welstand-TNC Block (mg/L).

SiteName	Date	MALK	EC	pH	Ca	Cl	Mg	NO3	PO4	SO4
		mg/L	mS/m		mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
BHu1	07-Aug-02	124	38	7.74	24	24	7	0	<0.01	31
BHu1	04-Oct-02	131	34	7.69	22	32	10	0	<0.01	31
BHu2	07-Aug-02	127	331	6.61	341	28	212	0	<0.01	1747
BHu2	04-Oct-02	151	113	6.95	112	43	66	1	<0.01	496
BHu3	04-Oct-02	327	128	7.42	116	47	48	0	<0.01	416
BHu4	07-Aug-02	285	231	7.59	212	19	129	0	<0.01	938
BHu4	04-Oct-02	270	202	8.18	223	30	131	0	<0.01	1060
BHu5	04-Oct-02	99	18	7.61	18	11	7	0	<0.01	14
BHu9	07-Aug-02	153	55	7.95	32	8	12	0	15.9	36
BHu9	04-Oct-02	164	42	7.79	28	12	11	0	<0.01	21
SiteName	**Date**	**K**	**Na**	**Fe**	**Si**	**As**	**Al**	**Sb**	**B**	**Ba**
		mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	<0.04	mg/L
BHu1	07-Aug-02	3	47	0.217	<1	<0.01	0.022	<0.006	<0.04	0.297
BHu1	04-Oct-02	4	48	0.550	11.8	<0.01	0.009	<0.006	<0.04	<0.01
BHu2	07-Aug-02	9	102	10.478	<1	<0.01	0.049	<0.006	<0.04	0.057
BHu2	04-Oct-02	6	63	4.110	8.6	<0.01	0.009	<0.006	<0.04	<0.01
BHu3	04-Oct-02	6	136	0.738	7.3	<0.01	0.009	<0.006	<0.04	<0.01
BHu4	07-Aug-02	6	123	0.073	<1	<0.01	0.029	<0.006	<0.04	0.071
BHu4	04-Oct-02	6	128	0.632	7.2	<0.01	0.009	<0.006	<0.04	<0.01
BHu5	04-Oct-02	5	23	0.648	16.9	<0.01	0.169	<0.006	<0.04	<0.01
BHu9	07-Aug-02	6	24	0.196	<1	<0.01	0.056	<0.006	<0.04	0.016
BHu9	04-Oct-02	4	34	0.945	22.1	<0.01	0.230	<0.006	<0.04	<0.01
SiteName	**Date**	**Be**	**Br**	**Cd**	**Cr**	**Co**	**Cu**	**F**	**V**	**Pb**
		mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
BHu1	07-Aug-02	<0.01	0.18	<0.01	<0.006	<0.005	<0.03	0.79	<0.01	<0.015
BHu1	04-Oct-02	<0.01	<0.01	<0.01	<0.006	<0.005	<0.03	0.850	<0.01	<0.015
BHu2	07-Aug-02	<0.01	0.04	<0.01	<0.006	0.027	<0.03	0.88	<0.01	<0.015
BHu2	04-Oct-02	<0.01	<0.01	<0.01	<0.006	<0.005	<0.03	0.920	<0.01	<0.015
BHu3	04-Oct-02	<0.01	<0.01	<0.01	<0.006	<0.005	<0.03	2.390	<0.01	<0.015
BHu4	07-Aug-02	<0.01	<0.01	<0.01	<0.006	<0.005	<0.03	1.11	<0.01	<0.015
BHu4	04-Oct-02	<0.01	<0.01	<0.01	<0.006	<0.005	<0.03	0.920	<0.01	<0.015
BHu5	04-Oct-02	<0.01	<0.01	<0.01	<0.006	<0.005	<0.03	0.270	<0.01	<0.015
BHu9	07-Aug-02	<0.01	1.02	<0.01	<0.006	<0.005	<0.03	0.13	0.019	<0.015
BHu9	04-Oct-02	<0.01	<0.01	<0.01	<0.006	<0.005	<0.03	0.060	<0.01	<0.015
SiteName	**Date**	**Li**	**Mn_**	**Mo**	**Ni**	**Se**	**Sr**	**Sn**	**Zn**	**SAR**
		mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
BHu1	07-Aug-02	0.016	0.043	<0.002	<0.01	<0.006	0.252	<0.01	0.008	2.171
BHu1	04-Oct-02	<0.005	0.256	<0.002	<0.01	<0.006	<0.01	<0.01	<0.008	2.120
BHu2	07-Aug-02	0.131	3.311	<0.002	0.057	<0.006	3.112	<0.01	0.044	1.067
BHu2	04-Oct-02	<0.005	1.390	<0.002	<0.01	<0.006	<0.01	<0.01	<0.008	1.160
BHu3	04-Oct-02	<0.005	<0.01	0.507	<0.01	<0.006	<0.01	<0.01	<0.008	2.680
BHu4	07-Aug-02	0.095	0.843	<0.002	<0.01	<0.006	3.485	<0.01	<0.008	1.635
BHu4	04-Oct-02	<0.005	1.660	<0.002	<0.01	<0.006	<0.01	<0.01	<0.008	1.680
BHu5	04-Oct-02	<0.005	0.250	<0.002	<0.01	<0.006	<0.01	<0.01	<0.008	1.180
BHu9	07-Aug-02	<0.005	0.118	<0.002	<0.01	<0.006	0.121	<0.01	<0.008	0.910
BHu9	04-Oct-02	<0.005	0.345	<0.002	<0.01	<0.006	<0.01	<0.01	<0.008	1.380

Chemical profiles done on boreholes BHu3 and Bhu4 in the Welstand - TNC Block are shown in Figure 5-15 and Figure 5-16.

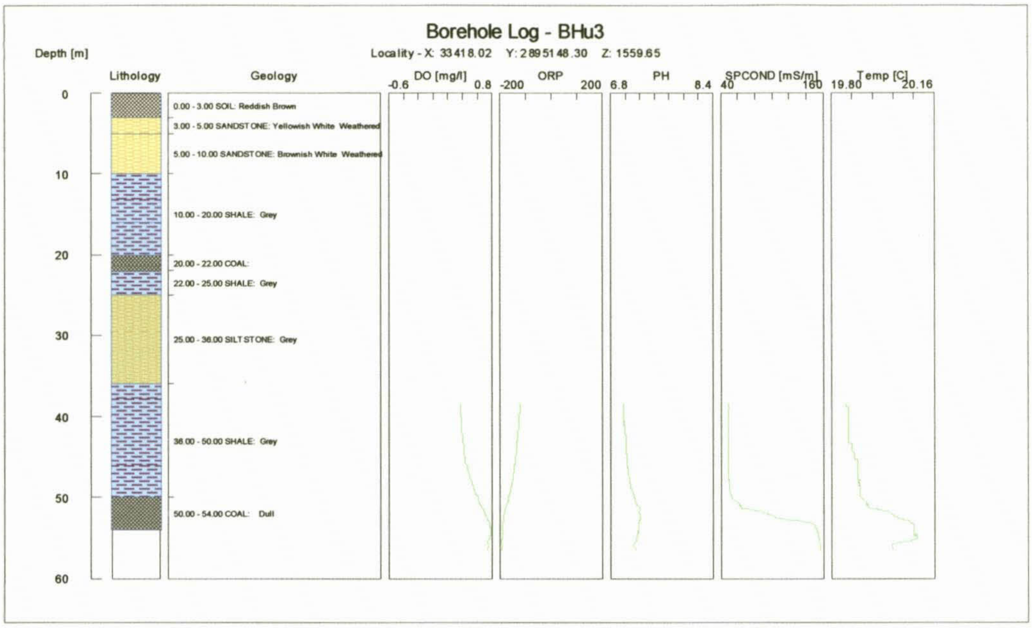


Figure 5-15. Chemical profile of BHu3.

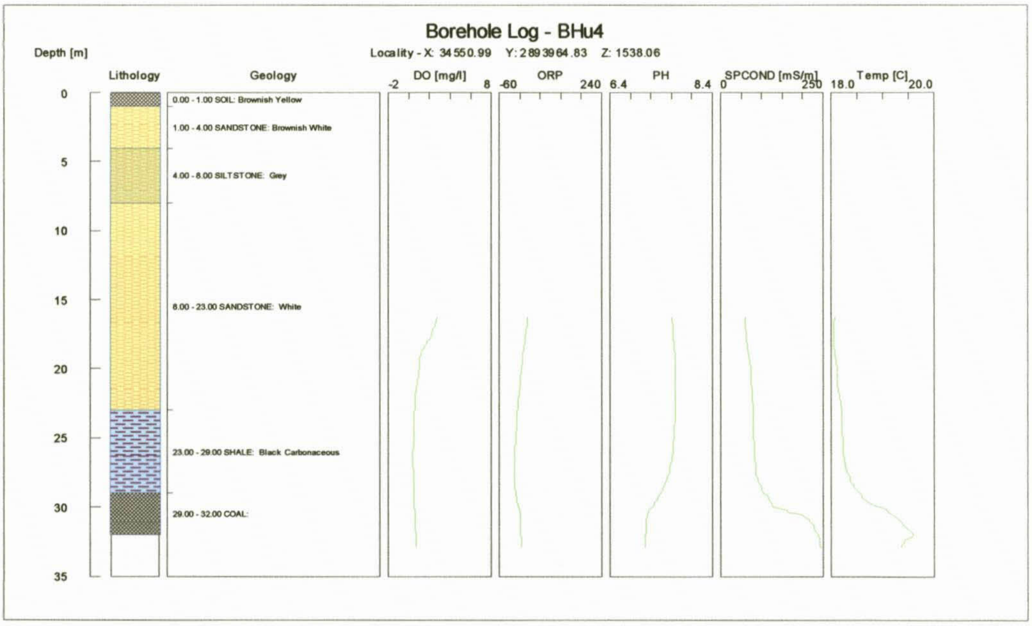


Figure 5-16. Chemical profile of BHu4.

- The water quality of this compartment is generally quite good. This can be attributed to the dynamic recharge into the mine, especially from flooding from the Olifants River.

- The chemical profiles show that the salinity of the water increases in the mining void. Above the void the specific conductance is 45 mS/m, compared to above 250 mS/m in the void. The pH levels are mostly above 7, confirming that some neutralising potential still exists in the mine. This, together with the high percentage of the underground workings already flooded, are favourable conditions for maintaining alkaline conditions.
- The sulphate concentrations, except for one analysis of Bhu2, are low for mine water. This is because oxygen is excluded from the compartment, and this prevents the oxidization of the pyrite.

5.6.2 Block C Underground

Block C Underground was mined by bord-and-pillar and stooping methods, as indicated in Figure 5-17. Figure 5-18 to Figure 5-19 show the water-related information, with the water-level graph indicating that the water level has dropped slightly during 2002. The volume of water in the mine cavity remained almost the same, since it is filled to above the mine workings.

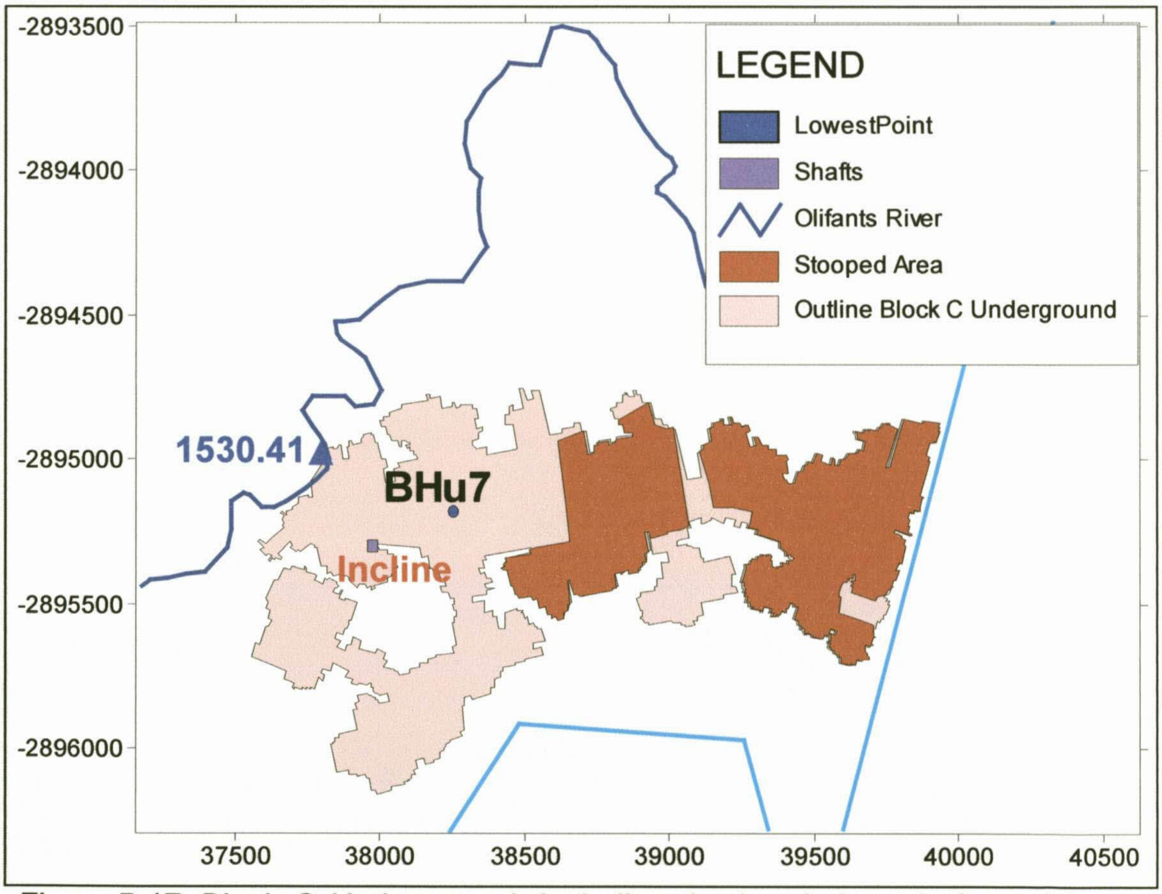


Figure 5-17. Block C Underground, including the boreholes, shafts and lowest surface point on mine perimeter.

A summary of the statistics for Block C Underground is included in Table 5-5.

Table 5-5: Statistics of Block C Underground.

Area Mined	146.53 ha
Area Stooped	60.38 ha
Water level January 2002	1532.63 mamsl
Water level January 2003	1532.38 mamsl
Water volume January 2002	2.86 Mm^3
Water volume January 2003	2.86 Mm^3
Water volume lost	0 m^3
Decant elevation	1546 mamsl
Volume water at decant	2.86 Mm^3
Percentage currently flooded	100%
Percentage flooded at decant	100%
Lateral influx:	
Gradient	0.03
Length of influx	2550 m
Transmissivity	0.3 m^2/d
Groundwater influx	7 600 m^3/a
Calculated water influx	
6% Recharge over stooped areas	17 000 m^3/a
4% Recharge over bord-and-pillar areas	16 000 m^3/a
Total water influx (recharge & flux)	40 600 m^3/a

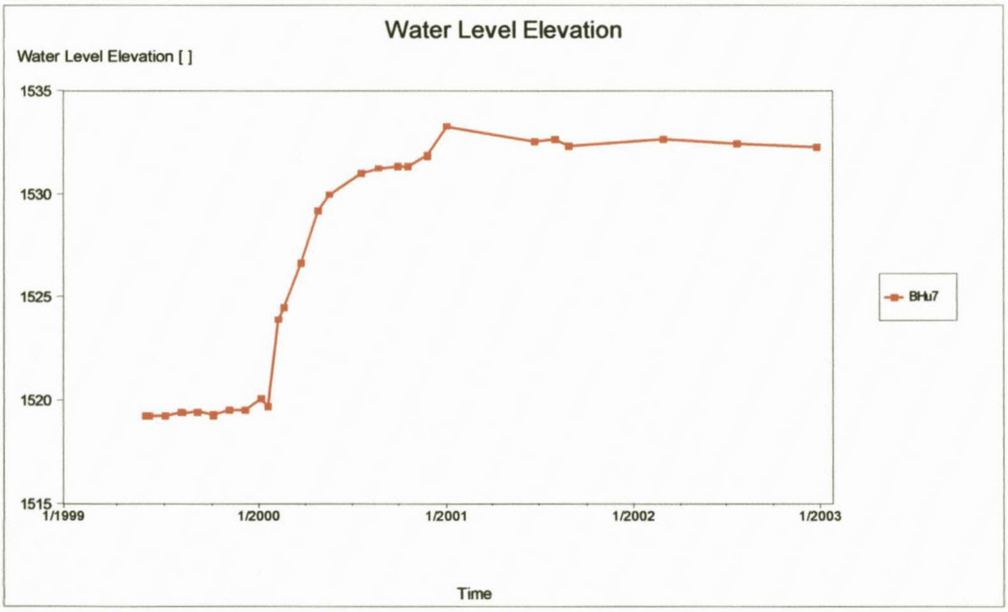


Figure 5-18. Water-level graph for Block C Underground.

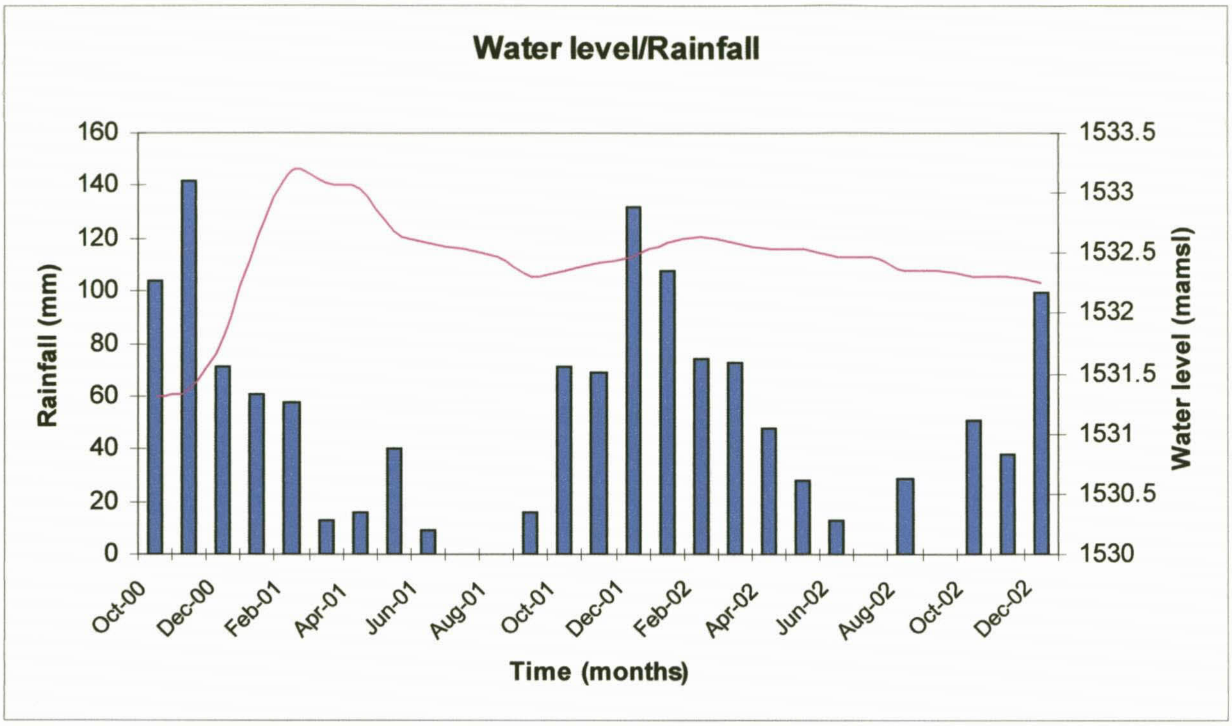


Figure 5-19. Rainfall / water level graph for Block C Underground

From the above information the following is concluded:

- As is the case with the Welstand-TNC Block, the water level rose sharply in Block C during 2000. Since then the water level of BHu7 has been stable at around 1532.5 mamsl. There seems to be a correlation between the water level fluctuations and rainfall (Figure 5-19).

5.6.2.1 Decant:

The surface elevation of the decline shaft is at 1548 mamsl, but the lowest point at the surface is at 1 530, next to the Olifants River, as illustrated in Figure 5-17. To decant at the shaft, the water level has to rise another 15 m, which seems to be highly unlikely. Monitoring of water levels in this section of TNC over a matter of time will provide a clearer indication of the final decanting/seepage level.

5.6.2.2 Water quality

Table 5-6 provides information on the water quality in Block C.

Table 5-6: Water qualities for Block C (mg/L).

SiteName	Date	MALK	EC	pH	Ca	Cl	Mg	NO3	PO4	SO4
		mg/L	mS/m		mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
BHu7	07-Aug-02	282	138	7.44	166	10	84	0	<0.01	573
BHu7	04-Oct-02	228	120	8.250	134	18	63	0	<0.01	458
SiteName	**Date**	**K**	**Na**	**Fe**	**Si**	**As**	**Al_**	**Sb**	**B**	**Ba**
		mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
BHu7	07-Aug-02	7	76	0.067	<0.01	<0.01	0.030	<0.006	<0.04	0.076
BHu7	04-Oct-02	8	68	0.101	5.2	<0.01	0.009	<0.006	<0.04	<0.01
SiteName	**Date**	**Be**	**Br**	**Cd**	**Cr**	**Co**	**Cu**	**F**	**V**	**Pb**
		mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
BHu7	07-Aug-02	<0.001	0.06	<0.001	<0.006	<0.005	<0.03	1.46	<0.01	<0.015
BHu7	04-Oct-02	<0.001	<0.01	<0.001	<0.006	<0.005	<0.03	0.900	<0.01	<0.015
SiteName	**Date**	**Li**	**Mn_**	**Mo**	**Ni**	**Se**	**Sr**	**Sn**	**Zn**	**SAR**
		mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
BHu7	07-Aug-02	0.136	0.424	0.010	<0.01	<0.006	2.612	<0.01	0.029	1.198
BHu7	04-Oct-02	<0.005	0.705	0.010	<0.01	<0.006	<1	<0.01	<0.008	1.210

The following is concluded:

- There has been very little change from one sampling episode to the next.
- The pH ranges between 7.5 and 8.2. With a base potential in excess of 200 mg/L, it is unlikely that this compartment will acidify.
- With the compartment completely filled, thus excluding oxygen, sulphate generation should be limited. The dilution of the compartment due to recharge and seepage will result in a slow improvement in the mine water quality over time. Figure 5-20, confirms the water quality values indicated in Table 5-6. The profiling also indicates a pH of 7-8 and an electric conductivity of less than 200 mSm.

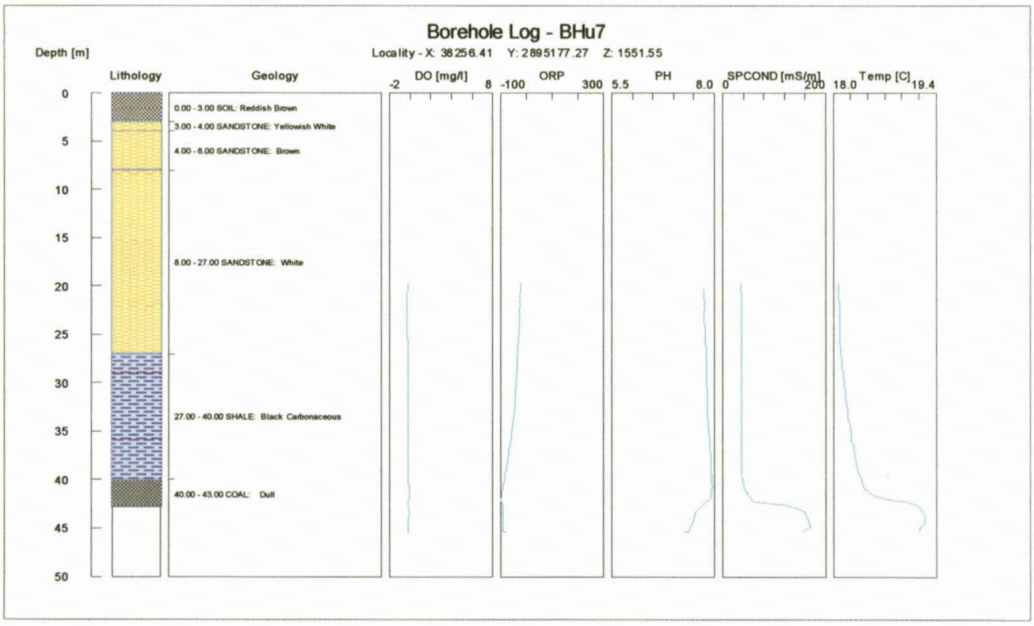


Figure 5-20. Chemical profiles for Block C .

5.6.3 Block G Underground and Block A Opencast

The layout for Block G and its interconnection with Block A is shown in Figure 5-21.

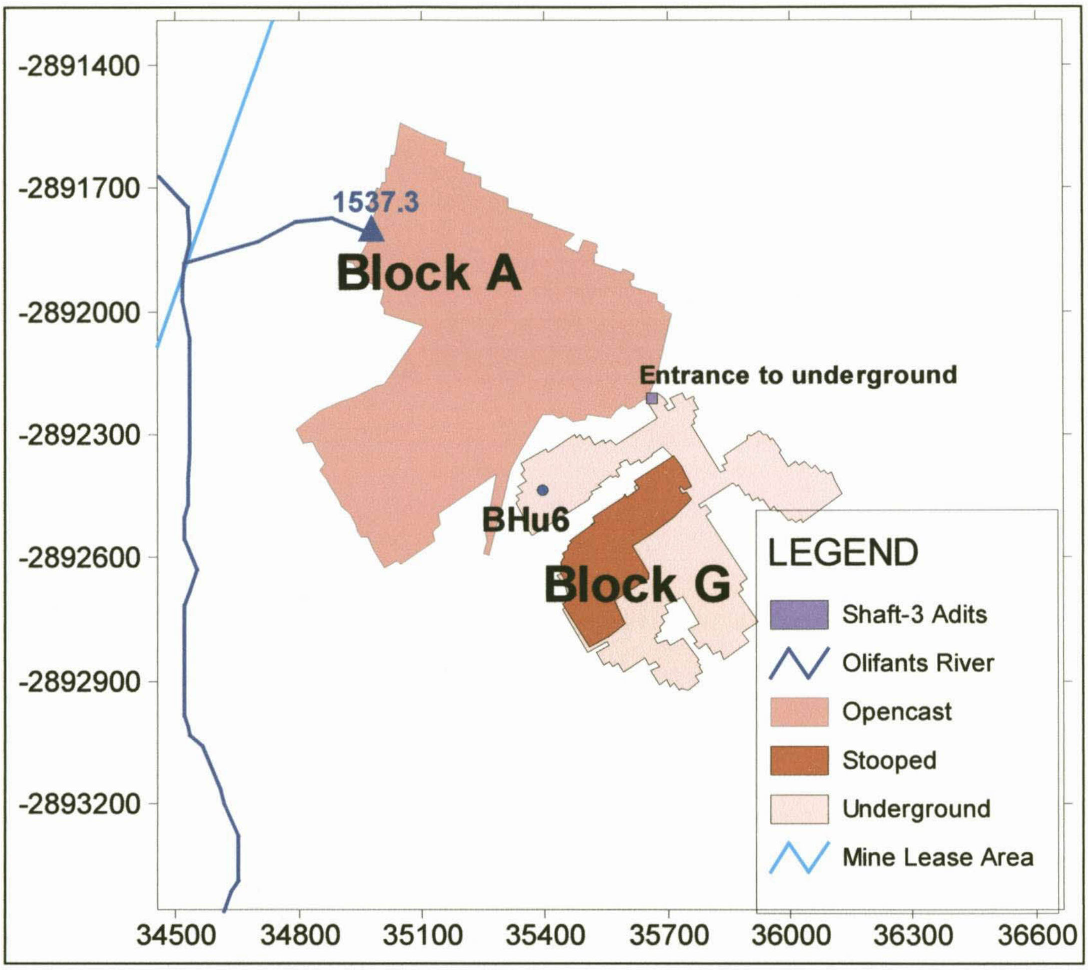


Figure 5-21. Block G Underground and Block A Opencast, including borehole, shafts and lowest surface elevations.

Block G has been mined by underground methods, and as illustrated in Figure 5-21, partially stooped. It links to Block A Opencast, from where access to the underground was gained during mining. As these two blocks are hydraulically interconnected, they will be dealt with as one.

Figure 5-22 shows the water levels of the two blocks. Table 5-7 lists the statistics for the two blocks as it relates to the water balance calculations.

Table 5-7: Statistics of Block G Underground and Block A Opencast.

Area Mined	25.4 ha
Area Stooped	6.4 ha
Area Opencast (Block A)	47.6 ha
Water level January 2002	1537.5 mamsl
Water level January 2003	1536.79 mamsl
Decant elevation (at opencast)	1537.3 mamsl
Block A Underground:	
Water volume underground January 2002	0.496 Mm^3
Water volume underground January 2003	0.496 Mm^3
Volume of voids underground	0.496 Mm^3
Volume water in mine underground at decant	0.496 Mm^3
Percentage underground currently flooded	100%
Percentage underground flooded at decant	100%
Block A Opencast:	
Water volume opencast January2002	1.25 Mm^3
Water volume opencast January2003	1.20 Mm^3
Volume water in opencast at decant	1.47 Mm^3
Percentage opencast currently flooded to decant level	82%
Lateral influx:	
Gradient	0.03
Length of influx	2250 m
Transmissivity	0.3 m^2/d
Groundwater influx	4 400 m^3/a
Calculated water influx	
6% Recharge over stooped areas	1 800 m^3/a
4% Recharge over bord-and-pillar areas	3 600 m^3/a
20% Recharge over opencast	44 800 m^3/a
Total water influx (recharge & flux)	54 600 m^3/a

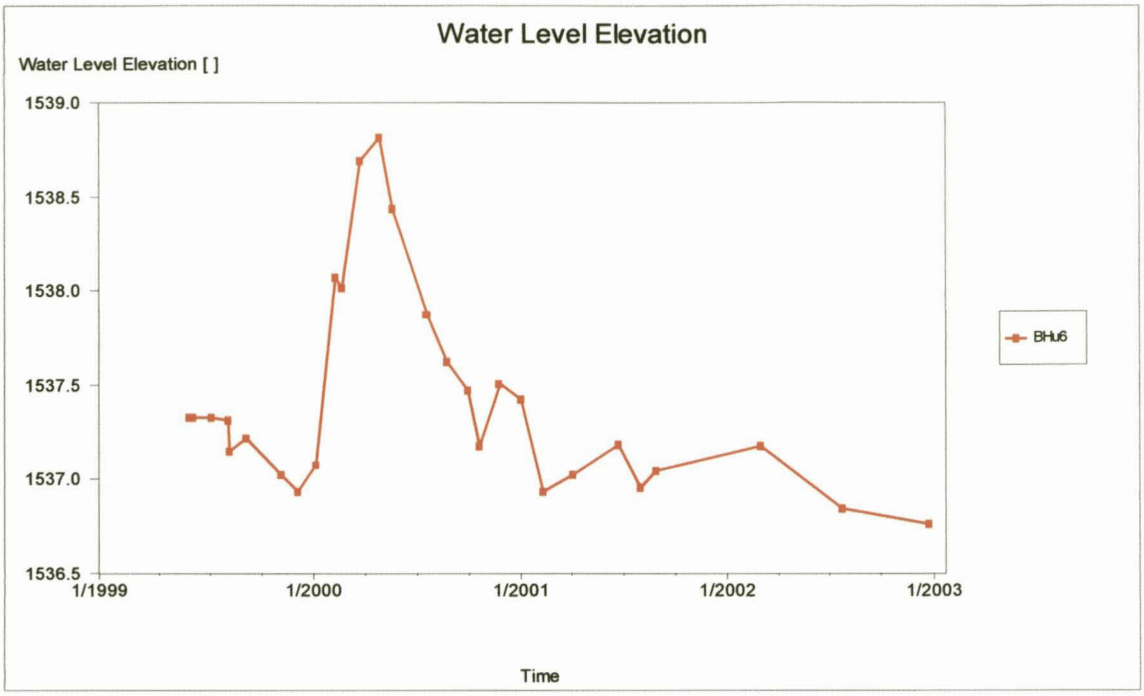


Figure 5-22. Water-level graph for Block G and Block A.

From the information above the following is concluded:

- With the two areas connected trough an adit, the water level in these two blocks should react simultaneously.
- The rise of 2 m in the water level during 2000, was followed by a drop in the water level, as the excess water seeped from the opencast into the nearby stream. Since then, the water level stabilised.

5.6.3.1 Decant

The water level has stabilised and influx is balanced by losses through seepage and decanting of the excess water. On average, a water loss of 2 L/s is envisaged (63 000 m^3/a).

5.6.3.2 Water quality

Table 5-8 lists the water qualities in these blocks.

Table 5-8: Water quality for Block G (mg/L).

SiteName	Date	MALK	EC	pH	Ca	Cl	Mg	NO3	PO4	SO4
		mg/L	mS/m		mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
BHu6	07-Aug-02	265	343	7.34	382	13	253	0.07	1.89	1784
BHu6	04-Oct-02	278	250	8.18	355	24	238	0.81	<0.01	1680
SiteName	**Date**	**K**	**Na**	**Fe**	**Si**	**As**	**Al_**	**Sb**	**B**	**Ba**
		mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
BHu6	07-Aug-02	10	54	0.165	<0.01	<0.01	0.014	<0.006	<0.04	0.011
BHu6	04-Oct-02	12	60	0.353	4.7	<0.01	0.009	<0.006	<0.04	<0.01
SiteName	**Date**	**Be**	**Br**	**Cd**	**Cr**	**Co**	**Cu**	**F**	**V**	**Pb**
		mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
BHu6	07-Aug-02	<0.001	0.04	<0.001	<0.006	<0.006	<0.03	0.39	<0.01	<0.015
BHu6	04-Oct-02	<0.001	<0.01	<0.001	<0.006	<0.006	<0.03	0.940	<0.01	<0.015
SiteName	**Date**	**Li**	**Mn_**	**Mo**	**Ni**	**Se**	**Sr**	**Sn**	**Zn**	**SAR**
		mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
BHu6	07-Aug-02	0.040	1.600	<0.002	<0.01	<0.006	1.774	<0.01	0.017	0.524
BHu6	04-Oct-02	<0.005	<1	1.980	<0.01	<0.006	<1	<0.01	<0.01	0.600

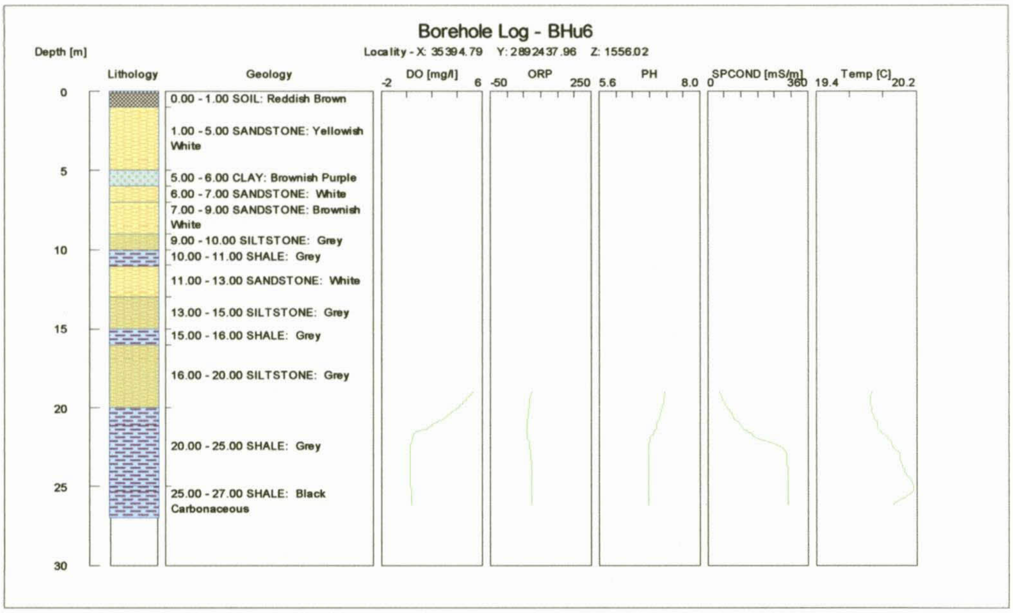


Figure 5-23. Chemical profiles for Block G.

- Both the water analyses in Table 5-8 and the chemical profiling in Figure 5-23 indicate water with a neutral pH, and moderately high salinity levels.
- The underground section is completely filled with water, and the opencast is 82% full. The chemical profiles also show that the oxygen in the water is depleted. In view of the high percentage of the workings that have been flooded, no significant further deterioration of mine water quality is expected.

5.6.4 Block F Underground

Block F is indicated in Figure 5-24.

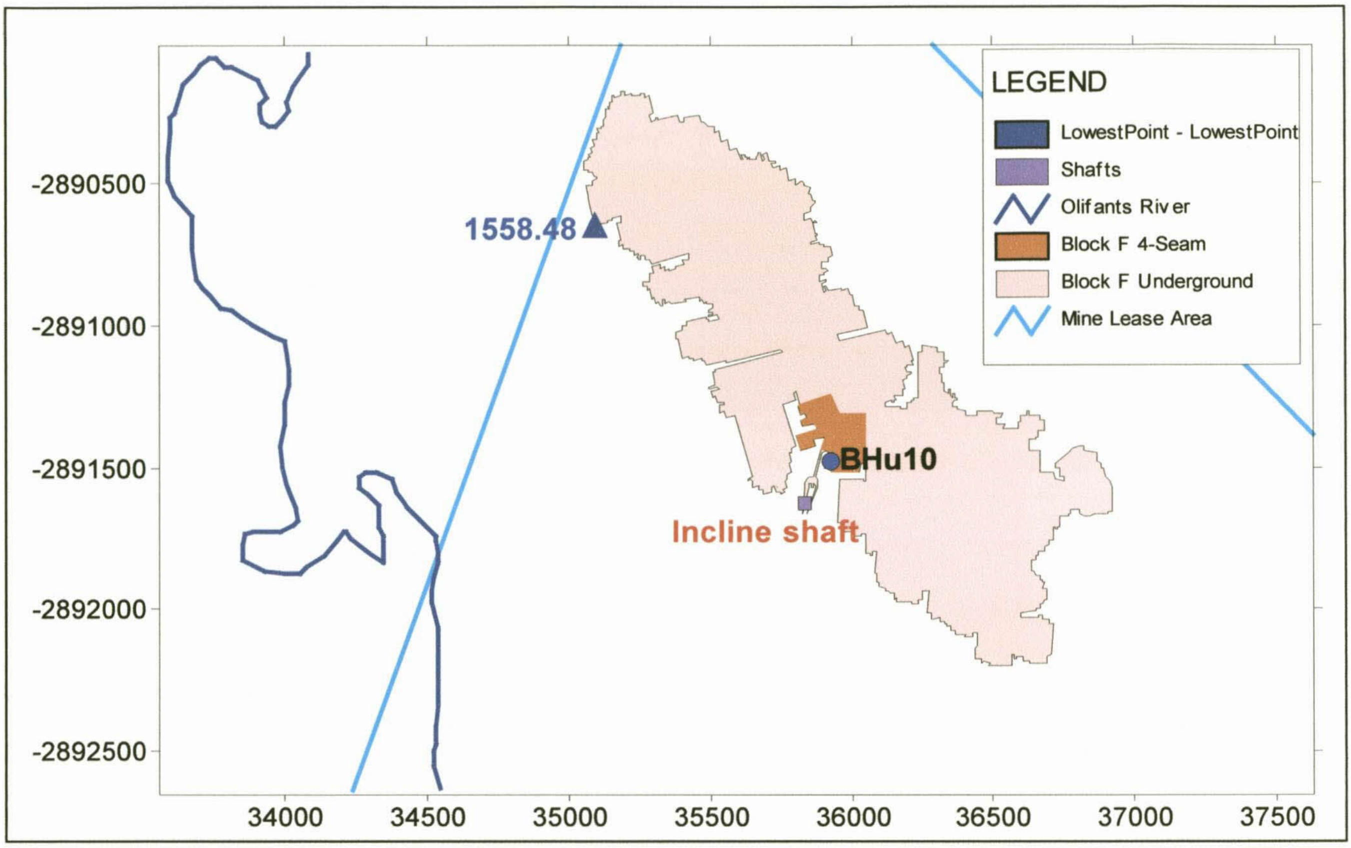


Figure 5-24. Block F Underground (all stooped), also indicating the lowest surface position and monitoring borehole.

Block F has been mined by bord-and-pillar methods, followed by stooping. At the entrance of the decline shaft, as illustrated in Figure 5-24, a small area of 4 ha from the No. 4 Seam was mined.

This block lies 1.2 km from the Olifants River. The surface area is sloping (Figure 5-10) with a high of 1 592 mamsl on the eastern side and 1 560 mamsl on the western decant side.

Figure 5-25 and Figure 5-26 show the main characteristics of the block as it relates to water, and Table 5-9 lists relevant statistics.

Table 5-9: Statistics for Block F Underground.

Area Mined	132 ha
Area Stooped	132 ha
Water level January 2002	1536.84 mamsl
Water level January 2003	1537.35 mamsl
Water volume January 2002	2.598 Mm^3
Water volume January 2003	2.604 Mm^3
Water volume gained	5750 m^3
Decant elevation	1558.48 mamsl
Total volume of voids	2.89 Mm^3
Volume water at decant	2.68 Mm^3
Percentage currently flooded	90%
Percentage flooded at decant	92.5%
Lateral influx:	
Gradient	0.02
Length of influx	3400 m
Transmissivity	0.3 m^2/d
Groundwater influx	6 600 m^3/a
Calculated water influx	
6% Recharge over stooped areas	37 200 m^3/a
Total water influx (recharge & flux)	43 800 m^3/a

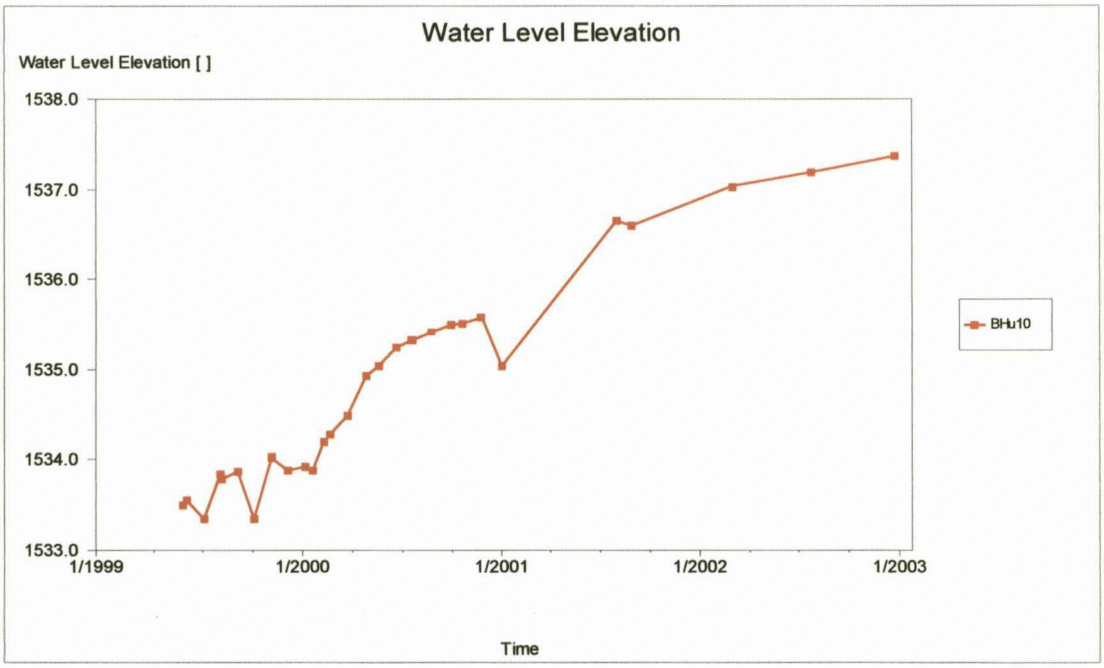


Figure 5-25. Water-level graph for Block F Underground.

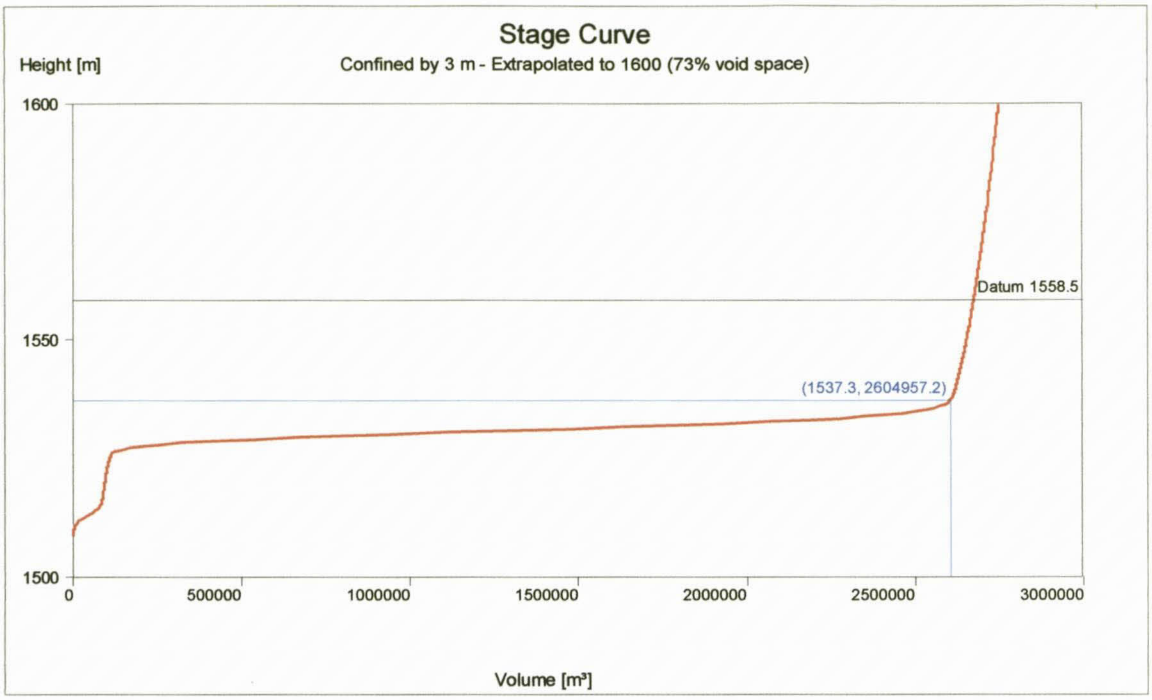


Figure 5-26. Stage curve for Block F at January 2003, with the decant level shown as the datum line.

The following is concluded:

- The rate of water level rise has been less during since 2000. This is due to lower rainfall over the last two years, resulting in less recharge.
- Currently 90% of the compartment is flooded to decant.

5.6.4.1 Decant:

- Block F will eventually decant. The lowest surface elevation above the perimeter of the mine is at 1558 mamsl. At the current rate of recharge, this will happen in 13 years time. If normal rainfall (690 mm) occurs in the next few years, it will result in additional water into Block F annually, and decant will occur within 11 years..

5.6.4.2 Water quality

The water quality analysis done for BHu10 is tabled in Table 5-10 and a chemical profile done in Bhu10 (Figure 5-27) confirms this.

Table 5-10: Water quality for Block F Underground (mgL).

SiteName	Date	MALK	EC	pH	NH_4	Ca	Cl	Mg	NO3	SO4
		mg/L	mS/m		mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
BHu10	07-Aug-02	324	320	7.62	4.9	371	10	206	0.03	1494
BHu10	04-Oct-02	331	222	8.19	<1	345	23	184	0.03	1375
SiteName	**Date**	**PO4**	**K**	**Na**	**Si**	**As**	**Al_**	**Sb**	**Ba**	**Be**
		mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
BHu10	07-Aug-02	0.46	11	49	<0.01	<0.01	0.017	<0.006	0.016	<0.001
BHu10	04-Oct-02	<1	13	54	6.0	<0.01	0.009	<0.006	<0.01	<0.001
SiteName	**Date**	**B**	**Br**	**Cd**	**Cr**	**Co**	**Cu**	**F**	**Fe**	**Pb**
		mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
BHu10	07-Aug-02	<0.04	0.05	<0.001	<0.006	<0.006	0.002	0.37	0.060	<0.015
BHu10	04-Oct-02	<0.04	<0.01	<0.001	<0.006	<0.006	<0.03	0.550	0.211	<0.015
SiteName	**Date**	**Li**	**Mn_**	**Mo**	**Ni**	**Se**	**Sr**	**Sn**	**Zn**	**SAR**
		mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
BHu10	07-Aug-02	0.012	0.425	0.002	<0.01	<0.006	1.984	<0.01	0.015	0.508
BHu10	04-Oct-02	<0.005	0.857	<0.002	<0.01	<0.006	<1	<0.01	<0.01	0.590

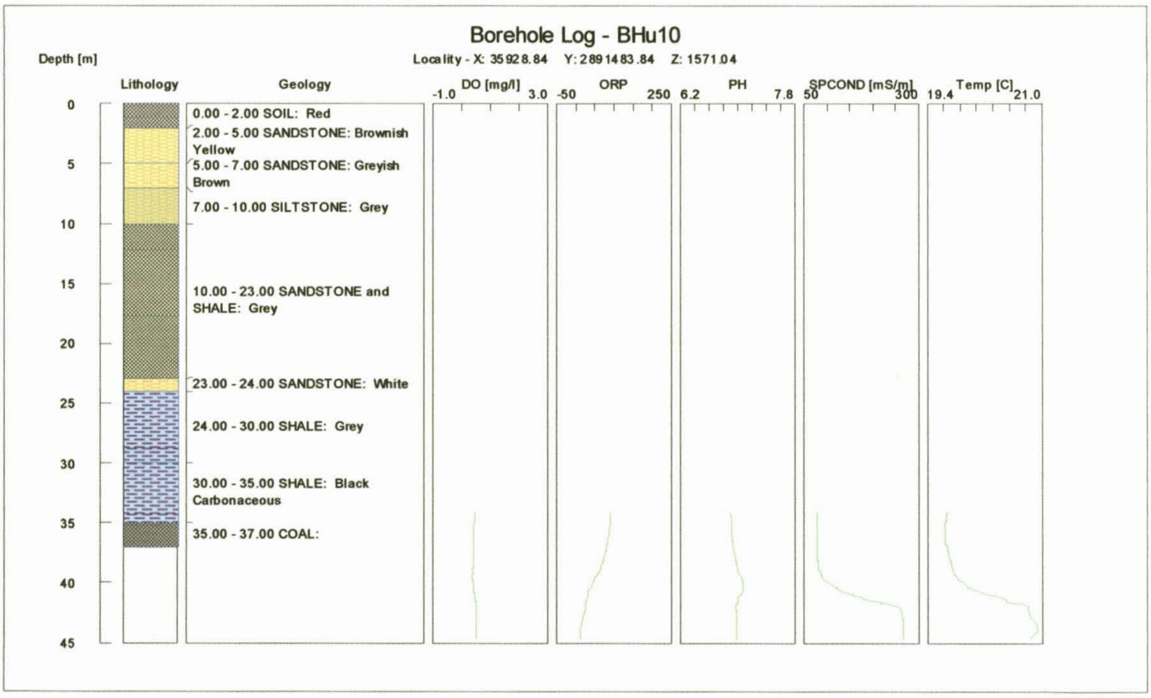


Figure 5-27. Chemical profiles for Block F Underground.

Conclusions from this information are:

- The pH of the water ranges between 7.6 and 8.2. The base potential in this compartment (>300 mg/L) should limit the acidification of the mine water.

- The EC ranges between 220 and 320 mS/m in the mine. Salinities are therefore relatively high but a slow improvement of the mine water quality should be expected once the mine is flooded.

5.6.5 Block OR Underground

The layout for Block OR Underground is detailed in Figure 5-28.

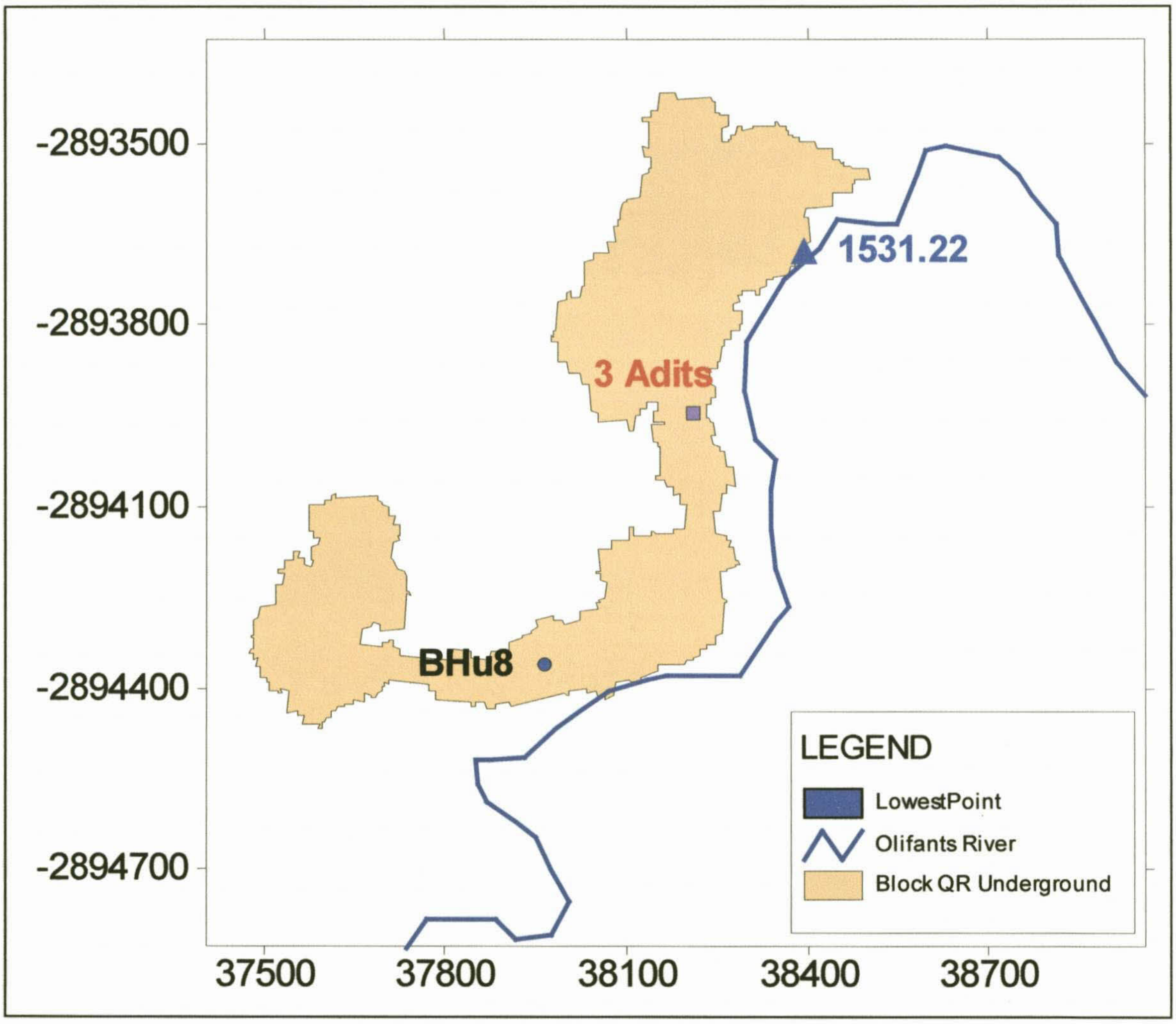


Figure 5-28. Block OR Underground, also indicating the lowest surface position and monitoring borehole.

Block OR has been mined by bord-and-pillar methods, and no stooping has been done. The surface is relatively flat, and the mining depth varies between 30 - 53 m below surface. This means that the mining was done at 25 - 28 m below the river elevation.

Information relevant to the water level is presented in Figure 5-29. A summary of the statistics is listed in Table 5-11.

Table 5-11: Statistics for Block OR Underground.

Area Mined	30.36 ha
Water level January 2002	1524.98 mamsl
Water level January 2003	1525.25 mamsl
Water volume January 2002	0.59 Mm^3
Water volume January 2003	0.59 Mm^3
Decant elevation	1531.22 mamsl
Total volume of voids	0.59 Mm^3
Volume water gained in aquifer above mine during 2003	246 m^3
Percentage currently flooded	100%
Percentage flooded at decant	100%
Lateral influx:	
Gradient	0.04
Length of influx	1150 m
Transmissivity	0.3 m^2/d
Groundwater influx	5 300 m^3/a
Calculated water influx	
4% Recharge over mined areas	5 700 m^3/a
Total water influx (recharge & flux)	11 000 m^3/a

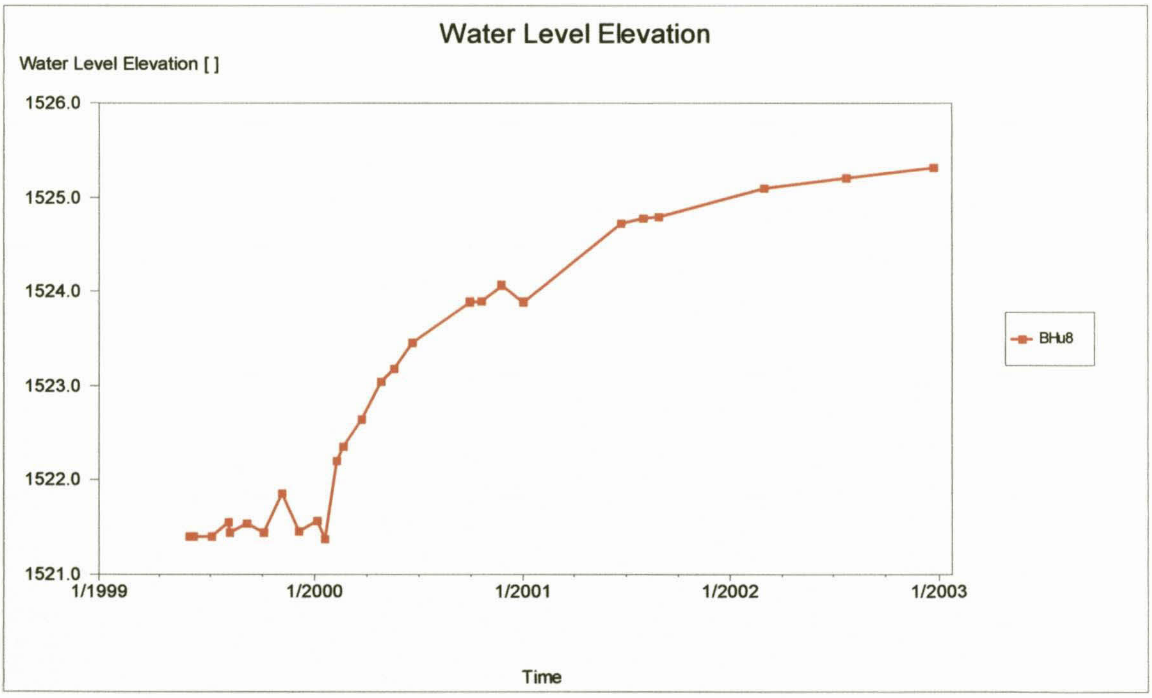


Figure 5-29. Water-level graph for Block OR.

The following is concluded:

- The rise in the water level has slowed down considerably during the past two years. This is due to less rainfall but could also, in part, be due to seepage from the mine into the weathered zone. During 2002 the water level rose by only 0.27 m
- The mine cavity is completely full and it is therefore not possible to calculate a volume difference from the water-level response.

5.6.5.1 Decant:

- The water level has to rise 6 m to reach the decant elevation of 1531.22 mamsl. In view of the fact that the underground workings are theoretically full, the rise in the water level merely constitutes as a rise into the formation above the mine workings. It is thus difficult to accurately calculate the time until decanting occurs, as seepage is an unknown factor.
- The volume of water gained according to the water level measurements, calculated with an S-value of 0.003 (based on calibrated values from a model of Van Tonder and Krantz done in the area), is only 246m^3. The water level has to rise 5.97 m to reach the decant elevation of 1531.22 mamsl, where Block QR will eventually decant. Using the S-value of 0.003, the volume water required till decant, is 5450 m^3. At the current rate of recharge, decant will thus occurs in 22 years time.

5.6.5.2 Water quality

The mine water quality is shown in Table 5-12 and the chemical profiling of Bhu8 in Figure 5-30.

Table 5-12: Water quality for Block OR Underground (mg/L).

SiteName	Date	MALK	EC	pH	Ca	Cl	Mg	NO3	PO4	SO4
		mg/L	mS/m		mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
BHu8	07-Aug-02	179	125	7.03	196	11	76	0.00	<0.01	576
BHu8	04-Oct-02	193	120	8.07	172	21	66	0.01	<0.01	567
SiteName	**Date**	**K**	**Na**	**Fe**	**Si**	**As**	**Al_**	**Sb**	**Ba**	**Be**
		mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
BHu8	07-Aug-02	4	20	0.182	<0.01	<0.01	0.027	<0.006	0.032	<0.001
BHu8	04-Oct-02	5	31	0.319	8.0	<0.01	0.009	<0.006	<0.01	<0.001
SiteName	**Date**	**B**	**Br**	**Cd**	**Cr**	**Co**	**Cu**	**F**	**Li**	**Pb**
		mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
BHu8	07-Aug-02	<0.04	0.02	<0.001	<0.006	0.004	0.002	0.22	0.014	<0.015
BHu8	04-Oct-02	<0.04	<0.01	<0.001	<0.006	<0.006	<0.001	0.260	<0.005	<0.015
SiteName	**Date**	**Mn_**	**Mo**	**Ni**	**Se**	**Sr**	**Sn**	**V**	**Zn**	**SAR**
		mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
BHu8	07-Aug-02	1.089	<0.002	<0.01	<0.006	0.866	<0.01	<0.01	0.010	0.310
BHu8	04-Oct-02	1.660	<0.002	<0.01	<0.006	<1	<0.01	<0.01	<0.01	0.510

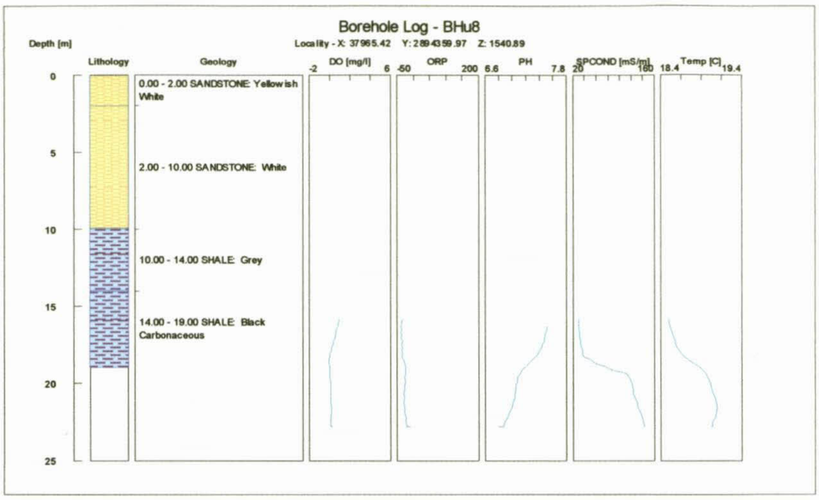


Figure 5-30. Chemical profiles for Block OR Underground.

Conclusions are:

- The pH is above neutral and the base potential is relatively high (170 mg/L). The EC is below the normal for coalmine water quality.
- Seepage/decant from the compartment will result in flushing over time, with subsequent improvement of the water.

5.6.6 Block H Opencast

The mine layout for Block H Opencast is shown in Figure 5-31

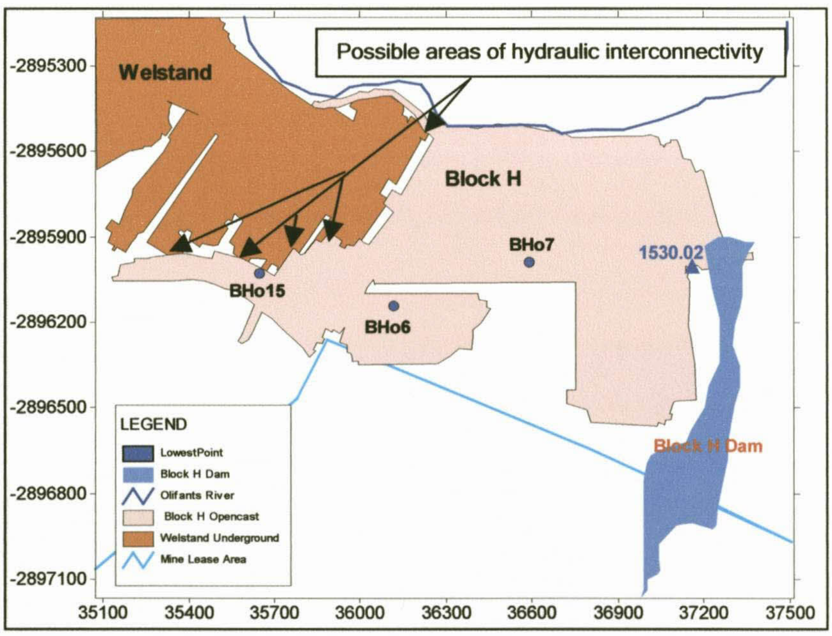


Figure 5-31. Block H Opencast in relation to Welstand, illustrating the dam and the borehole positions.

Block H lies directly south of the Olifants River. A river diversion has been done to mine the northern portion of the block. The rehabilitated opencast workings are separated from the Olifants River by a berm which has an elevation of 1 540 mamsl, 0,5 m above the 1:100 year flood line (Van Tonder and Krantz, 1997).

The pit links with the underground workings of the main Welstand-TNC Block. For many years a fire has been raging in the underground workings and a fire cut consisting of low permeability soil, shale, clay and slurry, was installed. According to Cohgo (Personal communication, 2003), the slurry originated from the coal processing plant. The cut is not an effective hydraulic barrier, and as illustrated in Figure 5-31, areas of direct contact exist.
A dam, constructed to keep water from the opencast workings, lies to the east of the opencast (Figure 5-32).

Figure 5-32. Block H Dam, adjacent to Block H Opencast.

Table 5-13: Statistics for Block H Opencast.

Area Mined	105 ha
Depth of mining	16-32 m
Water level January 2002	1528.54 mamsl
Water level January 2003	1528.03 mamsl
Decant elevation	1530.02 mamsl
Water volume January 2002	2.09 Mm^3
Water volume January 2003	1.97 Mm^3
Water volume at decant	2.47 Mm^3
Olifants River elevation	1528 mamsl
Volume water lost in compartment during 2002	123000 m^3
Percentage spoil currently flooded	80%
Lateral influx:	
Gradient	0.02
Length of influx	2200 m
Transmissivity	0.3 m^2/d
Groundwater influx	5 400 m^3/a
Calculated water influx	
20% Recharge over mined areas	98 600 m^3/a
Total water influx (recharge & flux)	104 000 m^3/a

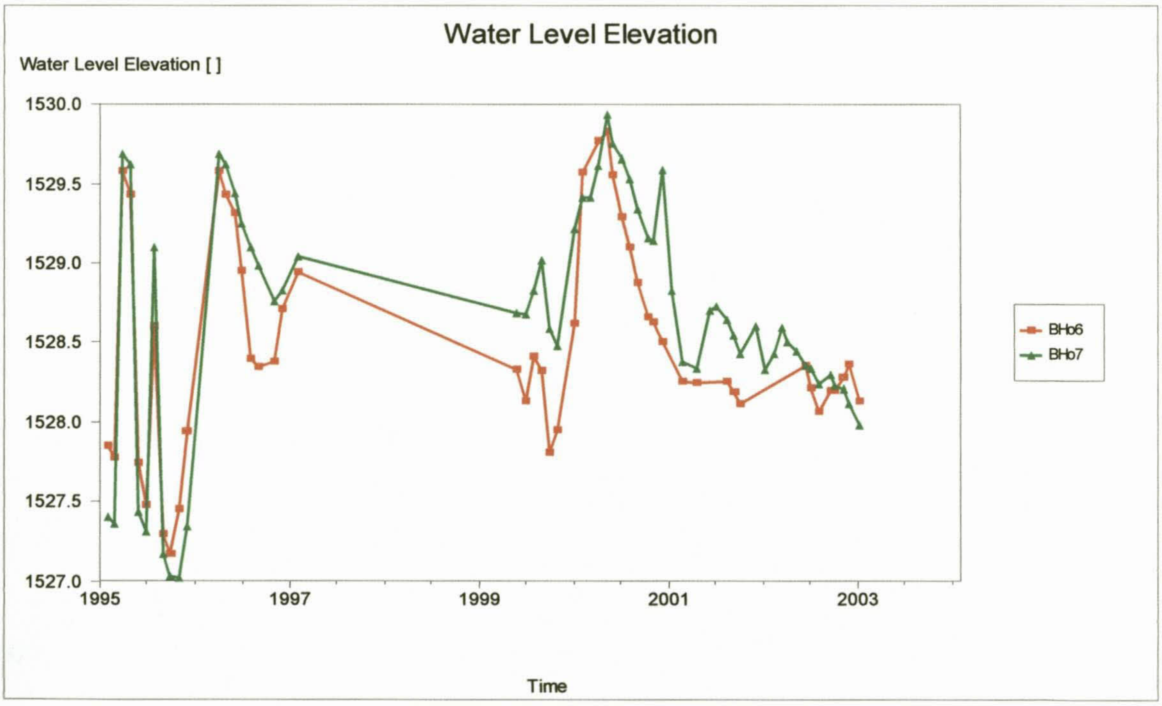


Figure 5-33. Water-level graph for Block H Opencast.

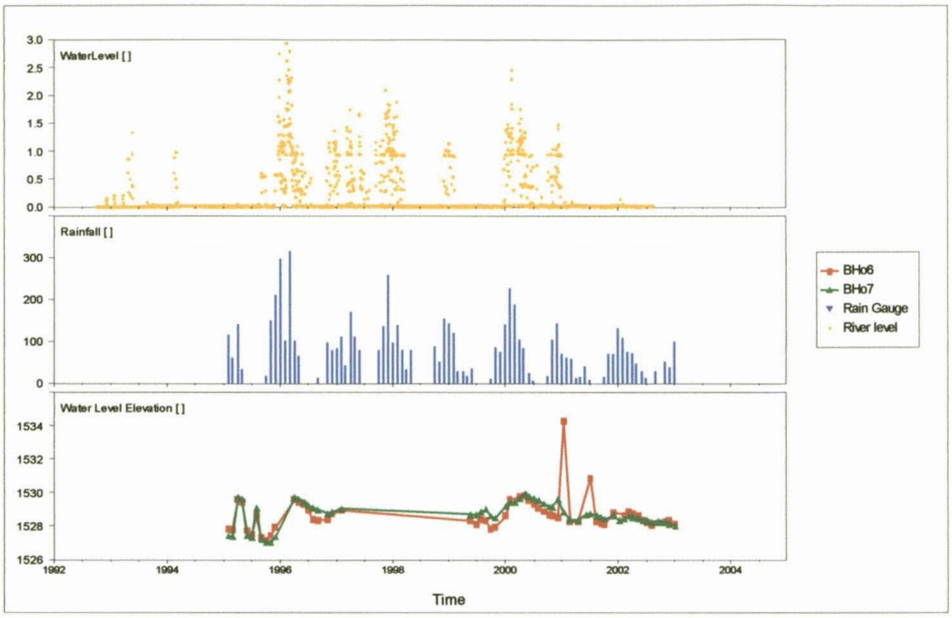


Figure 5-34. Graph illustrating the relationship between the water level of Block H, the rainfall and the water level of the river.

The following is concluded from the available information:

- The water level (Figure 5-33) usually fluctuates between 1 528 mamsl and 1 529 mamsl. The only time when the water rose above this level, were during 1996 and 2000 when all the workings at TNC adjacent to the river, were flooded. This occurred during exceptionally high rainfall periods, when the influx due to recharge was above normal.
- The rainfall was below normal for 2001 and 2002, resulting in less recharge into the spoils, and the water level has dropped since. This could be attributed to evaporation or seepage losses towards the Olifants River (Figure 5-34). The latter lies at an estimated elevation of 1 530 mamsl, but on the scale of the orthophotos, an error of 2 m is possible.

5.6.6.1 Decant:

- Interaction between the opencast and the Olifants River occurs, as the water level between them stays in equilibrium. Seepage should occur, as the decant level of 1530 mamsl is higher than the equilibrium level.
- Seepage is possible towards the Welstand Underground workings. With the water level of 1521 mamsl in the underground, the hydraulic gradient will cause part of the water to seep through the firewall into the underground.
- In view of the significant stretch along which seepage is anticipated, decanting from the Block H Opencast may not occur. Evaporation from the pans in Block H will also limit the rise in the water level.

5.6.6.2 Water quality

Block H has wide ranging chemistries due to the wide range of circumstances under which the spoils lies in the pit. Mining has been very shallow in this pit, leaving behind a large percentage of semi-weathered sediments. The spoil thickness varies from 2 - 22 m (Figure 5-35). Such sediments are usually prone to acidification because buffering material has been leached.

Table 5-14. Water chemistry of Block H Opencast (mg/L).

SiteName	Date	MALK	EC	pH	Ca	Cl	Mg	NO3	PO4	SO4
		mg/L	mS/m		mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
BHo6	07-Aug-02	148	62	7.29	69	7	39	0.00	0.00	212
BHo6	04-Oct-02	153	57	6.96	60	15	32	0.04	0.00	162
BHo7	07-Aug-02	1084	295	8.00	134	51	99	0.00	0.00	555
BHo7	04-Oct-02	1134	256	7.26	117	48	86	0.07	0.00	519
SiteName	**Date**	**K**	**Na**	**Fe**	**Si**	**Al_**	**Sb**	**As**	**Ba**	**Be**
		mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
BHo6	07-Aug-02	4	19	0.233	<0.01	0.125	<0.006	<0.01	0.037	<0.001
BHo6	04-Oct-02	4	23	0.808	12.8	0.336	<0.006	<0.01	<0.01	<0.001
BHo7	07-Aug-02	4	496	0.011	<0.01	0.038	<0.006	<0.01	0.034	<0.001
BHo7	04-Oct-02	2	498	0.208	12.9	0.009	<0.006	<0.01	<0.01	<0.001
SiteName	**Date**	**B**	**Br**	**Cd**	**Cr**	**Co**	**Cu**	**F**	**Li**	**Pb**
		mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
BHo6	07-Aug-02	<0.04	0.09	<0.001	<0.006	<0.006	0.002	0.2	0.008	<0.015
BHo6	04-Oct-02	<0.04	<0.01	<0.001	<0.006	<0.006	<0.006	0.250	<0.005	<0.015
BHo7	07-Aug-02	<0.04	1.8	<0.001	<0.006	0.011	0.005	0.33	0.009	<0.015
BHo7	04-Oct-02	<0.04	<0.01	<0.001	<0.006	<0.006	<0.006	0.460	<0.005	<0.015
SiteName	**Date**	**Mn_**	**Mo**	**Ni**	**Se**	**Sr**	**Sn**	**V**	**Zn**	**SAR**
		mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
BHo6	07-Aug-02	0.461	<0.002	<0.01	<0.006	0.115	<0.01	<0.01	0.012	0.457
BHo6	04-Oct-02	0.730	<0.002	<0.01	<0.006	<1	<0.01	<0.01	<0.01	0.590
BHo7	07-Aug-02	3.320	<0.002	<0.01	<0.006	0.774	<0.01	<0.01	0.012	7.886
BHo7	04-Oct-02	1.970	<0.002	<0.01	<0.006	<1	<0.01	<0.01	<0.01	8.480

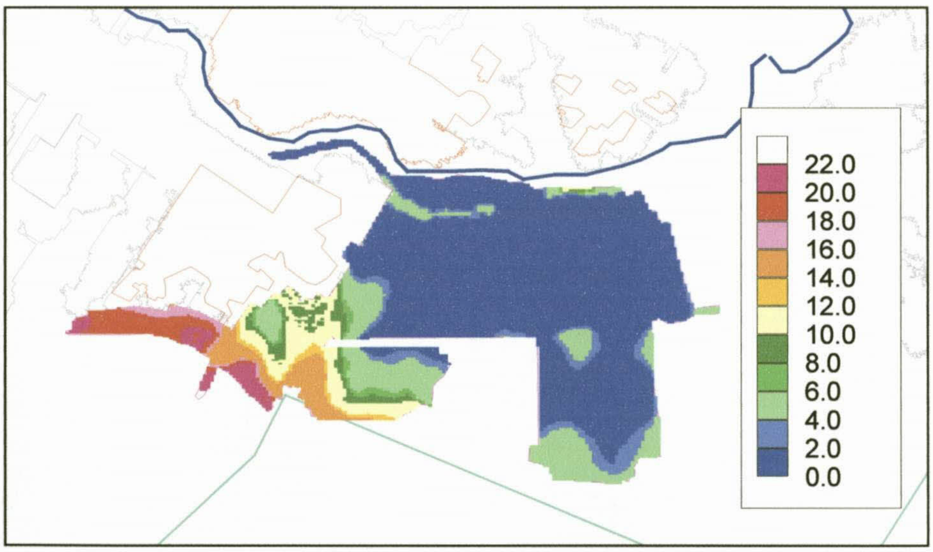


Figure 5-35. Spoil thickness above the decant level.

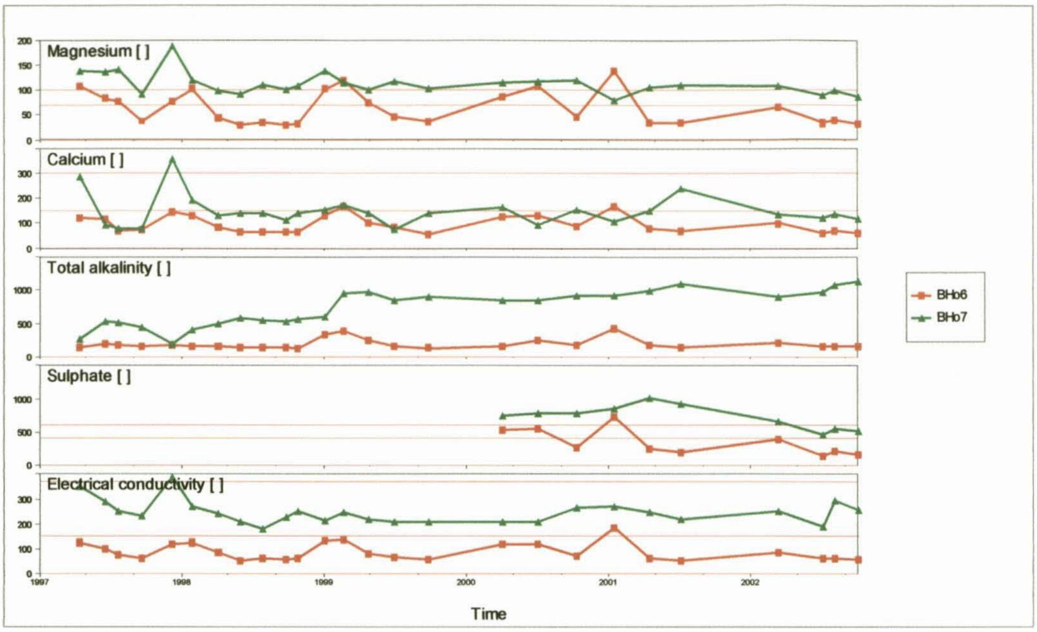


Figure 5-36. Graph of chemical analysis for Block H (mg/L).

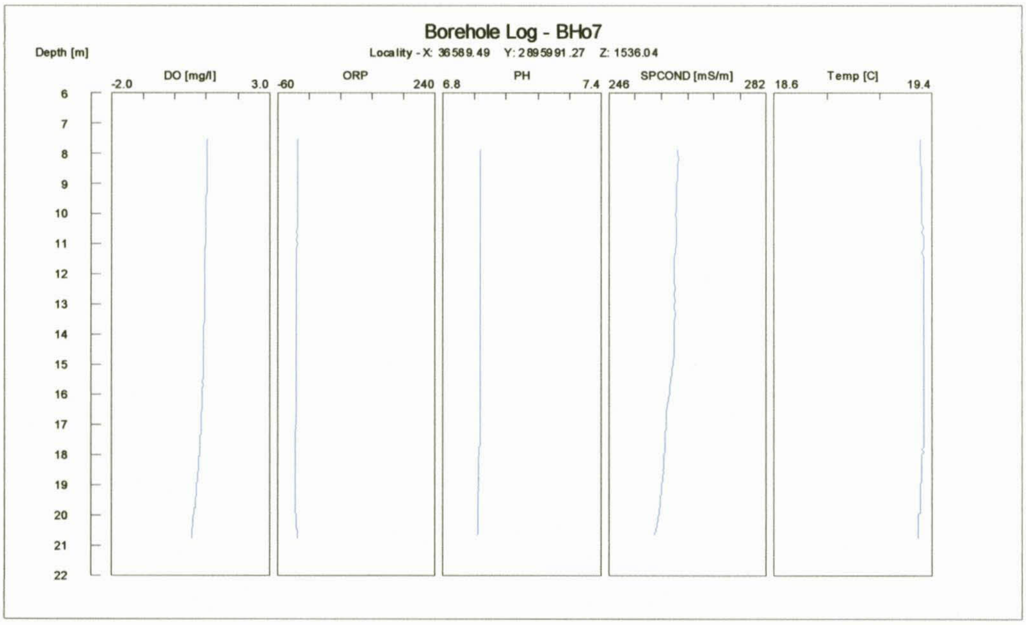


Figure 5-37. Chemical profile of Block H Opencast.

Conclusions are:

- There is no obvious long-term change in the chemistry of the water in Block H (Figure 5-36 and Figure 5-37).

- The chemical processes are not significantly retarded by partial flooding of the spoil.
- It is expected that chemical leaching and pyrite oxidation will continue for many years (centuries). Only when the spoil has totally disintegrated, will oxidation reactions stop.

5.6.7 Blocks B & C (Opencast)

Figure 5-38 shows the outline of opencast mining at Blocks B & C.

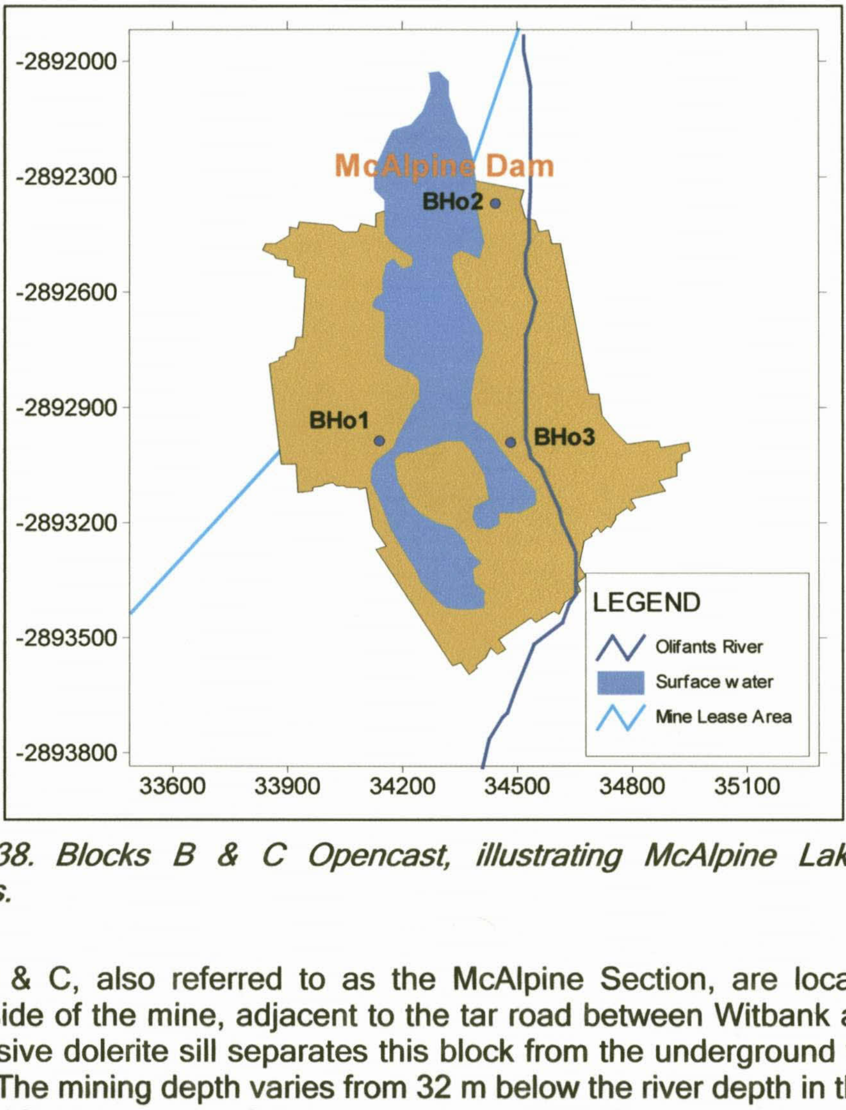


Figure 5-38. Blocks B & C Opencast, illustrating McAlpine Lake and the boreholes.

Blocks B & C, also referred to as the McAlpine Section, are located on the western side of the mine, adjacent to the tar road between Witbank and Kriel. A transgressive dolerite sill separates this block from the underground workings to the east. The mining depth varies from 32 m below the river depth in the south, to less than 20 m over most of the area.

Mining proceeded through the Olifants River Bed, and the river was re-established across the opencast after rehabilitation was completed. A lake formed next to the Olifants River in the final void (Figure 5-38). Two weirs separate the lake from the river. Under flood conditions, throughflow of water from the river flushes the lake. Another weir was constructed in the river at the same elevation as the outflow weir in the McAlpine Lake, ensuring that the water levels in the opencast workings and the river subside simultaneously (Figure 5-39 and Figure 5-40.

Figure 5-39. Weir at the outflow of McAlpine Lake.

Figure 5-40. Weir in the Olifants River (January 2003).

Information relevant to the water level is presented in Figure 5-41. A summary of the statistics is listed in Table 5-15.

Table 5-15: Statistics on the Blocks B & C Opencast.

Area Mined	79.66 ha
Depth of mining	16-32 m
Water level January 2002	1528.1 mamsl
Water level January 2003	1527.4 mamsl
Decant elevation	1528.4 mamsl
Water volume January 2002	3.49 Mm^3
Water volume January 2003	3.35 Mm^3
Water volume at decant	3.55 Mm^3
Olifants River elevation	1527.12 mamsl
Volume water lost in compartment during 2002	135 000 m^3
Percentage spoil currently flooded	94%
Percentage spoil flooded at decant	100%
Lateral influx:	
Gradient	0.02
Length of influx	2450 m
Transmissivity	0.3 m^2/d
Groundwater influx	5 300 m^3/a
Calculated water influx	
20% Recharge over mined areas	74 900 m^3/a
Total water influx (recharge & flux)	80 200 m^3/a

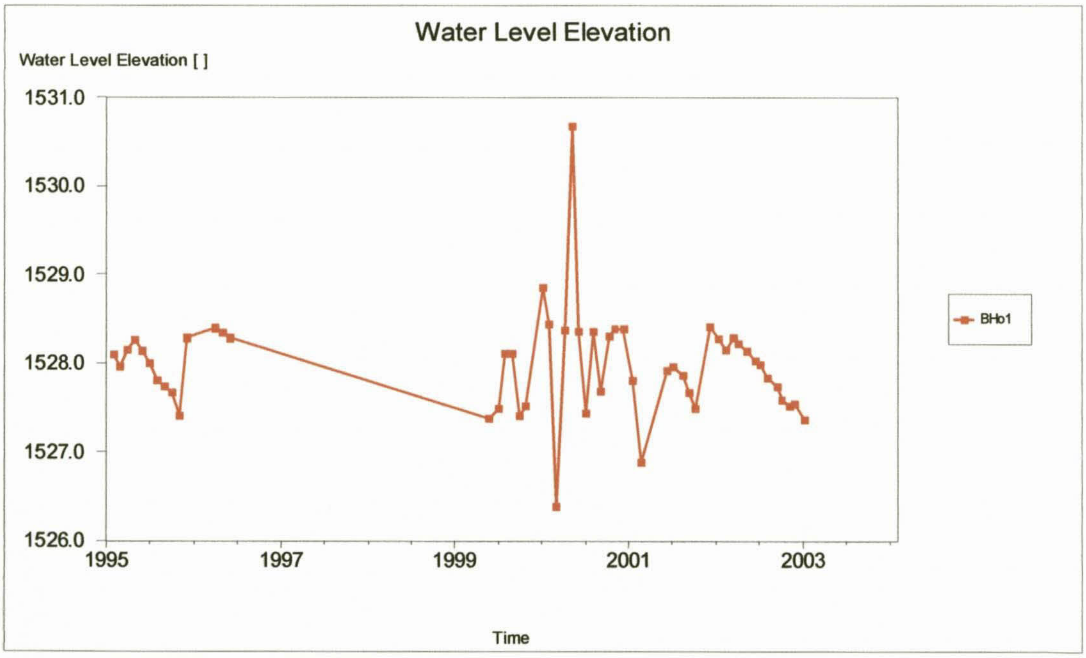


Figure 5-41. Water-level graph for Blocks B & C.

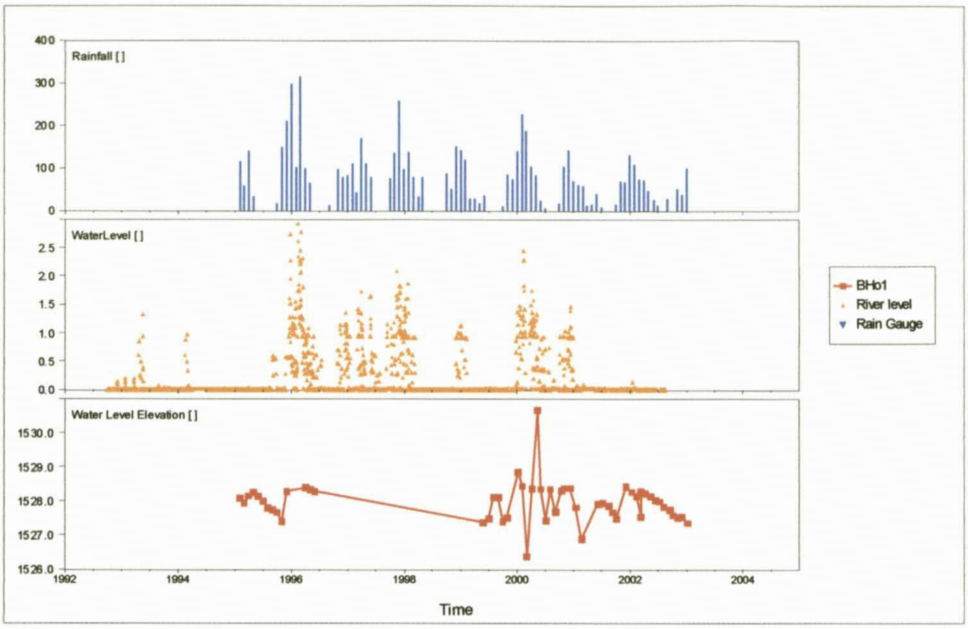


Figure 5-42. Graph illustrating the relationship between the water level in Blocks B & C, the water level of the Olifants River and the rainfall.

From the data available, the following conclusions are drawn:

- This opencast system is in steady state. The water level fluctuates between 1 527 mamsl and the decant level of 1 528,4 mamsl. The latter is also the level of the river. During high flow in the river, water seeps towards the McAlpine Lake and under low-flow conditions, a reverse flow gradient develops. A correlation between the water level in the opencast pit and the river is illustrated in Figure 5-42.

5.6.7.1 Decant:

- The physical decanting of water from Blocks B & C only occurs when the Olifants River is in flood and water overtops the two weirs. This last happened in 2000.
- Otherwise, seepage between the river and the opencast spoil occurs on a continuous basis, depending on the direction of the gradient.

5.6.7.2 Water quality

The McAlpine Lake plays an important part in the quality of water from the opencast. The water that seeps from the spoils into the lake dilutes the dissolved solids, thus improving the quality of the water. Table 5-16 depicts the water quality in the opencast and is confirmed by chemical profiling done into the spoils (Figure 5-44). Figure 5-43 shows the difference in the water qualities of the spoils and the river.

Table 5-16: Water quality for Block B&C Opencast mg/L).

SiteName	Date	MALK	EC	pH	Ca	Cl	Mg	NO3	PO4	SO4
		mg/L	mS/m		mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
BHo1	07-Aug-02	492	253	7.72	251	8	200	0.04	1.41	989
BHo1	04-Oct-02	501	198	6.72	238	15	182	0.08	0.17	935
BHo2	04-Oct-02	541	210	6.94	217	20	145	0.06	<0.01	878
BHo3	04-Oct-02	489	142	7.28	126	21	84	0.01	<0.01	421
SiteName	**Date**	**K**	**Na**	**Fe**	**Si**	**As**	**Al_**	**Sb**	**Ba**	**Be**
		mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
BHo1	07-Aug-02	13	49	0.043	<0.01	<0.01	0.010	<0.006	0.014	<0.001
BHo1	04-Oct-02	15	52	2.490	5.7	<0.01	0.009	<0.006	<0.01	<0.001
BHo2	04-Oct-02	6	162	1.018	11.5	<0.01	0.009	<0.006	<0.01	<0.001
BHo3	04-Oct-02	8	114	0.618	8.3	<0.01	0.009	<0.006	<0.01	<0.001
SiteName	**Date**	**B**	**Br**	**Cd**	**Cr**	**Co**	**Cu**	**F**	**V**	**Pb**
		mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
BHo1	07-Aug-02	<0.04	0.03	<0.001	<0.006	0.011	0.002	0.41	<0.01	<0.015
BHo1	04-Oct-02	<0.04	<0.01	<0.001	<0.006	<0.006	<0.002	0.450	<0.01	<0.015
BHo2	04-Oct-02	<0.04	<0.01	<0.001	<0.006	<0.006	<0.002	0.370	<0.01	<0.015
BHo3	04-Oct-02	<0.04	<0.01	<0.001	<0.006	<0.006	<0.002	0.450	<0.01	<0.015
SiteName	**Date**	**Li**	**Mn_**	**Mo**	**Ni**	**Se**	**Sr**	**Sn**	**Zn**	**SAR**
		mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
BHo1	07-Aug-02	0.017	2.127	<0.002	0.017	<0.006	0.699	<0.01	0.015	0.556
BHo1	04-Oct-02	<0.005	2.620	<0.002	<0.01	<0.006	<1	<0.01	<1	0.610
BHo2	04-Oct-02	<0.005	4.140	<0.002	<0.01	<0.006	<1	<0.01	<1	2.080
BHo3	04-Oct-02	<0.005	2.360	<0.002	<0.01	<0.006	<1	<0.01	<1	-1.000

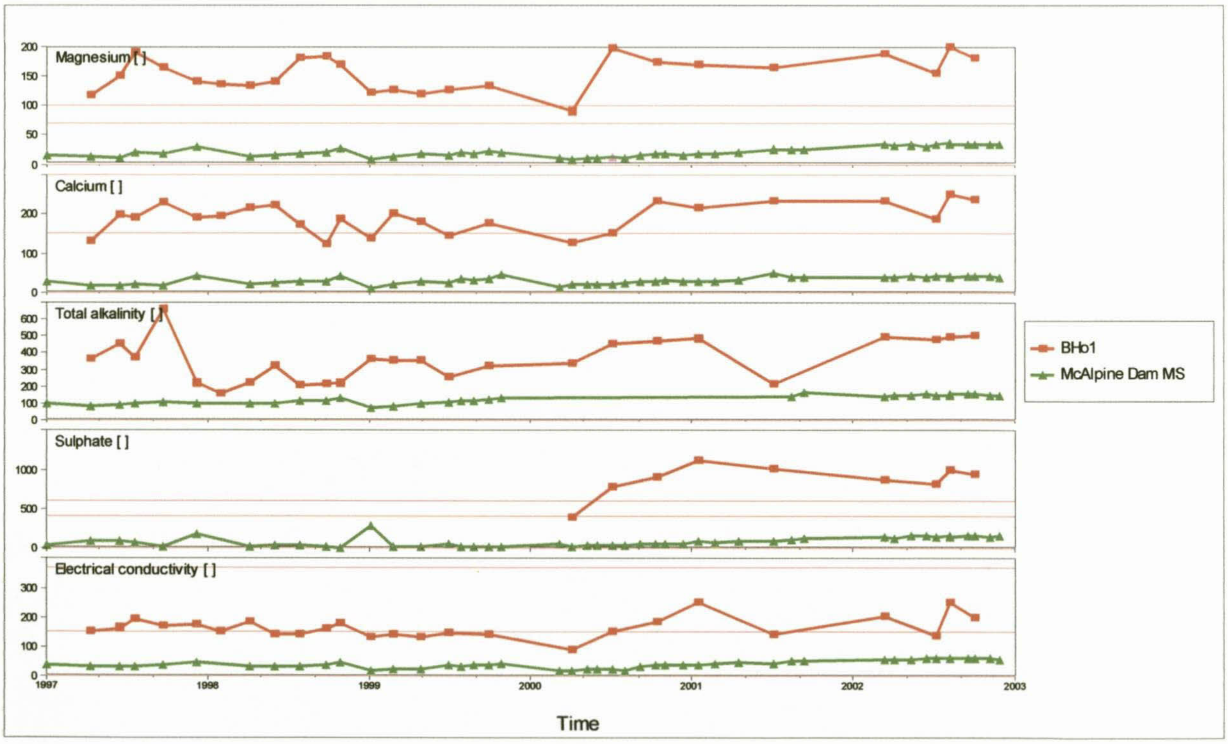


Figure 5-43. Graphs showing the water quality of Block B & C Opencast in relation to that of the McAlpine Lake (mg/L).

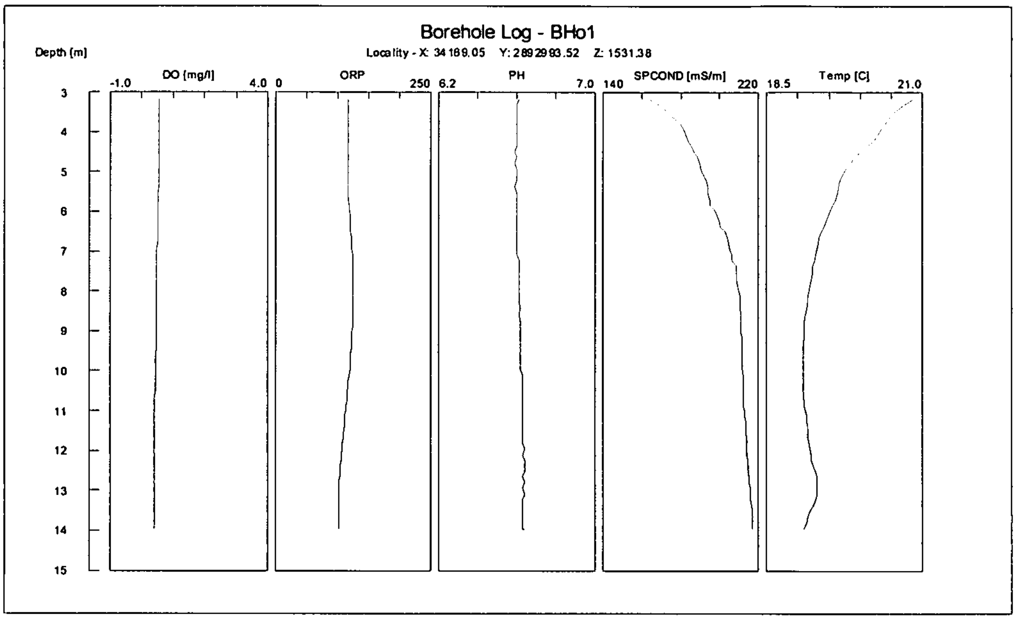


Figure 5-44. Chemical profiling of Block B&C Opencast.

Conclusions are:

- The difference in water quality of the spoil water and that in the lake confirms that flushing is a sound water quality management practice.
- The two weirs regulate the flushing, ensuring that flushing only occurs when the river is in flood.
- Many other collieries exist where this principle could be applied.

5.6.8 Blocks R1-3 Opencast.

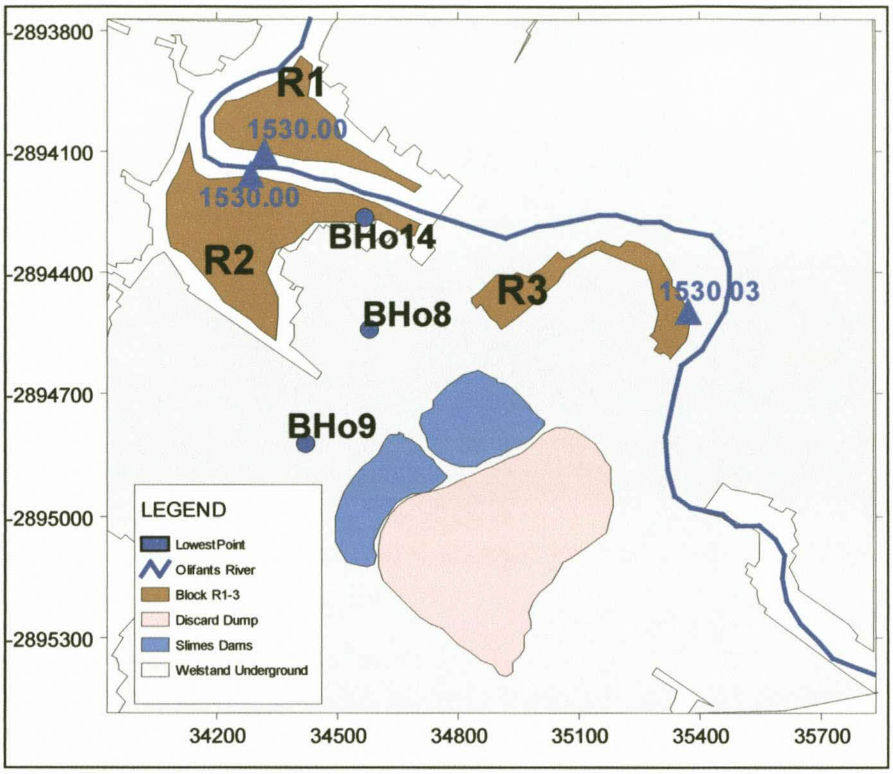


Figure 5-45. Blocks R1-3 in relation to the slimes dams and discard dump.

Blocks R1-3 consists of three small opencast areas below the slimes dams, on both sides of the Olifants River (Figure 5-45). There is no direct hydraulic conductivity between the R3 opencast and the Welstand Block, because the slurry has been pumped into the underground workings and this has a retarding effect on water flow. Pits R2 and R3 are shielded from the Olifants River by a berm (Figure 5-46).

Figure 5-46. Photograph of the rehabilitated berm along the Olifants River.

A summary of the statistics is listed in Table 5-17. Information relevant to the water level is presented in Figure 5-47.

Table 5-17: Statistics for Block H Opencast.

Area Mined	20.4 ha
Depth of mining	28-30 m
Water level January 2002	1524.49 mamsl
Water level January 2003	1524.6 mamsl
Decant elevation	1530 mamsl
Water volume January 2002	1.25 Mm^3
Water volume January 2003	1.20 Mm^3
Water volume at decant	1.25 Mm^3
Olifants River elevation	1528 mamsl
Volume water lost in compartment during 2002	46 000m^3
Percentage spoil currently flooded	97%
Lateral influx:	
Gradient	0.02
Length of influx	1400 m
Transmissivity	0.3 m^2/d
Groundwater influx	2 800 m^3/a
Calculated water influx	
20% Recharge over mined areas	19 000 m^3/a
Total water influx (recharge & flux)	21 800 m^3/a

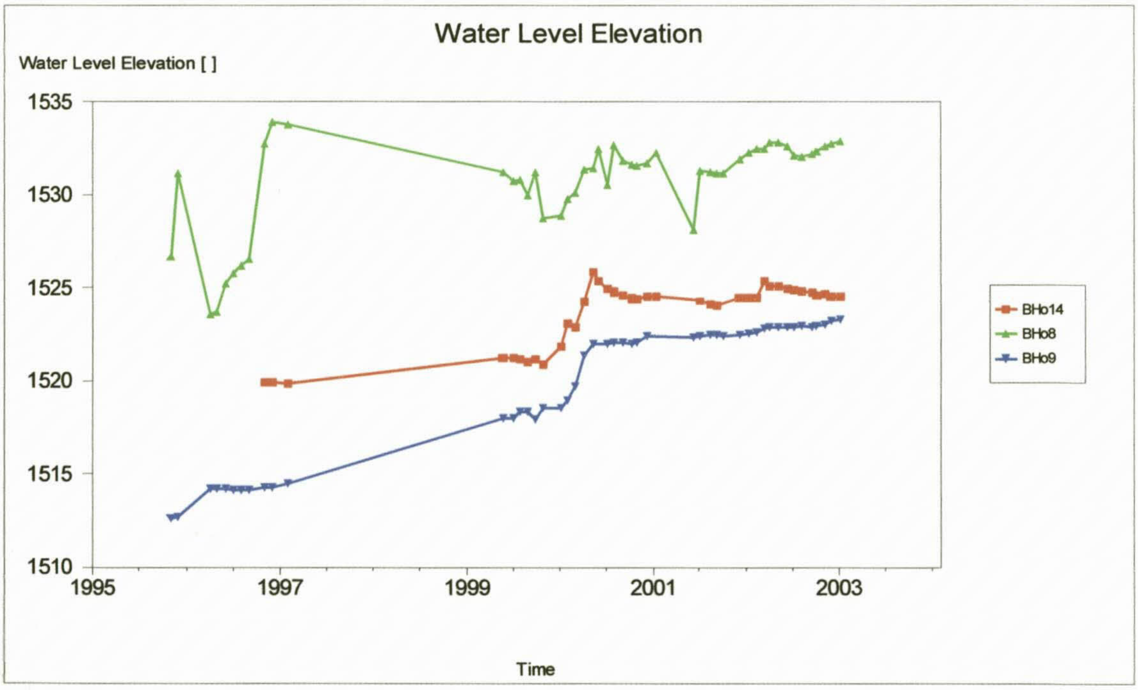


Figure 5-47. Water-level graphs for Blocks R1-3.

5.6.8.1 Decant:

- The water level has stabilised at 1 524.5 mamsl (Figure 5-47).
- This water level almost coincides with that of BHo9. The latter is drilled in the 2-Seam underground mining. This suggests that opencast R1 is in equilibrium with the surrounding underground mining. Bho8 is drilled in the aquifer and has a water level 9 m above that of the boreholes drilled into the mine. This represents the elevation of the normal groundwater system.
- The decant level at the river is at 1 528 mamsl, the elevation of the river. There is currently no decanting into the river.

5.6.8.2 Water quality

Table 5-18 provides information of the water quality in this area.

Table 5-18: Water quality for Block R1-3 Opencast (mg/L).

SiteName	Date	MALK	EC	pH	Ca	Cl	Mg	NO3	PO4	SO4
		mg/L	mS/m		mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
BHo8	07-Aug-02	657	346	8.12	234	15	308	0.03	0.00	1386
BHo8	04-Oct-02	494	198	7.81	153	19	196	0.06	0.00	862
BHo9	07-Aug-02	151	118	7.75	144	20	72	0.05	0.00	533
BHo9	04-Oct-02	151	106	7.40	121	28	57	0.25	0.00	455
BHo13	04-Oct-02	309	86	7.13	67	22	42	0.00	0.00	172
BHo14	07-Aug-02	294	98	7.91	76	19	51	0.03	0.00	238
BHo14	04-Oct-02	299	94	7.18	66	26	45	0.01	0.00	230
SiteName	Date	K	Na	Si	Fe	Al	Sb	As	Ba	Be
		mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
BHo8	07-Aug-02	8	124	<0.01	0.120	0.013	<0.006	<0.01	0.028	<0.001
BHo8	04-Oct-02	7	88	10.8	0.520	0.009	<0.006	<0.01	<0.01	<0.001
BHo9	07-Aug-02	8	48	<0.01	0.057	0.014	<0.006	<0.01	0.043	<0.001
BHo9	04-Oct-02	8	49	4.2	0.084	0.009	<0.006	<0.01	<0.01	<0.001
BHo13	04-Oct-02	5	81	14.0	0.228	0.009	<0.006	<0.01	<0.01	<0.001
BHo14	07-Aug-02	4	100	<0.01	0.231	0.015	<0.006	<0.01	0.023	<0.001
BHo14	04-Oct-02	5	102	12.3	0.516	0.009	<0.006	<0.01	<0.01	<0.001
SiteName	Date	B	Br	Cd	Cr	Co	Cu	F	Li	Pb
		mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
BHo8	07-Aug-02	<0.04	<0.01	<0.001	<0.006	<0.005	<0.002	1.03	0.009	<0.015
BHo8	04-Oct-02	<0.04	<0.01	<0.001	<0.006	<0.005	<0.002	0.640	<0.005	<0.015
BHo9	07-Aug-02	<0.04	0.14	<0.001	<0.006	<0.005	<0.002	0.5	0.028	<0.015
BHo9	04-Oct-02	<0.04	<0.01	<0.001	<0.006	<0.005	<0.002	0.390	<0.005	<0.015
BHo13	04-Oct-02	<0.04	<0.01	<0.001	<0.006	<0.005	<0.002	0.450	<0.005	<0.015
BHo14	07-Aug-02	<0.04	0.40	<0.001	<0.006	<0.005	<0.002	0.39	0.013	<0.015
BHo14	04-Oct-02	<0.04	<0.01	<0.001	<0.006	<0.005	<0.002	0.370	<0.005	<0.015
SiteName	Date	Mn	Mo	Ni	Se	Sr	Sn	V	Zn	SAR
		mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
BHo8	07-Aug-02	0.613	<0.002	<0.01	<0.006	2.451	<0.01	<0.01	0.008	1.243
BHo8	04-Oct-02	0.827	<0.002	<0.01	<0.006	<1	<0.01	<0.01	<0.01	1.110
BHo9	07-Aug-02	0.440	<0.002	<0.01	<0.006	1.162	<0.01	<0.01	0.023	0.803
BHo9	04-Oct-02	0.600	<0.002	<0.01	<0.006	<1	<0.01	<0.01	<0.01	0.930
BHo13	04-Oct-02	0.417	<0.002	<0.01	<0.006	<1	<0.01	<0.01	<0.01	1.896
BHo14	07-Aug-02	0.468	<0.002	<0.01	<0.006	0.907	<0.01	<0.01	0.011	2.166
BHo14	04-Oct-02	<0.002	<0.002	<0.01	<0.006	<1	<0.01	<0.01	<0.01	2.370

- The pH of the water in the opencast pit is between 7 and 8. this is confirmed by chemical profiling done into the spoils (Figure 5-48).The water monitored in the underground below the discard dam is also above neutral (BHo8). Enough base potential (300 mg/L) exists in the opencast to prevent acidification of the water. The opencast pits are almost totally flooded and oxidation reactions are limited.
- The sodium concentration is slightly elevated (100 mg/L) in comparison with the rest of the mining areas at TNC.

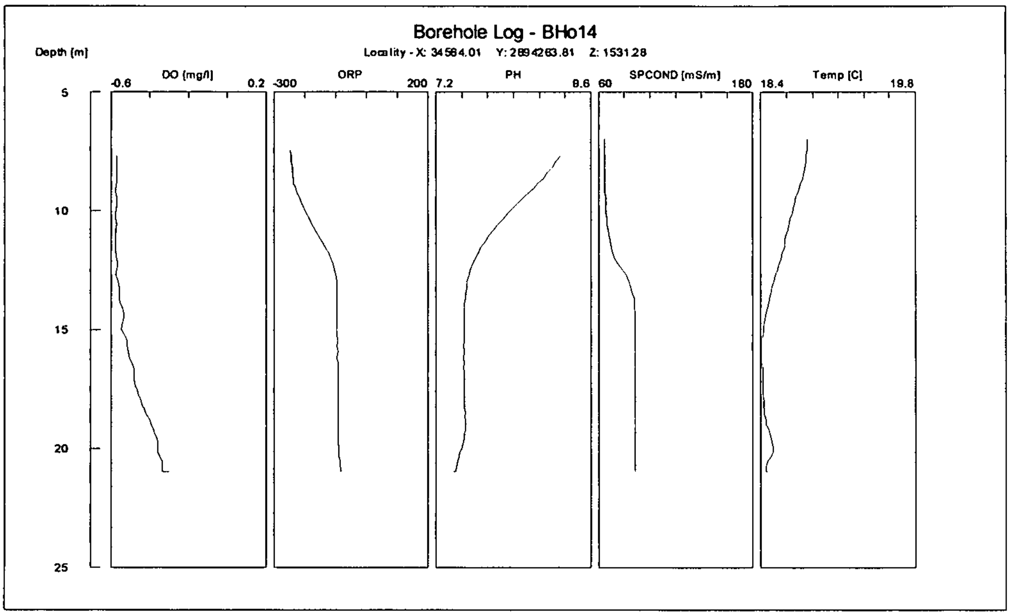


Figure 5-48. Chemical profiles for Block R1-3.

5.6.9 Flushing rates

The concentrations of various constituents along the reaction path will depend on the reaction and dilution rate from water that recharge into the mine. Mobilisation of these salts from the mine is regulated by the flux through the underground workings or the opencast.

In Table 5-19 the current concentrations of the constituents in the different blocks are tabled. Figure 5-49 shows a calculation of flushing in the underground at Welstand, based on the calculated influx rate for this block. This is obviously a simplistic approach but nevertheless demonstrates the importance of having a throughflow system to keep salinities down.

Table 5-19: Concentrations of various elements for different blocks at TNC (mg/L).

Block	SO_4^-	Ca^{++}	Mg++	Na^+	K^+
Welstand-TNC	498	150	89	75	6
Block C	458	134	66	68	8
Block G&A(opencast)	1680	355	238	63	3
Block F	1375	345	184	63	13
Block QR	567	172	66	31	13
Block B&C (opencast)	935	238	182	52	15
Block H (opencast)	519	117	86	498	4
Block R32 (opencast)	230	230	43	102	4

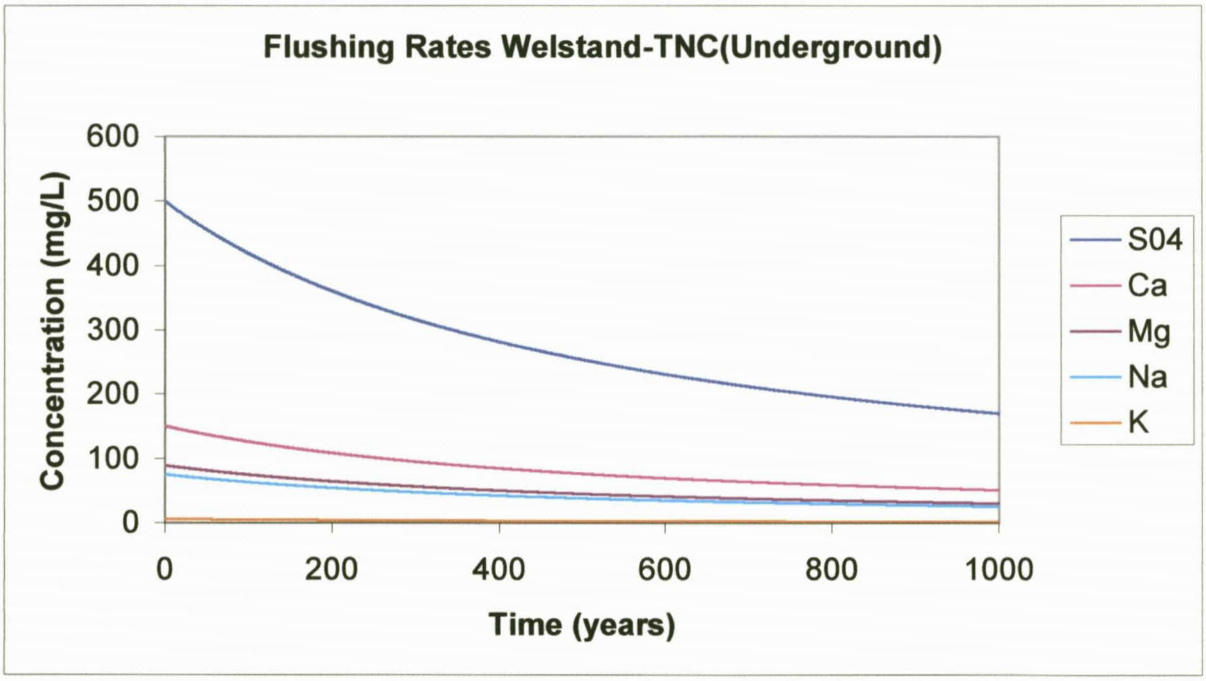


Figure 5-49. Flushing rate for constituents in the Welstand-TNC Block.

5.7 Surface water quality

The Olifants River runs through the area, and sampling has been done at various places along the river (Figure 5-50).

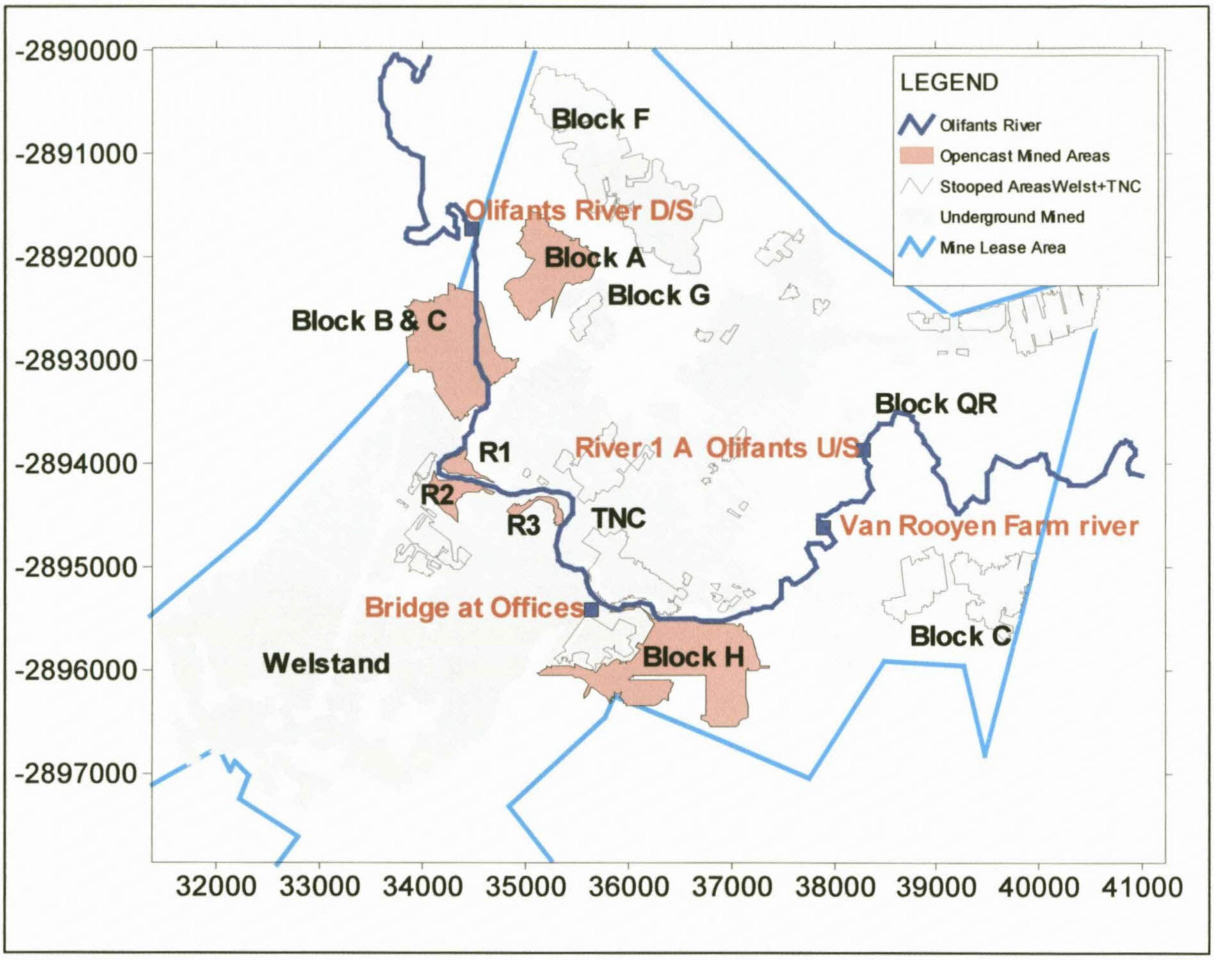


Figure 5-50. Map indicating the sampling positions in the river (data from Ingwe).

Water enters the TNC property at a 50% percentile of 57.6 mg/L sulphate and leaves the property at a 50% percentile of 106.5 mg/L. This gives a distorted view because the salt load is also related to the flow rate of the river. Figure 5-51 illustrates that concentration build-ups coincide with low-flow periods in the river. Anomalously high nitrate values are associated with cattle drinking from the river during low-flow conditions.

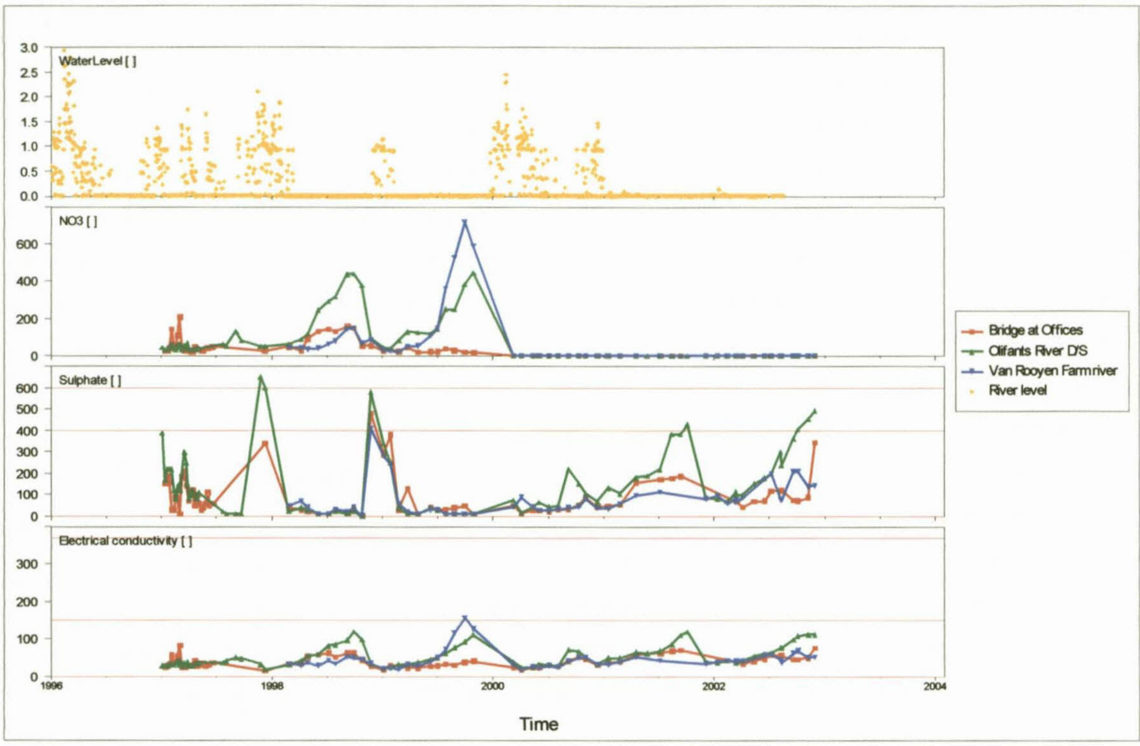


Figure 5-51. Water qualities of the Olifants River, measured at different places along the river, in relation to the flow in the river (mg/L).

Several ways of calculating the TDS in the mine water exist. Table 5-20 provides an outline of the correlation between EC and TDS. As a general rule for the TNC Area, the TDS is usually double that of sulphate value. Sulphate and TDS concentrations are important in calculating future excess salt loads that will be available from TNC.

Table 5-20: Relation between EC and TDS.

BH No	Mining Area	EC/TDS Correlation	Correlation percentage
BHo1	Block B&C	y = 7.5835x+397.99	80
BHo6	Block H	y = 9.4408x-77.809	89
BHo7		y = -0.1193x+2151.9	Low
BHo14	BlockR1-3	y = 7.746x+28.28	88
BHu2	Welstand-TNC	y = 7.6103x-23.231	96
BHu3		y = 8.199x+4.2497	75
BHu4		y = 9.7546x-121.92	97
BHu5		y = 5.5973x+41.298	99.5
BHu9		y = 1.9847x+174.15	34
BHu6	Block G&A	12.049x-186.37	95
BHu7	Block C	y = 7.3624x-10.703	94
BHu8	Block QR	y = 8.54676x-8.5599	94
BHu10	Block F	y = 9.8164x-128.19	98

Table 5-21 provides information on the calculated influx rates and expected salt loads for each of the sections at TNC. If water will ever decant from these sections, these are the values that need to be considered.

Table 5-21: Future flux and salt load from TNC.

Mining Area	Annual influx (m3)	Annual tonnage TDS	Daily influx (m3)	Daily tonnage TDS
Block B&C	80 200	150	220	0.41
Block H	104 000	108	285	0.30
BlockR1-3	21 800	10	60	0.03
Welstand	322 200	321	883	0.88
Block G&A	54 600	183	150	0.50
Block C	40 600	37	111	0.10
Block QR	11 000	12	30	0.03
Block F	43 800	120	120	0.33
Totals	678 200	942	1858	2.58

These values differ from that by Grobbelaar *et al.* (2000) in that the predicted influx is about 50% of that predicted previously. Considering the scale of the investigation and also the assumptions that had to be made, this is not considered to be a contradiction. Only through the acquisition of additional time series data will it be possible to refine current predictions.

5.8 Conclusions

The TNC investigation is an ideal example of mine water associated with a complex mine layout, which has been mined by different methodologies and which interact 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 high degree of confidence is attached to calculations in this report and it is unlikely that significant changes in the understanding of the system will result from future monitoring.

The natural rate of water influx into the mine amounts to about 2 ML/d. This has been calculated from assuming recharge factors for the various types of mining. Apart from this water, water from the Olifants River has been known to enter into the mine during extreme flood events. According to flow data available from Station B1H005-A01, this will occur less than 1:30 years. The rate of 2 ML/d is about 50% of that previously suggested, but it constitutes only the natural component.

As far as the salinity of the mine water is concerned, sulphate levels are generally lower than in many other collieries. This could be because of the river water that

has entered into some of the mine workings. The higher salinities in some of the underground workings away from the river confirm this conclusion.
pH-values of the mine water are generally in the neutral range. This is expected to remain such in much of the mine because of the high percentage flooded underground workings. Some of the opencast may eventually develop acid patches because of shallow mining conditions and spoil which lies above the static water level. As a management option, mixing of waters from the different areas should be considered to achieve the best possible water quality before considering treatment and/or release of excess water. Block H could, for instance, be developed into a surface holding area where mine water could be aerated.

The expected salt load that could be derived from the mine is in the order of 2,6 t/d (TDS). This is less than that previously expected because the salt load is linked to the expected volume of excess water. It is important to realize that predictions of this nature are at best, only estimates, based on the best available data.

6 New Largo

6.1 Introduction

New Largo Colliery is located in the Mpumalanga Province, north of the town Ogies. It forms part of the Witbank Coalfield (Erasmus *et al.*, 1981, Figure 1-1) and lies in the Olifants Catchment (Figure 1-2). Figure 6-1 shows a map of the colliery.

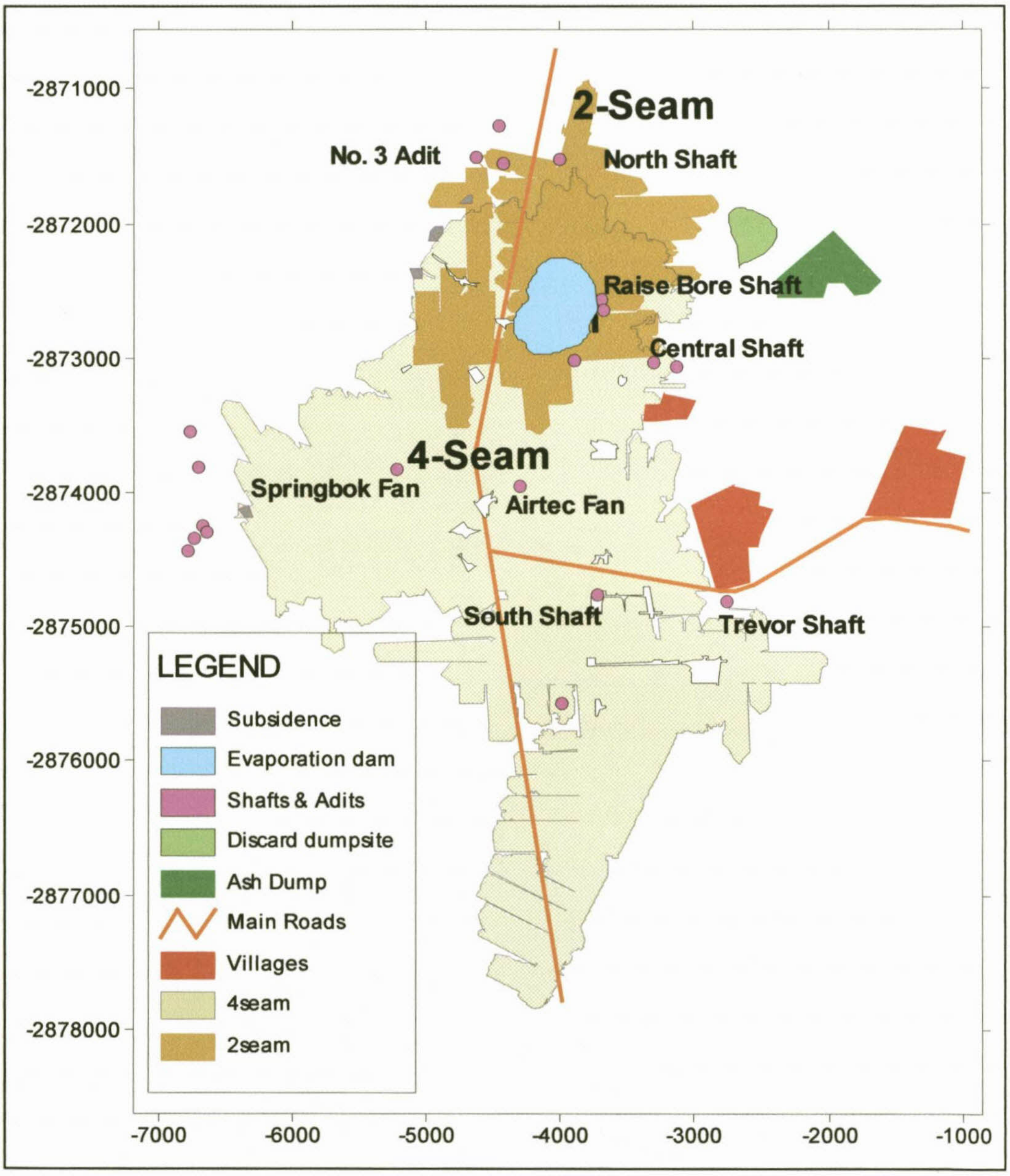


Figure 6-1. Map of New Largo.

Eleven old collieries lie around New Largo. To the southeast lies Alpha Colliery, which has been used in the past for the storage of crude oil. Oil seepage is known to have occurred from Alpha Colliery into New Largo during mining.

New Largo has ceased production in 1989. Many of the surface structures have been removed and rehabilitation of the area has commenced. Little evidence of past mining activities therefore remains on the surface.

There is no evidence of seepage from the rehabilitated coal discard dump (Figure 6-2) and its regional environmental impact is considered to be small.

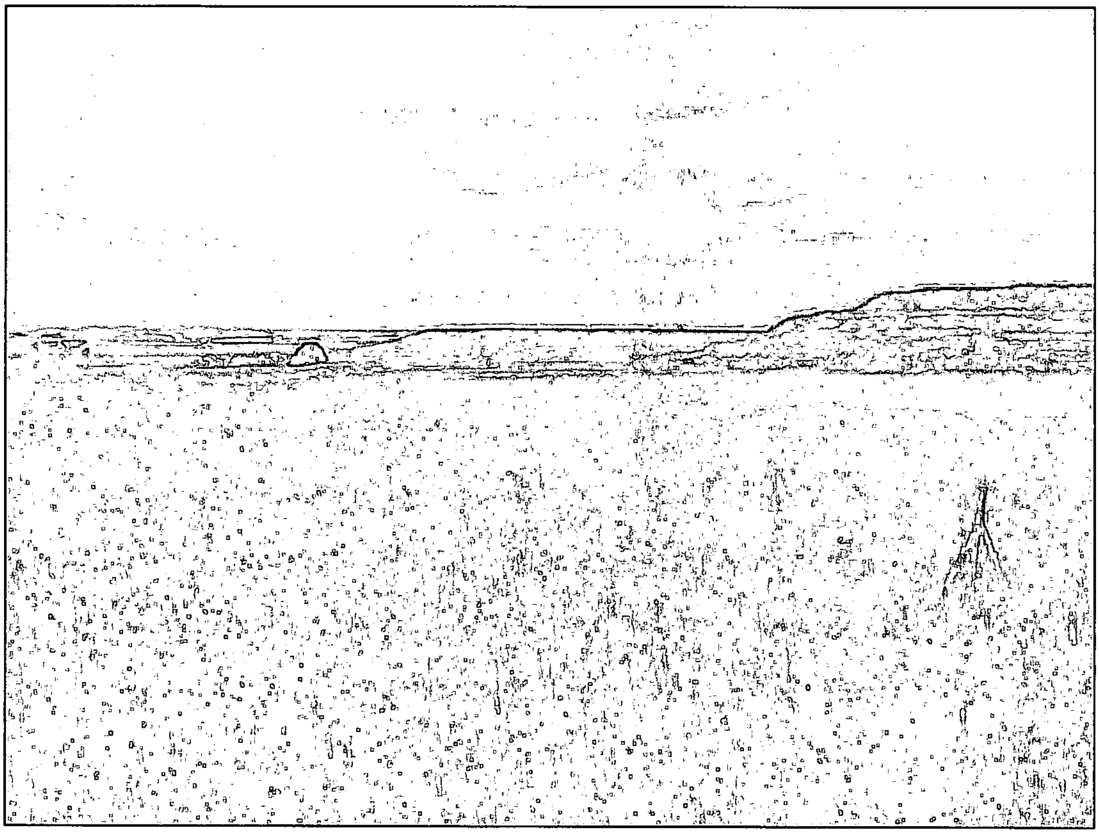


Figure 6-2. Coal discard dump in the front with the power station ash dam in the back.

6.2 Surface Hydrology

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 is located in the northern half of the mine (Figure 6-3), above the area where the No 2-Seam has also been mined. The surface area of the pan is 33 ha, with the runoff area of 95 ha into the pan. Surface runoff at New Largo is 7% of the rainfall, and the mean annual evaporation for the area is 1 650 mm (Midgley *et al,* 1994).

The average annual rainfall for the area is 681 mm (Ogies), with the 50% percentile at 659 mm. Figure 6-4 shows the rainfall since 1905, with the last few years below the average. The rainfall was 582 mm for 2001.

The runoff directions of the surface water are illustrated with arrows in Figure 6-3.

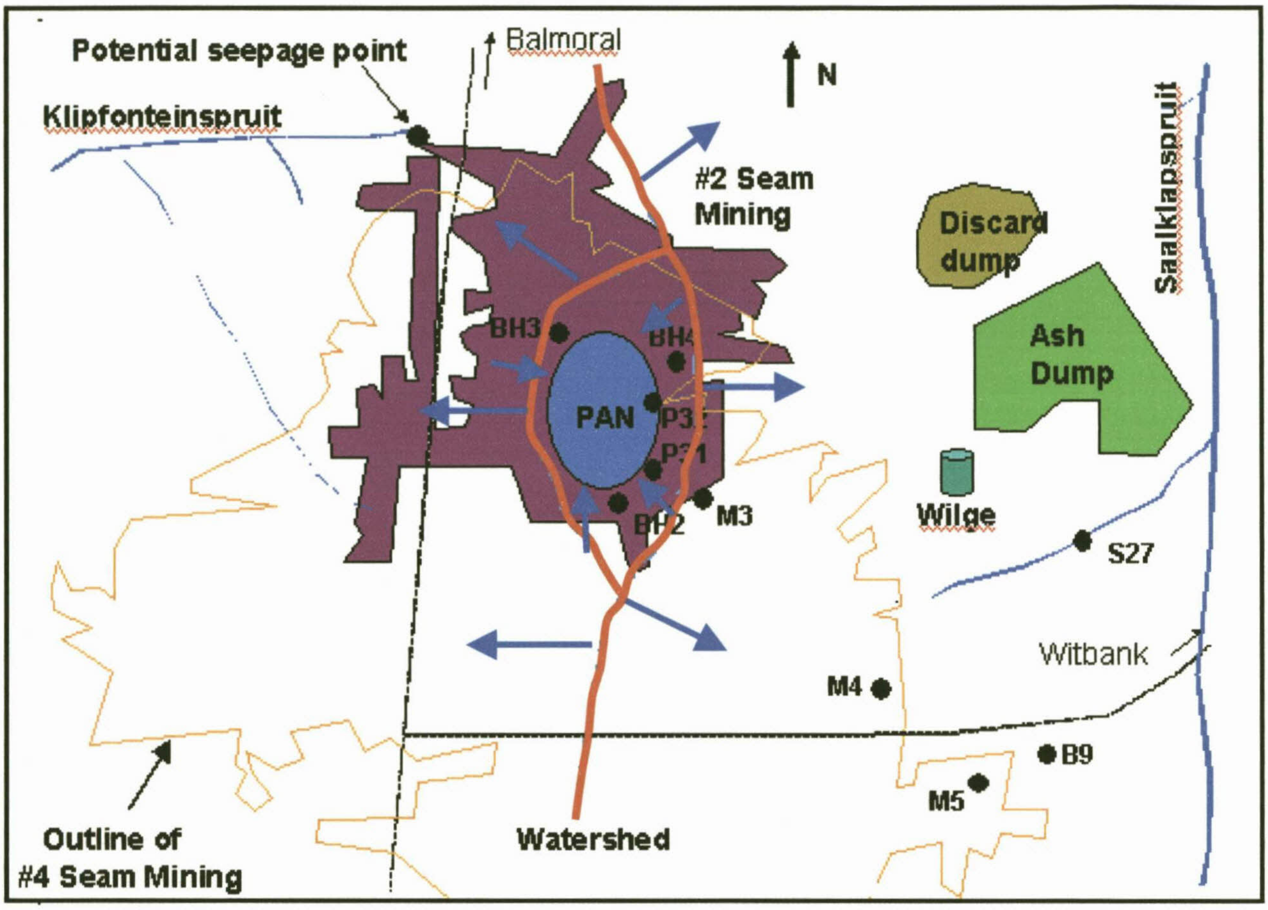


Figure 6-3. Map of the surface hydrological structures (courtesy of D. Salmon, Anglo Coal).

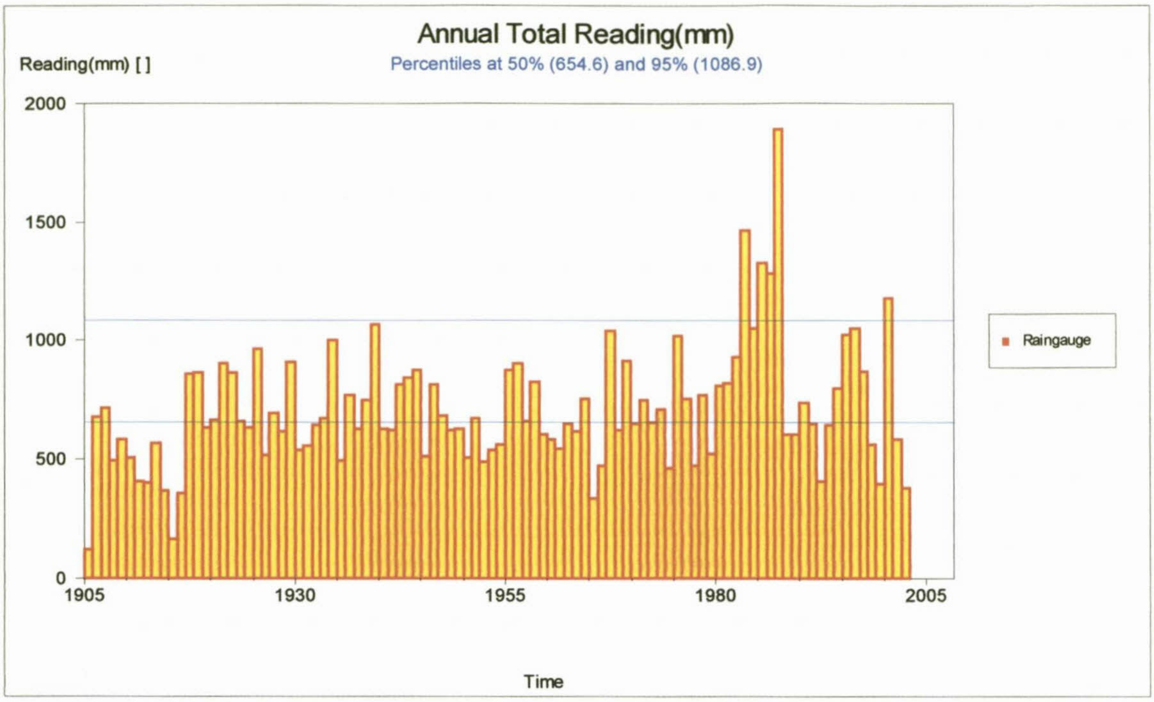


Figure 6-4. Rainfall graph for the New Largo area (Jan - Dec cycle).

6.3 Geology

The New Largo Coalfield is situated within a pre-Karoo basement valley on the northern margin of the Witbank Coalfield. The typical stratigraphy of the coalfield is illustrated in Figure 6-5.

The pre-Karoo basement comprises Pretoria and Rooiberg Group quartzite, shales, lava, pyroclastic and diabase and, to a much lesser extent, Bushveld Complex granites.

Overlying the pre-Karoo rocks, but not always present, is a succession of poorly sorted sandstones, granule stones and diamictites, with rare occurrences of varved and massive mudrocks forming the Dwyka Group. Thicknesses of up to 12 m have been intersected, but the entire Dwyka Group has been penetrated in only a few boreholes (Canbulat *et al.,* 2002). The upper surface of the Dwyka Group undulates with a relief of up to 70 m. It is postulated that regional palaeo-drainage was toward the south and southwest. A northwest-southeast trending palaeo-ridge in the northern part of the reserve area divides the coalfield into two discrete palaeo-valleys.

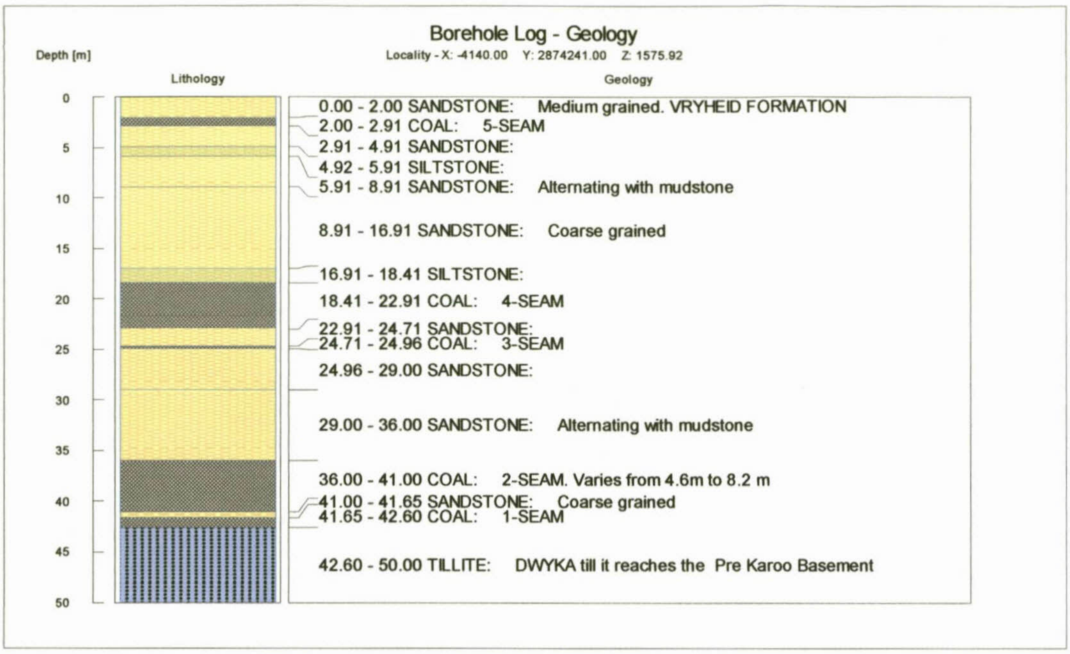


Figure 6-5. Geology at New Largo Colliery.

The Karoo Sediments attain a maximum thickness of about 75 m (average 40 - 45 m), but could be much thinner within the area owing to present day erosion. Typically 5 coal seams, numbered 1 through 5 in ascending order, are developed.

A schematic north-south cross-section across the reserve area illustrates the effects of erosion on coal seam preservation and Vryheid Formation thickness (Figure 6-6). The depth of weathering is generally between 7 and 15 m and has a significant influence on reserve limits. The No. 4 Seam reserves were particularly prone to weathering owing to the high permeability and variable feldspar content of the coarse-grained, pebbly sandstone overlying it over much of the area (Canbulat *et al.,* 2002).

The general structure of the coalfield is that of two shallow valleys separated by a northwest-southeast trending quartzite ridge, with coal seams generally dipping at less than 1° towards their respective axes. The cross section shows that the seams are generally flat lying or gently dipping.

There is no evidence of major faulting in the coalfield. Minor fault zones with displacements of less than 0.5 m have been encountered on rare occasions.

Rare dolerite dykes, usually less than 1 m thick and striking east to west and northeast to southwest, were encountered in the New Largo underground workings. They have not caused significant mining problems, and the presence of similar intrusions may be anticipated over the rest of the reserve area.

Dolerite intrusions in the form of sills are largely absent. However, in the south of the reserve area, transgressive sills, varying in thickness from a few cm to 8 m, intrude the No.'s 2 and 4 Seams. These intrusions have resulted in moderate to severe devolatilisation of coal in their immediate vicinity.

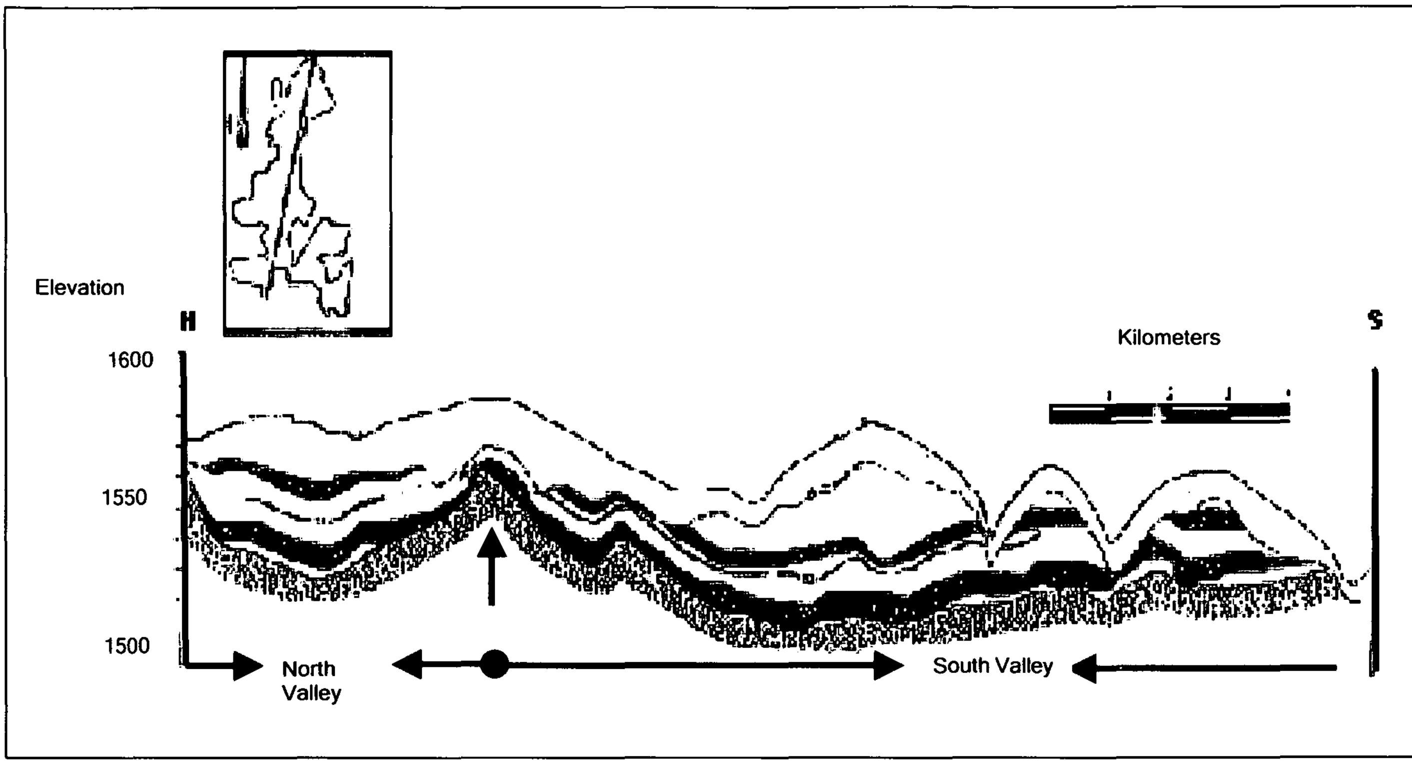


Figure 6-6. Geological N-S cross-section of New Largo (after Canbulat *et al., 2002).*

6.4 Geohydrology

The geohydrological conditions at New Largo are similar to those in the rest of the Mpumalanga area. Two distinct groundwater systems are present. The upper aquifer is associated with the weathered zone, where water is often found only a few metres below the surface. This aquifer is recharged by rainfall, which moves down until it reaches an impermeable layer. It then moves laterally with the gradient of the surface. Where natural barriers like dolerite dykes or sandstone outcrops obstruct it, this water usually emerges at fountains. The deeper aquifer lies within the consolidated formations below the weathered rocks. Dual porosity conditions occur, with groundwater in the formation and in the fractures, cracks and joints within these rocks. The coal itself also yields limited amounts of water.

6.5 Mining

Mining methods have been by 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. Stooping 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. Statistics on mining at New Largo Colliery are included in Table 6-1.

Table 6-1: Statistics on mining at New Largo.

Description	Value
Total area mined (ha):	1 429
No. 4 Seam (ha)	1 149
No. 2 Seam (ha)	280
Total area not mined (ha)	18
Area of evaporation pan (ha)	33
Total volume mined (Mm^3):	23.86
Volume No. 4 Seam (Mm^3):	20.62
Volume No. 2 Seam (Mm^3):	3.23
Average mining height No. 4 Seam (m)	2.78
Average mining height No. 2 Seam (m)	2
Average extraction rate	0.65
Mining depth below surface No. 4 Seam (m)	10-30

The coal floor contours are shown in Figure 6-7 and Figure 6-8. The elevation range for the surface contours is between 1 545 and 1 579 mamsl (Figure 6-9).

Depth of mining for the No. 4 Seam ranges from 10 m to 30 m below the surface. The shallowest conditions are in the northwest and west. The No. 2 Seam lies some 15 m below the No. 4 Seam, with no outcrops visible in the area.

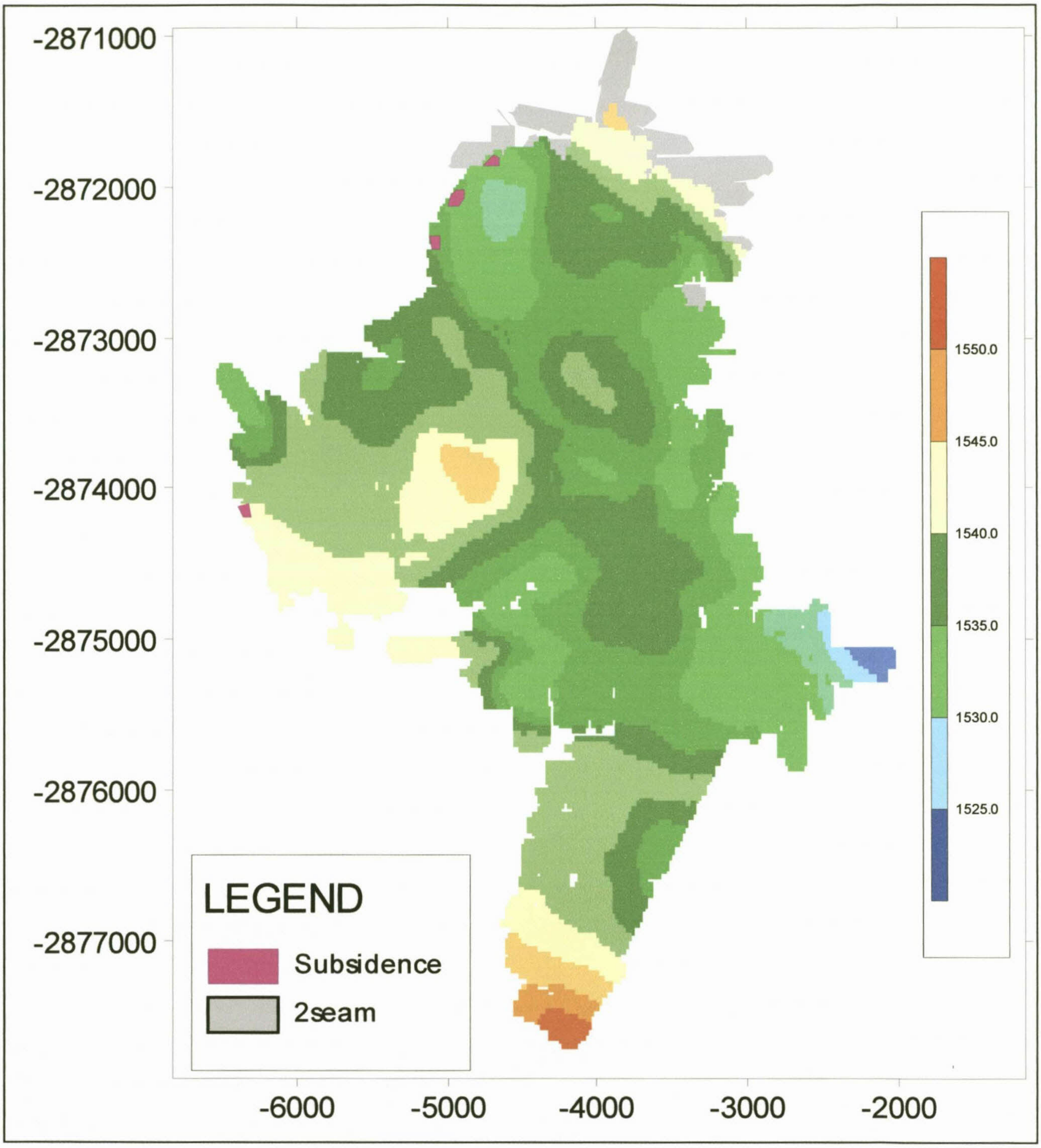


Figure 6-7. Floor contours of the No. 4 Seam.

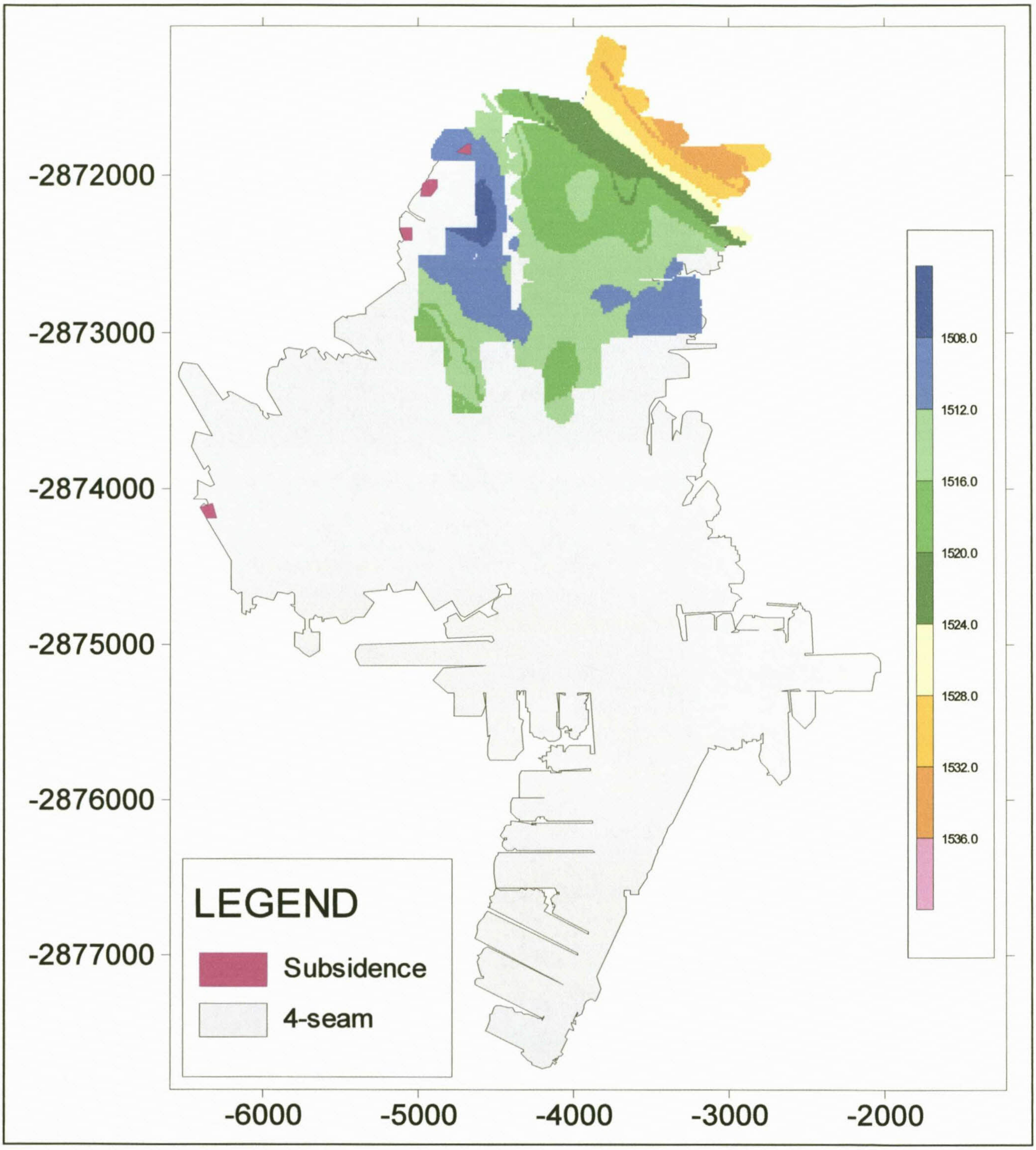


Figure 6-8. Floor contours of the No. 2 Seam.

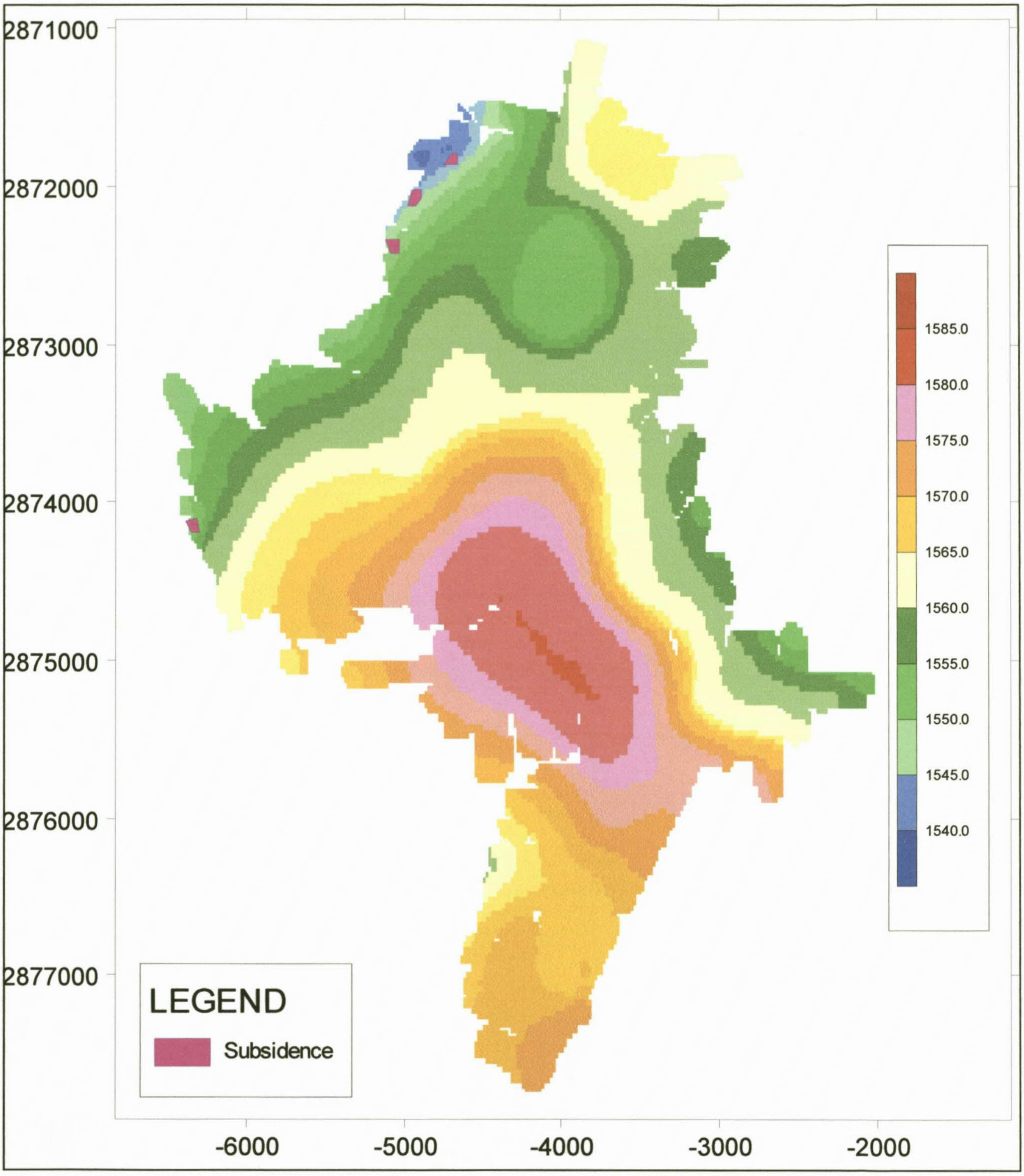


Figure 6-9. Surface contours at New Largo Colliery.

6.6 Conceptual Model

A conceptual model to illustrate the seams in relation to the surface and surface structures is shown in Figure 6-10. Elevations used in the model are averages, only for illustration purposes.

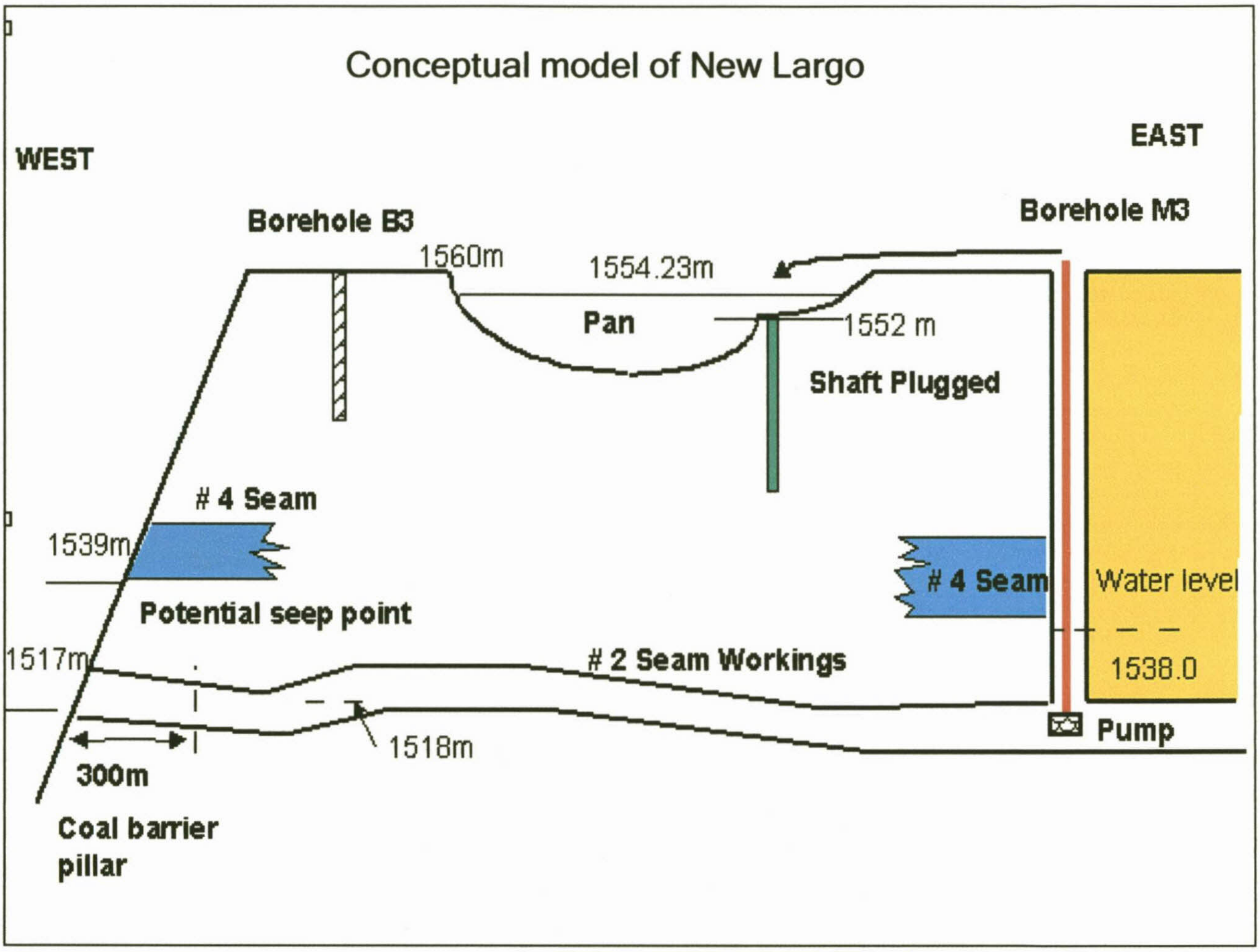


Figure 6-10. Conceptual model for New Largo (courtesy of D. Salmon, Anglo Coal).

6.7 Water Quantities

Figure 6-11 shows the water levels in the mine during 2000, and Figure 6-12 water levels over time. The water elevation in the main water body is at 1 534.5 mamsl and that in the two smaller water bodies at 1 537 mamsl. Also shown in this diagram are the positions of the monitoring holes. Borehole DCBH is a farmer's borehole, through which mine water can decant onto the surface. Boreholes BH4 and B9 are not drilled into the mine. The "M" boreholes are the original boreholes drilled by Hodgson (1992).

Of importance is the rise from 1 515 to 1 532 mams in M3I, showing the rise of the water levels on the No. 2 Seam horizon. Currently the water level in the No. 2 Seam is regarded to be at the same elevation as that in the No. 4 Seam i.e. at 1 535 mamsl. During the same time, the water elevation on the No. 4 Seam horizon has risen from 1 532 to 1 535 mamsl.

Stage curves showing the water holding capacities for the two coal seams are shown in Figure 6-13 and Figure 6-14. From this, a total water gain of approximately 8 Mm^3 has been recorded during the period 1992 - 2003 (11 y). This amounts to a daily average of 2 000 m^3. 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 the pan. From this pan, a maximum evaporation rate of 870 m^3/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 runoff 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%. Figure 6-15 shows the relation between water levels and the rainfall. This is a feasible amount and falls at the high end of the suggested recharge to the mine by Hodgson (1992).

The recharge to the mine constitutes two components, namely infiltration and regional flow towards the mine. Experience in the coal 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. Despite this information, it is not anticipated that more than 50% of the mine water is derived from regional flow. A more 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 top of Karoo sediments. It should, however, be remembered that portions of the underground workings did undergo stooping and that higher recharge rates are possible here. A map showing areas where future subsidence is possible, is included as Figure 6-16. It is currently not known to what extent these areas contribute to the water make in the mine.

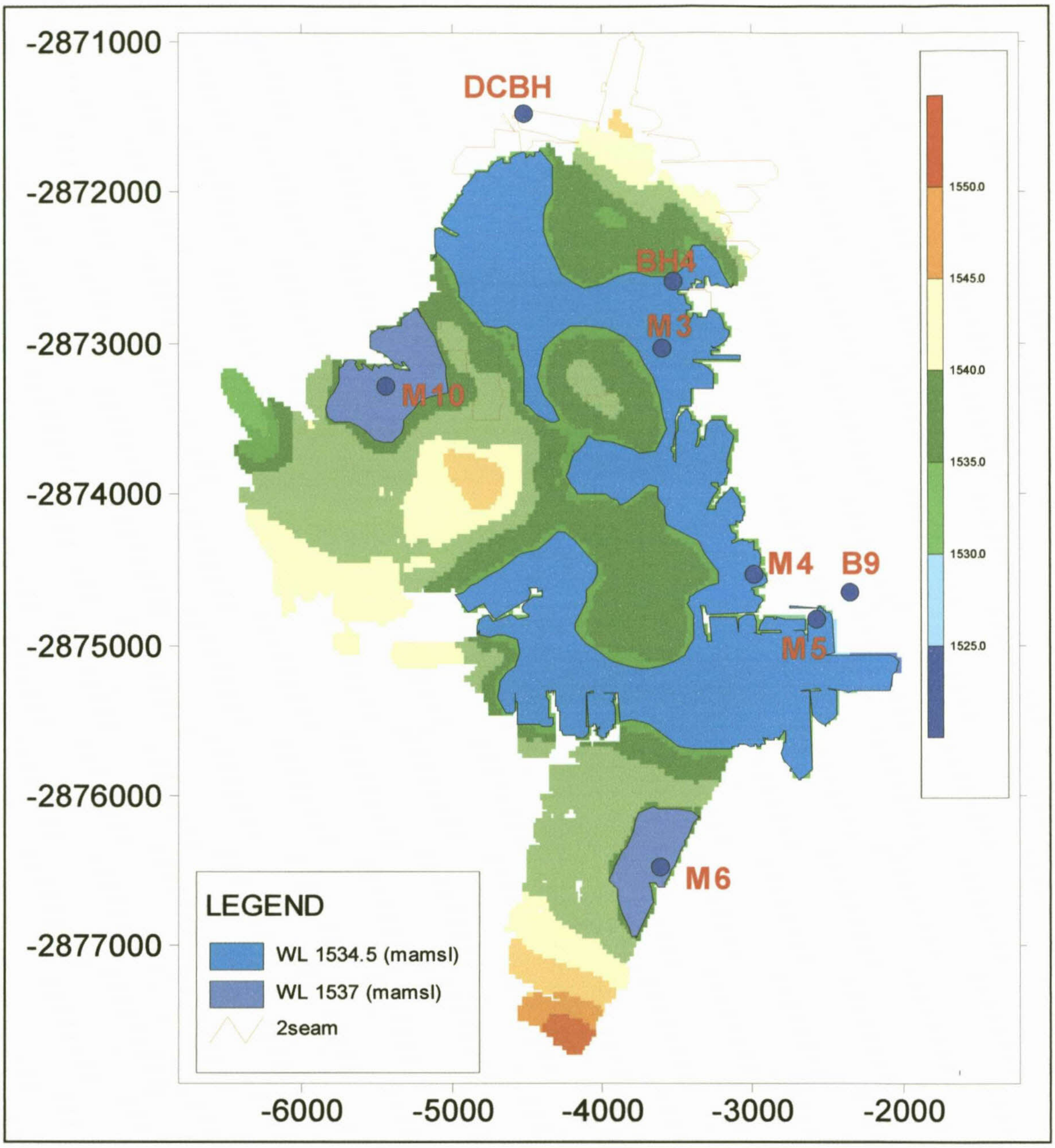


Figure 6-11. No. 4 Seam floor contour map of New Largo, illustrating the palaeo-ridge division, the areas filled with water and the monitoring boreholes.

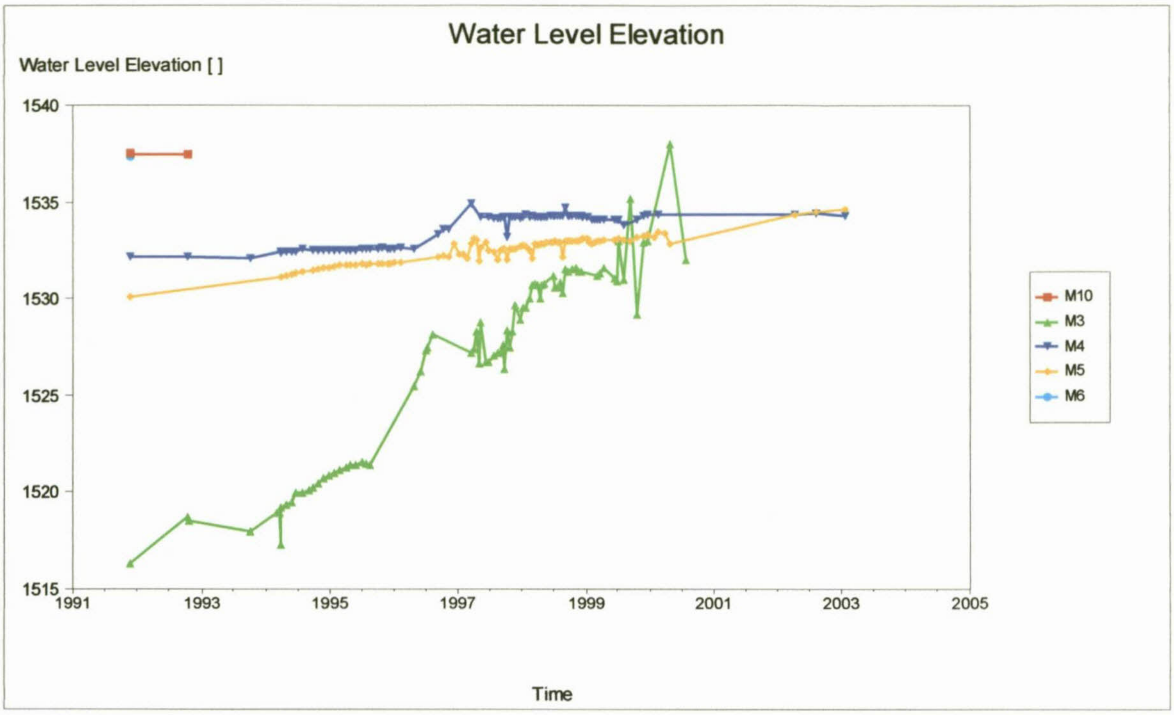


Figure 6-12. Graph of water levels at New Largo.

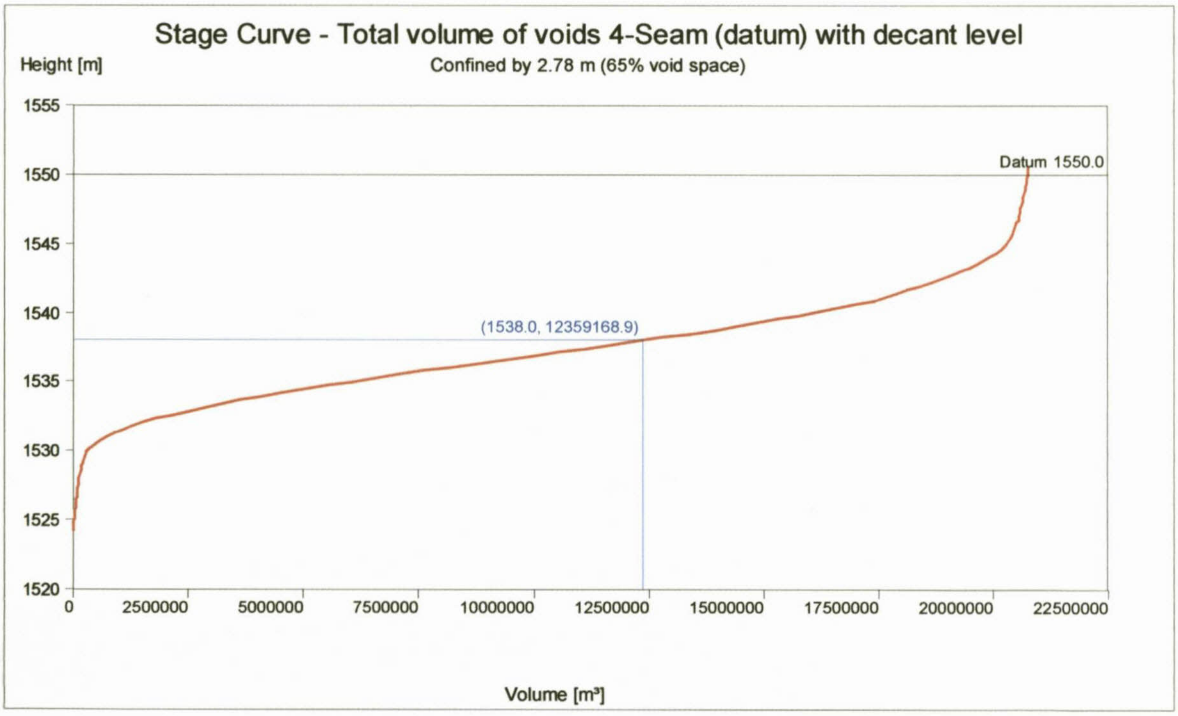


Figure 6-13. The total volume of voids in the 4-Seam in comparison with the decant volume.

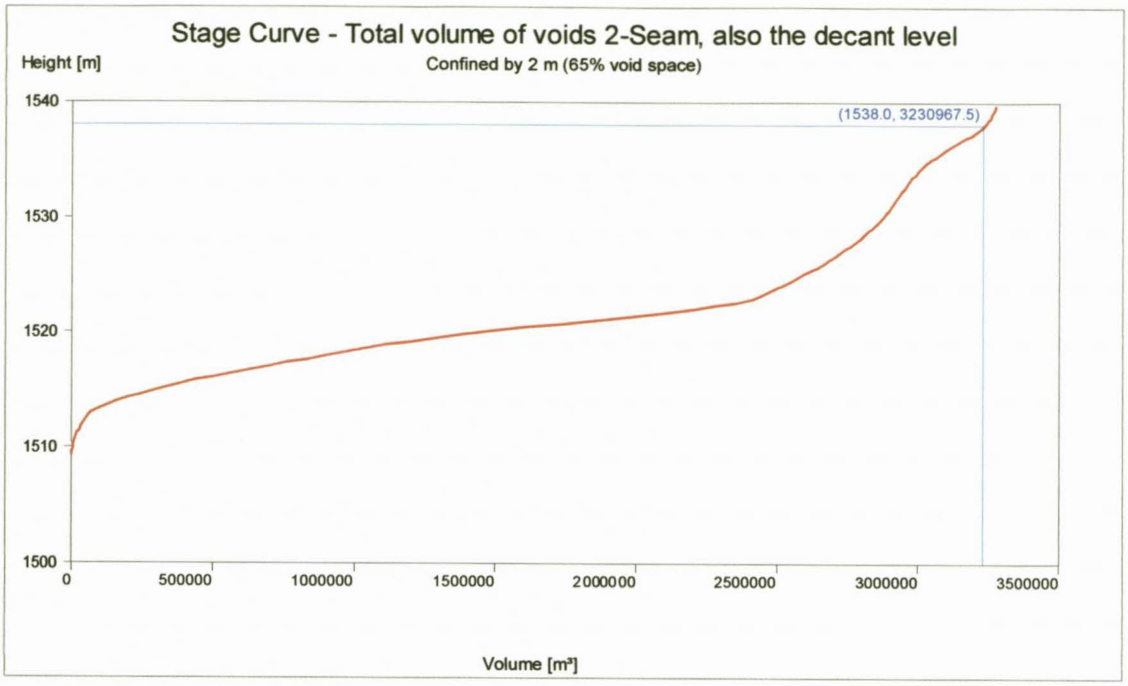


Figure 6-14. Total volume of voids in the 2-Seam, which also is the decant volume.

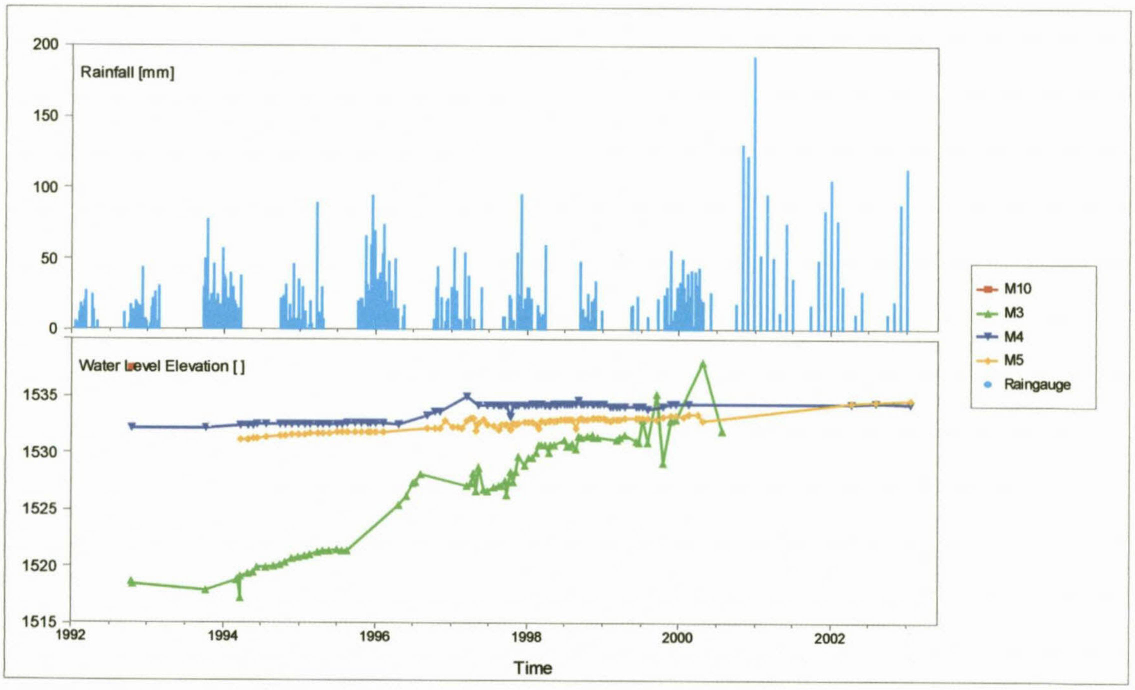


Figure 6-15. Comparison between rainfall and water levels for New Largo.

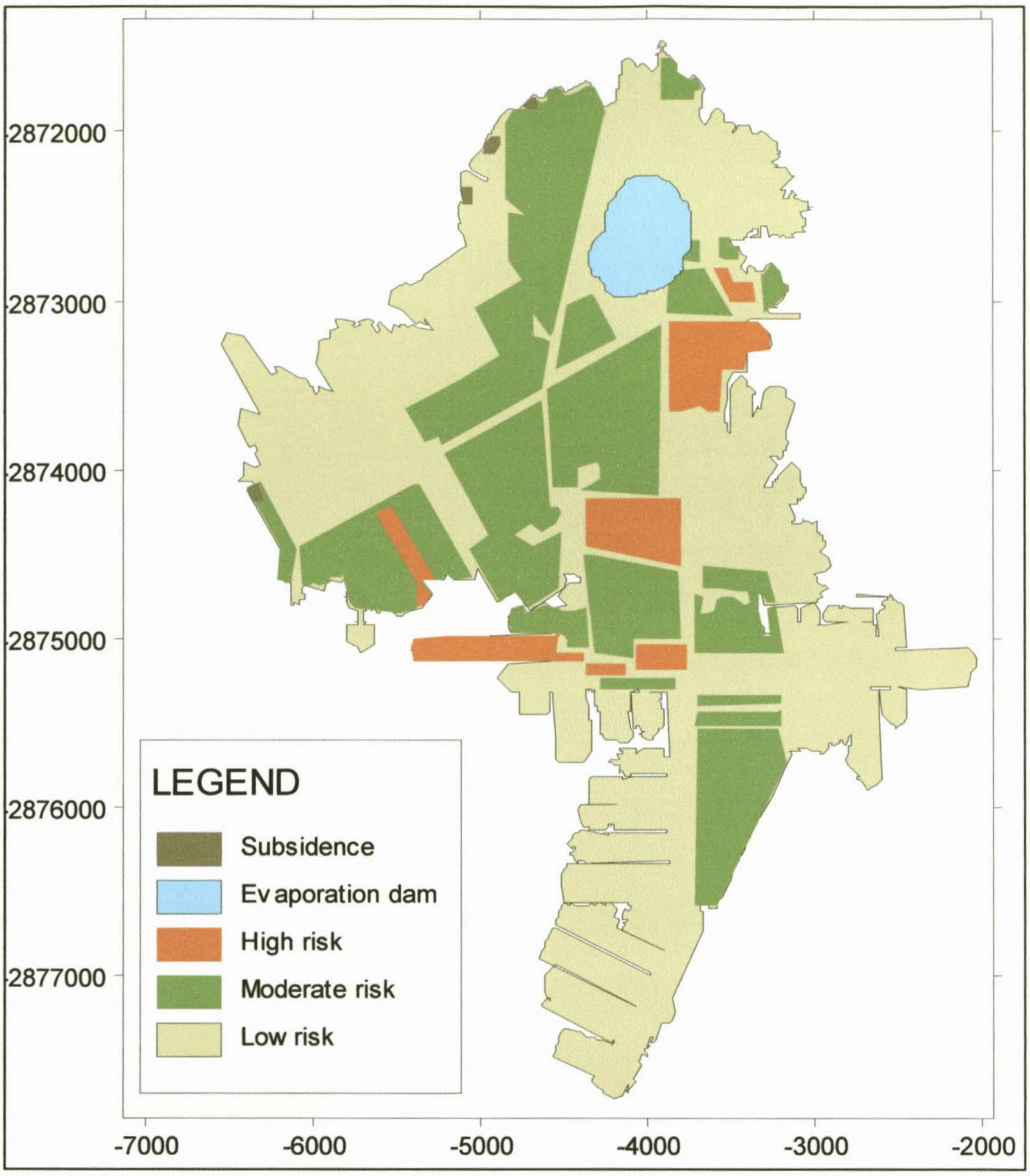


Figure 6-16. Risk analysis map for future subsidence at New Largo (courtesy of Ismet Canbulat, Coaltech Report).

Decant will occur at borehole DCBH. This is the lowest locality at which the No. 2 Seam is interconnected with the surface (Figure 6-11). The decant level is at 1 538 mamsl.

Evaporation of excess mine water from the pan will not be sufficient for mine water management in the long run. The available pan area is 32 ha, which could evaporate at a maximum rate of 870 m^3/d, on average. From this, the surface runoff into the pan has to be subtracted. The conclusion is that New Largo Colliery will fill up with water and seep/decant to the west of the mine at a rate of approximately 2 000 m^3/d, if nothing else is done.

6.8 Water Quality

6.8.1 Mine chemistry in general

The water quality in the mine water has been profiled in April 2002 and August 2002, using a multi-parameter probe. The results of borehole M5 have been plotted in Figure 6-17. The measurements from April 2002 are shown in red and those from August 2002 in blue.

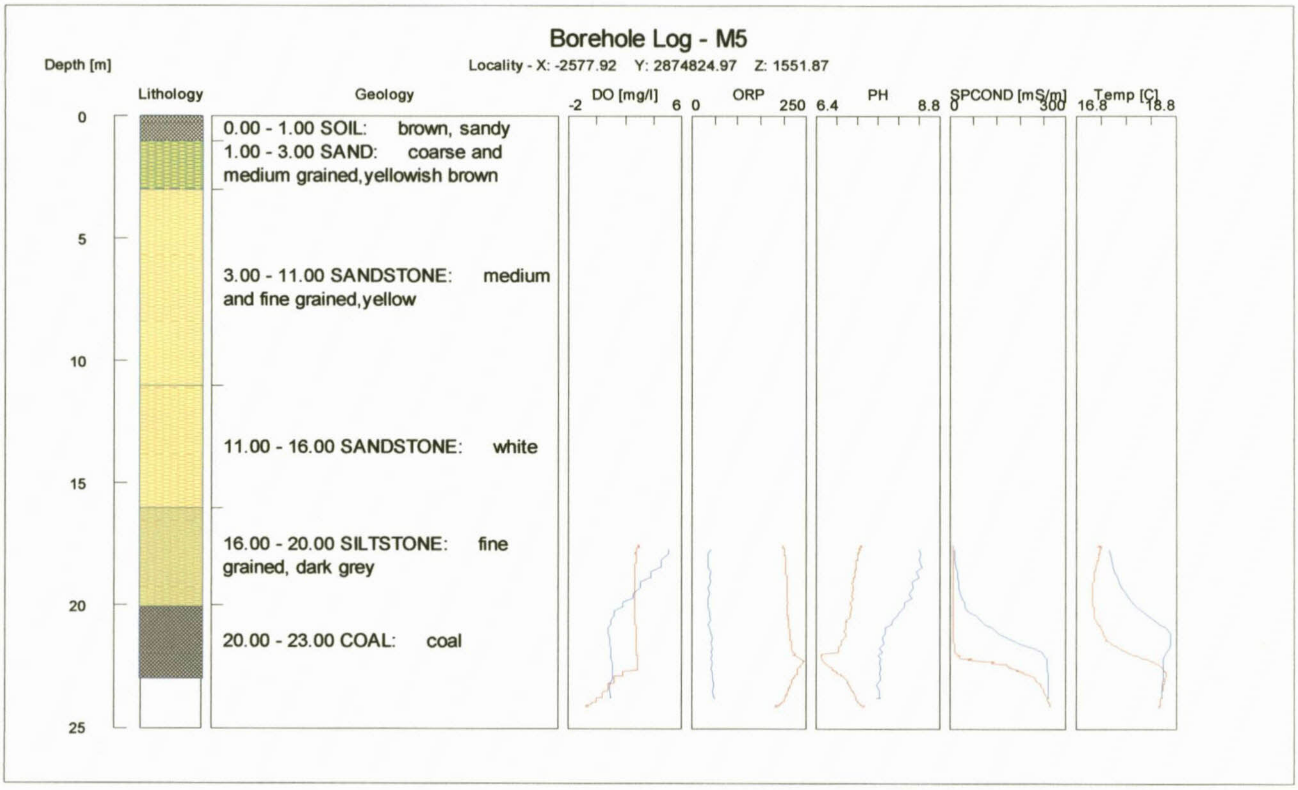


Figure 6-17. Results from multi-parameter probing into the colliery (M5).

The electrical conductivity values in the mine range from 260-280 mS/m (Figure 6-17).

Water sampling was done one metre from the bottom of the coal floor. The results are listed in Table 6-2. The water quality of the boreholes further away from the extraction area is worse than that of Borehole M3, where extraction occurs.

Table 6-2: Chemical analysis of water at New Largo (mg/L where applicable).

SiteName	Date	Malk	Palk	EC	pH	Ca	Cl	Mg	NO3	SO4
BH4	Apr-02	73	0	17.2	7.14	14	1	4	0	5
B9	Apr-02	16	0	4.8	6.33	4	2	1	0.05	5
B9	Aug-02	15	0	4.5	6.54	3	1	1	0	3
M3	Aug-02	73	0	212	6.22	383	5	57	0	1116
M4	Apr-02	173	0	385	6.36	786	3	209	0.03	2443
M4	Aug-02	216	0	383	6.46	687	2	205	0	2248
M5	Apr-02	424	0	351	7.07	780	5	149	0.04	1940
M5	Aug-02	385	0	352	7.31	721	4	135	0	1799
P32	Apr-02	61	0	290	7.09	535	13	98	0.04	1715
P32	Aug-02	72	0	334	7.77	549	11	104	7	1767

SiteName	Date	K	Na	Fe	Si	Al	Sb	As	Ba	Be
BH4	Apr-02	5	9	0.673	-1.00	0.018	<0.015	<0.01	0.085	<0.001
B9	Apr-02	3	4	0.074	-1.00	0.015	<0.015	<0.01	0.054	-0.001
B9	Aug-02	3	3	0.063	-1.00	0.005	<0.015	<0.01	0.040	-0.001
M3	Aug-02	6	15	0.021	-1.00	0.082	<0.015	<0.01	0.024	-0.001
M4	Apr-02	5	10	8.678	-1.00	0.013	<0.015	<0.01	0.038	-0.001
M4	Aug-02	5	8	23.547	-1.00	0.013	<0.015	<0.01	0.014	-0.001
M5	Apr-02	7	14	0.080	-1.00	0.017	<0.015	<0.01	0.028	-0.001
M5	Aug-02	5	11	0.075	-1.00	0.013	<0.015	<0.01	0.015	-0.001
P32	Apr-02	16	42	0.206	-1.00	0.126	<0.015	<0.01	0.031	-0.001
P32	Aug-02	14	40	0.020	-1.00	0.014	<0.015	<0.01	0.014	-0.001

SiteName	Date	B	Br	Cd	Cr	Co	Cu	F	Pb	Li
BH4	Apr-02	<0.04	<0.04	<0.005	<0.006	<0.005	0.005	0.04	<0.015	0.004
B9	Apr-02	<0.04	<0.04	<0.005	<0.006	<0.005	0.004	0.04	<0.015	0.002
B9	Aug-02	<0.04	<0.04	<0.005	<0.006	<0.005	0.002	0.03	<0.015	<0.001
M3	Aug-02	<0.04	<0.04	<0.005	<0.006	0.011	0.020	0.61	<0.015	0.047
M4	Apr-02	<0.04	<0.04	0.009	<0.006	<0.005	0.010	1.14	<0.015	0.058
M4	Aug-02	<0.04	<0.04	<0.005	<0.006	<0.005	0.002	0.78	<0.015	0.055
M5	Apr-02	<0.04	<0.04	0.009	<0.006	<0.005	0.006	0.56	<0.015	0.067
M5	Aug-02	<0.04	<0.04	<0.005	<0.006	<0.005	0.018	0.39	<0.015	0.055
P32	Apr-02	<0.04	<0.04	<0.005	<0.006	<0.005	0.006	1.02	<0.015	0.039
P32	Aug-02	<0.04	<0.04	<0.005	<0.006	<0.005	0.003	0.73	<0.015	0.040

SiteName	Date	Mn	Mo	Ni	Se	Sr	Sn	V	Zn	SAR
BH4	Apr-02	0.153	<0.002	<0.01	<0.006	0.010	<0.01	<0.01	0.019	0.54
B9	Apr-02	0.058	<0.002	<0.01	<0.006	0.013	<0.01	<0.01	0.008	0.52
B9	Aug-02	0.058	<0.002	<0.01	<0.006	0.030	<0.01	<0.01	0.020	0.40
M3	Aug-02	1.204	<0.002	0.033	<0.006	1.860	<0.01	<0.01	0.041	0.19
M4	Apr-02	2.860	<0.002	0.040	<0.006	4.923	<0.01	<0.01	0.018	0.08
M4	Aug-02	4.101	<0.002	0.025	<0.006	4.825	<0.01	<0.01	0.033	0.07
M5	Apr-02	2.083	<0.002	0.036	<0.006	4.648	<0.01	<0.01	0.021	0.12
M5	Aug-02	2.591	<0.002	0.023	<0.006	3.922	<0.01	<0.01	0.025	0.10
P32	Apr-02	0.007	<0.002	<0.01	<0.006	2.982	<0.01	<0.01	0.015	0.44
P32	Aug-02	0.004	<0.002	<0.01	<0.006	3.011	<0.01	<0.01	0.017	0.41

The following conclusions are drawn from Table 6-2:

- The pH of the mine water is near neutral, which contrasts with the historic acid mine water quality during mining. It is a common phenomenon that acid water in collieries is neutralised by the base potential of the remainder material in the mine during the flooding phase.
- The electrical conductivity of the mine water ranges from 350 - 385 mS/m. The higher EC in the pan than the EC in Borehole M3 is the result of the evaporation of the water.

- High calcium and alkalinity concentrations exist, suggesting that there is enough buffering potential in the remainder material, against mine water acidification (Figure 6-18).

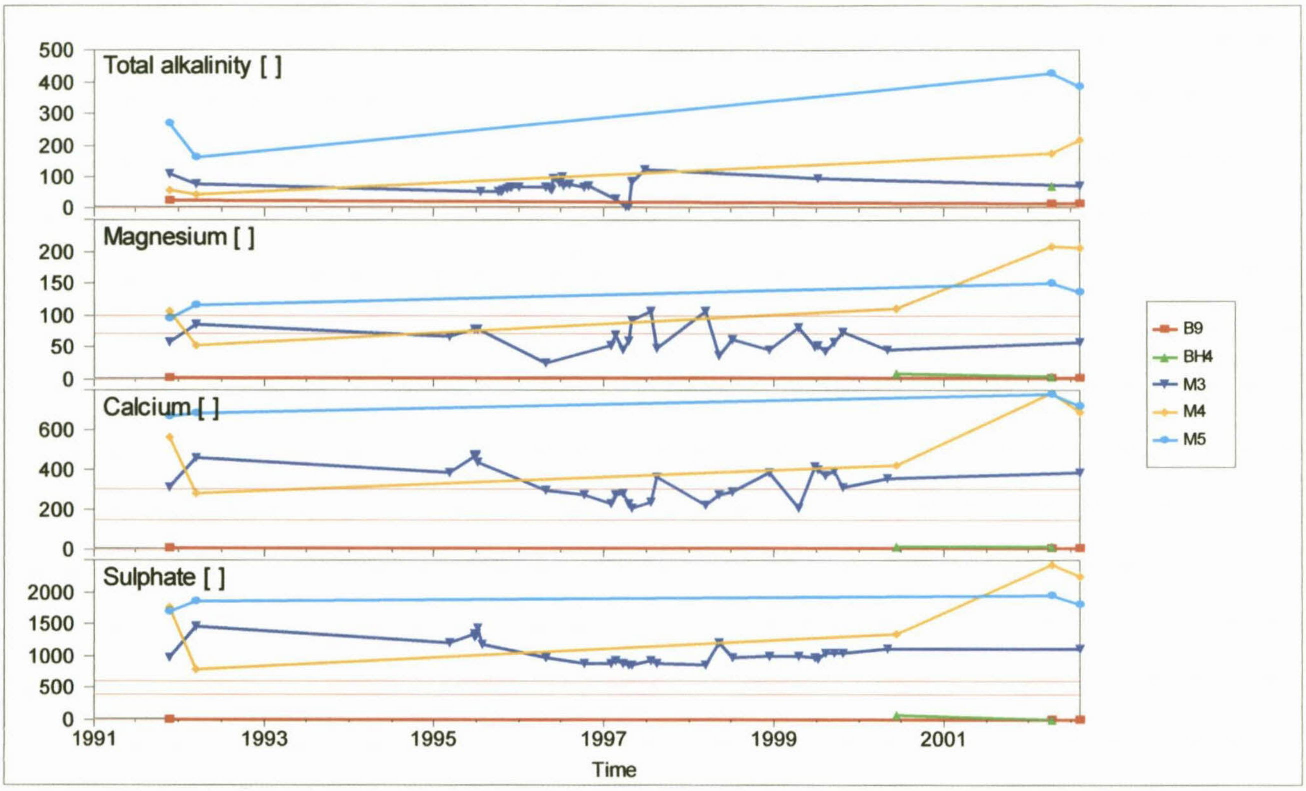


Figure 6-18. Chemical graphs for New Largo Colliery (mg/L).

6.9 Conclusions

During the past 10 years, the water level in the mine has risen by more than 10 m. This rise has been gradual and about 8 Mm^3 has entered into the mine in this time. The decant level from the mine is expected to be at 1 538 mamsl, which means that the water level in the mine can only rise by another 3,5 m before mine water will flow out onto the surface. At the current water levels, seepage of mine water into the weathered strata west of the mine is already possible. The conclusion is that past practices of regulating the mine water level through evaporation in the pan will not be sufficient to prevent the eventual decanting of mine water.

It is suggested that the mine should consider using the excess mine water for irrigation. Irrigation with the mine water should be possible in view of its neutral pH and low sodium content. This is the only long-term financially viable solution to prevent water from decanting into the stream west of the mine.

Irrigation using the mine water should be done with caution. About 50% of the mine workings are not flooded. This enhances the likelihood of the mine water becoming acid, as has been the case during the mining phase. If this happens, the mine water will have to be neutralised through lime addition before applied for irrigation.

The significance of this investigation lies in the quantification of the water and salt balance for the mine. The values calculated supplement and support information from the other five collieries described in this report.

7 Schoongezicht

7.1 Introduction

Schoongezicht Colliery is located in the Mpumalanga Province, west of Witbank. It forms part of the Witbank Coalfield (Erasmus *et al.*, 1981, Figure 1-1) and lies in the Olifants Catchment (Figure 1-2). Old diggings surround Schoongezicht Colliery. To the east of the colliery are the defunct collieries of Coronation and South Witbank, with Navigational and Landau Collieries to the south and west. Figure 7-1 shows a topographic map of the area and the mine outline.

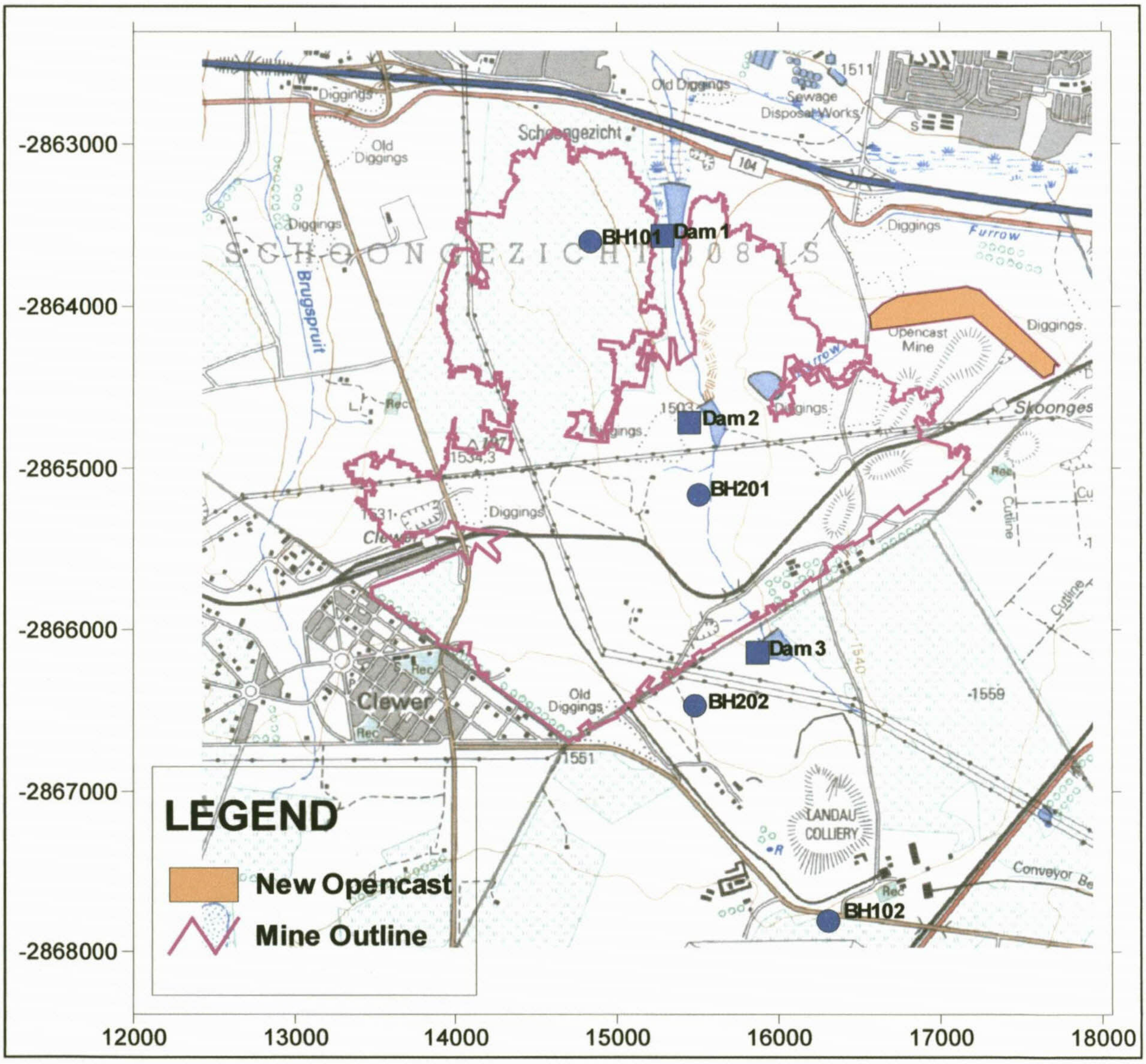


Figure 7-1. Topographic map and outline of Schoongezicht Colliery.

Schoongezicht Colliery has ceased production many years ago. No surface structures are visible and the area has been rehabilitated except for an opencast section in the east that is currently being mined. Figure 7-2 shows a surface view across the area. No farming occurs in the area. The mine decants into Dam 1 (Figure 7-3).

Figure 7-2. Photograph of the Schoongezicht surface area, taken from Dam 3.

Figure 7-3. Photograph of Dam 1, with the decant point in the foreground.

7.2 Surface Hydrology

Schoongezicht Colliery is dissected by a vlei area, rising to the west and east. Three dams exist in the stream (Figure 7-4). Dam 2 is a fresh water dam, with most of the surface run-off from rainfall channeled to it through a system of contours. All the decant water from the mine runs into Dam 1. All run-off below Dam 2, together with the overflow from this dam, are diverted along canals past Dam 1, and released in the Brugspruit below this polluted dam.

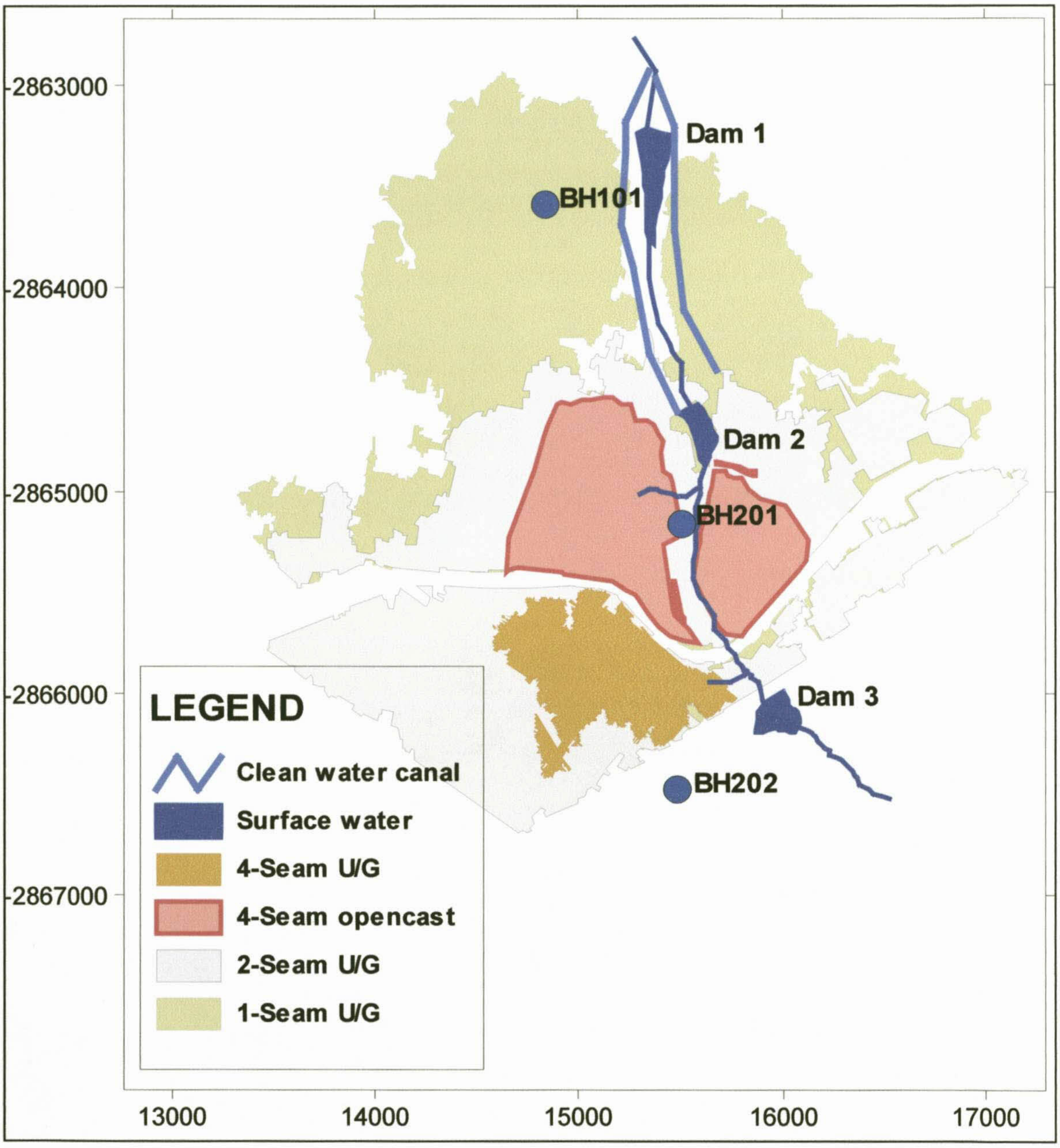


Figure 7-4. Surface water structures at Schoongezicht.

Runoff at Schoongezicht is 6.7% of the rainfall, and the mean annual evaporation for the area is 1 700 mm. The average annual rainfall for the surrounding area is 684 mm (SA Weather Service), with the 50% percentile at 621 mm. Figure 7-5 shows the rainfall since 1960 in the area, with 2001 well below the average, at 503 mm.

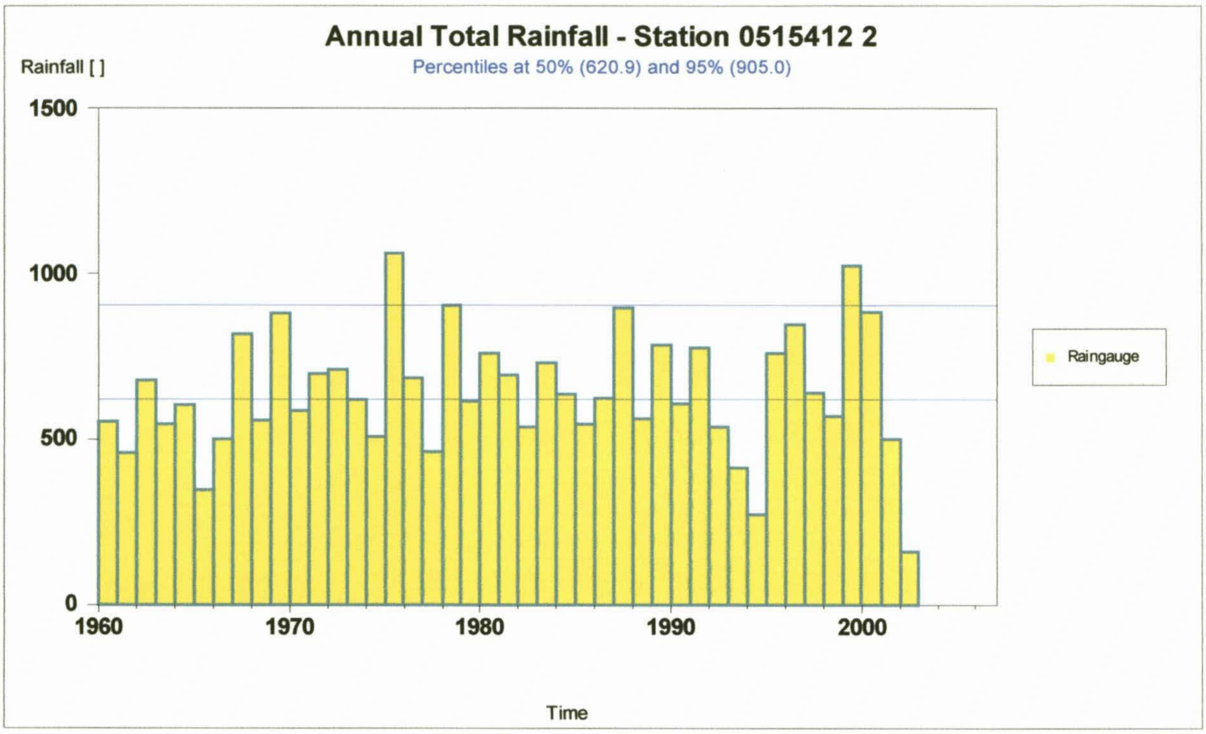


Figure 7-5. Rainfall graph for Schoongezicht area.

7.3 Geology and Mining

The general geological stratigraphy for the area is illustrated in Figure 7-6. The depth of mining varies between 7 and 54 m, as can be seen from Figure 7-7 and Figure 7-8. Figure 7-9 shows the surface contours, and Figure 7-10 and Figure 7-11 the floor contours for the No 1-Seam and the No 2-Seam.

Mining was by the bord-and-pillar method, with the No. 1-Seam being the most dominant seam. 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. Currently part of the No. 2 Seam is being mined at an opencast pit in the eastern part of the terrain. A summary of the respective coal seams for the Witbank area is included in Table 7-1.

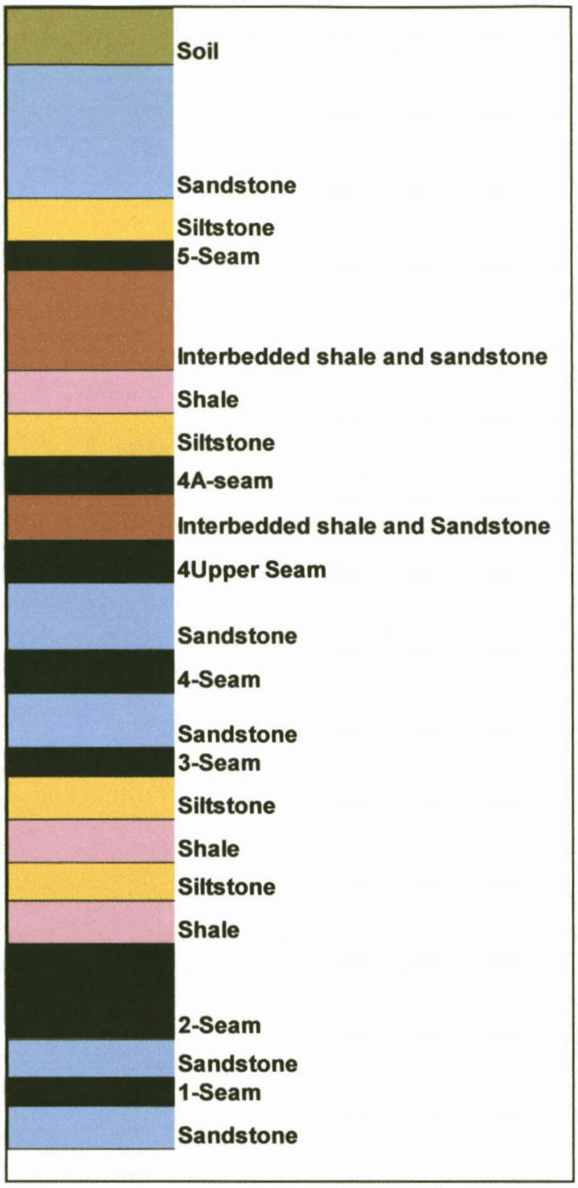


Figure 7-6. Typical stratigraphic column for the area (after Smith and Whittaker, 1986).

Table 7-1: Summary of the coal properties in the Witbank area (after Smith and Whittaker 1986).

Seam	Area mined (ha)	Width of seam (m)	Mineable width (m)	Moisture (%)	Ash (%)	Sulphur (%)	Fixed carbon
1-Underground	540	2.2	2.2	2	11.4	0.5	61.7
2-Underground	420	6.29	3.37	1.9	12.3	0.66	58.2
4-Underground	52	2.64	2.64	2.5	27.6	1.1	49.1
4-Opencast	92	2.64	2.64				

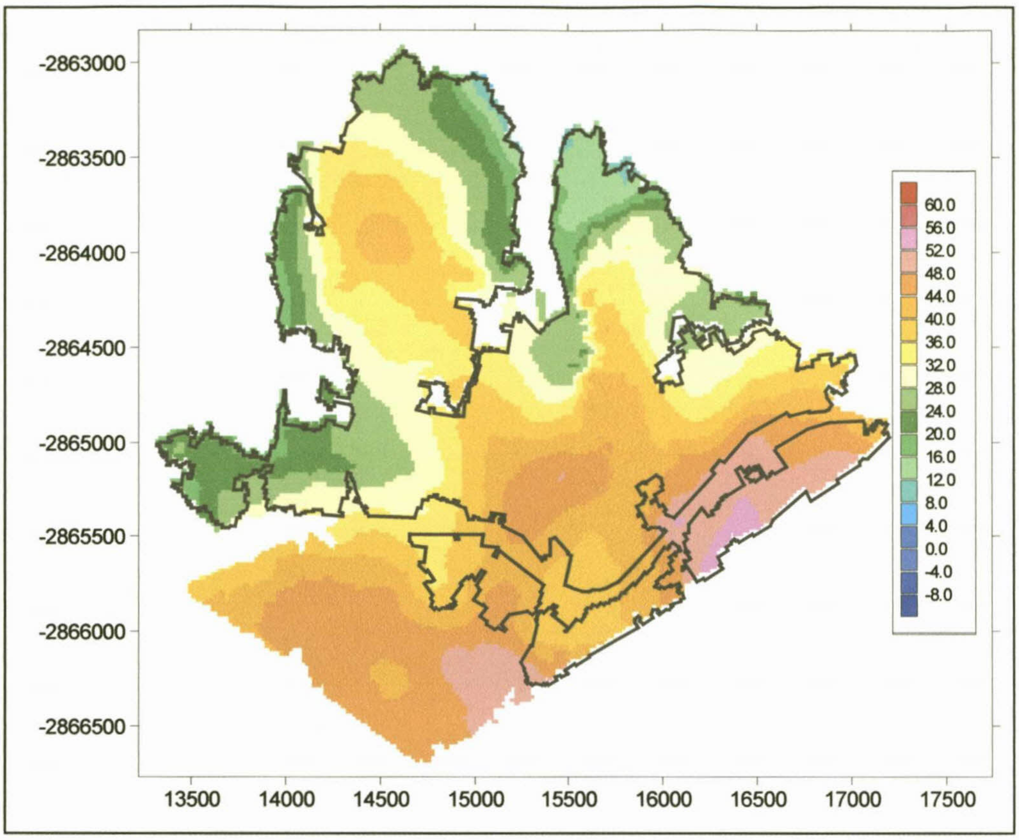


Figure 7-7. Mining depth of No 1-Seam at Schoongezicht Colliery.

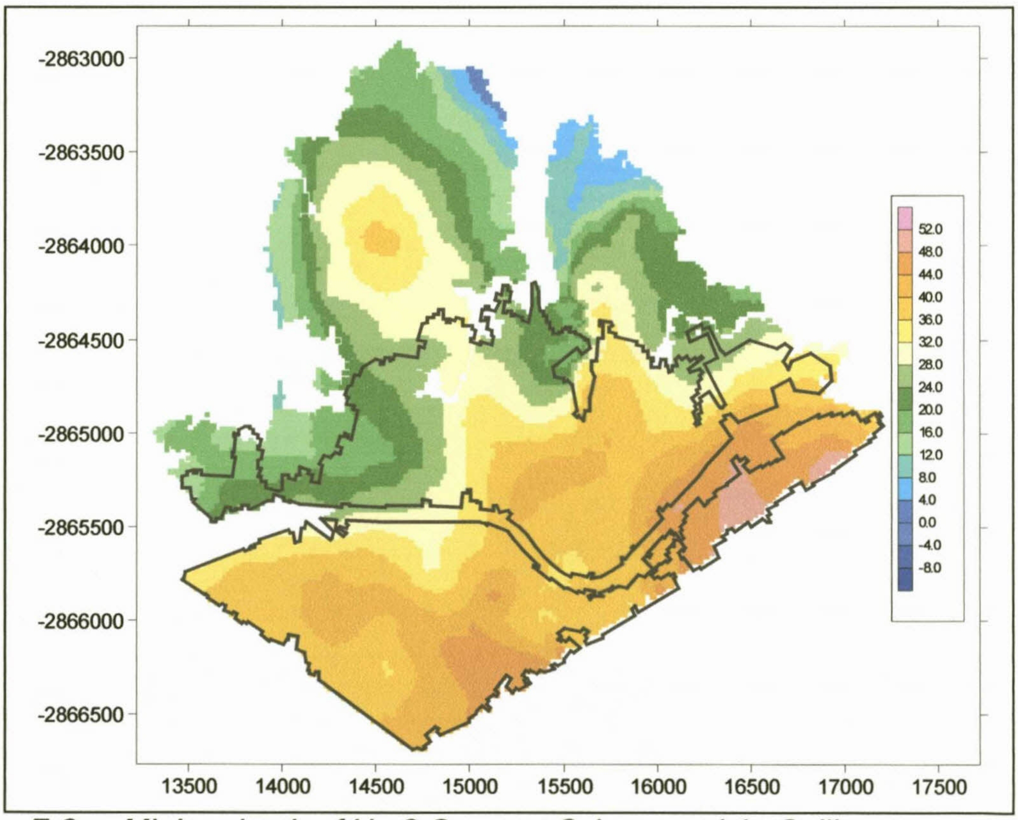


Figure 7-8. Mining depth of No 2-Seam at Schoongezicht Colliery.

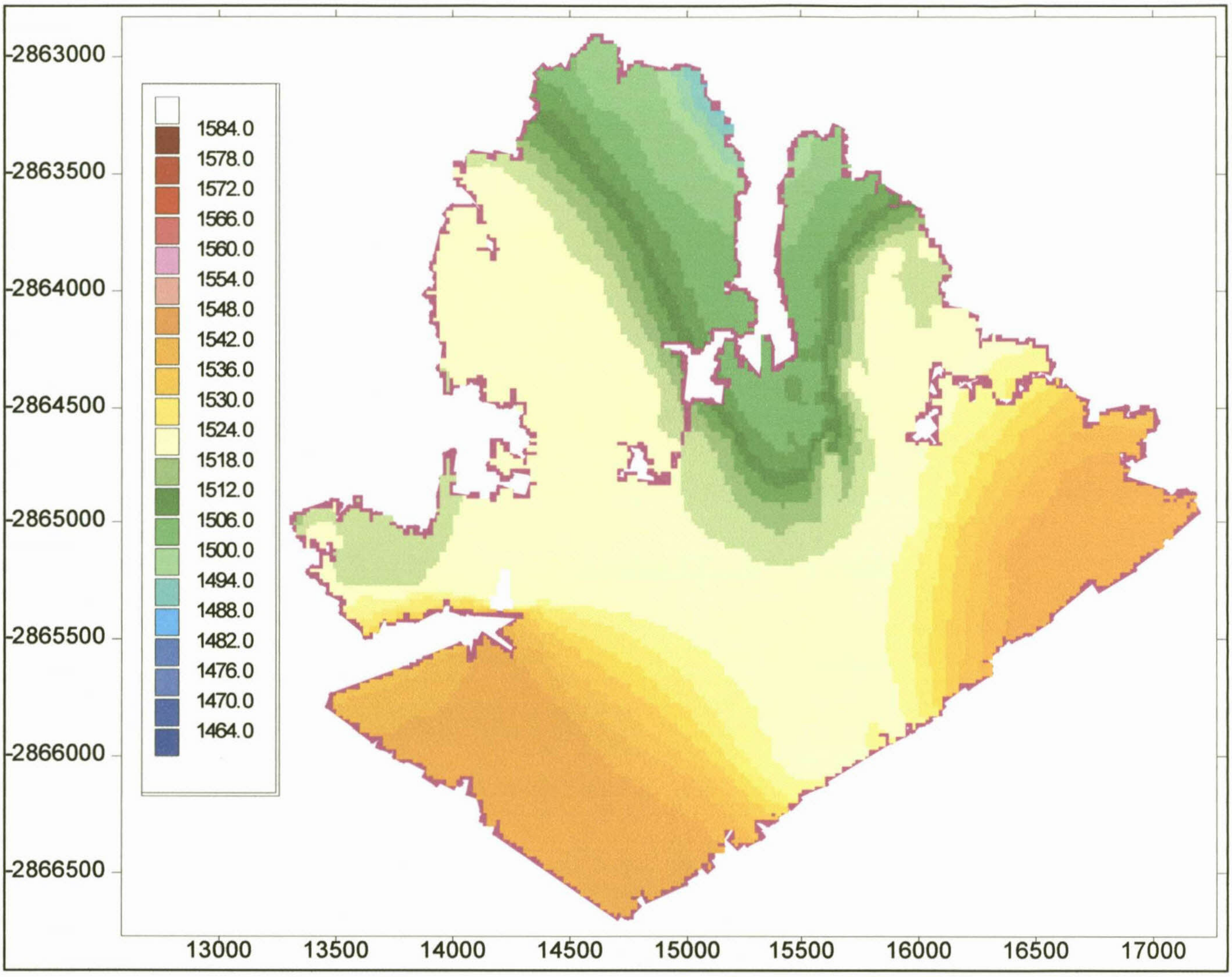


Figure 7-9. Surface contours at Schoongezicht Colliery.

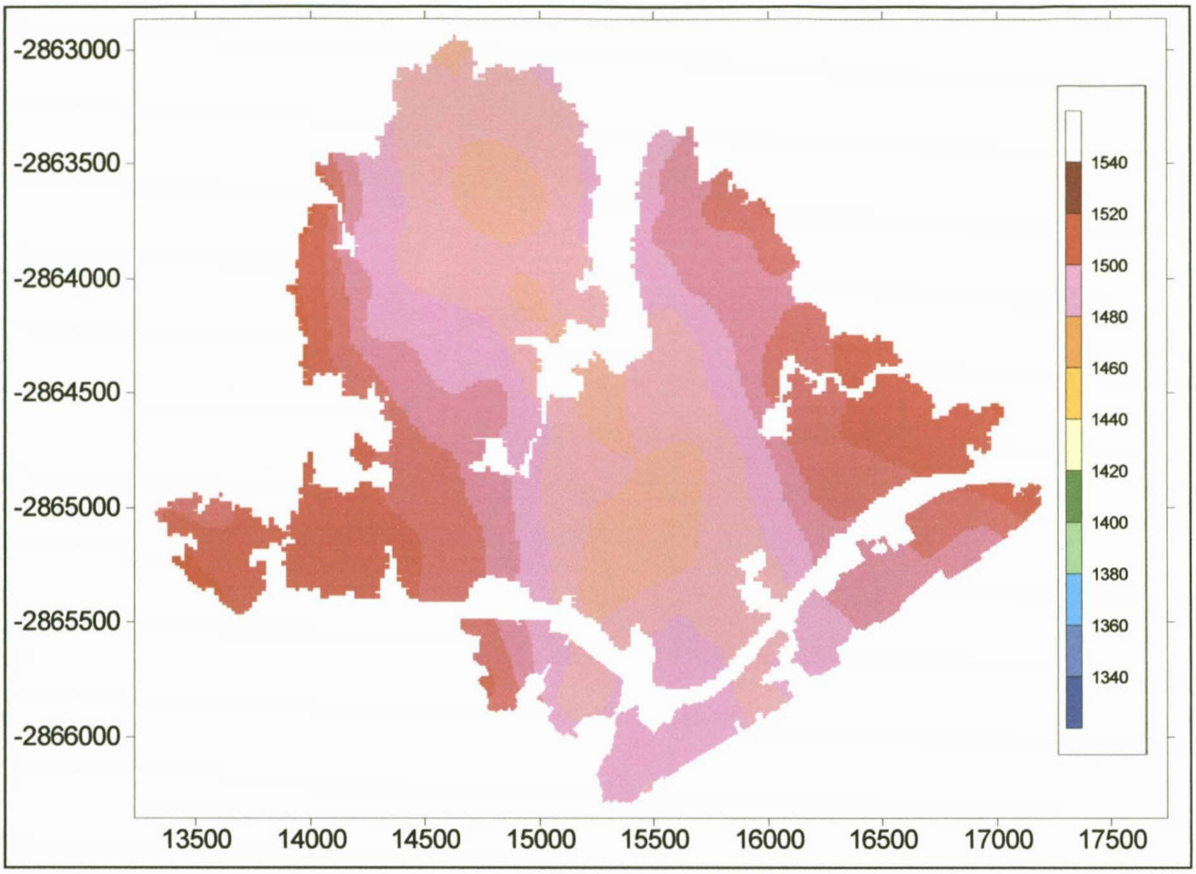


Figure 7-10. Floor contours of the No 1-Seam at Schoongezicht Colliery.

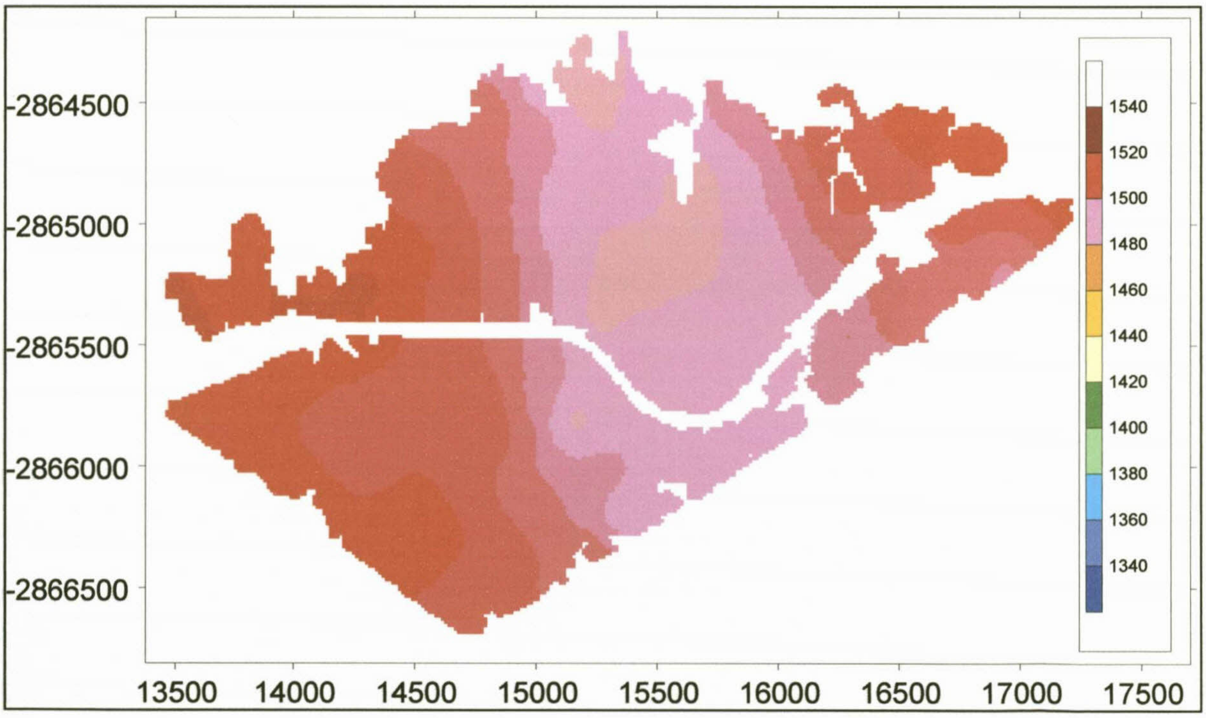


Figure 7-11. Floor contours of the No 2-Seam at Schoongezicht Colliery.

Two section lines have been selected for inclusion (Figure 7-12). The sections in Figure 7-13 and Figure 7-14 illustrate the synclinic nature of the coal seams (with the No. 1 Seam in yellow and the No 2 Seam in green).

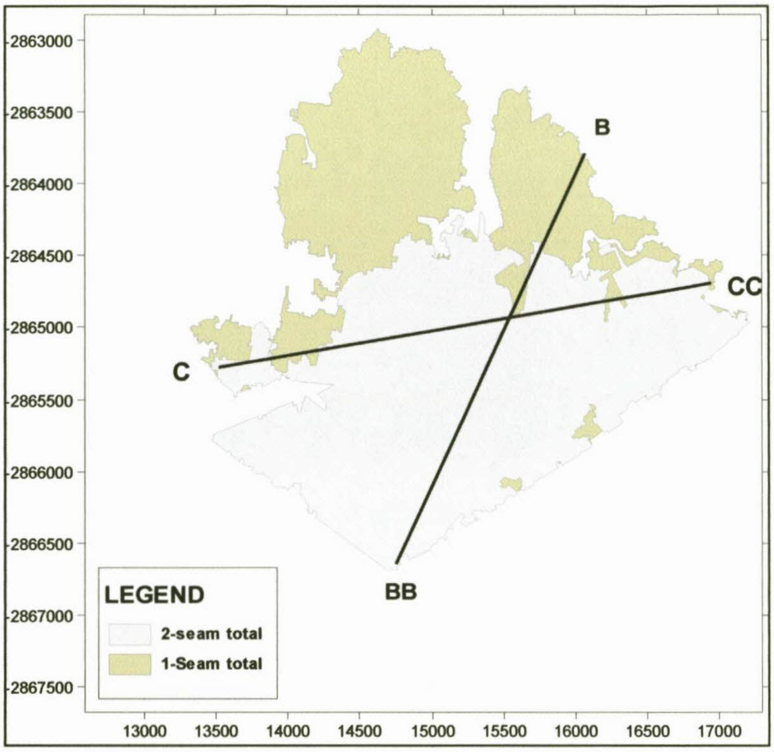


Figure 7-12. Map to illustrate the section lines.

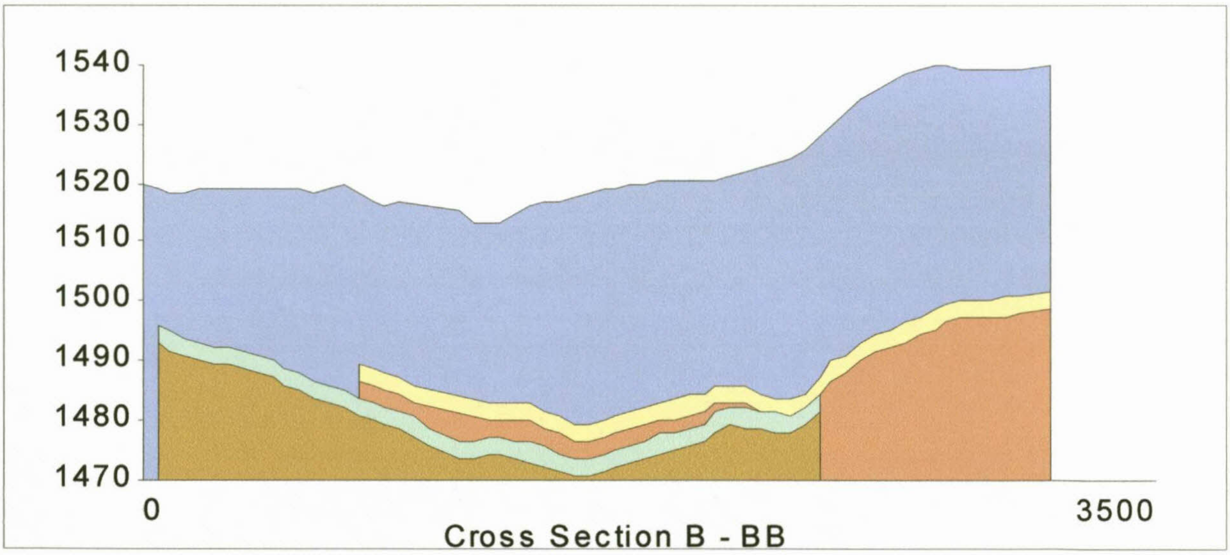


Figure 7-13. N-S Section through the colliery.

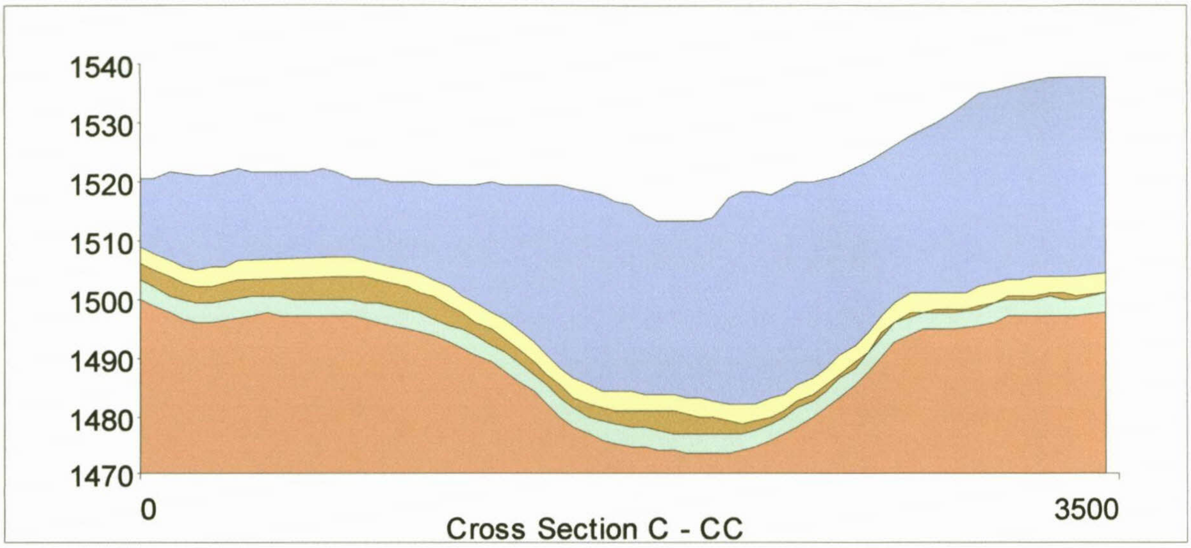


Figure 7-14. W-E Section through the colliery.

7.4 Water Quantity

7.4.1 Water levels and decant

There is no hydraulic connection between the Schoongezicht workings and mining to the south. This is confirmed through monitoring (Figure 7-15) and the water-level graphs (Figure 7-16).

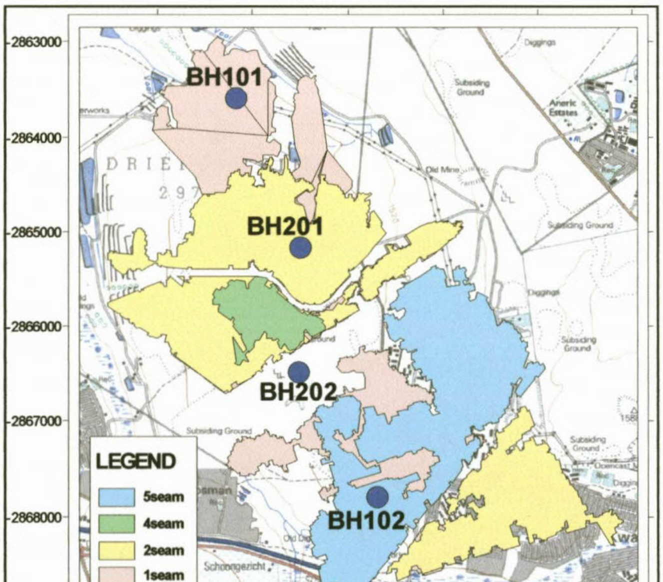


Figure 7-15. Localities of monitoring boreholes.

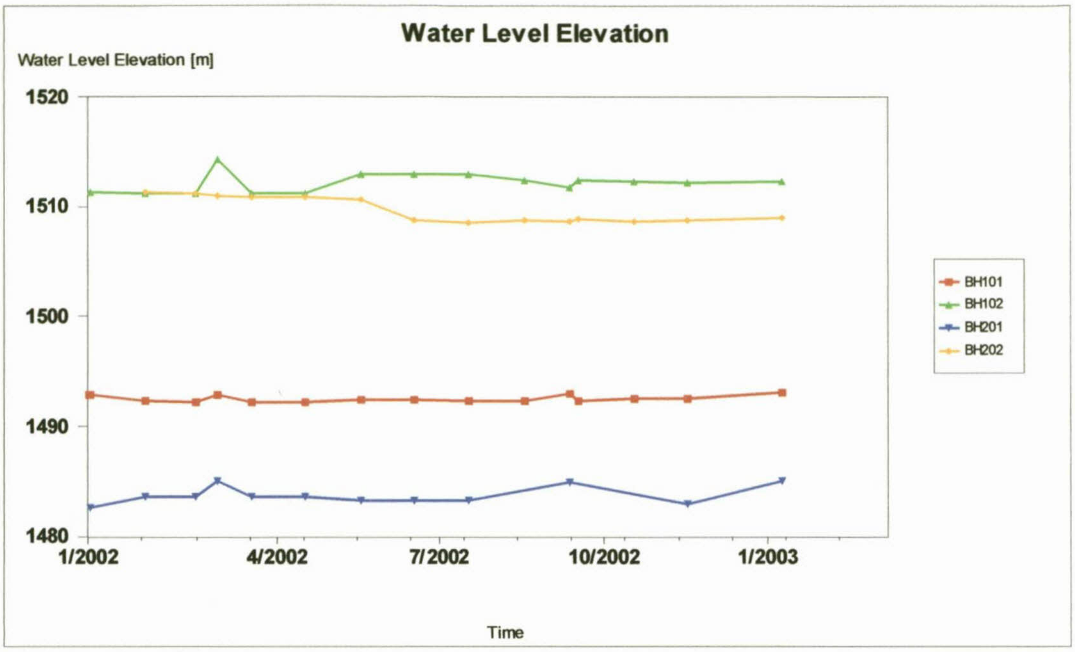


Figure 7-16. Water-level elevations for the monitoring boreholes.

Figure 7-17 shows the decant point. From this photograph the structural failure of pillars, resulting in the square opening where decant occurs, can be seen. Figure 7-18 shows another view towards the decant point.

Figure 7-17. The decant position next to Dam1.

Figure 7-18. Decant water from the colliery.

7.4.2 Water volumes

Figure 7-19 shows the outlines of the water bodies on the various seams.

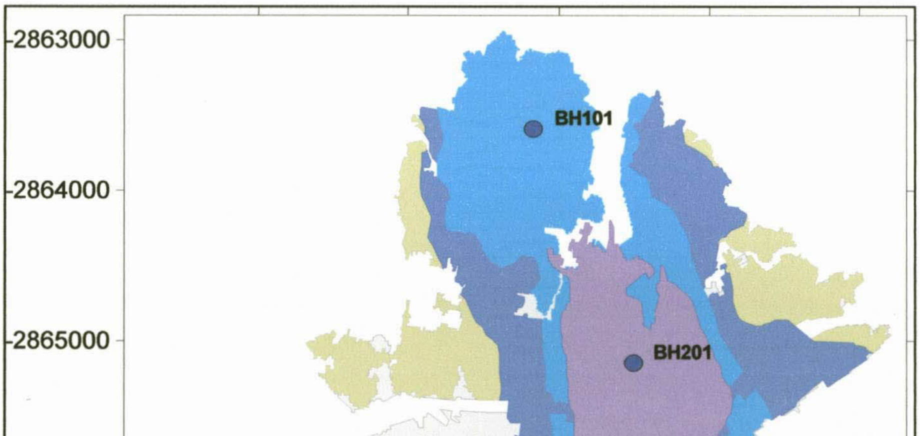


Figure 7-19. Water body outline for the No 1-Seam at Schoongezicht Colliery.

Currently the water level of BH101in the No. 1-Seam is higher than that of BH 201 in the No. 2-Seam, which is geohydrologically impossible. This may be a local phenomenon. Therefore water volumes for two different scenarios were calculated. Table 7-2 provides a summary of the current water volumes. Stage curves are shown in Figure 7-20 and Figure 7-21. The No 4-Seam is currently still dry.

Table 7-2: Current water volumes in Schoongezicht Colliery.

Scenario 1:	
1-Seam at 1485.03 mamsl:	
Total void volume (Mm³)	7.74
Decant volume (Mm³)	4.16
2-Seam at 1485.03 mamsl:	
Total void volume (Mm³)	9.16
Decant volume (Mm³)	2.30
Total water volume in mine at decant (Mm³)	6.46
Scenario 2:	
1-Seam at 1493.2 mamsl:	
Total void volume (Mm³)	7.74
Decant volume (Mm³)	6.06
2-Seam at 1485.03 mamsl:	
Total void volume (Mm³)	9.16
Decant volume (Mm³)	2.30
Total water volume in mine at decant (Mm³)	8.35

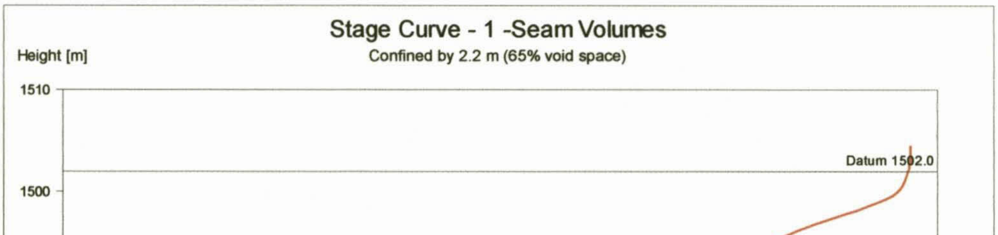


Figure 7-20. Stage curve for the total void volume in the No 1-Seam

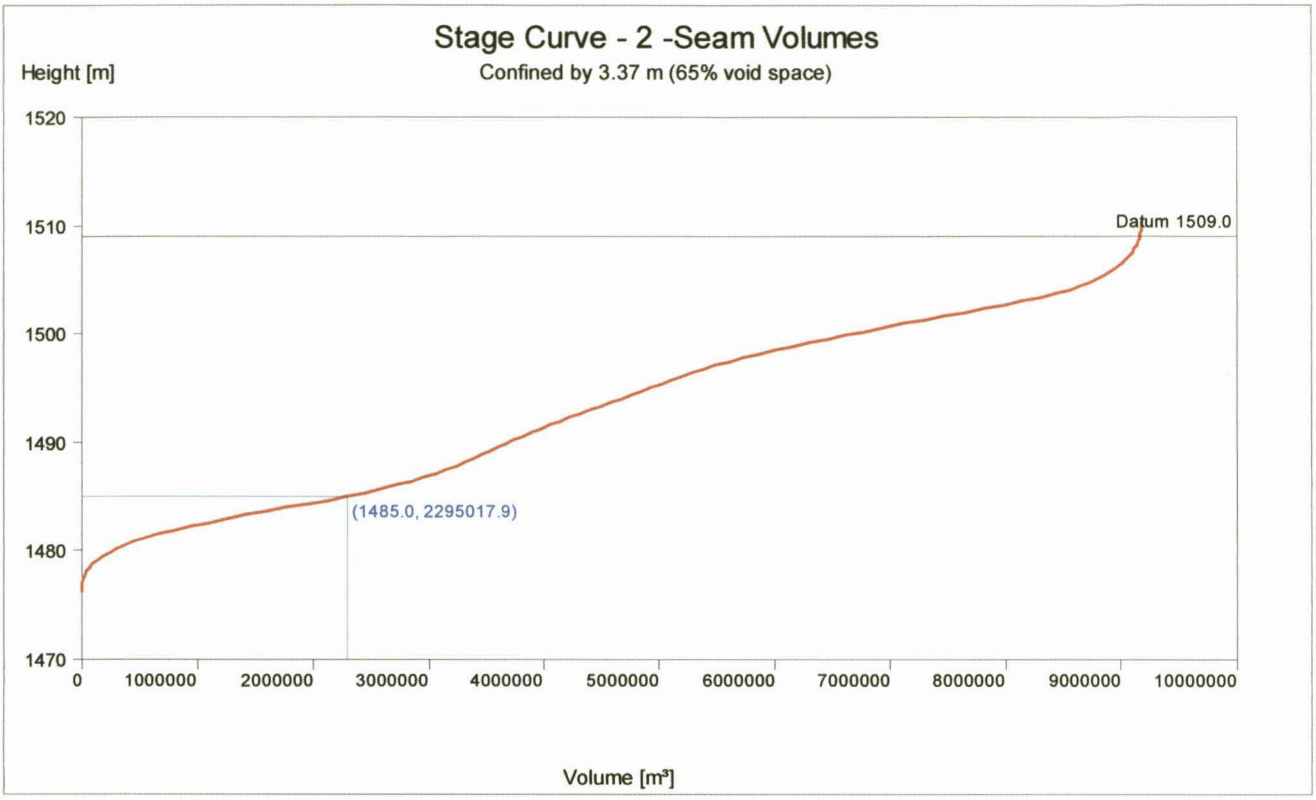


Figure 7-21. Stage curve for the total void volume in the No 2-Seam.

7.4.3 Recharge

Water that decants into Dam 1 is pumped into Dam 3, from where it is used for the coal washing plant. The average pumping rate per day is 944 m³ (Figure 7-22).

At a below average rainfall of 550 mm for 2002, this results in a recharge rate of 7%. A summary of the recharge calculations is included in Table 7-3.

Table 7-3: Recharge calculations for Schoongezicht Colliery.

Area (ha)	1040
Rainfall (m)	0.55
Total water from rainfall (m³)	5720000
Daily discharge (m³)	944
Annual discharge (m³)	344560
Lateral influx into mine cavities (m³)	13742
Dam area (ha)	4.6
Evaporation from dam (m)	1.2
Annual evaporation volume (m3)	55200
Recharge %	6.75

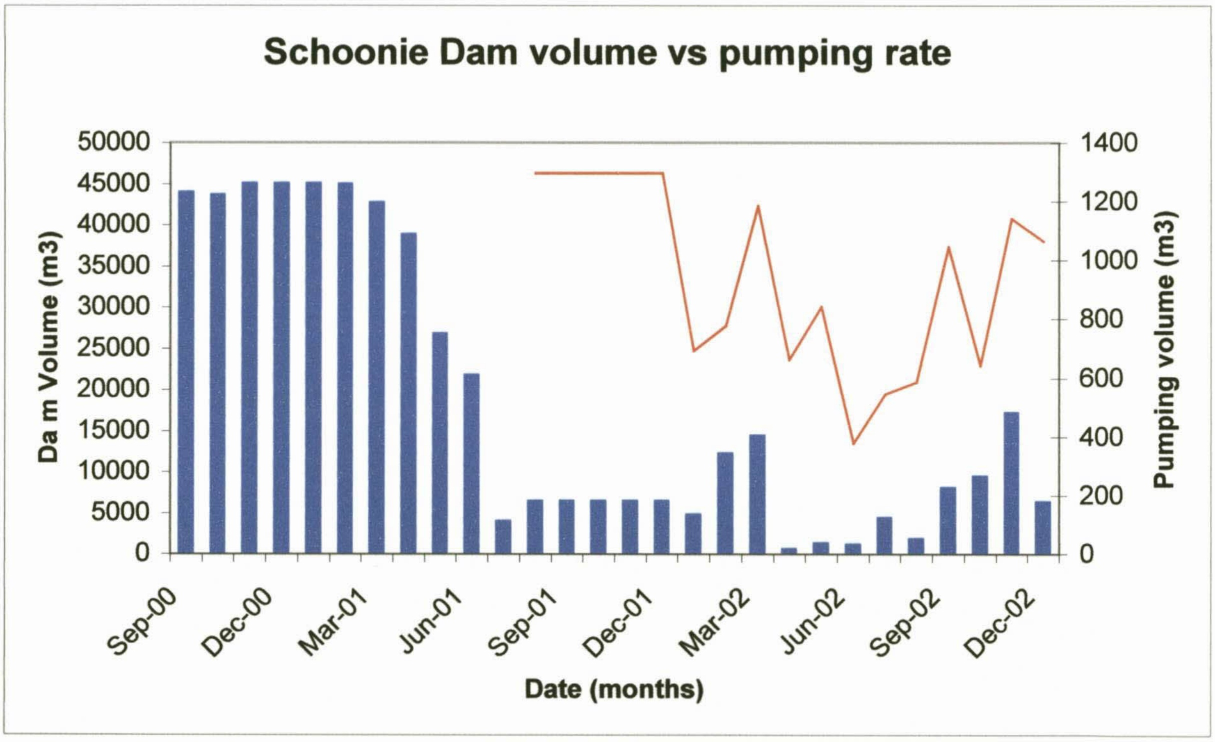


Figure 7-22. Graph of the volume of Dam 1 (blue columns), and the extraction rate from the dam (red line).

7.5 Water Quality

Table 7-4 illustrates the water chemistry for the boreholes at Schoongezicht, as well as for the dams in the area, and Figure 7-23 to Figure 7-25 show the multi-parameter probing done in the boreholes.

Table 7-4: Water analysis for Schoongezicht Colliery (mg/L where applicable).

SiteName	pH	EC	Ca	Mg	Na	K	MAlk	Cl	SO4	NO3
Dam1	2.86	325	444	172	53	7	0	19	2364	0.14
Dam2	2.80	232	291	84	27	11	0	8	1386	0.47
Dam3	2.55	369	506	169	43	7	0	15	2686	0.59
BH101	3.37	309	525	172	52	7	0	16	2412	<0.05
BH102	6.38	197	276	105	71	7	131	31	1199	0.04
BH201	5.08	321	555	188	58	8	9	23	2572	<0.05
BH202	3.71	484	518	223	66	8	0	60	4327	<0.05
SiteName	F	Al	Fe	Mn	B	Ba	Be	Br	Cr	Co
Dam1	1.78	18	181	12	0.11	0.02	<0.01	<0.04	<0.01	0.18
Dam2	1.61	33	14	14	<0.04	0.02	<0.01	<0.04	<0.01	0.33
Dam3	1.44	36	107	33	0.08	0.02	<0.01	<0.04	<0.01	0.61
BH101	1.87	16	283	12	0.10	0.04	<0.01	<0.04	<0.01	0.17
BH102	0.21	0	114	7	0.05	0.09	<0.01	<0.04	<0.01	0.16
BH201	1.98	4	346	13	0.14	0.03	<0.01	<0.04	<0.01	0.18
BH202	2.70	68	1285	34	0.39	0.03	<0.01	<0.04	<0.01	0.43
SiteName	Cu	Li	Mo	Ni	Pb	Sb	Se	Sn	Sr	Zn
Dam1	0.01	0.19	0.00	0.23	0.01	<0.01	<0.01	<0.015	2.23	0.64
Dam2	0.02	0.04	0.00	0.26	<0.015	<0.01	<0.01	<0.015	0.89	0.74
Dam3	0.07	0.11	0.00	0.36	<0.015	<0.01	<0.01	<0.015	1.59	0.90
BH101	0.01	0.18	0.00	0.22	0.06	<0.01	<0.01	<0.015	2.19	0.61
BH102	0.00	0.09	0.00	0.15	0.00	<0.01	<0.01	<0.015	2.08	0.23
BH201	0.00	0.19	0.00	0.23	0.02	<0.01	<0.01	<0.015	2.47	0.45
BH202	0.01	0.26	0.00	0.46	0.06	<0.01	<0.01	<0.015	2.76	1.34

The following includes important conclusions:

- The water character is generally acid. This is ascribed to mining under shallow conditions, in the zone where most of the base potential has been leached through circulating water, prior to mining.
- Additional characteristics of the water are high calcium and magnesium. This suggests that some neutralisation potential is still present in the form of dolomitic lime in the sediments, but not sufficiently in the right places to neutralise the acid water.
- The low sodium content is favourable in terms of using the mine water for irrigation, after adjusting the pH of the water though lime addition.
- The chemical profiles demonstrate the importance of using suitable sampling equipment; otherwise clean water from the zone above the underground mining will be sampled.

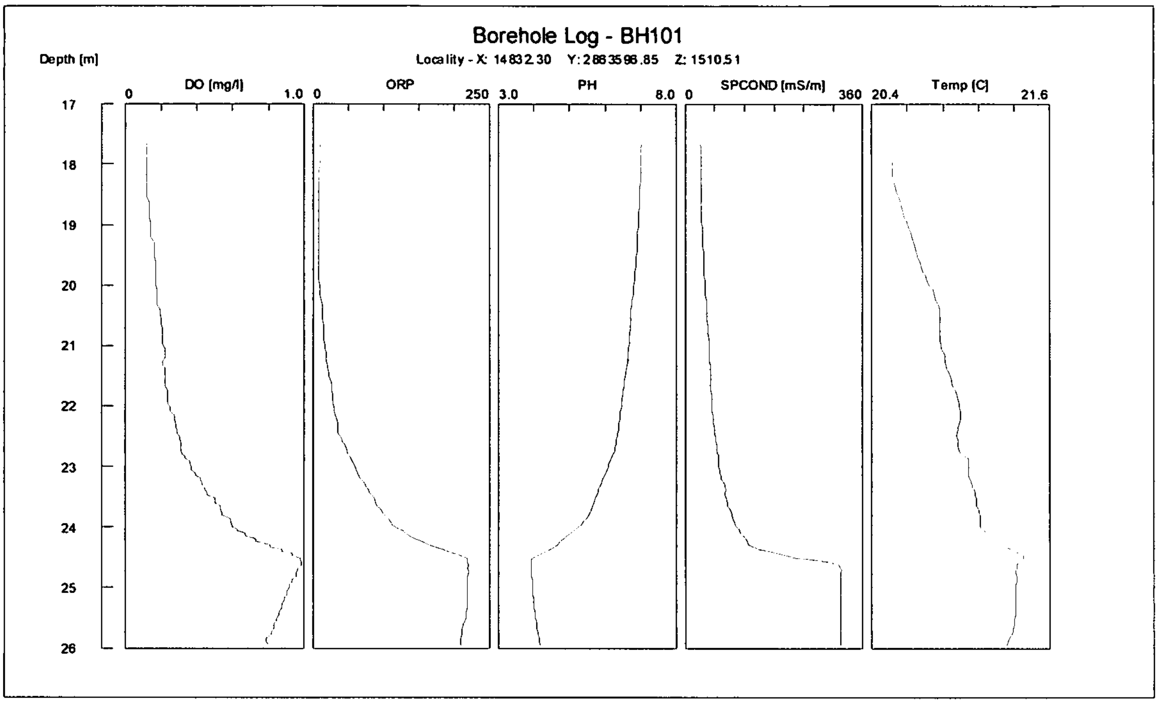


Figure 7-23. Multi-parameter probing in BH101.

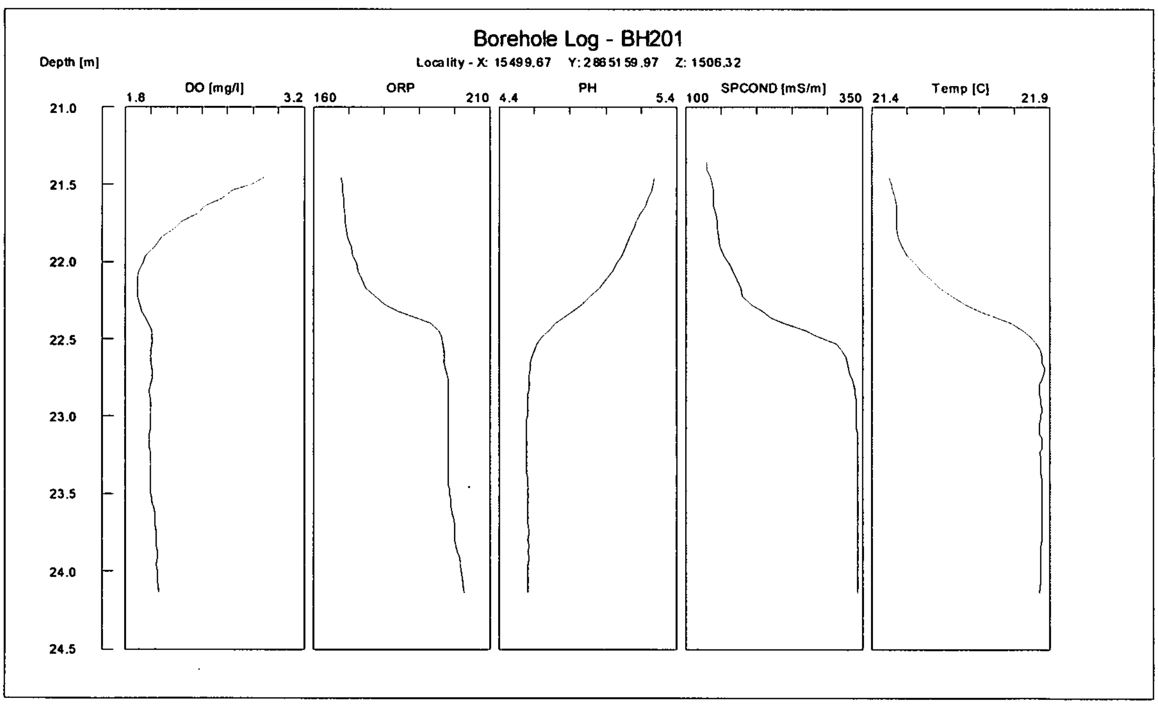


Figure 7-24. Multi-parameter probing in BH201.

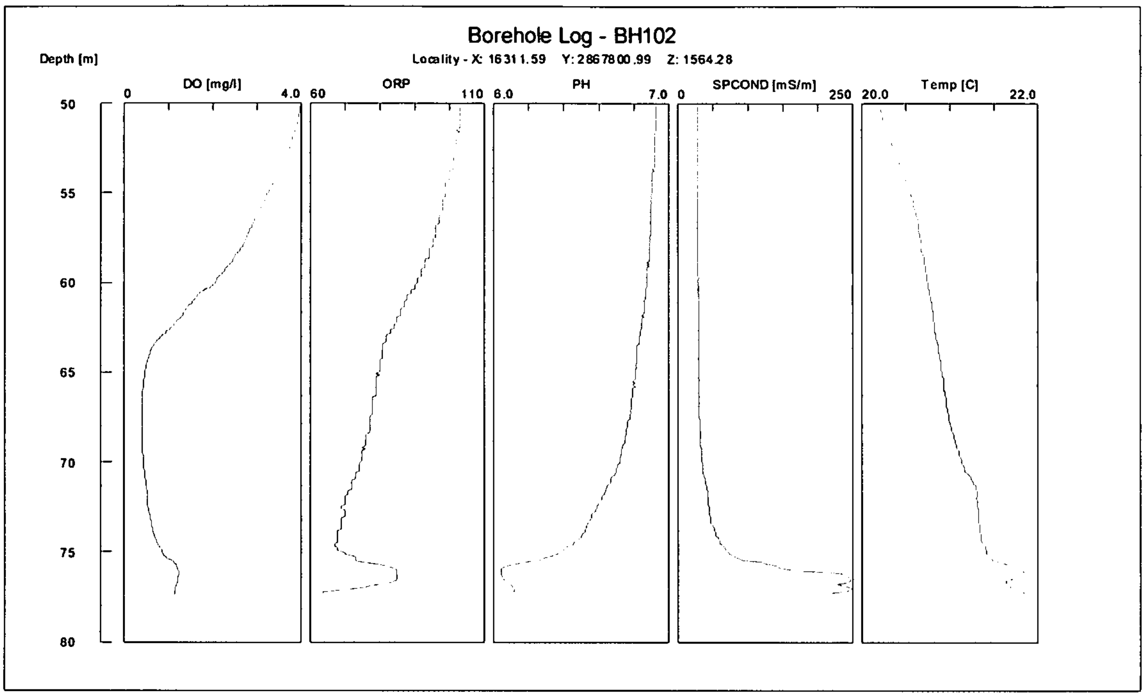


Figure 7-25. Multi-parameter probing in BH102.

7.6 Conclusions

The recharge rate of 1 ML/d for a mined area of 1 000 ha amounts to a recharge of 5.5% under normal rainfall conditions (684 mm). (Based on the decant volumes measured, a recharge rate of 6.75% was calculated for Schoongezicht Colliery in a below average rainfall year). 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, 5-6% recharge is a good average value. Other areas of possible higher recharge should be investigated separately.

As far as water quality is concerned, Schoongezicht Colliery contrasts well with that of Minnaar Colliery, for instance. The collieries have been mined under shallow conditions in close proximity to each other. Minnaar Colliery is totally flooded, whereas Schoongezicht Colliery is less than 50% flooded. The acid character of Schoongezicht Colliery is directly linked to the lack of flooding of the underground workings. The sulphate production rate at Schoongezicht is 23 t/d or 2.3 kg/ha/d, which is of the same order as that for the other collieries discussed in this document. The difference therefore does not only lie in the rate of oxidation but also in the lack of neutralising agents in Schoongezicht Colliery.

8 Kromdraai

8.1 Introduction

Kromdraai Colliery is located in the Mpumalanga Province, northwest of Witbank. It forms part of the Witbank Coalfield (Erasmus *et al.*, 1981, Figure 1-1) and lies in the Olifants Catchment (Figure 1-2). Underground mining ceased in 1966, and the underground workings are currently remined by opencast methods. Figure 8-1 shows the topography and mining.

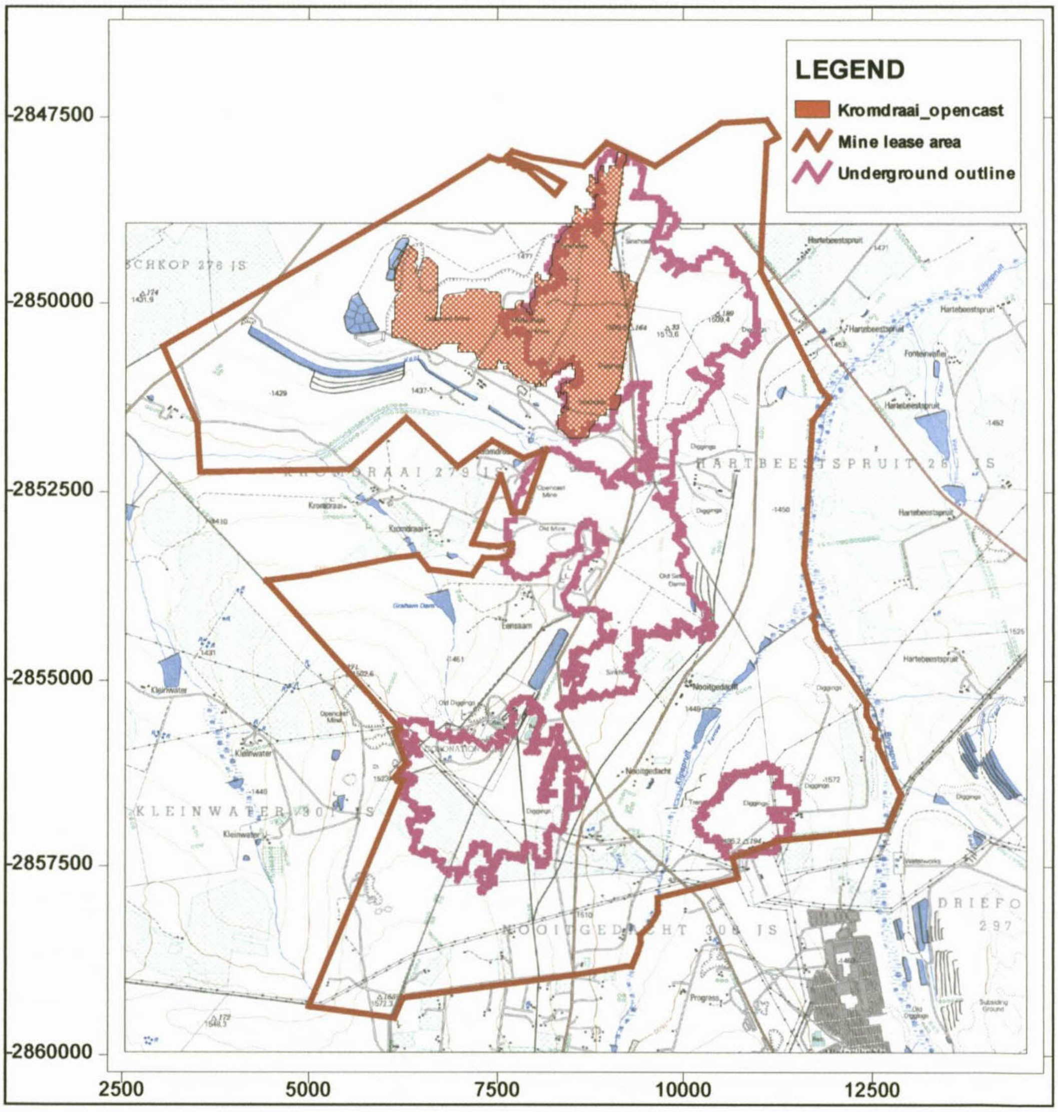


Figure 8-1. Topographic map of the Kromdraai area, also showing the mine outline and the opencast area.

8.2 Surface Hydrology

The average annual rainfall for the area is 684mm (SA Weather Service), with the 50% percentile at 621 mm. Runoff in the area is 6.7% of the rainfall, and the mean annual evaporation is 1 700 mm (Midgley *et al,* 1994).

Kromdraai is located on a topographic high (Figure 8-2). Run-off drains away from the mining area, reducing the chance of water ingress into the worked areas. The main streams all flow away from the mining area.

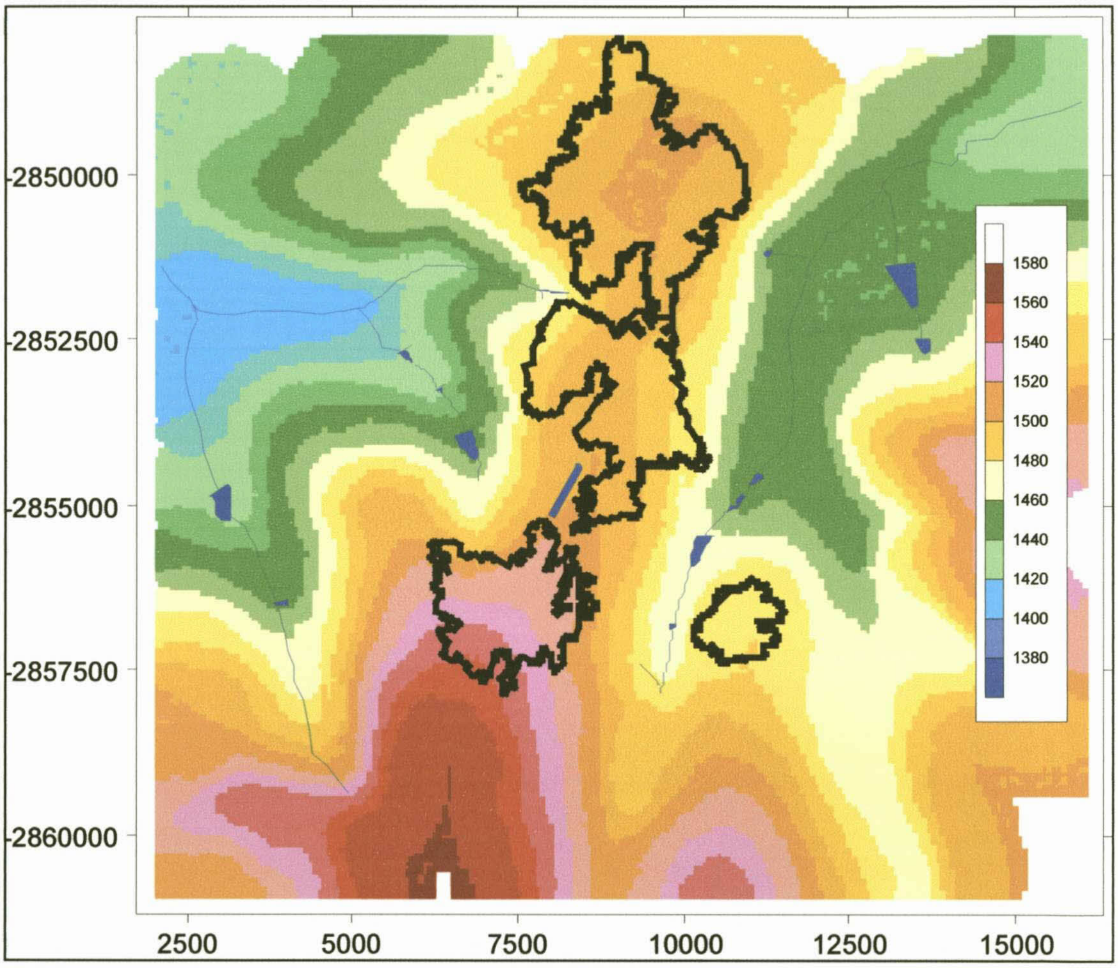


Figure 8-2. Surface contours for the Kromdraai area, also showing the mine outline and the streams.

8.3 Geology and Mining

The coal seams are discontinuous over prominent palaeotopographic highs, and at Kromdraai only the No. 2 Seam and the No. 1-Seam are present. Figure 8-3 shows the No. 2 Seam, overlain by sandstone, shale and weathered material.

Figure 8-3. The No. 2 Seam in relation to the overlying strata in the opencast pit at Kromdraai Colliery.

Figure 8-4 shows the floor contours for the No. 2 Seam. A cross-section, along the blue line in Figure 8-4, is shown in Figure 8-5 for the No. 1 Seam and the No. 2 Seam in relation to the surface. From this, the undulations in the coal floor are clear.

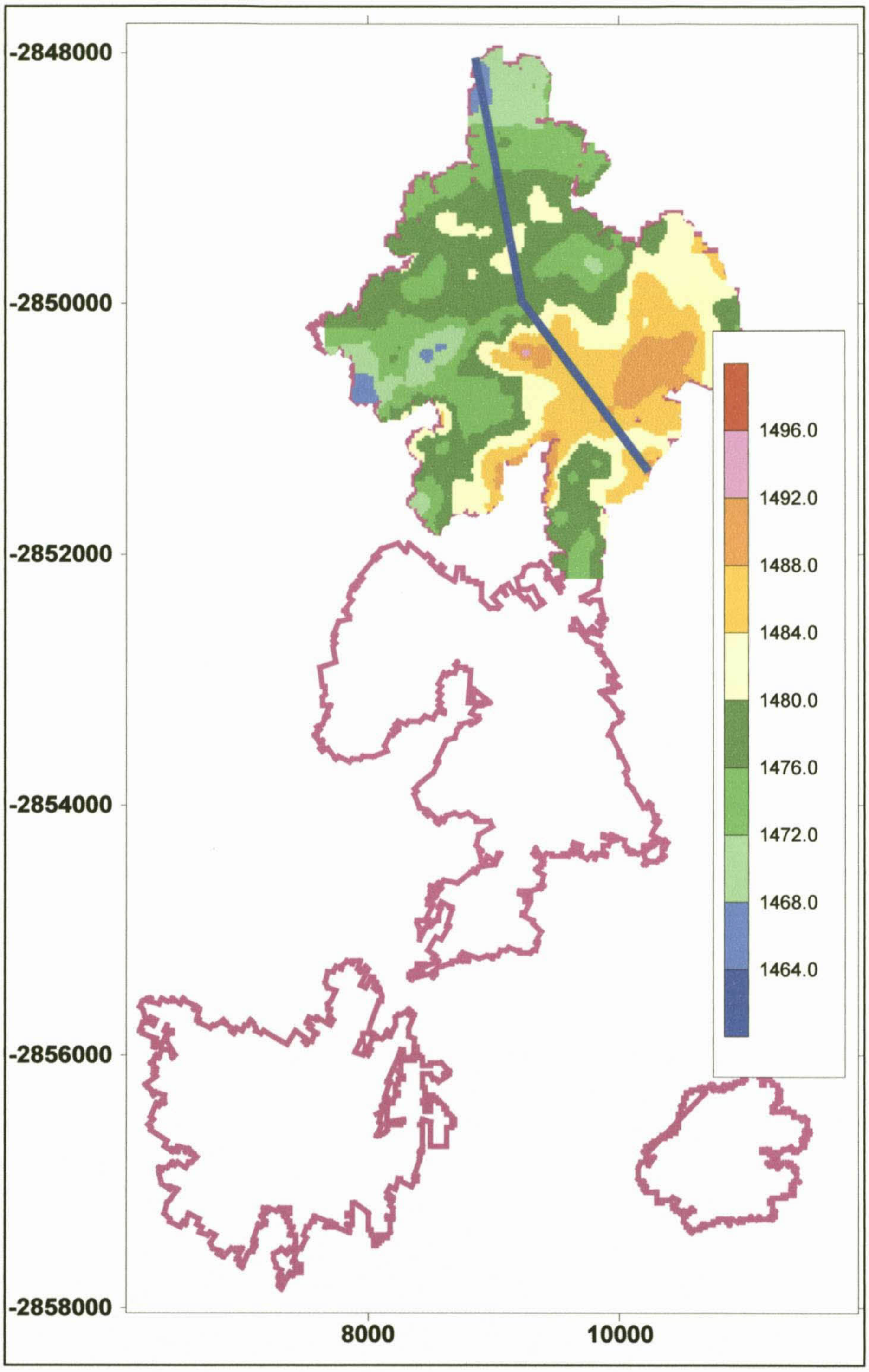


Figure 8-4. The No. 2 Seam for the opencast area at Kromdraai, with the section line in blue.

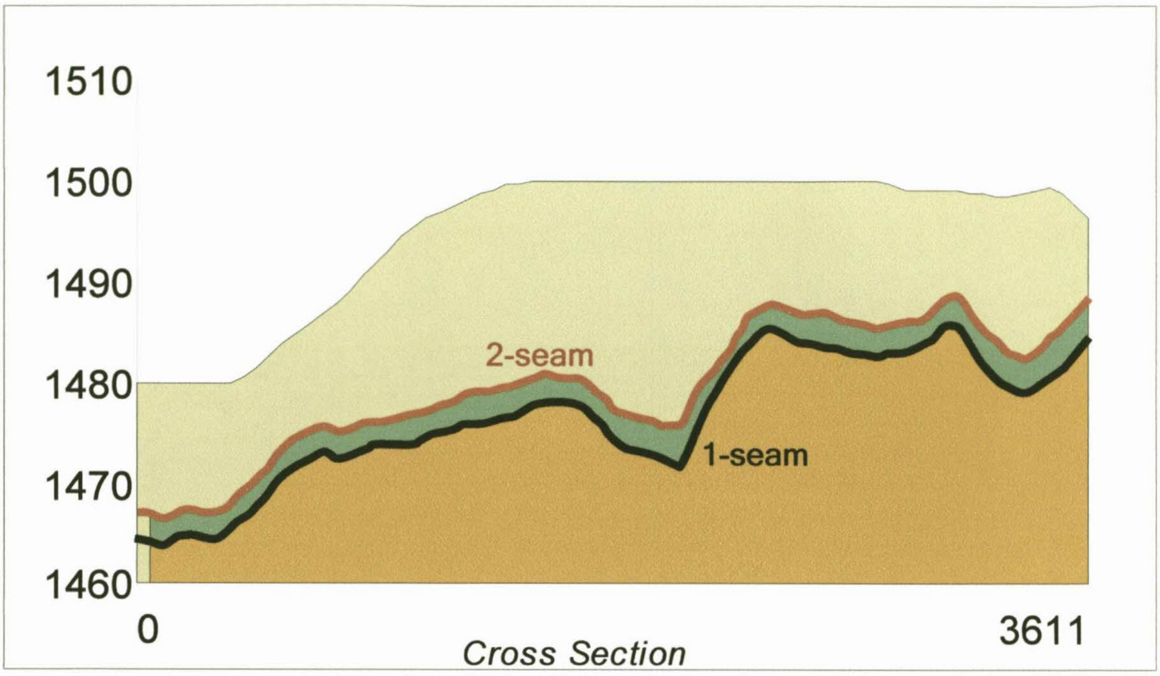


Figure 8-5. Cross-section for Kromdraai Colliery.

Underground mining was by conventional bord-and-pillar. The remainder of the pillars, and also the No. 1 Seam, are currently mined by opencast method. Figure 8-7 shows the state of the pillars in the current opencast. Figure 8-8 illustrates current and future opencast areas.

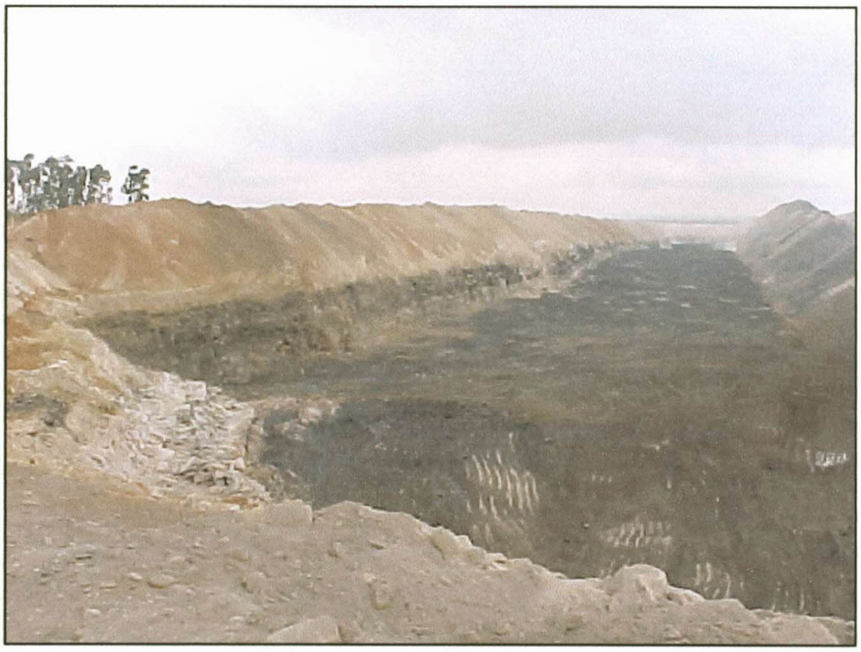


Figure 8-6. A 60 m wide cut at the opencast pit at Kromdraai.

Figure 8-7. Remainder of the pillars from the No. 2 Seam in the highwall, with the sandstone and shale layers above still intact.

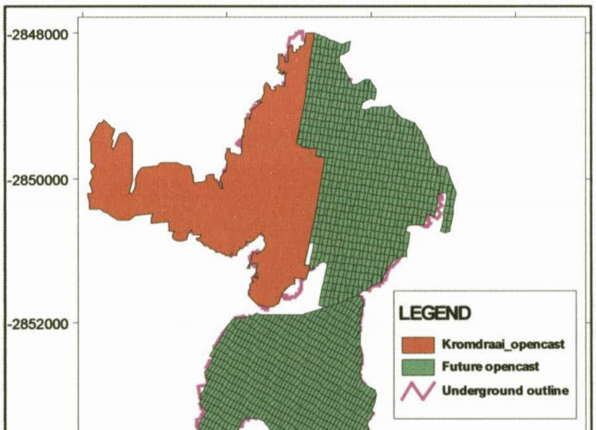


Figure 8-8. Current and future opencast areas at Kromdraai Colliery.

8.4 Water Quantity

Information received indicates water bodies on the No. 2 Seam as illustrated in Figure 8-9. Historic values suggest influx rates between 2 - 10 ML/d, with 3 ML/d as an average (measured Anglo Coal data). This constitutes a recharge of about 15% of the annual rainfall. This high recharge percentage is due to the shallow mining conditions, sandy soil and subsidence structures in the area. Water has been flowing from the underground workings for many years.

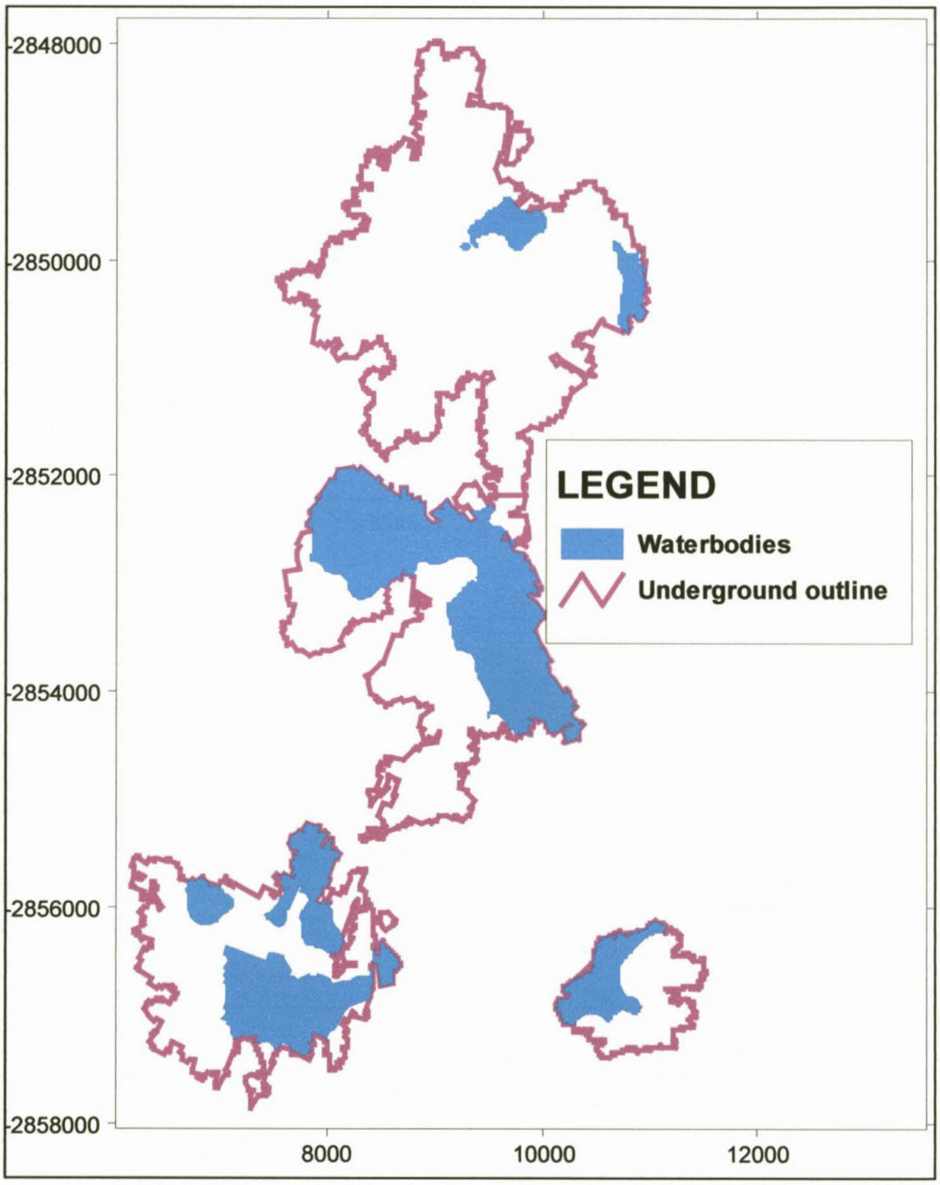


Figure 8-9. Water bodies in the No. 2 Seam underground.

8.5 Acid-Base Potential of the Colliery

Samples of the coal were taken at regular intervals at the highwall in the opencast. These were subjected to acid-base testing in the laboratory and the Abacus program (Usher, 2001) was used to interpret the results. The analysis is based on an open system, because CO_2 is released during opencast mining. The following graphs present a summary of the acid-base testing.

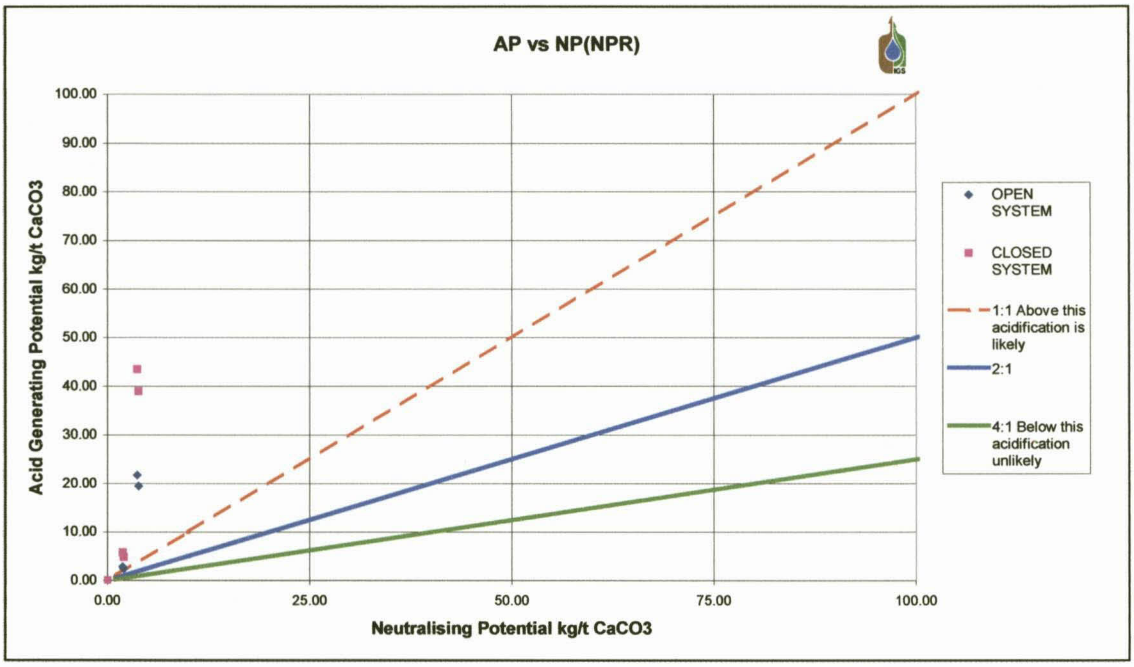


Figure 8-10. Acid potential vs neutralising potential.

In Figure 8-10 the acid potential is plotted against the neutralising potential of the samples. None of the samples have more base potential than acid potential. All the samples plot above the 1:1 red dotted line, implicating that all the samples are likely to acidify.

In Figure 8-11 the pH-levels are plotted against the net neutralising potential (NNP) for an open system. The NNP is calculated by subtracting the acid potential from the base potential. The result is expressed a kg/t as calcium carbonate. This value is a measure of the amount of lime that has to be added to neutralise acid conditions (negative values), or the amount of excess base potential for alkaline conditions (positive values). The conclusion is that all the samples acidified. Most of the samples have an acidity of >20 kg/t, with values of as high as 150 kg/t.

In Figure 8-12 where the neutralising potential ratio (NPR) is plotted against the %S, five of the seven samples plot in the range of very high probability to acidify.

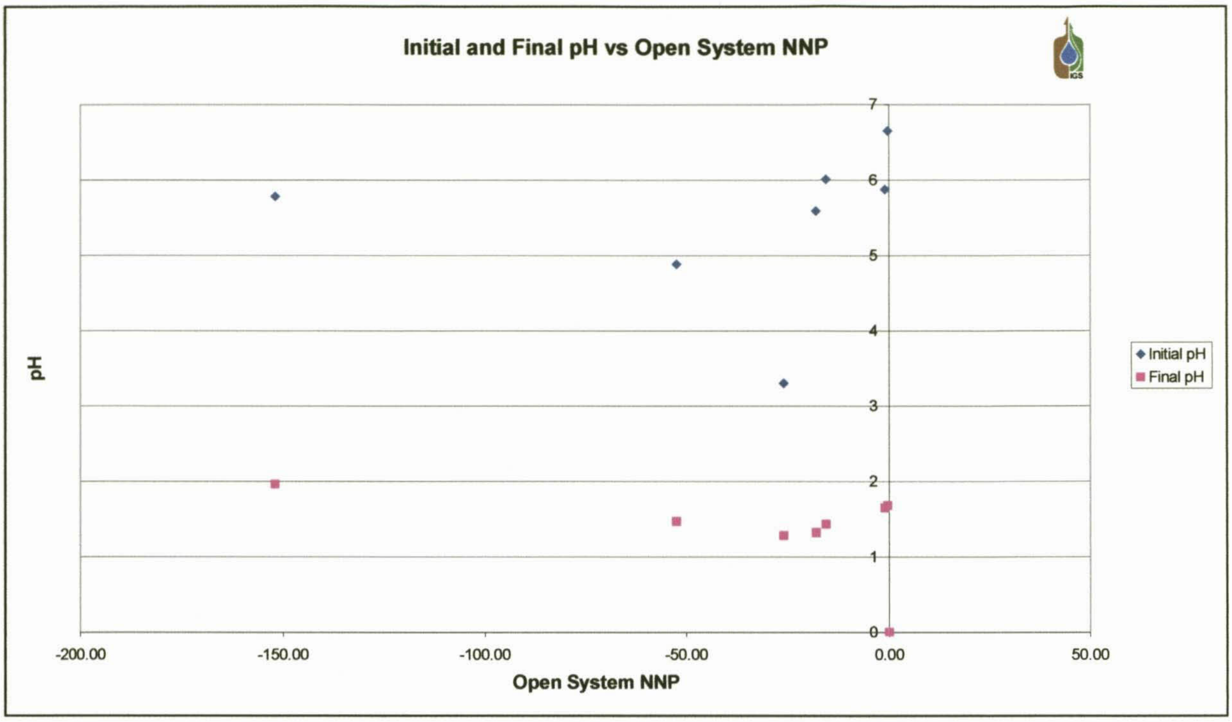


Figure 8-11. Natural and oxidised pH in an open system, plotted against their net neutralising potential values.

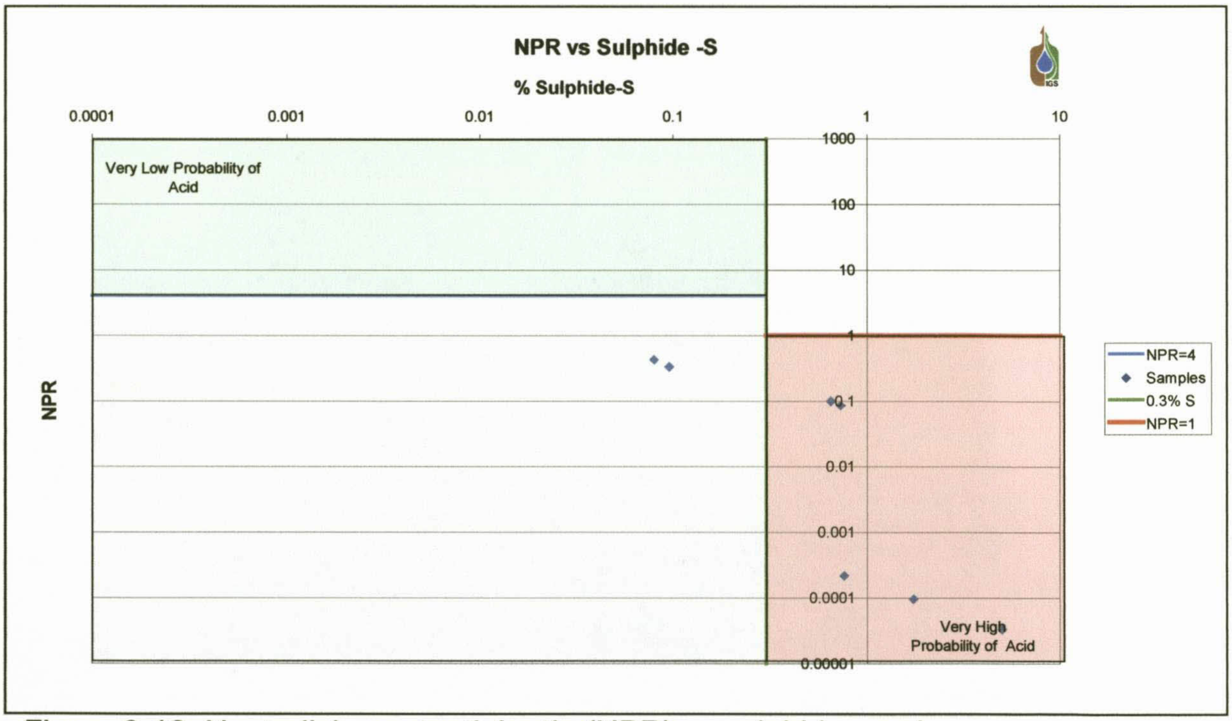


Figure 8-12. Neutralising potential ratio (NPR) vs sulphide graph.

Also available from these tests is the leaching potential of the samples after oxidation. From this graph (Figure 8-13) the availability of the major metal against various pH- levels can be calculated in kg constituent per ton of coal.

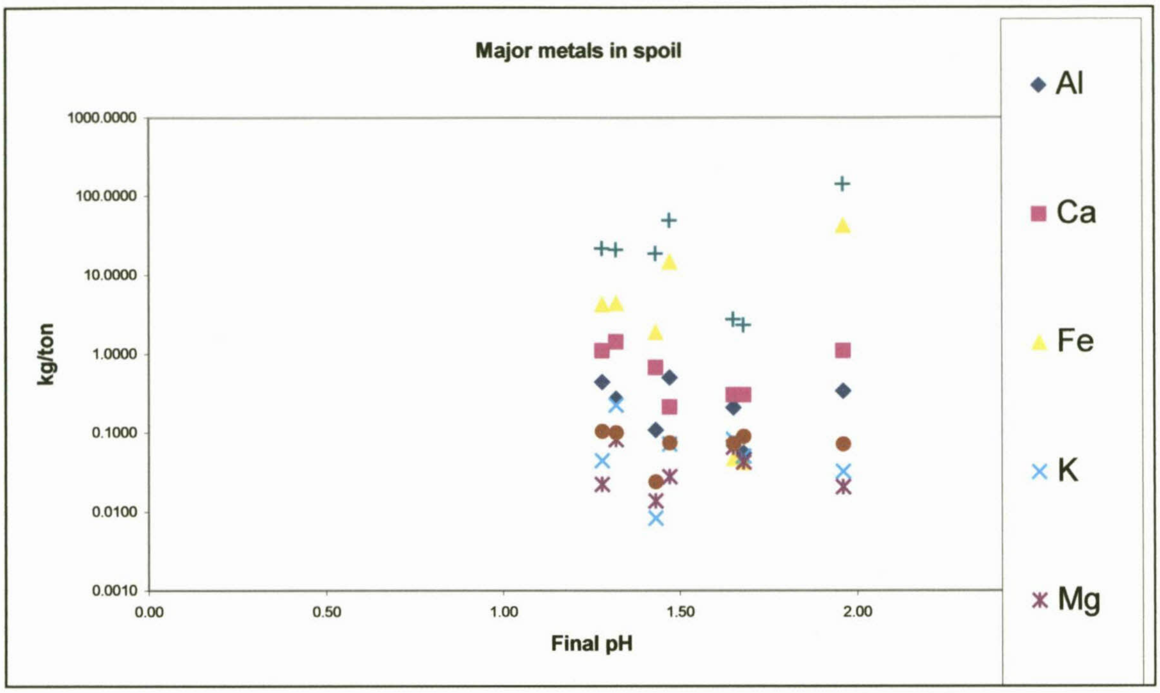


Figure 8-13. Major metal availability from coal samples under oxidising conditions

A summary and interpretation of the tests are included in Table 8-1.

Table 8-1: Summary of the acid-base potential of the coal.

Sample Number	Paste/Initial pH	Final pH	Acid Potential (Open System)	Base Potential	Net Neutralising Potential (Open)	Neutralising Potential Ratio(NP/AP)	Interpretation for Open System
1	5.78	1.96	150.00	-2.05	-152.05	0.0	Likely Acid Generator
2	3.3	1.28	22.81	-3.34	-26.15	0.0	Likely Acid Generator
3	4.88	1.47	51.88	-0.59	-52.46	0.0	Likely Acid Generator
4	6.01	1.43	19.45	3.86	-15.59	0.2	Likely Acid Generator
5	5.59	1.32	21.73	3.71	-18.02	0.2	Likely Acid Generator
6	6.65	1.68	2.40	2.04	-0.35	0.9	Likely Acid Generator
7	5.87	1.65	2.86	1.90	-0.97	0.7	Likely Acid Generator

8.6 Conclusions

Kromdraai Colliery has been decanting acid water into the treatment plant for many years. Acid-base tests show that remining the underground workings through opencast methods will not significantly change the chemistry of the decanting water. All samples tested acidified during testing, suggesting that the end result in terms of water chemistry would be similar to that prior to opencast mining. Higher salinities are possible in the mine water, seeing that the reactive surface area is increased through opencast mining.

By reworking the underground working through opencast methods, greater infiltration of rainwater should be possible. It has generally been accepted that 20% of the rainfall infiltrates and recharges opencast workings in South Africa (Hodgson and Krantz, 1998). This percentage is marginally higher than that previously recorded for the underground workings of Kromdraai (15%).

It is concluded that reworking the underground workings by opencast methods will not significantly change past trends and that mine-water treatment through liming will still be required in the long run. As in the past, heavy metals will precipitate in the liming plant. The precipitate can be disposed of under permit prescription.

The significance of this study lies in the fact that different mining methods do not necessarily have different impacts on water quantities and qualities. Each situation should be evaluated on its own.

9 Conclusions

This investigation was intended:

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

The six collieries for this investigation have been selected with specific intent. Each of them has specific merit for being included in this investigation. In this document, the collieries have been dealt with separately. For detailed information, the reader is referred to the relevant chapters. This chapter summarises only the important issues.

Mining method

The mining method and associated mining geometry dictates the end result in terms of water influx and water quality. Bord-and-pillar, stooping, longwall and opencast are the four categories of mining in Mpumalanga. In terms of a risk to the environment, and based on the relative amount of water associated with the different mining methods, these stand to each other in a ratio of 1:6:11:20. Higher numbers have greater risks. These values should not be taken as absolute. Shallow mining inherently involves a greater risk to the environment than deep mining. The undermining of streams and surface water bodies, using high extraction methods, carry significant risk. The sequence of mining and linkage of underground workings could be decisive in the flooding of the mine workings, thus reducing the rate of pyrite oxidation. These are but a few examples showing that other aspects should also be considered when calculating the risk. The relative weights assigned to the various mining methods therefore serve as guidelines only.

Too much water during the mining phase is a problem that all collieries have to cope with. Planning the mining sequence from low-lying areas to high ground can, to a large extent, solve this problem. This would also solve some of the other problems, such as excess water handling, pyrite oxidation and alkalinity depletion because the mined-out area will be flooded within a reasonably short time.

Decanting of water from collieries should be planned from the outset. If future prospect boreholes are not situated as such that it can be used as monitoring boreholes, it should be grouted. Collapsed surface areas should be rehabilitated to channel the run-off away from these areas.. Many of the larger collieries extend over several catchments, and through proper planning, catchments should be selected into which water can be forced to decant. Interconnecting collieries may have to be considered to channel mine water to specific points for treatment or utilisation, rather than having numerous small uncontrolled decants into streams.

The selection of the mining method should be done in conjunction with a full environmental evaluation. Since 1970, large-scale opencast and underground high extraction has been initiated without the availability of a long-term environmental plan. When considering the time span of water treatment after the mines have closed down (centuries), the companies may have opted for mining methods with lesser impacts on the environment.

In summary, the mining method and suitable planning is of overriding importance in minimising the environmental impact during and after mining.

Geology, mineralogy, geohydrology and hydrochemistry

On a regional scale, there is no significant variation in the geology, mineralogy and geohydrology of the collieries in Mpumalanga (Pinetown, 2003). Water that enters into collieries are controlled by well-defined evolutionary processes that can be observed and modelled. Unknowns are the mechanical and hydraulic variables. Examples of this are the reactive surface area in high extraction; flow rates though these areas; the degree of flooding; interconnectivity; availability of oxygen; CO_2 pressure, and many others. Datasets are often inadequate in time and space and best estimates have to be used for prediction purposes. Fortunately, many of the variables are related to each other and interpolations or extrapolations with high confidence are often possible. Examples are:

- Calculation of natural groundwater gradients from topographic information.
- Calculation of the mineralogy from static acid-base accounting.
- Volumetric calculation for mines based on extraction factors and floor contours.

In reality therefore, even though very little direct information on these topics is available, much can be concluded about each of them by processing subsidiary data. For all six case histories in this investigation, sufficient subsidiary data were available for processing.

Water balance

Water balances are of overriding importance in determining areas of recharge, water loss and reaction rates. These vary from mine to mine. Overriding 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. 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 1% of the rainfall.
- Stooping - 4 - 12% of the rainfall.
- Longwall - 6 - 15% of the rainfall.
- Opencast - 14 - 20% of the rainfall.

The actual percentages depend greatly on the specific circumstances.
The longwall mining value (Hodgson and Krantz, 1998) was not covered in this investigation, but is included for reference purposes.

Salt generation rate

The salt generation rate is regulated by numerous variables, many of which have never been quantified or measured in the coal industry. For some of these, test procedures do not even exist. To date, the only infallible way of determining the salt generation rate is by measuring the outflow and chemistry from a mine. This has been done at five of the six collieries during this investigation. The following are the main conclusions:

- From previous work, the accepted daily rate of sulphate generation in opencast mining is 5 - 10 kg/ha. For this study, a daily value of 7 kg/ha has been used.This investigation has found the daily sulphate generation rate for underground mining to be in the range of 0,4 - 2,7 kg/ha. These rates, which are lower than those for opencast mining, are mainly due to less available reaction surfaces in underground mines.In the Witbank Coalfield, sodium has been almost totally leached from the coal and overlying rock due to circulating groundwater. In the Highveld Coalfield, high sodium concentrations could be a problem. Dissolution chemistry therefore currently plays almost no role in the north, but soluble salts form an important buffer against the initial acidification of mine water in the southern collieries.Heavy metals in the coal are present right through the Mpumalanga Coalfields. Even though they temporarily mobilise during oxidation, most precipitate in the mines under local alkaline conditions. Of the mines investigated, four are alkaline although all collieries in South Africa have acid tendencies. When flooding collieries after mining has been completed, the remainder base potential in the coal is usually sufficient to neutralise the acidity in the mine. Exceptions occur in mines that are only partially flooded. Unflooded areas serve as breeder areas from where acid water emanates.

Mining method

Several options for selecting a mining method exist. A full cost analysis should be done for water handling, and treatment for at least the life of the mine should be done. This will indicate which of the mining methods is the appropriate one.

Mining sequence

Much can be done to improve mine-water planning in all collieries. It is essential that as much mine water as possible be kept underground during and after mining. To accomplish this, mining should be from low-lying areas to high ground. Natural compartments should be created that could fill up with water while mining continues in other sections of the mine. Water quality treatment is expensive and should be avoided if possible.

Flooding

Much more can be done in terms of mine planning to flood redundant mine workings. Flooding reduces oxygen in the mine workings. Mines that have a potential acid character can often be converted into alkaline systems by flooding the mine workings.

Flushing

Flushing of mines, once they are flooded, is inevitable. Water will always enter into the mines. Vast volumes of water should decant from current collieries within the next 40 years. Flushing of the Witbank Collieries and utilisation of this water for irrigation is a possibility that needs serious consideration by the authorities. Flushing of the Highveld Collieries, where high sodium levels are present, could lead to significant pollution of streams. Desalination of mine waters is not currently viable because of the high cost and expected time frame. Fortunately, the Highveld Mines are often deep and most of them can be flooded fully. This, together with flushing, will gradually improve the mine-water quality. It is envisaged that these mines will become future reservoirs from which water can be tapped for general use, centuries from now.

10. References

Appelo and Postma (1994) *Geochemistry, groundwater and pollution*. A.A Balkema Publishers, Netherlands, pp239-256. ISBN 90 5410 106 7

Barker, O.B. (1999) A techno-economic and historical review of the SA coal industry in the19th and 20th century. In:Pinheiro,H.J.(Ed) *Bulletin 113,South African Bureau of Standards: Coal and Mineral Services*, pp1-63.

Bredenkamp D.B. (1978) Quantitative Estimation of Groundwater Recharge with Special Reference to the use of Natural Radio-active Isotopes and Hydrological Simulation. *Unpublished. Ph.D. thesis*, UOFS, Bloemfontein, p367.

Cairncross,B (2001) An overview of the Permian (Karoo) coal deposits of southern Africa. *Journal of African Earth Sciences.*

Canbulat, I. (2002) Personal communication on Pillar stability October 2002.

Canbulat,I., van der Merwe, J.N., van Zyl, M.,Wilkinson, A., Daehnke A., and Ryder, J. (2002) The development of techniques to predict and manage the impact of surface subsidence. *Coaltech 2020 Task 6.9.1.*

Cogho, V.E. (2003) Personal communication - Transvaal Navigational Colliery, November 2002.

Energy Information Administration (2000) National Energy Information Centre,1000Independance Avenue, SW Washington, DC, USA.
Website: http://www.eia.doe.gov

Erasmus, B.J., Hodgson, F.D.I., Kirstein, F.E., Roper, C.B., Smit, J.S., Steyn, P.P.A. and Whittaker, R.R.L.G. (1981) Geological, hydrological and ecological factors affecting increased underground extraction of coal. *SAIMM Vacation School, Johannesburg.*

Falcon, R.M.S. *Classification of coals in Southern Africa*. In: Anhaeusser, C.R. and Maske,S. (Eds.) (1986) *Mineral Deposits of Southern Africa*, Vols.I & II, Geological Society of South Africa, Johannesburg, S.A.

Froneman, J. (2003). Personal Communication - New Largo Colliery, January 2003.

Funke, J.W. (1983) The environmental impact of coal mining and combustion. *SA Water , science and Technology 15,* pp 115-144.

Greenshields, H.D. *Eastern Transvaal Coalfield.* In: Anhaeusser, C.R. and Maske,S. (Eds.) (1986) *Mineral Deposits of Southern Africa*, Vols.I & II, Geological Society of South Africa, Johannesburg, S.A.

Grobbelaar, R., Cruywagen, L-M., de Necker, E. and Hodgson,F.D.I. (2000) Investigation into Geohydrological and Hydrochemical aspects relating to Mine Closure for Transvaal Navigational Colliery. *Confidential Report to Ingwe S.A.*

Grobbelaar, R., Usher,B., Cruywagen,L-M., de Necker, E. and Hodgson, F.D.I. (2000) Long term impact of Intermine flow from Collieries in the Mpumalanga area. Submitted *report to the Water Research Commission of South Africa.*

Grobbelaar, R. (2001) Long term impact of intermine flow from collieries in the Mpumalanga area. *Unpublished MSc thesis, Dept of Geohydrology, University of the Free State, Bloemfontein, South Africa.*

Hodgson F.D.I., Usher,B.H., Scott, R., Zeelie,S., Cruywagen, L-M. and de Necker, E. (2001) Prediction techniques and preventative measures relating to the post -operational impact of the underground mines on the quality and quantity of groundwater resources. *WRC Report No 699/1/01.*

Hodgson, F.D.I, Wagner, H. and Shipman, B.J. (1985) *Guidelines for Environmental protection.* Pollution problems and Hydrological disturbances resulting from increased underground extraction of coal. UOFS Press, Bloemfontein, South Africa.

Hodgson, F.D.I. (1992) Geohydrological implications of closure of New Largo Colliery. *Confidential Report to Anglo Coal.*

Hodgson,F.D.I. and Grobbelaar, R (1999) Investigation into long-term water quantity and quality trends at Ermelo Colliery. *Confidential Report to Ingwe S.A.*

Hodgson,F.D.I. and Grobbelaar, R (2000) Water and Salt balance for Minnaar Colliery. *Confidential Report to Ingwe S.A.*

Hodgson.F.D.I and Krantz,R.M.(1998) Groundwater quality deterioration in the Olifants River Catchment above the Loskop Dam with Specialised Investigations in the Witbank Dam Sub-Catchment. *WRC Report No 291/1/98.*

Hodgson, F.D.I. Personal communication, February 2002 to May 2003. Institute for Groundwater Studies, Free State University, Bloemfontein, South Africa.

Jordaan, J. *Highveld Coalfield.* In: Anhaeusser, C.R. and Maske,S. (Eds.) (1986) *Mineral Deposits of Southern Africa*, Vols.I & II, Geological Society of South Africa, Johannesburg, S.A.

Kirchner, J., Van Tonder, G.J. and Lukas, E. (1991) Exploitation Potential of Karoo Aquifers. *Report to the WRC, Report 170/1/91, Water Research Commission, Pretoria, 283 p.*

Latilla+Olivier (1998) Report on stability of pillars for mine closure of Ermelo Mine Service. *Confidential Report to Ingwe S.A.*

Le Roux, P. (2002) Personal communication. Dept of Soil Science, FreeState University, Bloemfontein, South Africa.

Midgley, D.C., Pitman, W.V., and Middleton, B.J. (1994) Surface Water Resources of SA 1990. *WRC Report No 298/1.4/94 Second Edition.*

Naudé,C. (2002) Personal communication, May 2002-January 2003. bhpbilliton, Middelburg, Mpumalanga.

Naudé,C. (2002) Rehabilitation of Ermelo Mines Services, A case study. *Conference on Mine Closure Report. Randfontein Estates Sports Club (23-24 October 2002).*

Pinetown,K.L. (2003) Quantitative evaluation of Minerals in Coal Deposits in the Witbank and Highveld Coalfields and the potential impact on acid mine drainage. *Unpublished MSc thesis, Dept. of Geology University of the Free State, Bloemfontein, South Africa.*

Salmon,D. (2002) Personal communication, October 2002.

Salmon,D. (2002) Water management during the closure of New Largo Colliery, Mpumalanga Province. *Conference on Mine Closure Report. Randfontein Estates Sports Club (23-24 October 2002).*

SA Weather Service - Rainfall Figures
www.weathersa.co.za

Smith, D.A.M. and Whittaker, R.R.L.G. *The Coalfields of Southern Africa: An Introduction.* In: Anhaeusser, C.R. and Maske,S. (Eds.) (1986) *Mineral Deposits of Southern Africa*, Vols.I & II, Geological Society of South Africa, Johannesburg, S.A.

Smith, D.A.M. and Whittaker, R.R.L.G. *The Springs-Witbank Coalfield.* In: Anhaeusser, C.R. and Maske,S. (Eds.) (1986) *Mineral Deposits of Southern Africa*, Vols.I & II, Geological Society of South Africa, Johannesburg, S.A.

Snyman, C.P. (1998) *Coal.* In: Wilson, M.G.C. and Anhaeusser (Ed) *The mineral resources of South Africa.* Handbook 16, Council for Geoscience, 6th Edition. ISBN 1-875061-52-5

Steenkamp, A. (2002) Personal communication - farmer at Minnaar Colliery, February 2002 to January 2003.

Usher,B (2001) Acid Base Accounting Cumulative Screening Tool. *Part of a submitted Water Research Commission Project 2001.*

Usher,B (2003) The evaluation and development of hydrochemical prediction techniques for long-term water chemistry in South African Coalmines. *Unpublished PhD Thesis, Dept of Geohydrology, Faculty of Natural Science and Agriculture, University of the Free State, S.A.*

Usher,B (2003) Personal communication, February 2002 to May 2003. Institute for Groundwater Studies, Free State University, Bloemfontein, South Africa

Van Tonder, G. and Krantz, R (1997) TNC Groundwater model to assess water management options, *Confidential Report to Ingwe S.A,* p5.

Van Tonder, G. (2002) Personal communication, February 2002 to May 2003. Institute for Groundwater Studies, Free State University, Bloemfontein, South Africa

Wagner,H (1980) Pillar design in coal mines. *J.S. Afr. Inst. Min. Metall., Vol. 80, 1980, pp.37-45.*

Wates, Meiring and Barnard (1997) EMPR: Tweefontein Colliery. *Confidential Report.*

WISA (2002) Conference on Mine Closure Report. Randfontein Estates Sports Club (23-24 October 2002).

www.ingwe.co.za

www.WISH.co.za

Summary

This investigation was intended:

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

Six collieries where mining has ceased have been selected for detailed geohydrological and hydrochemical investigation. The scope is to provide sufficient time-related information with which the industry and authorities can associate to promote standardisation of water management methodologies. The mines selected for this investigation are:

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
Kromdraai	Underground mine currently being reworked by opencast methods; impact of change in mining method.	Bord-and-pillar Secondary opencast

The main conclusions are:

- The mining method and associated mining geometry dictates the end result in terms of water influx and water quality.
- On a regional scale, there is no significant variation in the geology, mineralogy and geohydrology of the collieries in Mpumalanga (Pinetown, 2003).
- Water balances are of overriding importance in determining areas of recharge, water loss and reaction rates. These vary from mine to mine. Overriding 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. 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 - 1% of the rainfall.
  - Stooping - 4 - 12% of the rainfall.
  - Longwall - 6 - 15% of the rainfall.
  - Opencast - 14 - 20% of the rainfall.

The longwall mining value (Hodgson and Krantz, 1998) was not covered in this investigation, but is included for reference purposes.

- Daily sulphate production rates range from 0.4 - 2.7 kg/ha in the mines. Sulphate constitutes about 50% of the salt load and concentrations typically ranging from 400 - 2 000 mg/L.
- Flooding of the mines should minimise oxygen ingress and sulphate production will decline under alkaline conditions. Four of the six collieries currently have alkaline water. Long-term projections indicate that three of these collieries should remain alkaline.
- It is suggested in this document that more should be done in terms of planning mine-water handling, during and after mining. Projections indicate that flushing is a viable option to reduce salinity in the mine water. Mine water from the northern collieries is low in sodium content, which makes it usable for the irrigation of crop. In the southern part, the Mpumalanga Collieries generally have high sodium concentrations, which limits the possible applications of this water.
- Management options for mine water during and after mining can be reduced to a few simple concepts. Endless branching into more sophisticated, sometimes more complex, procedures is possible. The following is a list of simple management options that include all the important issues:
  - Select the mining method based on environmental considerations.
  - Mine from low-lying areas to high ground.
  - Flood the mine workings as soon as possible.
  - Flush the mines after being flooded.

Opsomming

Die doel van die ondersoek was die volgende:

1. Om die mynbou metodes, skedulering, geologie, geohidrologie, hidrochemie, water- en sout balanse van ondergrondse steenkoolmyne wat of besig is om oor te loop, of waar oorloop onafwendbaar is, te ondersoek en te beskryf.
2. Om bestuursopsies, waardeur die kwaliteit van water in bestaande steenkoolmyne beinvloed kan word, te ondersoek en sodoende die langtermyn soutladings wat in die omgewing vrygestel gaan word, te verminder.
3. Om ses gevalle studies te dokumenteer vir toekomstige verwysings, en om sodoende die tydsafhanklikheid van die sisteem te bewys.
4. Om bestuursopsies vir bestaande steenkoolmyne uit te lig en te bespreek, rakende die langtemyndoelwit om die versouting van die omgewing te minimaliseer.

Ses steenkoolmyne waar produksie reeds gestaak is, is gekies vir `n deeglike geohidrologiese en hidrochemiese ondersoek. Die doel daarmee is om voldoende inligting aan die owerheid en die industrie beskikbaar te stel, sodat eenvormigheid oor die bestuur van water bereik kan word. Die myne wat gekies is vir die ondersoek, is as volg:

Myn	Eienskappe
Minnaar	Klein ondergrondse myn met kompartemente; kunsmatige aanvulling; besproeiing met mynwater
Ermelo	Groot ondergrondse myn met gedeeltelike pilaar herwinning; besig om vol te loop; deurspoeling `n opsie.
TNC	Komplekse samestelling van ondergrondse en oopgroef mynboumetodes; gedeeltelik gevul met water; bestuur van waterkwaliteit is moontlik deur vermenging.
New Largo	Ondergrondse myn met baie min insakkings; waterbalansberekeninge; waterverlies deur uitsypeling
Schoongezicht	Ondergrondse myn; huidiglik vloei dit oor; water- en soutbalanse
Kromdraai	Ondergrondse myn wat huidiglik herwerk word deur oopgroefmetodes; impak van veranderde metodes ondersoek.

Die belangrikste gevolgtrekkings is as volg:

- Die mynboumetode en gepaardgaande mynligging bepaal die eindresultaat rakende waterinvloei en -kwaliteit.

- Op `n regionale skaal is daar nie betekenisvolle verskille tussen die steenkoolmyne in Mpumalanga wat betref geologie, mineralogie en geohidrologie nie.

- Waterbalanse is die belangrikste aspek in die bepaling van aanvulling, waterverliese en reaksietempos in myne. Dit verskil egter van myn tot myn. Faktore wat in ag geneem moet word, is die mynbou metodes, diepte van mynbou en oppervlakhidrologie. Hoë ekstraksiemetodes versteur die oorliggende gesteentes meer, as wanneer kamer-en-pilaar metodes toegepas word. `n Opsomming van die persentasie aanvulling wat verwag kan word vir die verskillende metodes van mynbou, is as volg:
    - o Diep kamer-en-pilaar met geen insakking - 1% van die reënval
    - o Pilaar herwinning - 4-12% van die reënval
    - o Strookafbouing - 6-15% van die reënval
    - o Oopgroef - 14-20% van die reënval

- Daaglikse sulfaat generasietempos wissel van 0.4 - 2.7 kg/ha in die myne. Sulfaat maak omtrent 50% van die totale soutlading uit en konsentrasies wissel meestal tussen 400 - 2000 mg/L.

- Oorstroming van die myne verminder suurstofinvloei, en gevolglik behoort sulfaatgenerasie te verminder onder alkaliese toestande. Vier van die ses myne het tans alkaliese water. Langtermynprojeksies dui daarop dat drie van hierdie myne alkalies behoort te bly.

- In hierdie dokument word voorgestel dat meer gedoen word met die beplanning van die hantering van myn water, gedurende produksie en na die sluiting van `n myn. Projeksies dui daarop dat spoeling `n werkbare opsie is om die soutgehalte van mynwater te verminder. Water van die noordelike steenkoolmyne het `n lae natrium inhoud, wat dit geskik maak vir besproeiing. Die suidelike steenkoolmyne in Mpumalanga het gewoonlik `n hoë natrium inhoud, wat veroorsaak dat die nuttige aanwending van hierdie water beperk is.

- Bestuursopsies vir mynwater, gedurende produksie en daarna, kan tot `n paar eenvoudige opsies beperk word. Die uitbreiding hiervan tot meer gesofistikeerde, soms meer komplekse metodes, is wel moontlik. `n Lys van eenvoudige bestuursopsies, wat al die belangrike aspekte insluit, is as volg:
    - o Kies die mynbou metode volgens omgewingsvereistes.
    - o Myn vanaf laagliggende gebiede na hoër dele.
    - o Oorstroom die myn so spoedig moontlik.
    - o Deurspoel die myn nadat dit gevul is.