THE INFLUENCE OF FLOODING ON UNDERGROUND COAL MINES

by

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DECLARATION

November 2011

I, Nicolaas Lessing van Zyl, declare that the dissertation herby submitted by me for the Masters of Science degree at the University of the Free State, is my own independent work and has not previously been submitted by me at another University/Faculty. I further cede copyright of the thesis in favor of the University of the Free State.

Nico van Zyl

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CHAPTER 1
INTRODUCTION

1.1 Introduction to the study

Predicting flooding in coal mines is highly uncertain. The prediction of mine water quality and mine water stratification is even more challenging. Closed or orphaned mine sites cover approximately 240 000 km^2 of the earth's surface and can be a hazard to both humans and the environment according to Wolkersdorfer (2008).

Balkau (1999) states that among the outstanding environmental problems confronting the mining industry, that of abandoned mine sites has been practically slow to tackle. Such publications are categorized as "unused", "closed", "abandoned", or "orphaned" mines. Mining is no longer taking place, but someone has to take care of the legacy.

Acidic water discharging from underground mines in sulphur-rich coal deposits is usually acidic, and may be distinguished into two classes (Chen and Soulsby, 1999)

- Above surface drainage
- Below-surface drainage elevation

Above-drainage mines often remain largely dry after closure and may continue to discharge acidic water for long periods according to Chen and Soulsby (1999). In contrast, below-drainage mines tend to partially or completely fill with water (flood) to high levels, according to Burke and Younger (2000).

Such flooded mines tend to have restricted oxygen infiltration in comparison with free-draining above-drainage mines. This fact has been long recognized to influence the chemistry of mine discharge, motivating early efforts to reduce acid discharges from mines by bulk heading and flooding mines and reducing the oxygen supply, according to Donovan, Leavitt & Werner (1978). Some of these 'flooding' efforts have reported some long-term success. In a study done by Stoertz, Hughes, Wanner and Farley (2001) a change inferred in pH from 2.7 to 5.3 and the conductivity changed from 2 700 to 600 µsiemens/cm for the discharging Ohio coalmine over a 20-year timeframe.

It is well known that flooding improve water chemistry, but the precise timeframe and controlling factors, such as acid-neutralizing capacity, by which such changes might occur in specific mines, have yet to be identified. An understanding of the details by which changes in chemistry would occur following mine flooding, would be very relevant to the long-term control of mine-water acidity (Younger, 2000).

Mines fill up with water after closure. As a result, hydraulic gradients develop between them and different hydraulic water pressures are exerted onto peripheral areas or compartments within mines. This results in water flow between mines, or onto the surface. This flow is referred to as intermine flow. Intermine flow as a concept includes the quantity and quality of the water (Grobbelaar, *et al*, 2004).

Information available in the South African coalmining industry states that mines fill up with water and decant after closure. This usually occurs within 10 years. At the more isolated collieries, rebound of the water level may take up to 50 years. Apart from the fact that mine water is saline, low pH-values may also be encountered (Grobbelaar *et al.*, 2004).

Mine water has historically been pumped from active mine workings to allow unhindered coal production. Almost no consideration has been given to the best management strategy for water while mining. Yet, this is simple: Mine from deep areas to shallow areas and leave water behind in the mined-out workings. This strategy has, for the past few years, been applied in several of the larger collieries with significant success. The advantage of this mining sequence does not only lie in managing water volumes, but also in water quality management. Mined-out areas are flooded, thus excluding oxygen. Furthermore, the natural alkalinity of water is not flushed from the rock. This counteracts acidification in these mines (Grobbelaar; *et al.*, 2004).

Flooding of open cut mines can be a very real problem if a mine is located in a valley or in the path of a stream or a river with a significant upstream catchment. Depending on how quickly it occurs and how severe it is, flooding can cause a variety of problems such as loss of life or injury, damage to machinery and infrastructure, and far more likely, loss of access to the pit due to water and silt and the subsequent loss of production. All of these scenarios are highly undesirable to mine operators (Bedient, Rifai & Newell, 1994).

The main reasons for mine flooding according to Wolkersdorfer (2008) are the following:

- The mine is no longer economical.
- All the raw material has been exploited.
- Accident, war, or political reasons.
- Geotechnical stability of the abandoned mine workings.
- Prevention of disulphide oxidation.
- Safety reasons.

The Mpumalanga province and the KwaZulu-Natal province are the focus areas in this thesis, as both case studies are located in these provinces. Both the mines are coalmines which have been flooded for approximately 20 years.

1.2 The History of coal mining in South Africa

The history of coal mining in South Africa is closely linked with the economic development of the country. Commercial coal mining started out in the Eastern Cape near Molteno in the year 1864. The discovery of diamonds in the late 1870s led to expansion of the mines in order to meet the growing demand for coal. Commercial coal mining in KwaZulu-Natal and on the Witwatersrand commenced in the late 1880s following the discovery of gold on the Witwatersrand in 1886. In 1879 coal mining commenced in the Vereeniging area and in 1895 in the Witbank area to supply both the Kimberly mines and those on the Witwatersrand. South Africa began a period of major economic development after World War II. New goldfields were discovered and developed in the Welkom, Klerksdorp and Evander areas; a local steel industry was established with mills being built at Pretoria, Newcastle and Vanderbijlpark; an oil-from-coal industry was established, initially at Sasolburg and later at Secunda; mining of iron, manganese, chromium, vanadium, platinum and various other commodities commenced and expanded; and power stations were erected on the coalfields to supply energy to these developing industries and to the growing urban population in the country. In addition to meeting local needs, coal mining companies began to develop an export market, making South Africa a major international supplier of coal (Mccarthy; Pretoruis, 2009).

1.3 Background to the research

In the Ermelo and Newcastle area, a situation occurs where the mines have been flooded to prevent the water quality from degrading. Managing the mine after closure and protecting the environment after production has ceased are important considerations. After this opencast mining was introduced to increase the life of a mine, for example Vunene opencast mining at Usutu colliery. This study was done to determine the influence of flooding and the potential chance of the decanting of polluted water, looking if stratification occurs. A further aim was to compare end examine the quality of the water over time and to establish whether it was influenced by the quantity of the mine water.

The challenge of underground coal mines is the management of the mine water following the closure of the mines after they were flooded. Developing a cost-effective and sustainable mine water management program is of great value. The water qualities expected and the volumes may be investigated using a program called WACMAN. Plotting the water quality in Stiff and expanded Durov diagrams may reveal a trend over time in the water quality. This research comprises case studies of a shallow- and a deep underground mine where the mine was flooded after operation stopped.

- The main aim of the proposed work is to determine what influence flooding has comparing the two case studies.
- The two studies are very different from each other. Usutu mine is located at a flat area and is deep, while Kilbarchan mine is located on a steep area and is quite shallow.
- How this may influence the water quality looking at something like residence time.
- The quantity of water and quality of water after mine closure.
- The study aims to find answers to the following questions:
- Flooding: What influences do stooping, flow zones, faults and recharge have on the effects of flooding?
- Mine water quality: Will flushing take place? Does the water quality deteriorates or improve or stay the same? What is the quality at different depths? What influences the residence time?
- Mine water quantity: What is the influx into the mine? What area the pumping volumes? Will decanting take place?

1.4 Geographic information system (GIS)

Grobbelaar *et al* (2004) give a good discussion on the GIS used in this study. The WISH (Windows Interpretation System for Hydro-geologists) software package was selected for the visualization and interpretation of the data. The reasons for this are as follows:

- WISH is easy to use, sponsored in part of its development by the Water Research Commission (WRC), and available from the Institute for Groundwater Studies (IGS).
- It consists of a map drafting and display facility. Maps may be integrated from other applications that are commonly in use at the collieries.
- Datasets from Microsoft Excel may be superimposed onto the maps. With regard to relevant data processing, the processing power of WISH is unsurpassed by other software.

1.5 The Scope of the investigation

The purpose of the study is to investigate the effects of flooding on the groundwater resources at Usutu colliery, Ermelo and Kilbarchan mine, Newcastle. The activities carried out to achieve the overall objective of the study include the following:

- Physiographical description and overview of the regional geology, including the structure of the study area.

- Summary on dewatering of mines.
- The mine layout and mining.
- Overview of the mining methods used.
- Geology.
- Hydrogeology.
- Data collection, analysis and interpretation.
- Water quality.
- Water quantity.
- Calculation of recharge by various methods.
- Analysis of spatial and temporal variation of groundwater levels and qualities.
- Calculation of the water influx into the mine.
- The effects of high extraction on the groundwater resource.
- Available management strategies.

1.6 Previous mine flooding case studies

Currently there is no case study known where the stratification of a mine was predicted precisely and where remediation methods based on stratification predictions were successful. The most comprehensive study of a single mine water stratification so far was constructed at the Niedersclema/Alberoda/Germany uranium mine done by Wolkersdorfer, (2008). Between June 1992 and December 1994, a total of 115 depth profiles in seven underground shafts were measured and the stratification was observed by Wolkersdorfer, (2008).

The conceptual model for an individual mine or interconnected block is based on a general model. The model is based on the general development of mining in the UK and assumes four basic depth controlled mining units, A-D, which may or may not be interconnected. Water inflows into all the units can then be put into three basic categories (Whitworth, 2002).

1.7 Thesis layout

Chapter 1: Introduction.

Chapter 2: The effects of dewatering are discussed in detail as well as methods of dewatering used in previous studies.

Chapter 3: The Usutu case study is discussed.

Chapter 4: The Kilbarchan case study is discussed.

Chapter 5: Gives a comparison of the two case studies looking at differences encountered when considering the influences of flooding on underground mines.

CHAPTER 2

DEWATERING

2.1 Introduction

Dewatering is an effect of the flooding of a mine. In this chapter dewatering will be discussed, looking at different aspects of dewatering and their effects.

The three most costly expenses to a mine according to Morton, 2009 that can save mines millions of capital is:

- Compressed air
- Water control (mine dewatering)
- Labor

According to Morton (2009) dewatering means the removal of water by lowering the water table from a high-wall or underground mine. The problem in South Africa is that mine dewatering is only looked at when it becomes a problem for the mine. The low rainfall and low-yielding aquifers have meant that the control of mine water inflows was covered in the design of the mine. Designs for different resources of coal, gold and diamonds do not differ much.

Essential to any operating mine, according to Result and Vermilion (2007), is the dewatering process whereby water is expelled from the mine. The efficiency and effectiveness of this process is directly proportional to the operating cost of the mine. It is vital that the engineers and supervisors overseeing the dewatering process should know the parameters within which the dewatering system operates.

A functional specification of the dewatering system involves the water mapping of the entire dewatering process and calculating water flows in and out (water balance) of pumping stations. Consequently as the mine expands its production, the dewatering system finds itself in unknown territory (Result and Vermilion, 2007).

In the majority of surface mines, groundwater will generally not be encountered below 50-150 metres. The amount of groundwater present, the rate at which it will flow through the rock, the effect it may have on stability and the influence it will have on the economical development of the pit, depend on many factors (Connelly and Gibson, 1985).

The most important of these factors, according to Brawne (1982), are the topography of the area, precipitation and temperature variation, the permeability of the rock mass and overburdened soil, and the fragmentation and orientation of structural discontinuities in the rock.

Water influences the mine in many ways, according to Connelly & Gibson (1985):

- Inflows may flood the mine and hold up production.
- Water flowing in affects the cost of drilling new boreholes.
- Slopes becomes unstable
- Equipment is damaged
- The mine has to decide where to go with the water after it has been abstracted

Carter (1992) states that groundwater is by far the greatest natural cause of problems in civil engineering. Very good ground investigations will do much to stop unexpected problems.

Figure 1: Klipspruit mine pit, where water is seeping into the pit.

2.2 Coal mining

The coal is usually found in fractured or secondary aquifers. The coal can also sometimes act as an aquifer. So the hydrogeology can be called a layered system. This means that the different layers need to be dewatered individually. The structures can be dewatered by using geophysics to site anomalies and these structures (Morton, 2009).

Morton (2009) states if water gets in contact with exposed coal not on virgin coal that is not exposed the quality of the water degrades in pH, TDS and colour. This requires that the water should be tested and treated before pumping it into streams and lakes. In open pit mines, the main problem is storm water control. The clean and dirty water needs to be managed. Figure 2 shows plates 1, 2, 3 and 4 in the area of sump pumping from Grootgeluk coal mine in the North West of South Africa.

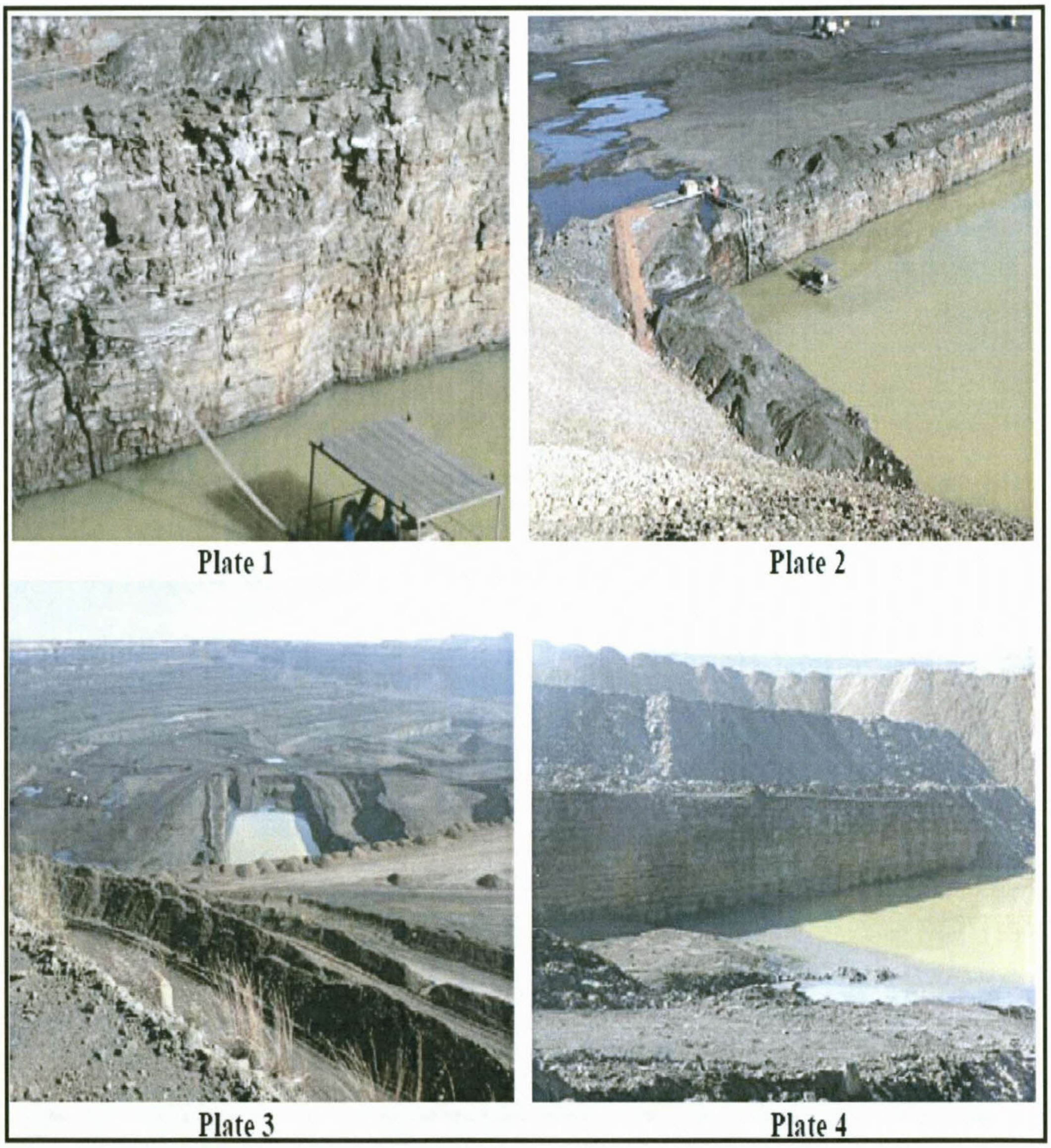


Figure 2 : Plates 1, 2, 3 and 4 area of sump pumping from Grootgeluk coal mine in the North- west of South Africa (Morton, 2009).

Thomas (2002) states that open pits need to be dewatered for the mine to operate successfully and functionally. The basic idea is to stop water from flowing into the pit in order to a maintain slope stability and protect water for abstraction outside the mine area. The hydrogeology and geology of the mine site plays the most important role in choosing the dewatering method.

The standard process is usually that the water level is excavated by the mine. This then requires that the water table be lowered to avoid flooding. Installing a pump in the sump at the pit bottom usually solves this problem. However, this method does not always work for every situation.

According to the Minerals Council of Australia (1997), dewatering is commonly carried out to lower the water table by pumping water out of the aquifer and away from the mine. A series of bores or spear points may be positioned in areas of good hydraulic connectivity to allow pumping at a sufficient rate to draw down the aquifer. Drawdown of the water table reduces the flow through the area of groundwater near the mine pits. Ideally, the water table should be drawn down below the floor of the pit so that groundwater inflows are eliminated altogether. Figure 3 indicates the effect produced by dewatering.

According to Libicki (1993) other methods are used when there are geological discontinuities (faults, folding, etc).

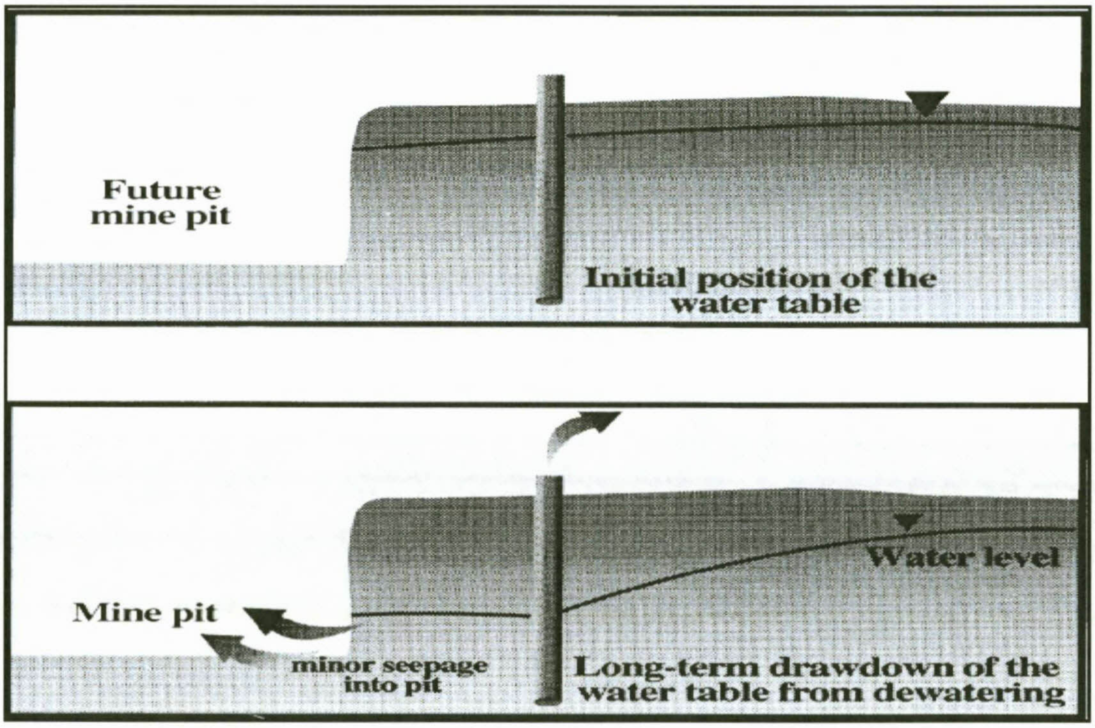


Figure 3: Effects of dewatering around a pit (Minerals Council of Australia, 1997).

Brawne (1982) states that based on field investigations, a design can be prepared for the control of groundwater in the slope and in the pit. Methods of control include the use of horizontal drains, blasted toe drains, the construction of adits or drainage tunnels and pumping from wells in or outside of the pit. Recent research indicates that subsurface drainage can be augmented by applying a vacuum or by selective blasting. Instrumentation should be installed to monitor the groundwater changes created by drainage. Typical case histories are described that indicate the approach used to evaluate groundwater conditions.

Morton (2009) explains that the use of gravity is always the first option when pumping is done from sumps and collector dams. When pore pressures are high and gravity drainage is insufficient, then active pumping from specific permeable horizons of structures is used to supplement the drawdown created by the passive drainage. Where groundwater flow is predominantly vertical, horizontal drainage is most effective, in for example, drainage galleries. When the dominant flow is horizontal, flow vertical methods of dewatering, such as vertical pit perimeter boreholes, are more effective. As the direction of flow and mine development change with time, the methodology can be adapted to suit the new conditions.

2.3 The Phase approach in mine dewatering

This approach covers phases to go about tackling a dewatering problem according to Morton & van Miekerk (1993).

- Phase 1: Desk study and borehole senses

This phase consists of all the information one can get from the mine without incurring any expenses. Information consists of the regional groundwater level of the area, borehole information, where water strikes occurred, maps of the mine etc.

The borehole census is there to determine the regional groundwater level of the area. This can be done by doing a hydrocensus.

- Phase 2: Impact of mining on the groundwater
- Phase 3: How to remove/reduce the hazard.

The hazard may be removed either by handling or diverting the flow, depending on where the water is coming from. All this can be accomplished through experience using trail dewatering and computer modelling. Dewatering is the removal of groundwater from an area through the lowering of the water table.

2.3.1 Different methods of removal

The different methods of mine dewatering are summarized in Figure 4. There are a large number of dewatering methods to choose from, but one has to find the method that best suits the situation.

- Well points
- Deep boreholes
- Dewatering galleries

- Drains
- Sump pumping
- A combination of some of the above.

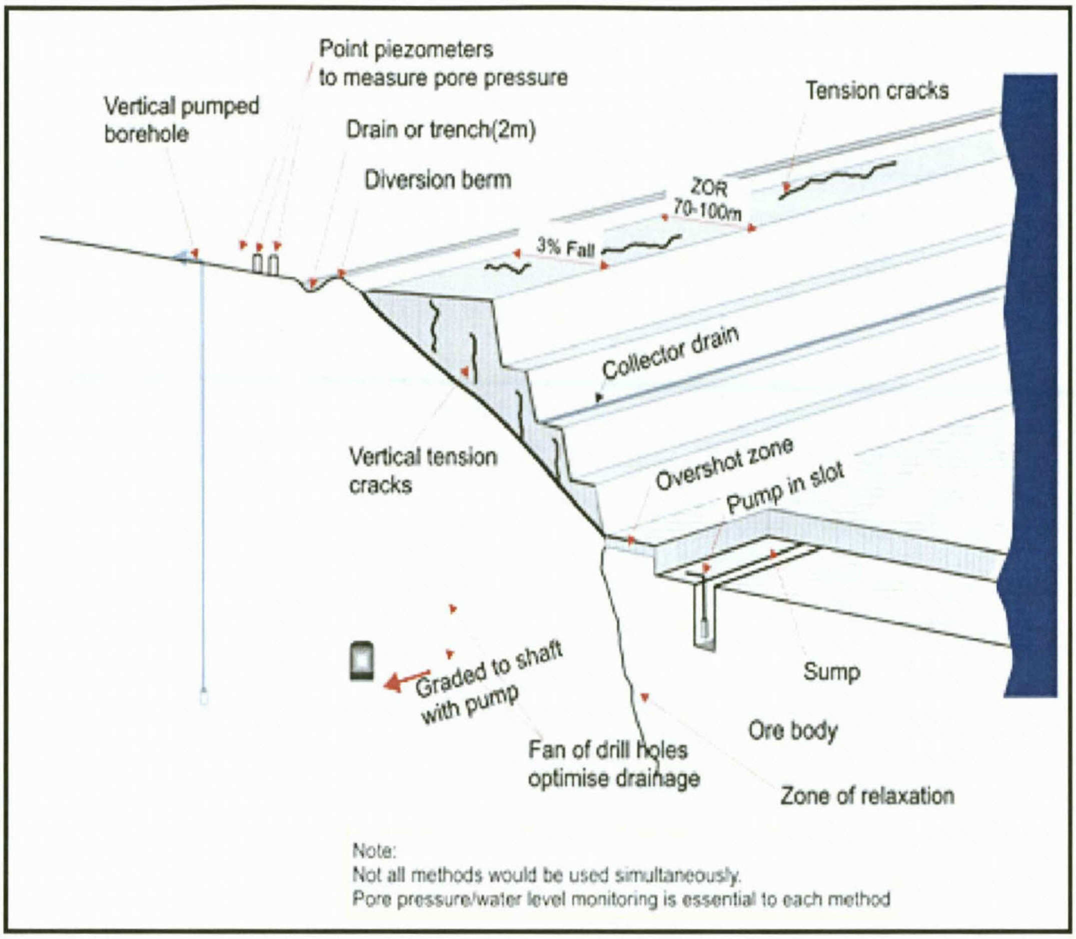


Figure 4: The different methods in mine dewatering summarized (Morton, 2009).

Table 1 shows a comparison between a few dewatering methods constructed by Hustrulid (2000), giving the advantages, disadvantages and the best application for the `method.

Table 1: Comparison of different dewatering methods (Hustrulid, 2000).

Method	Advantages	Disadvantages	Best application
Perimeter wells	Usually have a long life of mine; have large space for drilling; can be installed proir to mining; can intercept lateral inflow; logistiacally simple	Impacts on centre of pit may be limited; must usually be deeper (hence higher cost) ; might be in less permeable rock	Where flow to pit is lateral for small pit; where hydraulic conductivity is primarily horizontal
In-pit wells	Creates most drawdown in pit; located in zone of potensial large hydraulic conductivity (often the core zone); relatively shallow; can intercept vertical flow through bottom of pit	Hard to mine aroun; short life; drilling logistics; need to deliver water and power to and from well; potential drilling problems; can be installed only after mining commences	Compartimentilized rock mass; very asymmetric pits; mine in which large permanent benches are established early
In-pit horizontal/drain holes	Increase slope stability; can drain/ depressurize through targeted structures; passive dewatering; no specail location needed; inexpensive	Winter freezing; drains/depressurize only limited area; can only be installed after mining begins; water delivery	Deep pits; permeability rock masses; higly anisotropic rock masses; to breach groundwater "dams"(e.g. gouge zones)
Drainage galleries	Dewaters from below the mine; can intercept structures at optimum angles; can handle large qauntiities of water	High cost of excavation; large lead time for construction	Long mine life; good tunnelling conditions; where construction can be done for dual purpoese (e.g. exploration or high grading)

Carter (1992) states that the excavation of the water level in dewatering falls into two categories:

- Pumping methods
- Exclusion methods

Pumping methods include:

- Simple pumping
- Well pointing
- Specialized well pointing
- Filter wells
- Electro-osmosis

These methods are best used for sands. Gravels are generally too permeable and clays are just ignored.

2.3.1.1 Simple drainage

Carter (1992) describes surface water inflows that are intercepted by surface drainage ditches as shown in Figure 5. This is a very simple method.

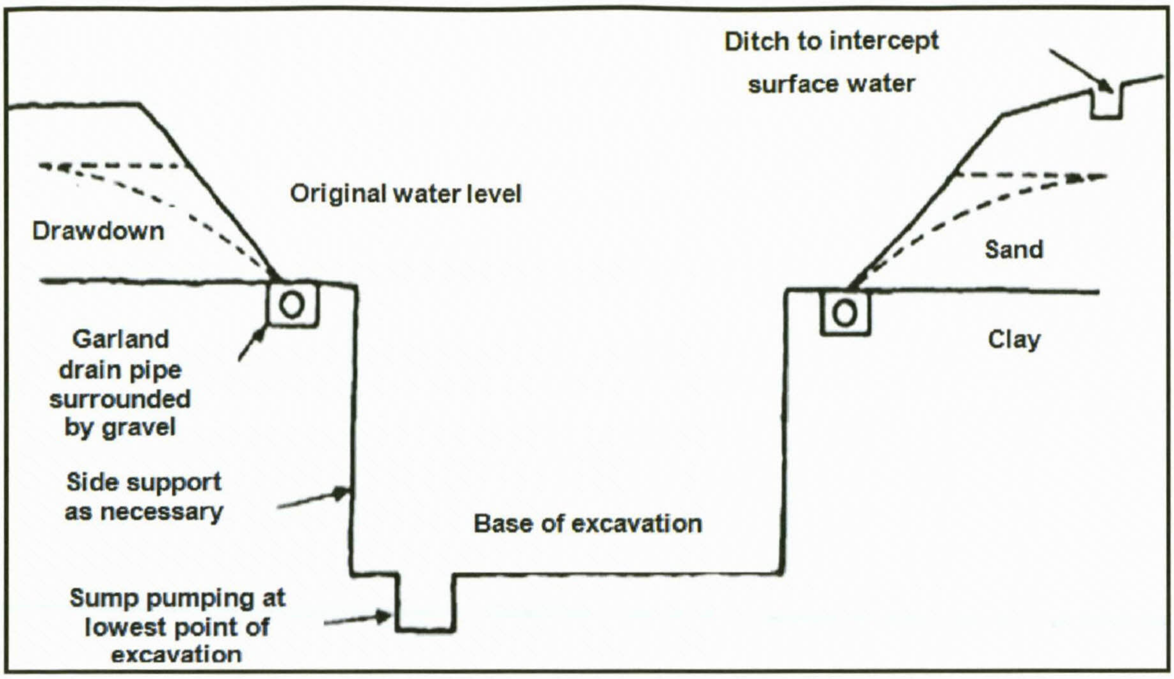


Figure 5: Simple drainage from excavation (Carter, 1992).

2.3.1.2 Boreholes and well points.

Morton *et al.*, (1993) explain that interference pumping through boreholes causes a deeper cone of depression between the boreholes. The more boreholes there are the more effective the dewatering will be. Example: Letlhakane diamond mine, Northern Botswana.

Well points are used in unconsolidated sediments. This method dewaters shallow aquifers; it is usually used in combination with deep boreholes to dewater multi layer aquifers. Example: Vaal River Channel, Northern Free State.

According to Libicki (1993) drainage wells between 20 and 400 metres drilled from the ground surface. The depth of the boreholes varies from 20 m- 400 m, with drilling diameters from 350 to 1200 mm. The yield varies from 1.6 l/s to 166 l/s in extreme cases, but in average cases the yield varies between 3.3 l/s – 25 l/s. These boreholes are sited in the area where the water flows into the mine. This is done to intercept the water before it flows into the pit. The boreholes are usually fitted with submersible pumps (Brawne, 1982). Where very heavy seepage is expected, pumping from deep wells located around the periphery of the pit may prove practical and economical. Facilities of this type have been installed in excess of 125 metres with success. Where the groundwater flow is large and when the influence on stability of pore water pressures and seepage pressures is significant, the pumping system must be designed with reasonable over capacity. If one pumping unit becomes inoperative, there is sufficient excess of pumping capacity to prevent the development of local areas of high water pressure which might cause instability.

In addition to drainage control within the pit itself, the control of surface drainage outside the pit boundaries is necessary to ensure that surface water does not flow into the pit. Besides the extra pumping capacity required, water flowing into the pit percolates into surface fractures and openings. This aggravates rock falls and the occurrence of local slides between benches. It is only desirable not only to determine the influence of groundwater on stability but also to determine whether drainage of the pit slopes will allow an increase in the overall slope angle.

For the same safety factor, reducing pore pressures by 6 to 10 metres will usually allow an increase in slope angle approximating 3 to 6 degrees. An evaluation can be made of the cost of drainage versus the economical benefit to be gained by the increase of the slope angle that the drainage will allow. In order to evaluate the effectiveness of drainage, it is necessary to install piezometers at key points in and around the pit to measure cleft water pressures. It will normally be adequate to read instrumentation on a monthly basis, with more frequent readings during the spring runoff period, following heavy rains and during the late winter period.

As the open pit deepens the probability of high pore water pressures developing in the base area of the pit increases. These pressures could conceivably become sufficiently large to cause a blow up of the base of the pit. This probability increases where the bedrock structure is horizontal or where significant horizontal tectonic stress exists in the rock. To reduce the water pressures in the base of the pit, pressure relief wells should be considered. The design of drainage control in open pit mines should always be preceded by a moderately detailed field permeability testing program me, unless extensive previous experience at the site is available (Brawne, 1982).

Morton (2009) explains that in some areas the sediments in the area overlying the source have high clay content and depressurization is required through well points. Figure 8 and Figure 9 show a cross-section of a Well-point dewatering system, and an isometric view of a multi-layered system.

Well points are used in combination with good storm water control and sump pumping. Mining up gradient is the best, where possible at a slope of >1.5 degrees to let the water drain down the walls, towards pumps or a decline. Figure 10 shows a plan view of a room and pillar mine. In this example the main haulages are used to drain water towards the shaft but there are also areas of ponding (shown in blue) that are undrained. The mine also has an area of subsidence where there is stream flow capture, which is then drained to the main haulage. This is a problem when the water in the mine becomes dirty.

Carter (1992) shows in Figure 6 the lowering of the original water level under the excavation. This method is used in shallow excavations and is relatively cheap. The chemistry of the water needs to be known to prevent clogging of the equipment.

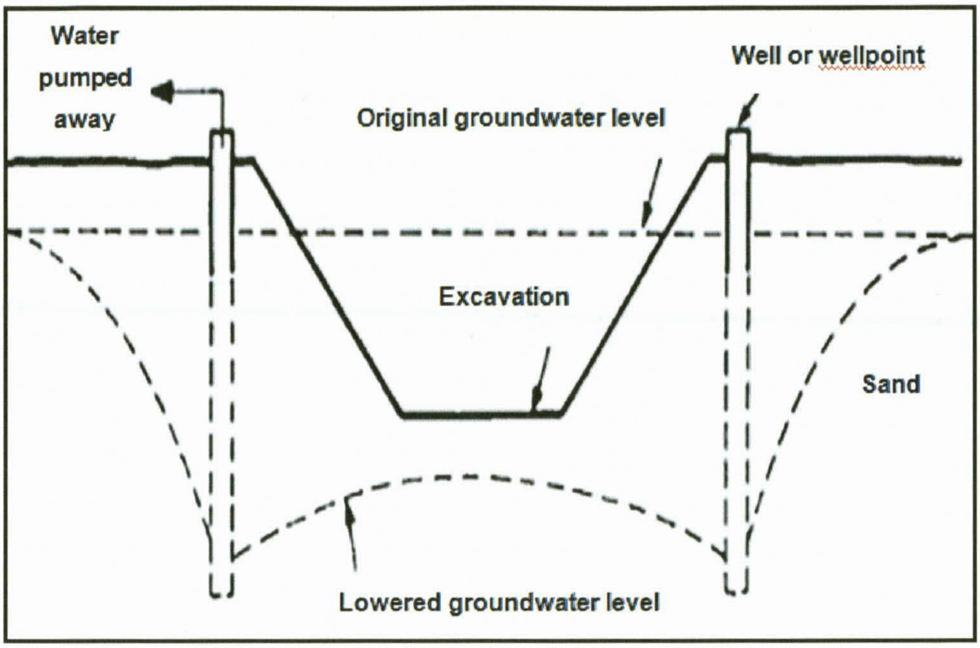


Figure 6: Groundwater lowering through wells (Carter, 1992).

Boreholes can be used to dewater a mine. By drilling a borehole every 25 m; each pumping 0.1 l/sec; 100 m from mine shown in Figure 7.

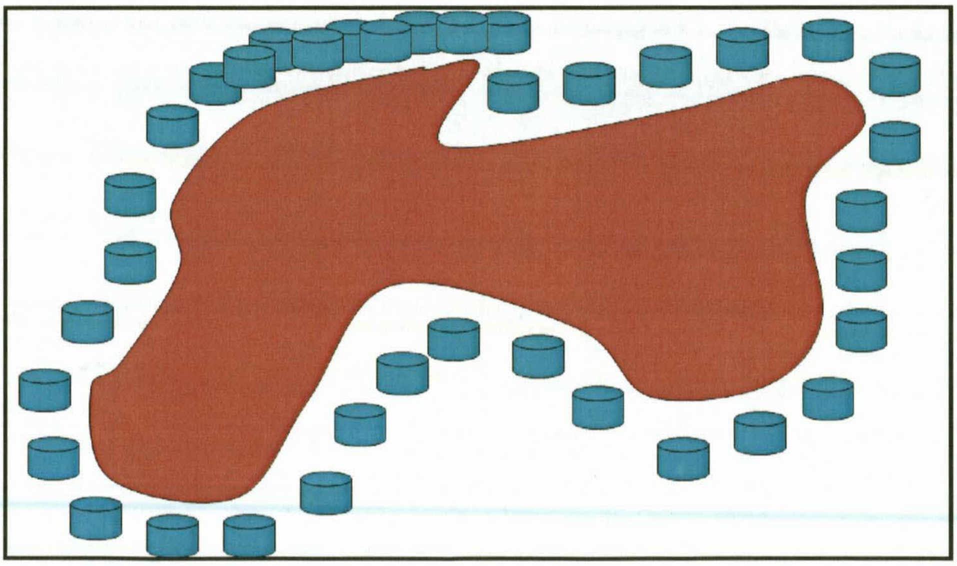


Figure 7: Coal mine dewatering by surrounding boreholes (source: UFS mine water course, 2008).

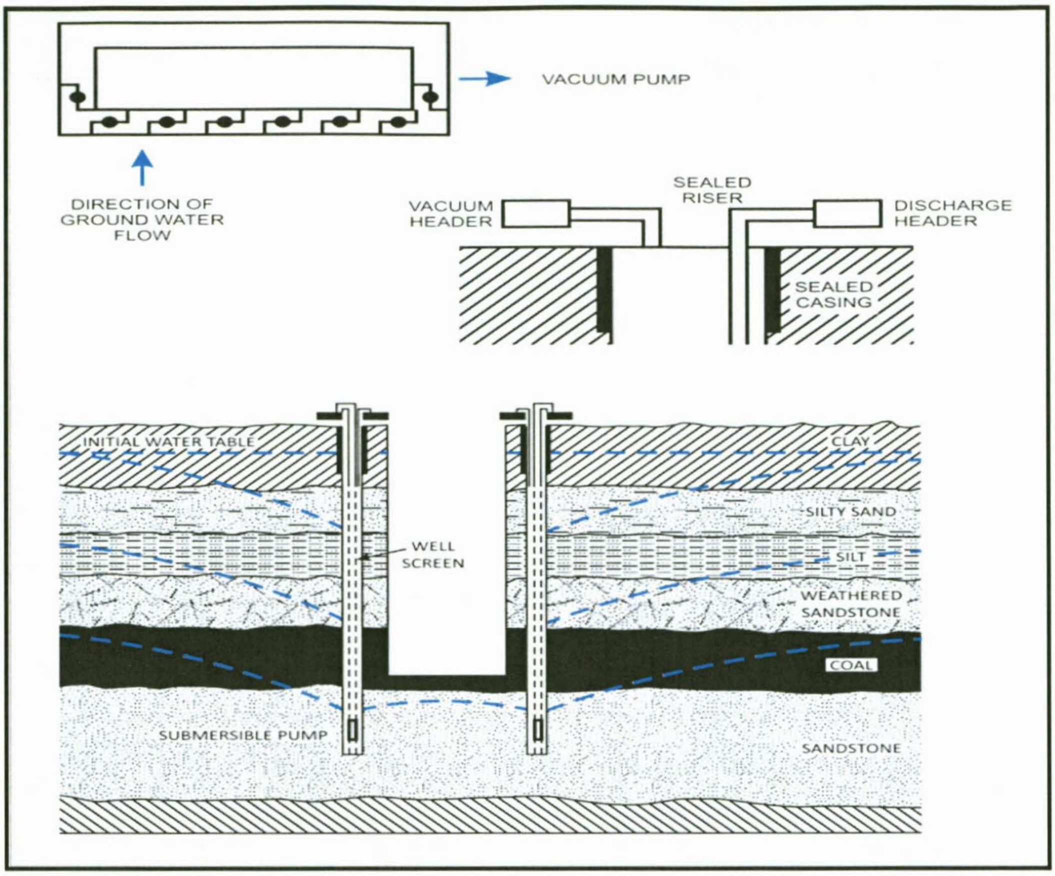


Figure 8: Design of well point system to dewater upper sediments (Morton, 2009).

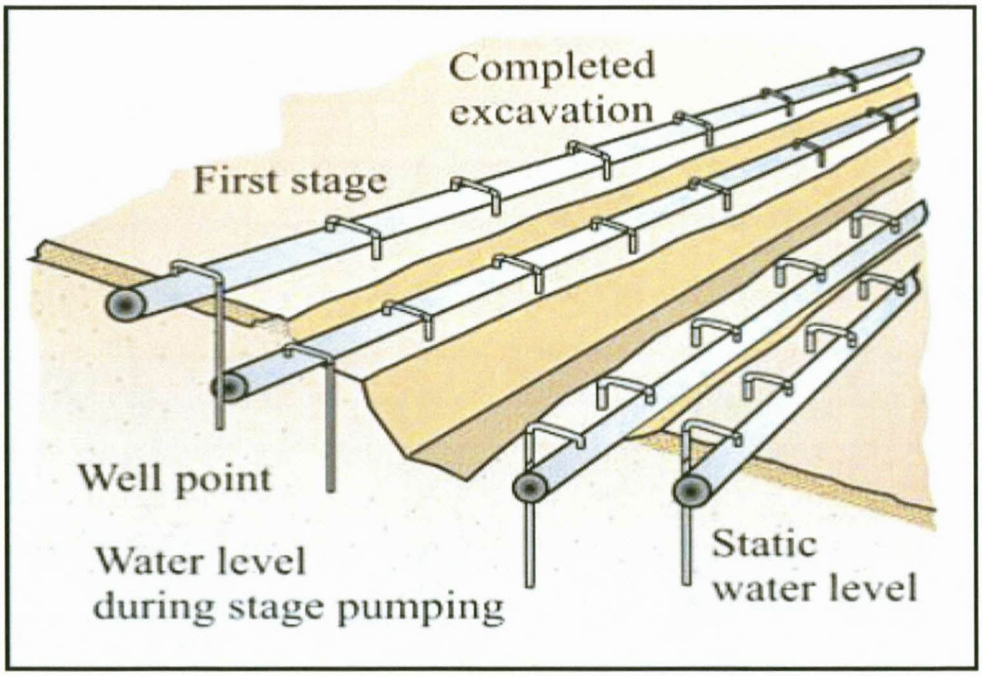


Figure 9: Isometric view of a two stage well-point system to dewater an elongated open pit (Morton, 2009).

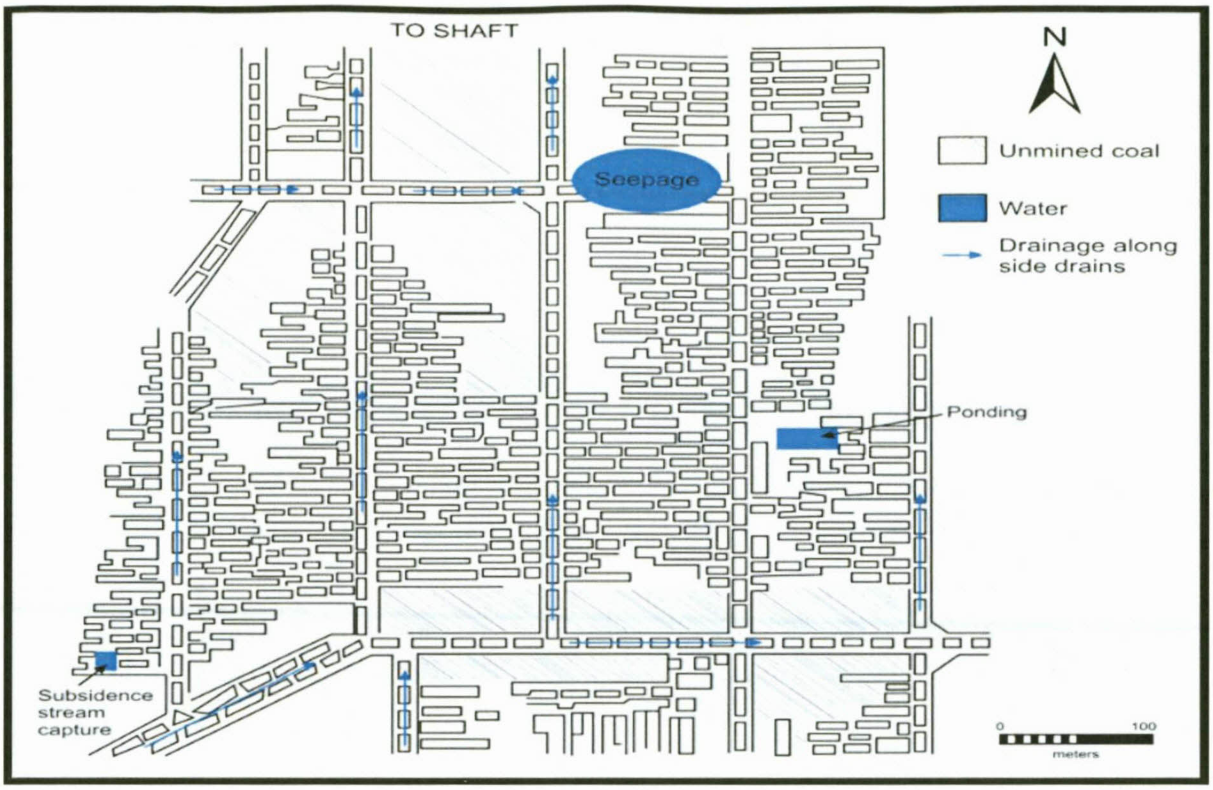


Figure 10: Plan view of a room and pillar mine showing seepages (Morton, 2009).

2.3.1.3 Electro-osmosis

According to Carter (1992) electro–osmosis is a rarely used method. It is occasionally used to dewater very fine grain soils such as silts. An electric current is induced through the soil which causes water to move from the positive anode to a negative cathode.

- Anodes are metal stakes driven into the ground
- Cathodes consists of well points

2.3.1.4 Horizontal drains

Brawne (1982) describes a technique which may be utilized to improve the stability of the rock slopes, namely to install horizontal drains, a technique which is commonly used to stabilize earth landslide. Holes 5 to 8 cm in diameter are drilled near the toe of the slope on about a 5 per cent grade for a distance of 50 to 100 metres into the slope. If the holes cave, a perforated drain must be installed. To reduce drilling time it is common to fan 3 to 5 holes from one drill location.

Groundwater flows into the drain holes, lowers the groundwater level and improves stability. During the cold winter weather in northern climates it may be necessary to protect the outlets of the drains from freezing and to collect the water with a frost free collector system. In the winter months in northern climates, it is common for the pit slopes to freeze so that seepage does not exit from the slopes. As a result high pore water pressures frequently develop. This factor appears to account for the fact that many failures occur in the February to April period in Canada (Brawne, 1982).

An alternative to horizontal drainage is to minimize the buildup of pore water pressures in the slopes to blast the entire lower bench 10 to 13 metres wide around the toe of the slope in the open pit and not to - excavate this blasted toe during the winter months. This area will have high permeability and will act as a large drain in allowing water to seep from the slope. Water from this area must be collected in one or more sump areas and pumped from the pit (Brawne, 1982).

Horizontal drains can be a very effective method if used as a depressurizing method, together with the other system set in place to dewater. These drains are drilled in the benches of a mine pit. Drains are set to intercept the anticipated inflow of water or where water is already flowing into the mine. The length of these drains is 150 m with a diameter of 100 mm. When working in sandy layers, a PVC pipe can be used to filter (Libicki, 1993).

2.3.1.5 Needle filters

These drains are 50 mm pipes 10 m length in the soil to dewater, a group of 20-30 pieces 2-4 m apart. All these connected to one pump allow one to lower the water level by 6-7 m. These are extra if it is necessary to dewater more (along the roads). The ditches inside the pit only take up the rainwater and water from the slopes. These ditches are dug on the slopes to provide a sort of permanent structure. The water is then fed to pumping stations that can be moved. This method is used with great effect in Poland (Libicki, 1993).

2.3.1.6 Interconnected wells

Interconnected wells are used to dewater the open pit under the excavation. Figure 11 shows a two-stage dewatering scheme to lower the water level below the two levels of excavation (Price, 1996).

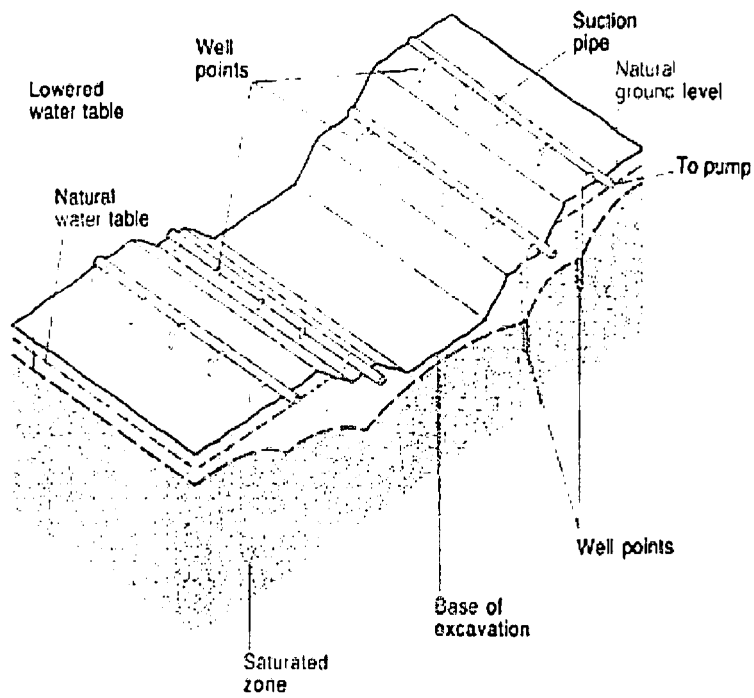


Figure 11: Site dewatering, using a two-stage dewatering system with wells to lower the water table beneath the excavation (Michael Price, 1996).

2.3.1.7 The gravity wells

Gravity wells drain water from an upper aquifer to a lower aquifer below the level of the pit bottom. The rate of pumping is maintained steadily to form a cone of depression; this level is monitored by taking water levels. The cone of depression will influence the areas outside the mine site. Figure 12 shows the dewatering of open pit mines using several methods of excavation. The wells are installed through the overburden, coals and footwall sequence (Clarke, 1995).

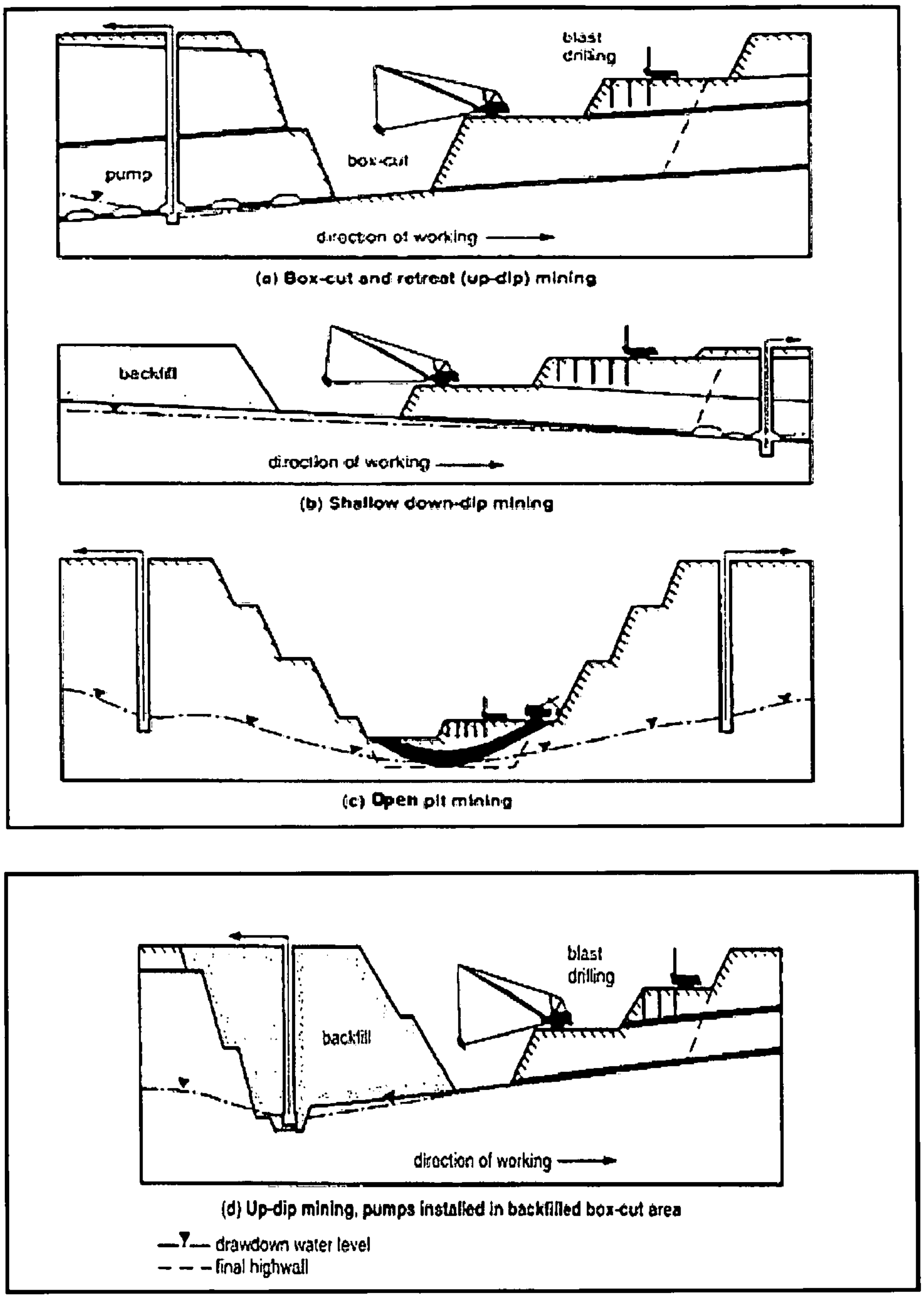


Figure 12: Types of open cast mining in advanced dewatering. From Clarke 1995 with permission of IEA Coal research.

2.3.1.8 Cut-off wells

This is one of the best methods in open pit protection against water that flows into the mine, especially overburden. There are different types of cut-off wells. The easiest one to make is the dug one. This is a ditch dug by a special excavator of 0.4 - 0.7 m. The cut-off wells are leak-proof, because of a special sealing substance. One disadvantage of this method is that the range of depth is only 70 m (Libicki, 1993)

Grouting is another method. Boreholes are drilled and special sealing substances are injected into the borehole. The advantage is that the depth of investigation can be at 300

m. A disadvantage is that it is extremely complicated. Cut-off wells are best used in areas with high permeability and where the surface water is recharging the aquifer (rivers or lakes). Another advantage of this method is that it does not involve a cone of depression. From an environmental point of view this is ideal, because streams will not be affected and shallow wells are safe (Libicki, 1993).

2.3.1.9 Underground galleries

Together with gravity flow, filters are also used for drainage. This method is effective in disturbed aquifers and shallow low yielding wells. The reason is that the sediment in the water does not affect them as much as it affects submersible pumps. This method was used in the 1950s and 1960s. It is much scarcer today and is used less and less. The method is mostly used in old mine operations, because of the cost of labour (Libicki, 1993)

2.3.1.10 Pumping stations

These pumping stations are equipped with pumps and sump pumps. They are placed at the lowest point in an open pit to pump out the water from inflows and rainfall. Other actions include the sealing of river beds so that the surface water does not come into contact with the cone of depression (Libicki, 1993).

2.3.1.11 Drainage adits

Brawne (1982) show that in some instances it may be practicable to construct an adit under the ore body and use it as a drainage gallery from which water is pumped or drained by gravity. For large volumes of water or for deep pits, drainage galleries at more than one elevation may be required. To increase the effectiveness of the drainage gallery, drill holes can be drilled in a fan pattern outward from the adit to increase the effective drainage diameter. Drainage adits have been used at Marcopper and Atlas in the Philippines, Similkamene Mining in Canada, Anamax Twin Buttes in the U.S.A. and the Deye Mine in China. It is recommended that the drains or adit be placed under a partial or complete vacuum.

Recent research at Gibralter Mine, Canada, showed a dramatic reduction in pore water pressure when the vacuum was applied. Drainage galleries may be particularly adaptable where open pits are located on steep mountain side slopes so that the edit may be drained by gravity.

2.3.1.12 Channel dewatering

The Minerals Council of Australia (1997) found that groundwater may also be intercepted outside the pit if the topography, groundwater regime and mine plan allow this. A channel may be constructed to lower the water table and drain the water to downstream catchments. However, lowering of the water table in this manner is generally less effective because of the reliance on steady gravity drainage. Figure 13 shows the method of channel dewatering. When groundwater flows are not highly significant, the water is often intercepted in the pit, collected in a sump and pumped to a retention dam for treatment or storage as required.

Each method of managing groundwater inflows will have different environmental impacts. These will need to be evaluated prior to implementing a control technology. Issues such as volume of flows, water quality and the effect on other users of the groundwater, surface drainage systems and receiving water bodies should be addressed.

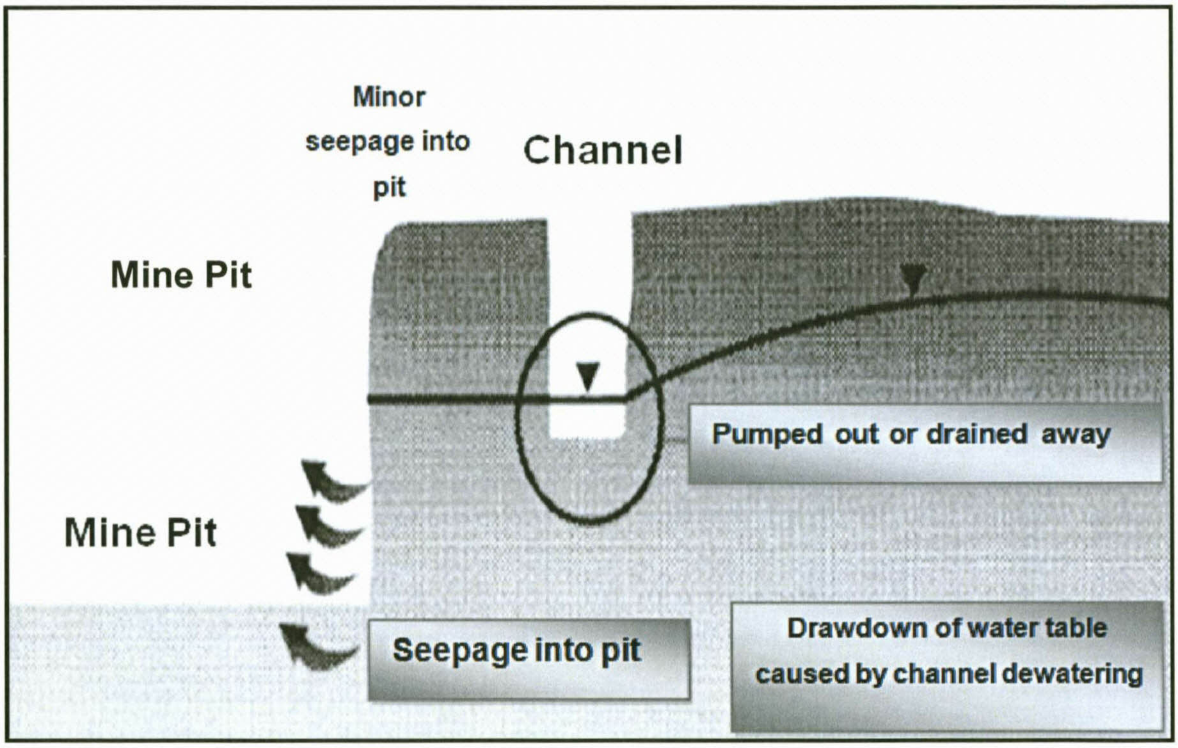


Figure 13: Channel dewatering (Minerals Council of Australia, 1997).

CHAPTER 3
USUTU COLLIERY, ERMELO: CASE STUDY

3.1 Background

Usutu Colliery is the first case study that will be investigated with regard to the influence of flooding on a mine where the mine has been flooded for 20 years. Chanzo Investment Holdings (Pty) is the current owners of Usutu Colliery. Vunene Mining currently operated an opencast mine above the old Usutu Colliery, and also plans to mine underground in future. To come to a conclusion the mining depths of the coal seams must be observed underneath the opencast

Opencast areas have been mined at points where the underground seams are in danger of being mined into. This could have an influence on the recharge in the underground areas of the mine, thus influencing the quantity of the mine water. It is therefore important for Eskom, the owners of Usutu, to understand the geohydrology of the mine for future liabilities during mine closure.

Usutu is applying for partial closure (Usutu East and South), and also needs to know what the current groundwater status in both the north and south mines are. The coal mine has been flooded (recharged) with water since production was stopped between 1987 and 1990.

In 2002 there were ten operating collieries in the Ermelo coalfield, most of which were small to medium-sized. Mining in this coalfield has been dormant for some time with most mines closed with reserves. Of the total saleable production of 222 551 Mt in 2001, the Ermelo coalfield contributed about 7.2 million tons. Most of the high-grade steam coal produced by Xstrata Coal SA in the Ermelo Coalfield is destined for export (Jeffrey, 2005).

Figure 14 shows a map of the coal fields in Mpumalanga.

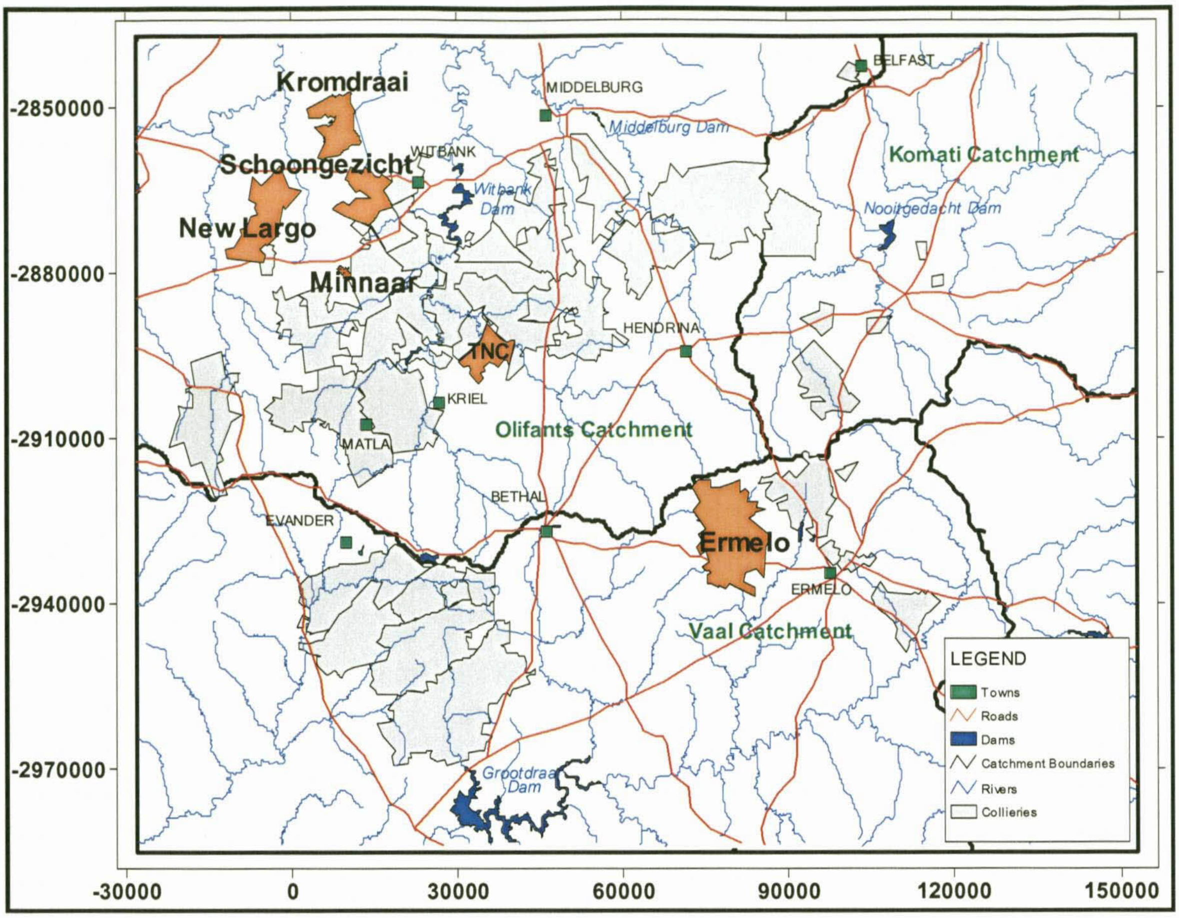


Figure 14: Map of the Mpumalanga coal fields focusing on Ermelo (source: UFS mine water course, 2008).

In the past, the now closed Ermelo mines and Usutu colliery supplied Eskom's Camden power station, with defunct Majuba colliery supplying the Majuba power station. Camden was brought back on-stream by the end of 2004 and managed by a black empowerment consortium operating Golang colliery, incorporating Golfview colliery and the former Usutu Colliery (Jeffrey, 2005).

The following methodologies were used to sample the boreholes:

- Measuring water levels

An electronic dip meter was used for this operation to determine the depth of the water level below the collar of the borehole. It is important always to measure this from the collar of the casing, thus ensuring uniform measurement.

- Water sampling

Sampling included either a sophisticated pressurized depth sample or a flow-through bailer (depending on the depth of the sample).The bailer was cleaned with de-ionised water before each sample was taken. The samples were stored in 500 ml plastic bottles and transported to the IGS laboratory for analysis.

It is essential that samples should always be taken at exactly the same depth in order to obtain a uniform true estimation of the water quality.

Chemical analysis for macro- and micro-parameters as specified by the contract was performed by the laboratory at the IGS.

- Inorganic parameters:

pH, EC, Ca, Mg, Na, K, p-Alk, m-Alk, Cl, SO_4, NO_3 and PO_4. Si, Al, Fe, Mn and B

E.C profiling was also performed on a number of mine boreholes to determine whether any stratification occurs.

3.2 Location

Usutu Colliery is situated 8 km outside the town of Ermelo in Mpumalanga, close to Camden power station on the N2 road to Piet Retief. Figure 15 shows the location of the mine by indicating the coal seams of the mine. Above the coal seams normal grasslands exist. Maize, cattle, potatoes, beans, wool, pigs, sunflower seeds, lucerne and sorghum are the main farming produce of this area. Anthracite, coal and torbanite mining is practised here.

Figure 15: Location of Usutu colliery in South Africa (www.places.co.za).

The Google image in Figure 16 shows the coal seams with the roads superimposed on them. There is still farming activity taking place around the closed mine. The map in Figure 17 indicates the mine in relation to the power station. The direction of the town of Ermelo is shown with an arrow. The location of a mine that has been flooded can have n massive effect on flooding. Different locations mean different rainfalls, topography etc.

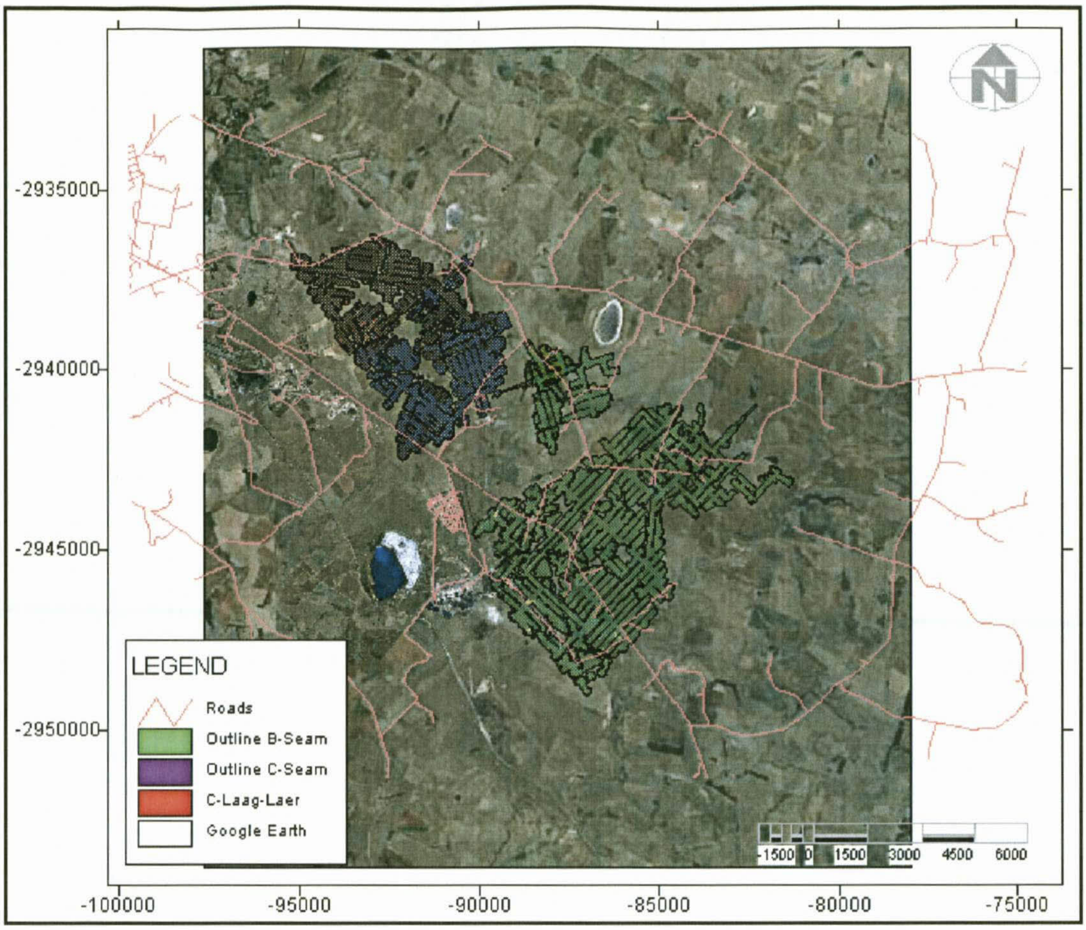


Figure 16: The location of Usutu colliery in Google earth image (Google earth).

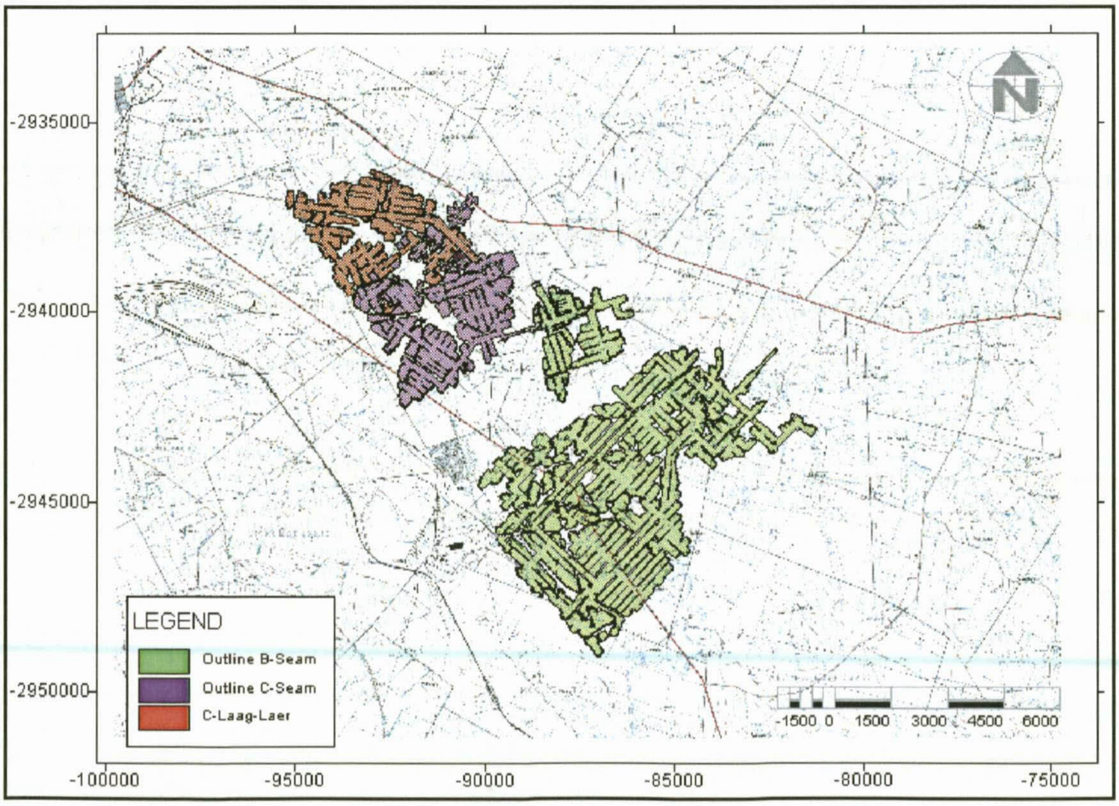


Figure 17 : Location of the coal seams at Usutu colliery near Camden power station.

3.3 Topography and drainage

Ermelo is situated in the upper reaches of the Vaal River, about 1 720 m above sea level. The town lies in the midst of a varying topography, superb layout and vivid green flora. Together with its high rainfall Ermelo is unmistakably known as the garden town of Mpumalanga. The topography is of a gentle, rolling nature. Steeper slopes are present at sandstone outcrops. Studies by the mining industry indicate that surface run-off for this area is in the order of 6 to 10% of the annual rainfall of 710 mm, with 8% as an average in a study by Grobbelaar *et al.*, (2004).

The surface drainage system is obviously important in intermine flow management explained by Grobbelaar *et al.*, (2004), because topographically low areas would be the areas where decanting from mines is expected. The most vulnerable areas would be areas where connections between mines and the surface occur, and where these coincide with a surface low.

The regional surface contours of the mine itself are illustrated in Figure 18. The area topography slopes mostly away from the mining area towards the south with an average 3.2%, as the mining area is situated on a topographic high in the northern part at 1 750 mamsl decreasing towards the southern part to 1 625 mamsl. The unit for the map is mamsl

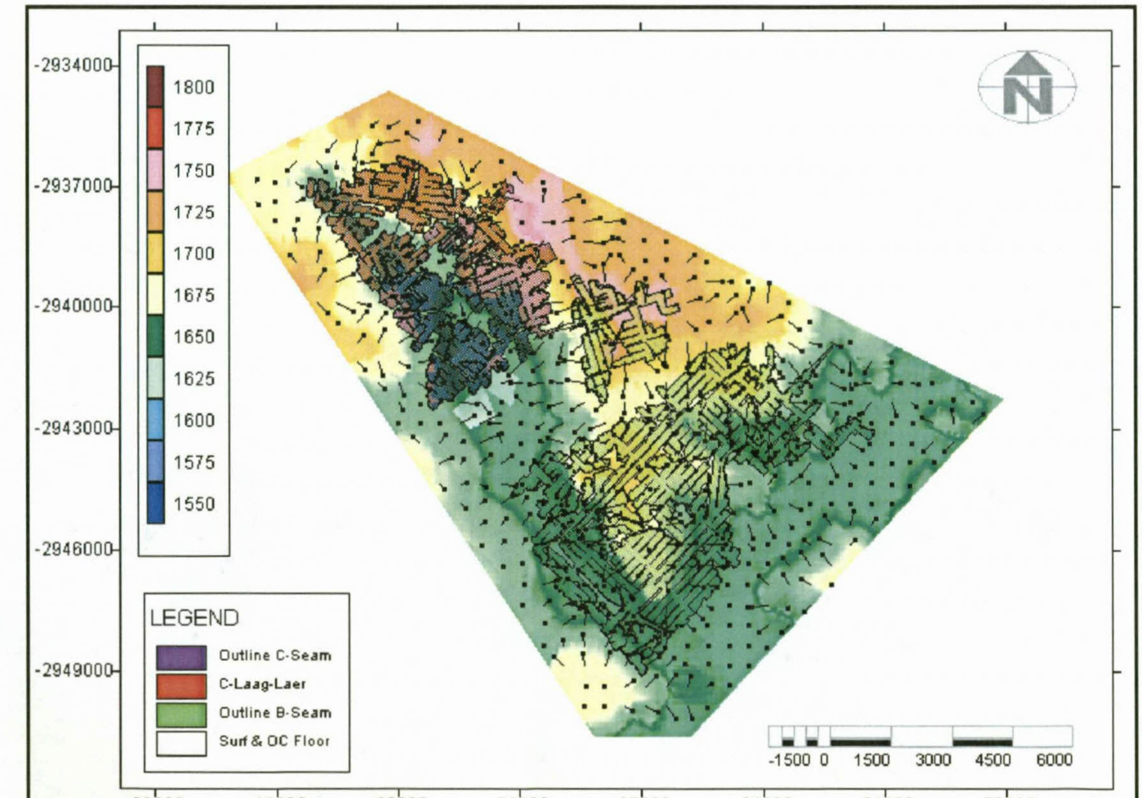


Figure 18: Surface contours of the mine area.

In Figure 19 the surface topography is displayed in 3D, with the topographic high to the north of the mining area clearly visible. The high towards the north-west of the Southern Mine is also visible (pink colour towards the green). The 3D image helps us get an idea of the topography in the way we see with our eyes when looking at hills or mountains.

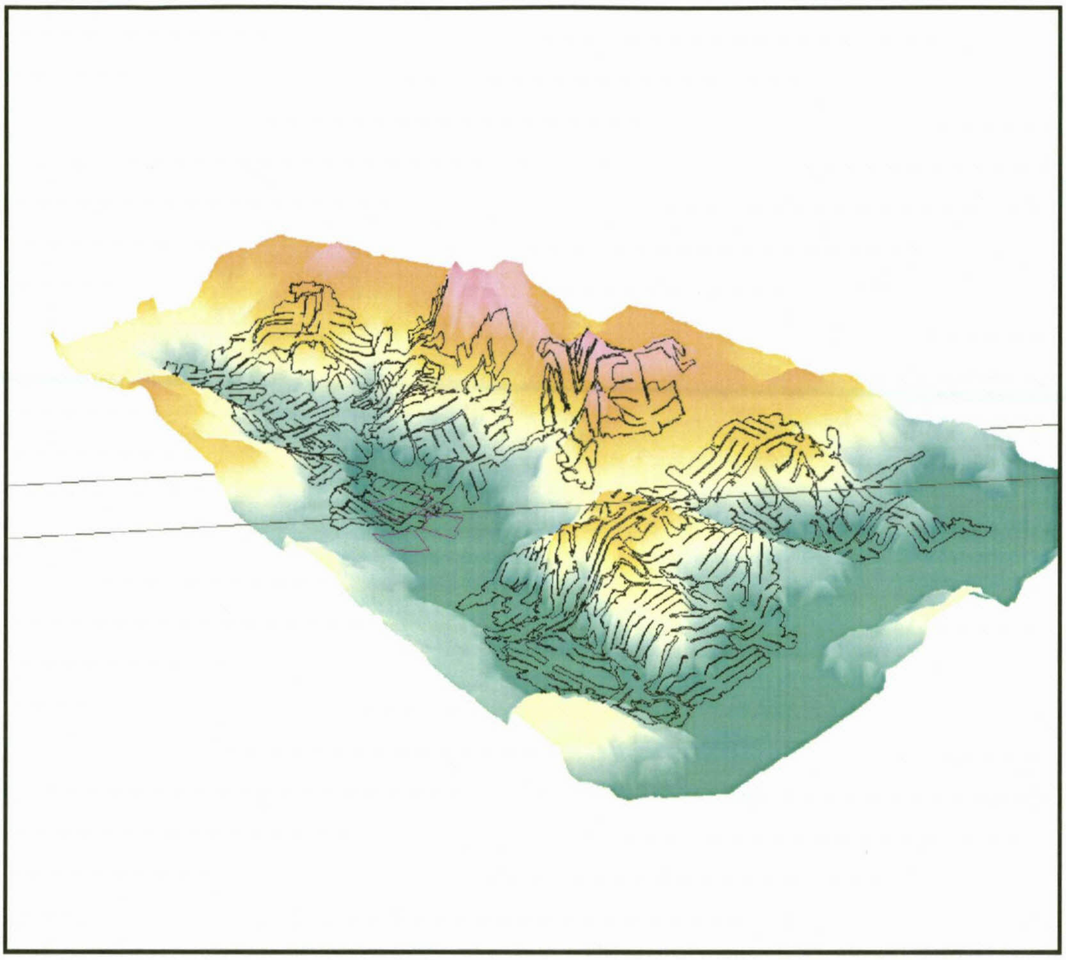


Figure 19: 3D visualization of the surface contours with projected underground and opencast.

Figure 20 shows the rivers and dams in the area together with the coal seams. A non-perennial stream system exists in the area and runoff accumulating in the surface can persist for several weeks until water has evaporated or infiltrated into the ground. Water that is polluted needs to the treated before it can be released into a river system.

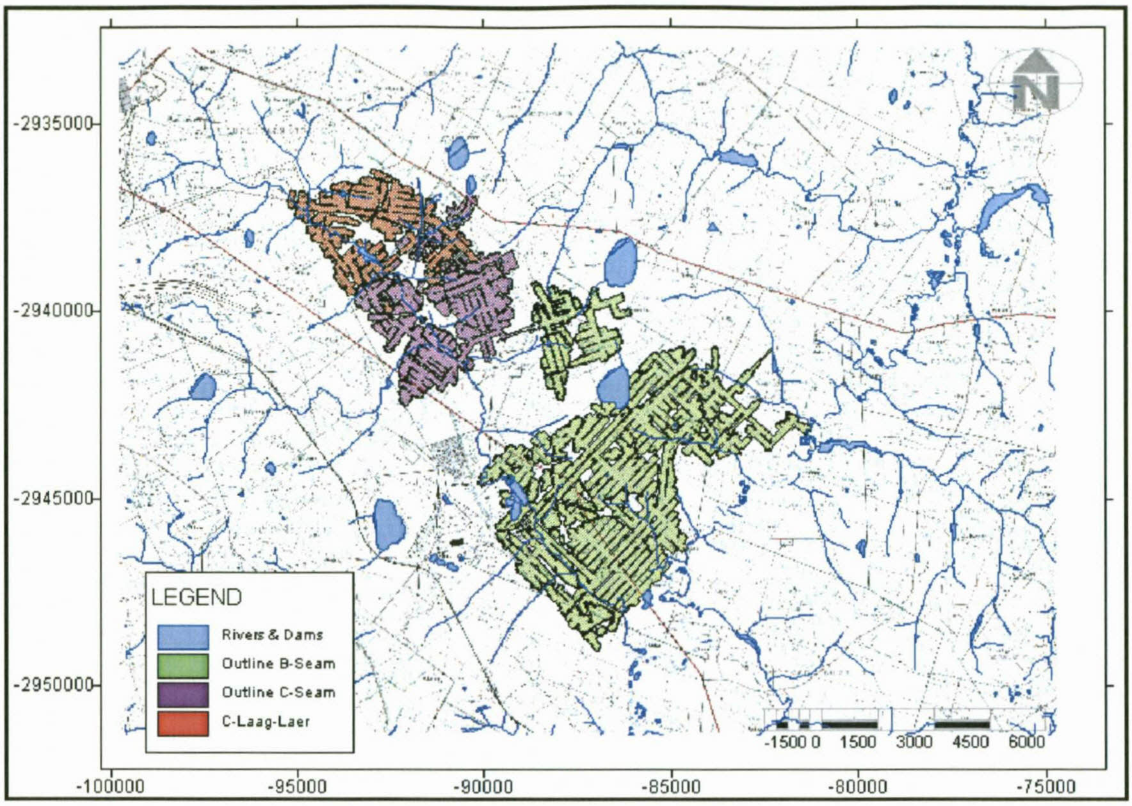


Figure 20: Rivers and dams in the area of the mine.

In Figure 21 the regional surface contours of the area around the mine are displayed in 3D with the rivers and dams superimposed on that. According to this picture the local drainage pattern is towards the south-east.

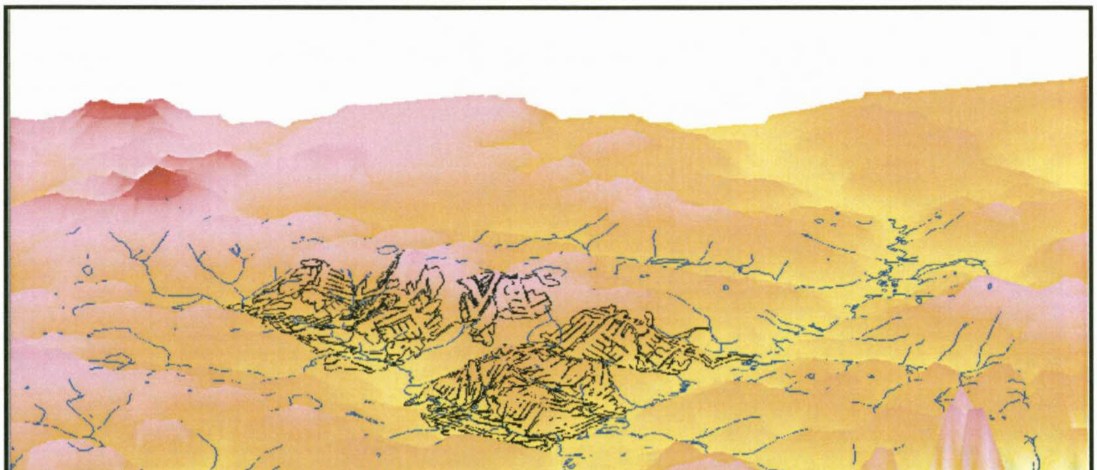


Figure 21: Regional surface contours of the area around the mine with rivers and dams.

3.4 Land use

In Mpumalanga most land which is currently not mined is used for commercial grain and livestock farming and, where possible, farmers make use of mine water to irrigate their crops. In Mpumalanga, mining still has a future of more than 20 years, and in some areas up to 50 years, if one takes into account the life of existing coal mines, the mining of new coal reserves and the mining of new minerals. The energy industry in the area is also growing, with suppliers intending to increase the number of electrical power stations in the area. Most former mining land has been rehabilitated and then converted into farming land, with both crop and livestock farming succeeding. Most farms in the vicinity of former mining land use water from the closed mine for irrigation (Nthabiseng, Molapo & Chunderdoojh, 2006). In the hydrosensus done some of these farms around the closed Usutu mine were investigated. The tap water in some houses had an unpleasant smell. Some of the farmer's wives complained that clothing after washing were yellowish in colour. After looking at the quality of the water no problems were detected. The regional water quality was the same as the "top" sampled samples.

3.5 Rainfall and climate

The highest temperatures in this region according to WeatherSA are from December to March (24 to 25°C). The coldest months in winter are June and July (16 °C). Most of the rainfall occurs in the summer months from November to January and this can also be seen in the water levels. Rainfall from April to September is low.

The annual rainfall (MAP) for the area is 705 mm (SA Weather Service - Rainfall stations: Ermelo airport no. 0442841 8; 0442812 8; 0480170 4; 0479870 X; 1049107 8). Figure 22 shows the rainfall from 1960-2011.

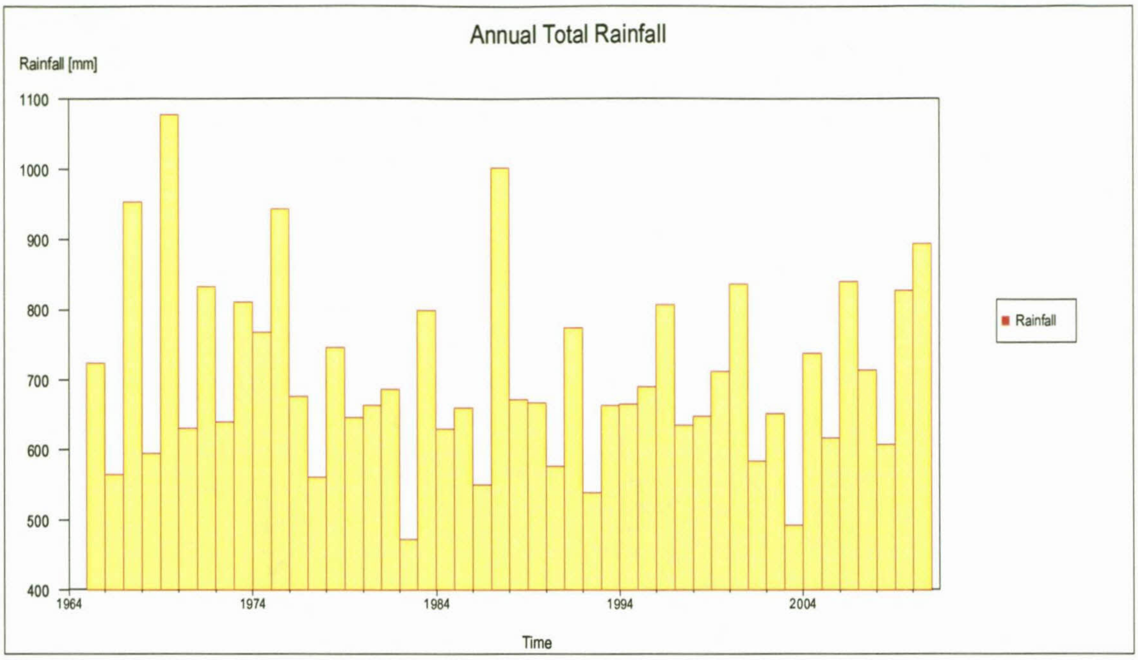


Figure 22: Rainfall graph for Ermelo.

3.6 Recharge using Chloride method

The assumption necessary for the successful application of the chloride method to determine recharge is that there is no source of chloride in the soil water or groundwater other than that from precipitation. Chloride levels are low in the system. Steady-state conditions are maintained with respect to long-term precipitation and chloride concentration in the case of the unsaturated zone. However, this assumption may be invalidated if the flow through the unsaturated zone is along preferred pathways (Van Tonder and Xu, 2000). According to Vegter (1995) groundwater recharge can be read off a map indicated in Figure 23

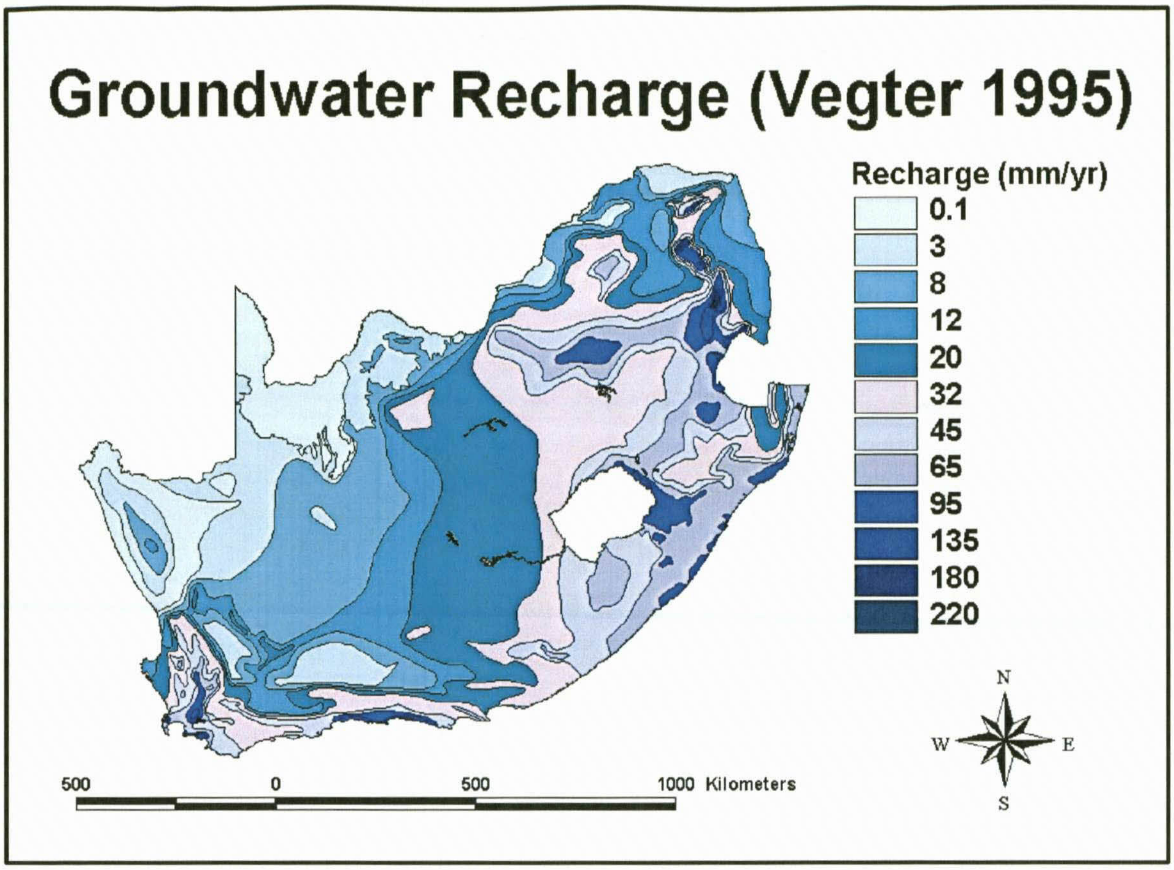


Figure 23: Recharge according to Vegter (1995).

Rainfall that infiltrates into the weathered rock soon reaches an impermeable layer of shale or dolerite underneath the weathered zone. The movement of groundwater on top of this layer is lateral and in the direction of the surface slope. The groundwater reappears on the surface at fountains where the flow paths are obstructed by a barrier, such as a dolerite dyke, 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. The rest of the water is evapotranspirated or drained by some other means (Hodgson, Vermeulen, Cruywagen & de Necker (2007).

In areas of extensive underground high extraction, it can be safely assumed that all recharged water will migrate downwards to enter into the collapsed mine workings. Under undisturbed conditions, 3% of the annual recharge would be an acceptable average value. Under disturbed conditions above long wall panels, recharge is likely to be greater and 5% of the annual rainfall would be a good first estimate (Hodgson et al., 2007).

Water in operating opencast pits is derived from various sources. Table 2 provides a breakdown of these sources as a function of the average annual rainfall or the total ingress of water into a pit. (Hodgson & Krantz, 1998)

Table 2: Water recharges characteristics for opencast mining (Hodgson et al., 1998).

Sources which contribute water	Water sources into opencast pits	Suggested average values
Rain onto ramps and voids	20-100% of rainfall	70% of rainfall
Rain onto unrehabilitated spoils (run-off and seepage)	30 - 80% of rainfall	60% of rainfall
Rain onto levelled spoils (run-off)	3 - 7% of rainfall	5% of rainfall
Rain onto levelled spoils (seepage)	15 - 30% of rainfall	20% of rainfall
Rain onto rehabilitated spoils (run-off)	5 - 15% of rainfall	10% of rainfall
Rain onto rehabilitated spoils (seepage)	5 - 10% of rainfall	8% of rainfall
Surface run-off from pit surroundings into pits	5 - 15% of total pit water	6% of total pit water
Groundwater seepage	2 - 15% of total pit water	10% of total pit water

General Equation: $R = (P\ Cl_p + D)/Cl$

[R = recharge (mm/a); P = mean annual precipitation (mm/a); Cl_p = chloride in rain (mg/l); D = dry chloride deposition (mg/m^2/a); $Cl_w = Cl_{sw}$ = chloride concentration (mg/l) in soil water below active root zone in unsaturated zone OR $Cl_w = Cl_{gw}$ = chloride concentration (mg/l) of groundwater where for many boreholes the Cl_{gw} = harmonic mean of the Cl content in the boreholes]

The regional recharge was calculated as 5.7% by using the chloride method. The chloride values measured at boreholes in the mine area are displayed in Table 3. See Appendix E for the chloride values of all the boreholes.

Table 3: Chloride method for recharge.

HARMEAN (mg/l)	Cl- rainwater (mg/l)	Recharge (%)
17.54	1	5.7

3.7 Hydrogeology

3.7.1 Pre-mining groundwater occurrence

Three distinct superimposed groundwater systems are present within the Oliphants catchment. They can be classified as the upper weathered Ecca aquifer, the fractured aquifers within the unweathered Ecca sediments and the aquifer below the Ecca sediments (Hodgson et al., 2007).

3.7.2 The Ecca weathered aquifer

The Ecca sediments are weathered to depths of 5 to 12 m below the surface throughout the Mpumalanga area. The upper aquifer, typically perched, is associated with this weathered zone and water is often found within a few metres below surface. 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 in other parts of the country (Hodgson et al., 2007).

Observed flow within the Mpumalanga Area confirmed isolated occurrences of recharge values as high as 15% of the annual rainfall. It should, however, be realized that within a weathered system, such as the Ecca sediments, highly variable recharge values can be found from one area to the next. This is due to variations in the composition of the weathered sediments, which range from coarse-grained sand to fine clays (Hodgson et al., 2007).

The aquifer within the weathered zone is generally low yielding (range 100 - 2000 L/h), because of its insignificant thickness. Few farmers therefore tap this aquifer by borehole. Wells or trenches, dug into this upper aquifer, are often sufficient to secure a constant water supply of excellent quality (Hodgson et al., 2007).

The excellent quality of this water can be attributed to the many years of dynamic groundwater flow through the weathered sediments. Leachable salts in this zone were washed from the system long ago and it is only the slow decomposition of clay particles which presently releases some salt into the water (Hodgson et al., 2007).

3.7.3 The fractured Ecca aquifers

The pores within the Ecca sediments are too well-cemented to allow any significant permeation of water. All groundwater movement is therefore along secondary structures, such as fractures, cracks and joints. These structures are better developed in competent rocks such as sandstone, hence the better water-yielding properties of the latter rock type (Hodgson et al., 2007).

It should, however, be emphasized that not all of the secondary structures are water-bearing. Many of these structures are closed because of compressional forces that act in the earth's crust. The chances of intersecting a water-bearing fracture by drilling decrease rapidly with depth. At depths deeper than 30 m, water-bearing fractures with significant yield were observed in opencast coal-mines to be spaced at 100 m or greater. Scientific siting of water-supply boreholes is necessary to intersect these fractures. The conclusion is drawn that boreholes have insufficient yields for organized irrigation. This is confirmed by a survey of the catchment, during which no irrigation from this aquifer could be found (Hodgson et al., 2007).

Coal seams are often fractured and have some hydraulic conductivity. Underlying the coal is the Dwyka tillite. It is impermeable to groundwater flow due to its massive nature and fine matrix, forming a hydraulic barrier between Pre-Karoo aquifers and those high up in the succession (Hodgson et al., 2007).

In terms of water quality, the fractured Karoo aquifer always contains higher salt loads than the upper weathered aquifer. This is ascribed to the longer residence time of the water in the fractured aquifer ((Hodgson et al., 2007).

Although the sulphate, magnesium and calcium concentrations in the Ecca fractured aquifer are higher than those in the weathered zone, they are well within expected limits. The occasional high chloride and sodium levels are from boreholes in areas where salt naturally accumulates on the surface, such as at pans and some of the fountains ((Hodgson et al., 2007).

3.7.4 Pre-Karoo aquifers

In only a few instances, drilling has intersected basement rocks underneath the Karoo Super group. Very few, if any, of the farmers tap water from the aquifer beneath the Dwyka formation. Reasons for this are (Hodgson et al., 2007):

- The great depth.
- The low-yielding character of the fractures.
- Inferior water quality, with high levels of fluoride, associated with granitic rocks.
- Low recharges characteristics of this aquifer, because of the overlying impermeable Dwyka tillite.

In the southern portion of the catchment, dewatering of this aquifer has occurred to some extent, because of the pumping in the Evander Goldfields. This does not impact on the Ecca Aquifer due to the presence of the (Hodgson et al., 2007).

3.7.5 Pre-mining surface hydrology

Annual rainfall in the areas where underground high extraction is done ranges from 650 – 760 mm per annum. Surface slopes are gentle. Run-off is in the order of 8(Surface water in streams gains from groundwater seepage. Seepage into streams is mainly from the weathered aquifer. This is generally not sufficient to cause significant flow in the streams (Hodgson et al., 2007).

3.7.6 Coal Seam (mine)

This system is mined out, with a much higher transmissivity value than the layers above and below it.

- The transmissivity (T-value) of the mined coal seam (Alfred and Gus Seams were mined as a single seam) is very high (in the order of thousands) and the storativity (S) is also very high (65% in the mined out section as opposed to approximately 0.1% in typical Karoo aquifers).
- Once the mine has filled up with water, a horizontal piesometric level will occur (this piesometric level is also horizontal during the filling up process). If the piesometric level intersects the surface, decant could take place at the point of intersection if there is a link between this position and the mine (e.g. a borehole).

The rate at which the piesometric level rises is dependent on the amount of influx from the top layers (or along subsidence areas) and the amount of lateral groundwater outflow

The Ecca Group consists mainly of shales, with thicknesses varying from 1 500 m in the south, to 600 m in the north. Since the shales are very dense, they are often overlooked as significant sources of groundwater. However, as illustrated in Figure 24, their porosities tend to decrease from ~0.10% north of latitude 28°S, to < 0.02% in the southern and southeastern parts of the basin, while their bulk densities increase from ~2 000 to > 2 650 kg.m-3 (Woodford & Chavallier, 2002).

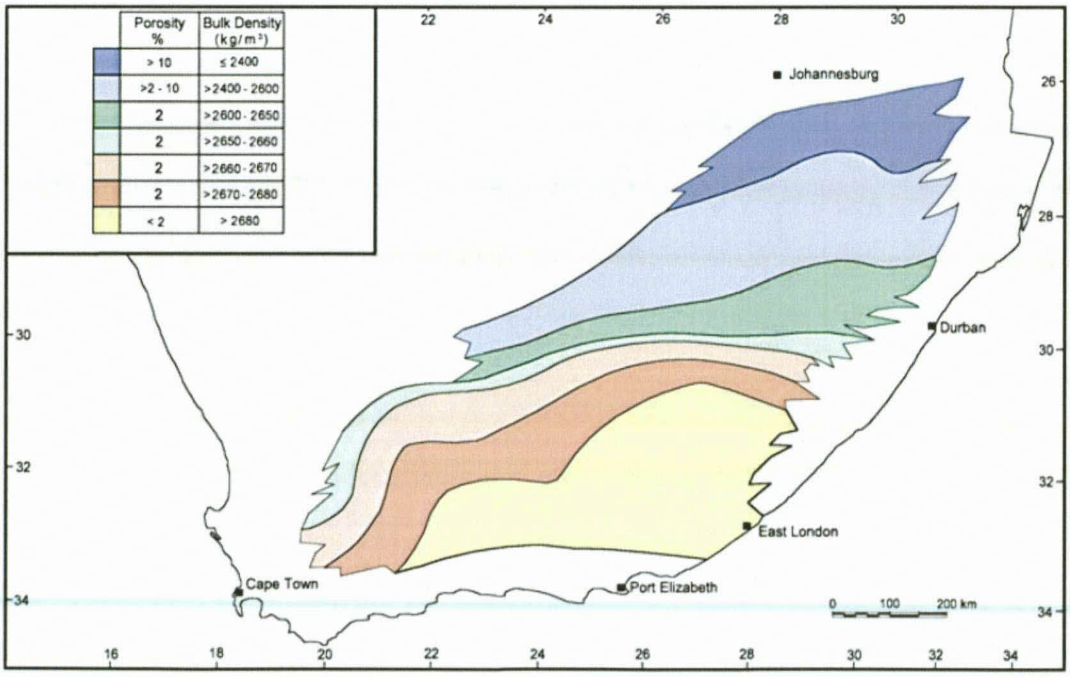


Figure 24: Porosity and bulk density variations in shales of the Karoo Basin (Woodford & Chavallier, 2002).

The possibility exists that economically viable aquifers may exist in the northern parts of the Basin underlaid by the Ecca shale. It is therefore rather surprising to find that there are areas, even in the central parts, where large quantities of water are pumped daily from the Ecca formations. One should thus not neglect the Ecca rocks as possible sources of groundwater, especially the deltaic sandstone facies. Rowsell and De Swardt (1976) report that the permeability's of these sandstones are usually very low (Woodford & Chavallier, 2002).

The main reason for this is that the sandstones are usually poorly sorted, and that their primary porosities have been lowered considerably by diagenesis. The deltaic sandstones represent a facies of the Ecca sediments in which one would expect to find high-yielding boreholes. Unfortunately, Rowsell and De Swardt (1976) have found that the permeability of these sandstones is also usually very low. However, the Vryheid Formation sandstones in KwaZulu-Natal (west of Pietermaritzburg) appear to be more permeable, with a median borehole yield of 0.33 ℓ/s and 62% yielding greater than 1 ℓ/s (KwaZulu-Natal project, 1995, unit 8) (Woodford & Chavallier ,2002).

3.8 Geology

The Geology of Usutu mine lies within the Karoo group, Ecca subgroup in the Vryheid formation (Jeffrey, 2005).

The Permian-aged Ecca Group comprises a total of 16 formations, reflecting the lateral facies changes that characterize this succession. Except for the fairly extensive Prince Albert and Whitehill formations, the individual formations can be grouped into three geographical zones, the southern, western - northwestern and northeastern. The basal sediments in the southern, western and north-western zones (Prince Albert and Whitehill formations) of the basin will be described first, followed by the southern Collingham, Vischkuil, Laingsburg, Ripon, Fort Brown and Waterford formations. The remaining western and northwestern sediments of the Tierberg, Skoorsteenberg, Kookfontein and Waterford Formations and the north-eastern Pietermaritzburg, Vryheid and Volksrust Formations will then be considered. In addition, a relatively small area along the eastern flank of the Basin, between the southern and north-eastern outcrop areas, contains 600 – 1 000 m of undifferentiated Ecca mudrock, which has not yet been studied in detail (Woodford, Chevallier, 2002).

According to Grobbelaar *et al.*, (2004) the sediments of the coal-bearing Ecca Group of the Karoo Sequence were deposited on an undulating pre-Karoo floor, which had a significant influence on the nature, distribution and thickness of many of the sedimentary formations, including the coal seams. Post-Karoo erosion has removed large parts of the stratigraphic column, including substantial volumes of coal over wide areas. The Karoo Super Group comprises the Ecca Group and the Dwyka Formation. A general thickening occurs from north to south. The Ecca sediments consist predominantly of sandstone, siltstone, shale and coal.

Furthermore, Grobbelaar *et al.*, (2004) explain that Ecca sediments overlie the Dwyka group (loosely referred to as the Dwyka tillite). This formation consists of a proper tillite, siltstone and sometimes a thin shale development. The upper portion of the Dwyka sediments may have been reworked. The Dwyka sediments are underlaid by a variety of rock types, such as the Bushveld Complex in the north, Witwatersrand Super group in the south, Waterberg Super group in the north-west and Transvaal Super group to the west. Technically, the Karoo sediments are practically undisturbed. Faults are rare, except for displacement along dolerite ring structures. Fractures are common in competent rocks such as sandstone and coal.

The Vryheid Formation thins towards the north, west and south from a maximum of approximately 500 m in the Vryheid-Nongoma area. The uneven pre-Karoo topography in the vicinity of the northern and north-western margins of the basin, directly on pre-Karoo rocks or the Dwyka Group, gives rise to marked variations in thickness. In these areas, the Vryheid Formation pinches out against numerous local basement highs. Thinning and pinch-out towards the southwest and south are due to a facies gradation of its lower and upper parts into shales of the Pietermaritzburg and Volksrust Formations respectively (Woodford & Chavallier, 2002).

The Vryheid Formation comprises mud rock, rhythmite, siltstone and fine- to coarse-grained sandstone (pebbly in places). The Formation contains up to five (mineable) coal seams. The different lithofacies are mainly arranged in upward-coarsening deltaic cycles (up to 80 m thick in the south-east). Linear coastline cycles are, however, fairly common, particularly in the thin north-western part where they constitute the entire Vryheid in places (see *Figure 25*).

A relatively thin fluvial interval (60 m thick) which grades distally into deltaic deposits towards the south-west and south occurs approximately in the middle of the formation in the east and north-east. Fining-upward fluvial cycles, of which up to six are present in the east, are typically sheet-like in geometry, although some form valley-fill deposits. They comprise coarse-grained to pebbly, immature sandstones with an abrupt upward transition into fine-grained sediments and coal seams (Woodford & Chavallier, 2002).

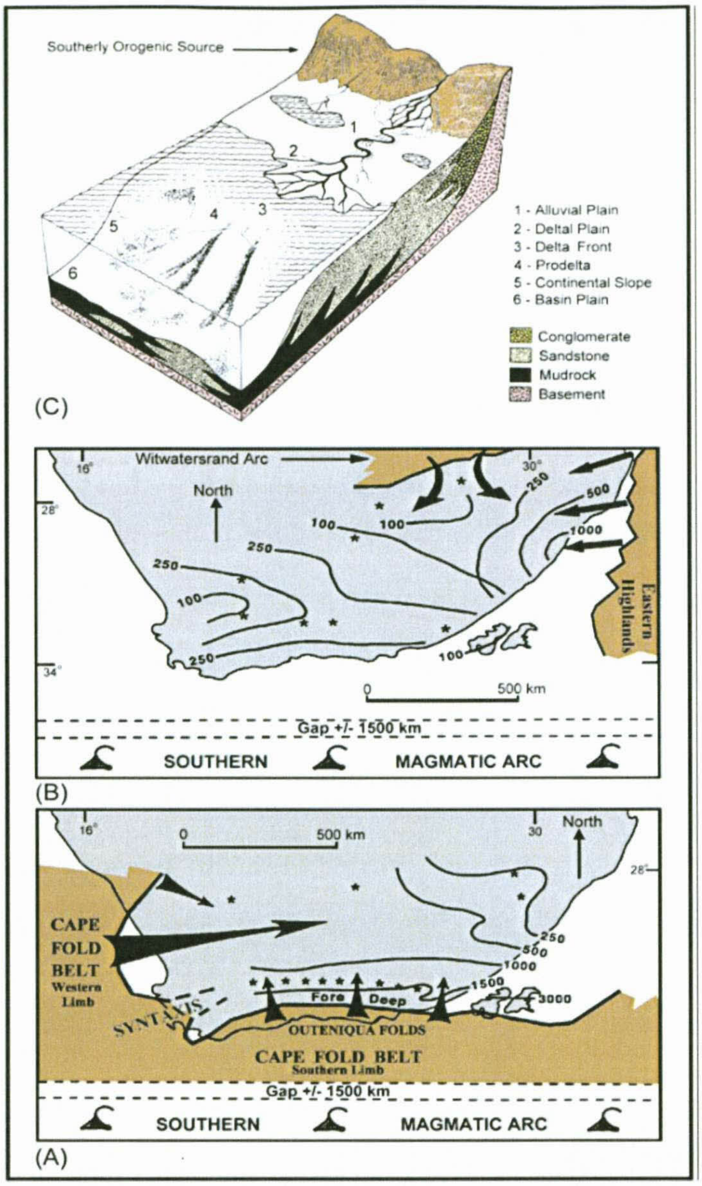


Figure 25: Source areas for the southern and western Ecca Formations (B) and the northern Pietermaritzburg, Vryheid and Volksrust Formations (C). Depositional environment of the Ecca Group in the southern Karoo (Woodford & Chavallier, 2002).

Ermelo 0 to 100 m geology shown below:

3.8.1 Vryheid Formation

- E Seam (0 to 3 m),
- D Seam (0.6 m),
- C Lower Seam (1.5 m, sandstone partings in upper section),
- C Upper Seam (well developed, 0.7 to 4 m, sandstone, siltstone or mudstone partings split seam into 2 to 3 plies, devolatilized / destroyed by dolerite over large areas)
- B Lower Seam, B Upper Seam (may coalesce in south, 0 to 3 m), A (isolated outliers, 1 m),

- A Seam (0 to1.5 m, mainly removed by erosion). Dip gently southwest, minor folding; dykes (2 to 5 m) common, up to 8 sills (10 to 250 m) transgress and uplift the seam.

3.8.2 Quality of the coal

The Ermelo coalfield's E Seam is of reasonable quality but the economic potential of the seam decreases southwards as it becomes torbanitic and/or shaly whereas in other areas it might be too thin to be viable for mining.

The D Seam is of good quality and has no clastic partings but has a high proportion of vitrain with minor durain bands. The C Lower Seam is the most important seam as it is the main source of export coal. The C Upper Seam is generally of poorer quality, has no in-seam partings and may be torbanitic in the upper part; however, the lower part of the seam is usually of good quality, making it the main target for mining. It is typically mined to supplement the C Lower. The B-seams are low quality, dull coal that contains fewer vitrain bands compared with the lower portion of the C Upper Seam (Jeffrey, 2005).

The coal seams at Kilbarchan were mined through the method of Bord-and-pillar extraction. Information sources vary, but seem to suggest that the Alfred and Gus Seams were mined as a single seam. The seams are separated by a very thin sandstone parting, forming a composite coal seam in some areas (Hodgson, 2006).

3.9 Hydrocensus

The hydrosensus were performed on the boreholes on the mine and the surrounding farms in the area (Figure 26).The hydrocensus gives one a very good idea of the quality and water levels of the area before starting an investigation.

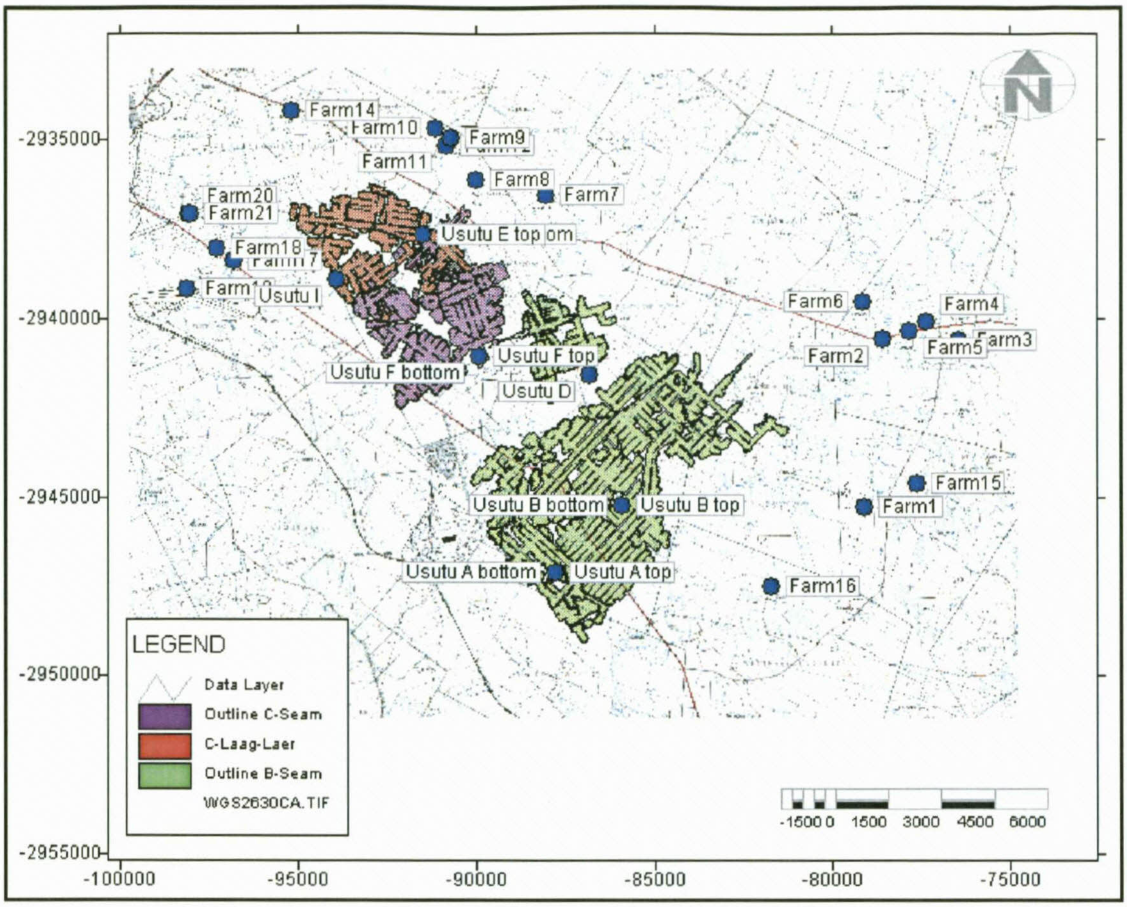


Figure 26: Location of the boreholes in the hydrocensus for the investigation.

The information of all the boreholes in the hydrosensus is shown in Figure 26. Information on the date, water level and comments on the person's name or anything observed during the hydrosensus. As previously discussed many of these farmers complained about the colour and odour of the water at their farms.

Table 4: Information of the boreholes received during the hydrocensus

Name	Date	Water Level (mbgl)	Comment
Usutu F top	2011/02/15	21.6	Running water
Usutu A top	2011/02/15	3.3	Running water
Usutu A top	2009/07/03	6.2	
Usutu B top	2011/02/15	12	Running water
Usutu B top	2009/07/03	24.5	
Usutu D	2011/02/15	18	Running water
Usutu D	2009/07/03	26.3	
Usutu E top	2011/02/15	28	Running water
Usutu E top	2009/07/03	34.8	
Usutu I	2011/02/15	49.7	Running water
Farm1	2011/02/15	3.6	Vlakfontein
Farm2	2011/02/15	4.2	P.Cilliers-Roodewal
Farm3	2011/02/15	3.98	ROSENDAL
Farm4	2011/02/15	4.02	ROSENDAL
Farm5	2011/02/15	4.07	ROSENDAL
Farm6	2011/02/15	3	Water smells like swael S. Cloete 0835661929
Farm7	2011/02/15	20.39	Saambou
Farm8	2011/02/15	6.26	Jan Theron 1666-ERMELO-Jan Hendriksfontein
Farm9	2011/02/15	9.77	Jan Theron 1666-ERMELO-Jan Hendriksfontein
Farm10	2011/02/15	19.5	Jan Theron 1666-ERMELO-Jan Hendriksfontein
Farm11	2011/02/15	4.08	Jan Theron 1666-ERMELO-Jan Hendriksfontein
Farm12	2011/02/15	30.98	Kleinveld
Farm13	2011/02/15	8.2	van Outshoorn stream
Farm14	2011/02/15	20.12	van Outshoorn stream
Farm15	2011/02/15	2.25	van der Merwe
Farm16	2011/02/15	3.3	Bethesda
Farm17	2011/02/15	10.6	Trucks
Farm18	2011/02/15	3.9	Guesthouse
Farm19	2011/02/15	4	Panelbeaters
Farm20	2011/02/15	4.26	Panelbeaters
Farm21	2011/02/15	2.1	Panelbeaters

Table 4 show information from the hydrosensus done at Usutu mine. The date, water level and comments are recorded during the hydrosensus

It is important to know whether the boreholes are drilled into the mine. 3D models together with the coal seams will tell whether this occurs. Water quality also comes into account, to know whether the qualities inside the mine are really inside the mine, but is it clear that the quality inside the mine is poorer than the quality not inside the mine.

Table 5: The sample depth of the boreholes.

Site name	Sample depth (mbgl)	Depth of borehole
Usutu A top	5	90
Usutu A bottom	89	90
Usutu B top	15	112
Usutu B bottom	111	112
Usutu D	20	
Usutu E top	30	50
Usutu E bottom	49	50
Usutu F top	23	26
Usutu F bottom	25	26
Usutu I	48	46

3.10 Boreholes under investigation

In general it was difficult to locate the boreholes, with the grass being long and the boreholes not well marked.

3.10.1 Usutu A

- This borehole is 90 m deep and the water level is at 3.3 m.
- The borehole is not locked, as the photograph below shows.

3.10.2 Usutu B

- This borehole is 112 m deep and the water level is at 12 m.
- The sound of running water can be heard at the borehole.

3.10.3 Usutu D

- The water level in Usutu D was 18 m.
- The sound of running water can be heard at the borehole.
- The borehole is not locked, as the photograph below shows.

3.10.4 Usutu E

- This borehole is 50 m deep and the water level is at 28 m.
- The sound of running water can be heard at the borehole.
- The borehole is not locked, as the photograph below shows.

3.10.5 Usutu F

- This borehole is 26 m deep and the water level is at 21.6 m.
- The sound of running water can be heard at the borehole.
- The borehole is not locked, as the photograph below shows

3.10.6 Usutu I

- This borehole is 48 m and the water level is at 46.7 m.
- The sound of running water can be heard at the borehole.

- The borehole is not locked as the photograph below shows.
- It is difficult to locate.

3.11 Water levels

The water levels in the mine were measured in July 2009 and again during the hydrocensus. These levels and all the others from the farm boreholes are presented in the time graph in Figure 27. There has been a definite rise in the water levels since 2009, but this may be attributed to the exceptional rainy season during 2010/2011. These levels should be monitored over time to draw meaningful conclusions as only 4 boreholes water levels were measured previously in 2009 as to mismanagement. These levels should be monitored over time to draw meaningful conclusions. Figure 28 illustrates the proportional water level distribution for February 2011.

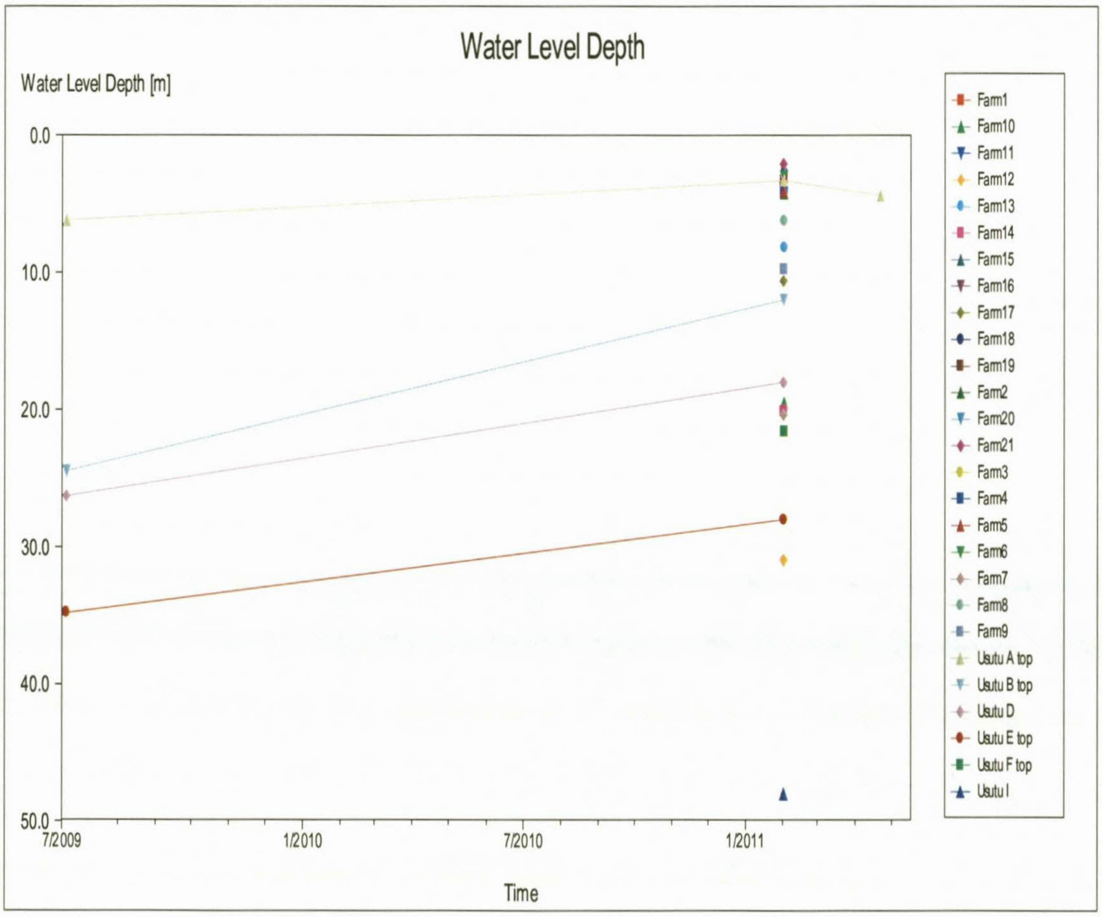


Figure 27: Water level time graph of a few boreholes measured since 2009.

The proportional distribution of the water levels in Figure 28 clearly indicates that extraction occurs in some farming boreholes, namely the farm boreholes north of the mine. The average regional water level is currently less than 4 m. Boreholes displayed as blue dots.

The water levels of the boreholes inside the mine differ between the two mines. The water levels in the southern mine are shallower than those in the northern mine. However, the water levels differ substantially in the different boreholes, most likely the result of compartmentalization due to the ventilation walls. This makes interpretation of the mine water levels very difficult, and a number of additional boreholes have to be drilled to obtain a clear indication of the exact water levels in the mine.

Once the mine has filled up with water, the piesometric level of the mine will rise with the storage coefficient value of the mine (and not the specific yield) as conditions have changed from unconfined to confined. The flux from the overlying aquifers into the mine aquifer will decrease as the two water levels approach each other.

What is clear from the water levels is that the aquifers above the mining areas are not fully recharged yet, as these pressure levels differ from the regional water table aquifer water levels.

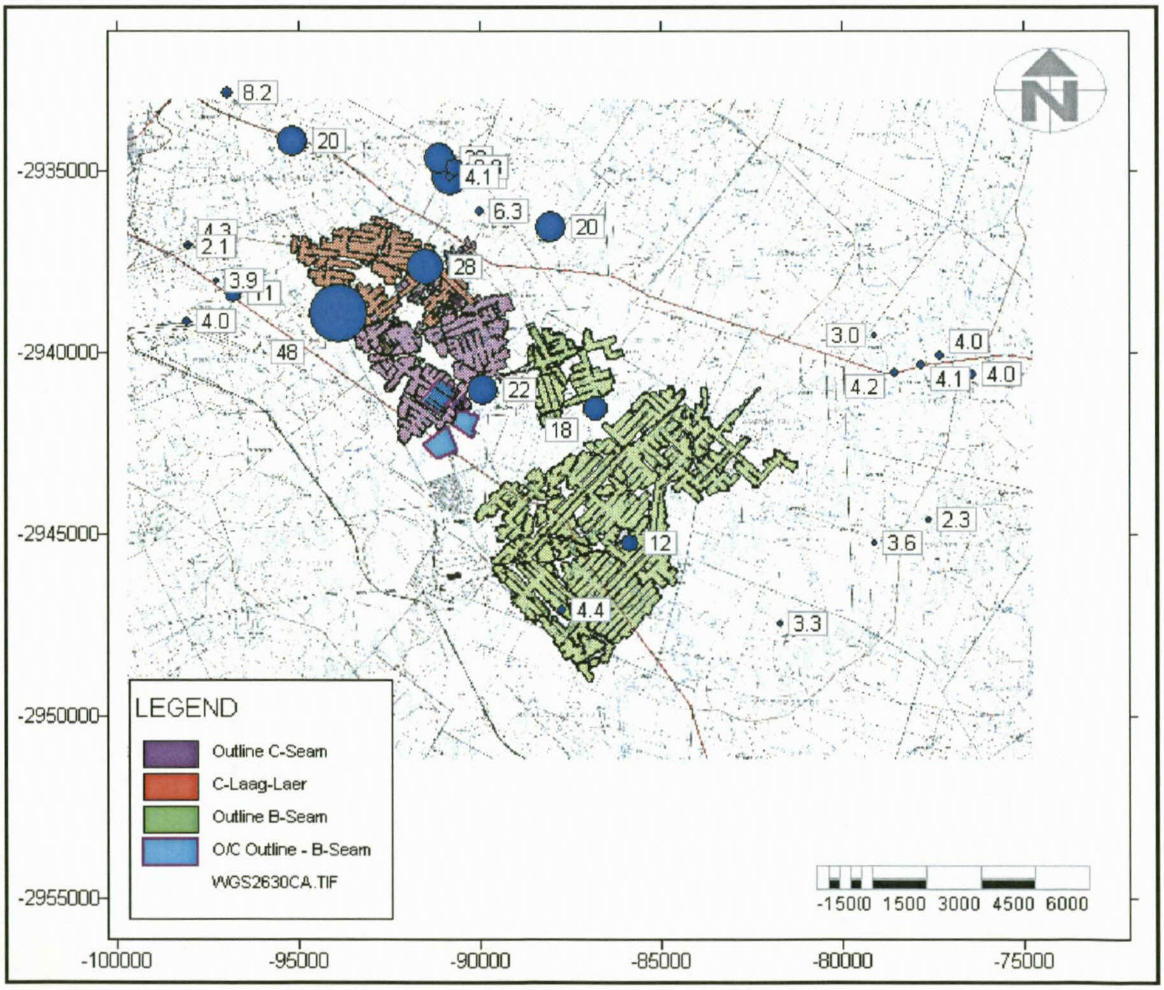


Figure 28: Proportional distribution of the water levels last measured.

3.12 Mining methods

According to Grobbelaar *et al.*, (2004) coal extraction has been ongoing in the Mpumalanga coalfields for more than 100 years. At first, mining was mainly confined to the west of Witbank. Many of these mines have closed down and are presently a major source of pollution. This poor quality should serve as a warning of what would happen in the rest of the mining area, if intermine flow commenced there. Through the years, mining extended from its original position to the south and east. Many new collieries commenced with mining, particularly during the past 30 years. Since 1970, mining has increasingly been mechanized. All modern coal-mining methods are currently employed. These are:

- Bord-and-pillar extraction.
- Secondary mining through pillar extraction. This is commonly referred to as stooping.
- Underground high extraction through long wall and short wall methods.
- Auger mining is presently considered on a limited scale for the extraction of thin coal seams.
- Opencast mining, using truck and shovel or dragline methods.

Initial underground mining was relatively shallow, in the range of 10 - 50 m below surface. Mining was mainly through underground methods. Access to the underground workings was commonly through inclined shafts.

3.12.1 Bord-and-pillar extraction

- Bord-and-pillar extraction has been the primary method of mining throughout the Mpumalanga coalfields. The reasons for this are Grobbelaar et al., (2004):
- It allows access to the coal in a structured and organized way.
- It can be manoeuvred around geological or coal quality constraints.
- The extraction rate is reasonably high, ranging from 70% in the shallow mines to 50% in deeper areas.

3.13 Mine layout

Grobbelaar; *et al*, 2004 state as follows: Water in mined-out areas will flow along the coal floor and accumulate in low-lying areas. This is a simplistic view of the situation. In reality, water would accumulate in many isolated areas, where it would dam against barriers of coal or dolerite dykes left

The layout plan for Usutu colliery gives the B-seam; C-seams (see Figure 29). Mining activity ceased in the late 1980s and then the mine was flooded. Usutu has mined two seams underground namely, the B and C-seam respectively; with an average mining height of 1.6 m. Currently Vunene Mining has an opencast mine above the C-seam of the northern mine. This may result in cracks and water moving into the underground.

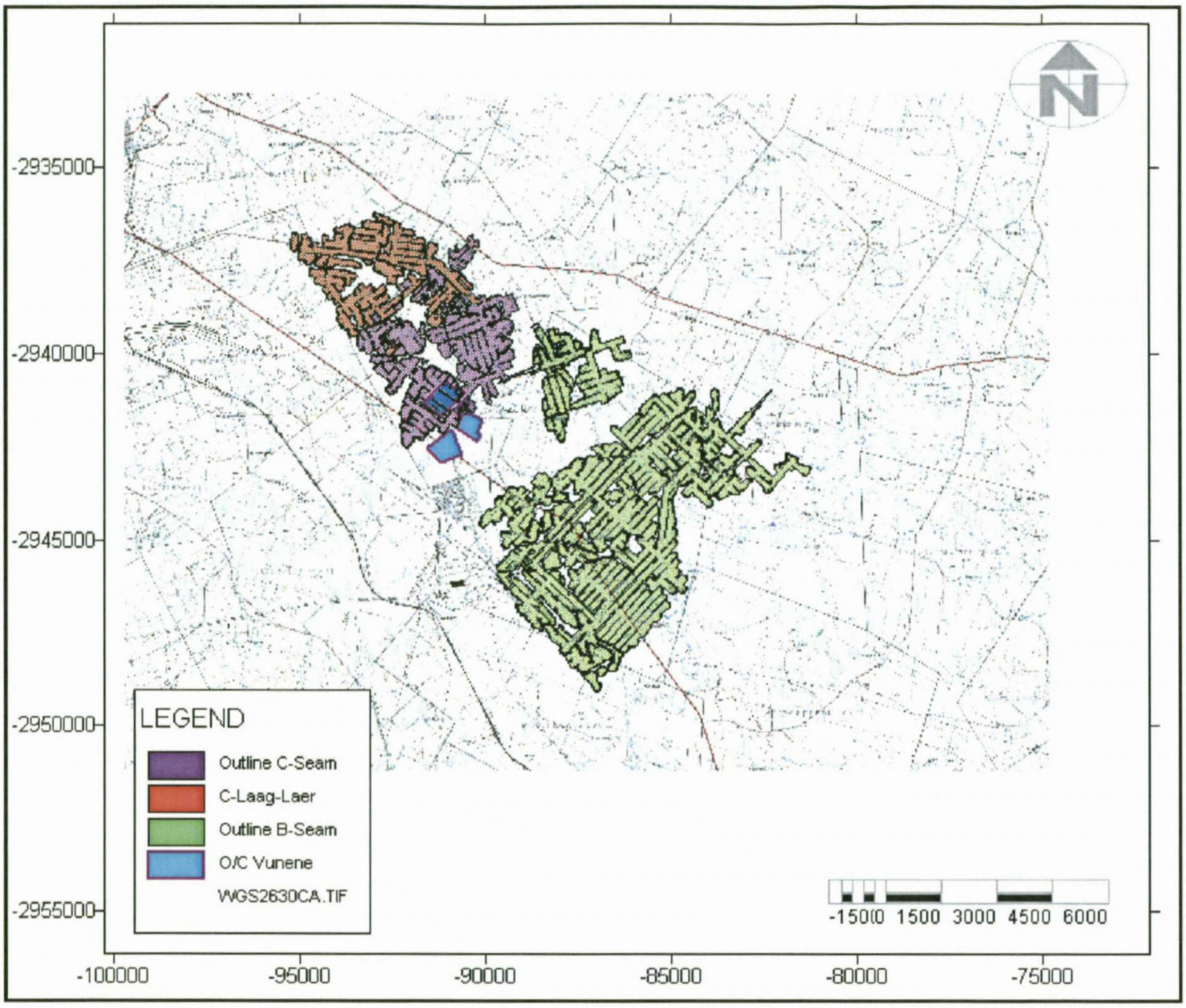


Figure 29: Layout of the B- and C-seams at Usutu colliery, together with Vunene opencast.

3.13.1 Roof thicknesses

The combined C-seam varied in depth from very shallow (1.4 m) to nearly 80 m in the north, the shallowest part of the roof as illustrated in Figure 30. The southern mine, where the B-seam was mined, varied between 75 m and 160 m, as illustrated in Figure 31.

The combined floor contours for both seams are illustrated in Figure 32. From this the difference in depth between the two seams is very clear, with the B-seam much deeper than the C-seam.

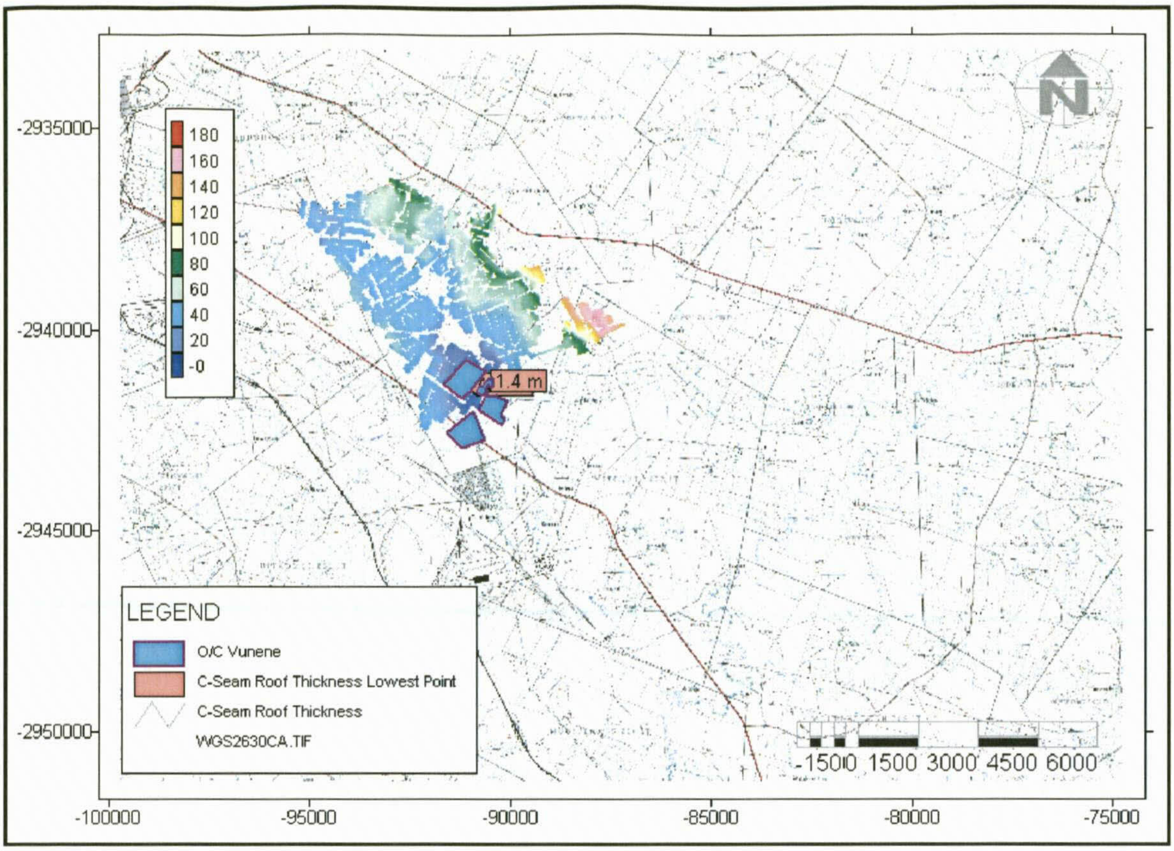


Figure 30: Roof thickness of the C-seam (northern mine) displayed in mamsl.

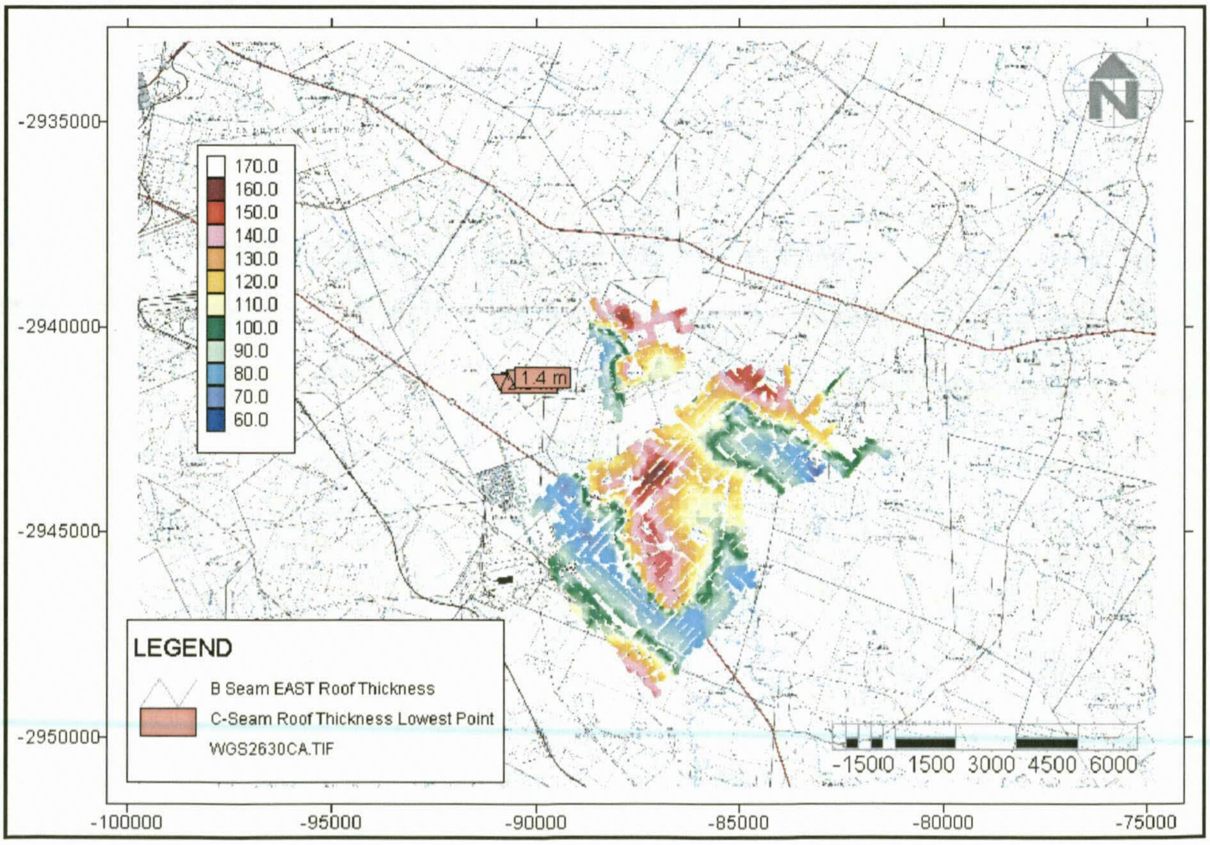


Figure 31: Roof thickness of the B-seam (southern Mine) displayed in mamsl.

3.13.2 Floor contours

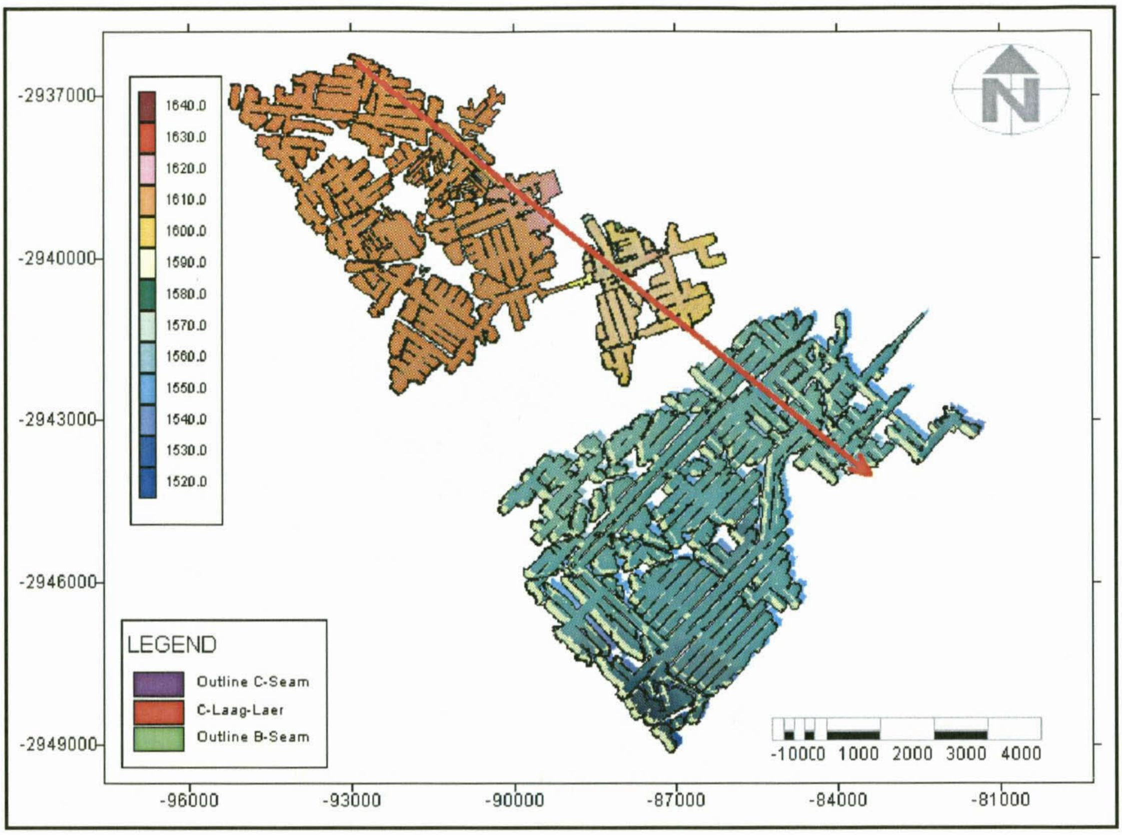


Figure 32: The combined floor contours of both the B and C-seam (illustrated in mamsl).

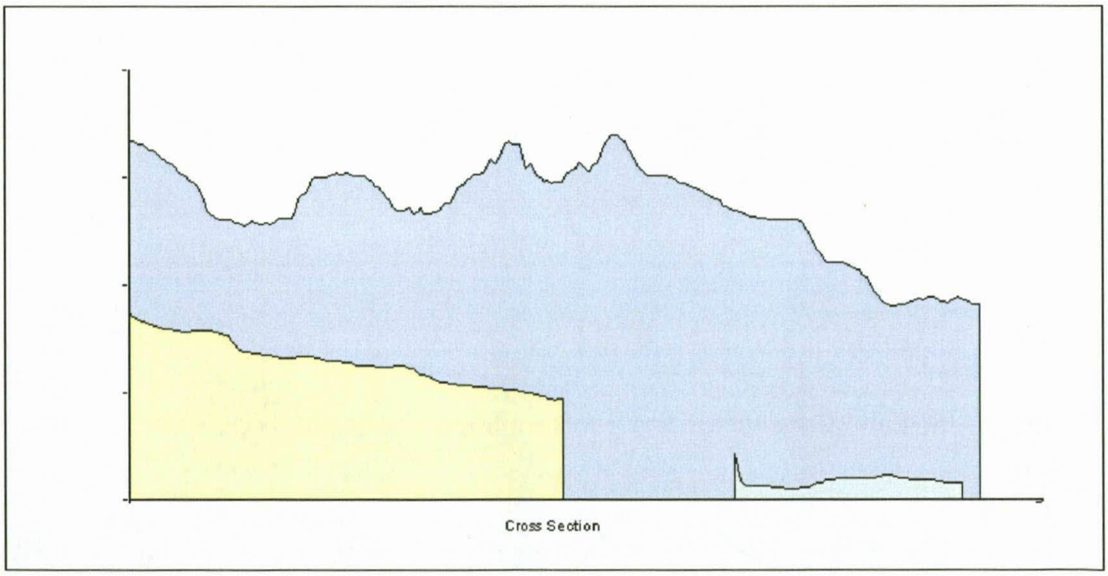


Figure 33: Cross section of the floor contours together with the surface topography

Shows a cross section of the floor contours together with the surface topography. The section line is indicated with a red line in the previous figure.

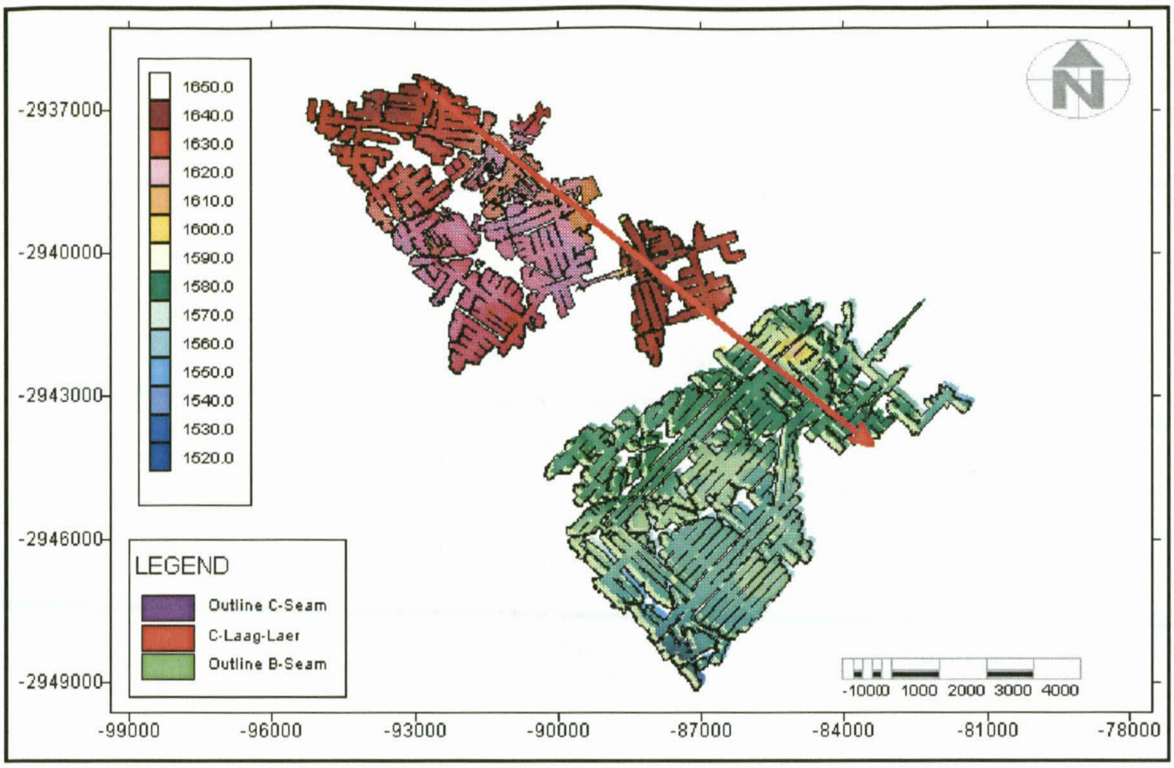


Figure 34: The combined roof contours of both the B and C-seam (illustrated in mamsl).

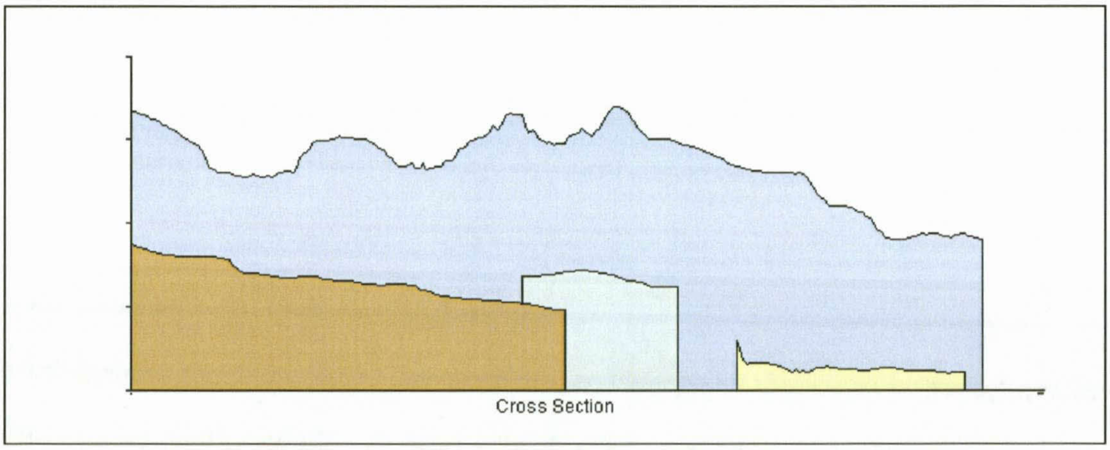


Figure 35: Cross section is shown of the roof contours.

In the cross section is shown of the roof contours. The blue indicates the surface topography. The section line is indicated in the previous figure by a red line.

In Figure 36 the surface in relation to the two seam elevations is illustrated in 3D. From this the surface elevation to the north is clear, and the difference in depth for the two seams in relation to the surface is also illustrated. Also illustrated is the position of the Usutu boreholes that are drilled into the mine.

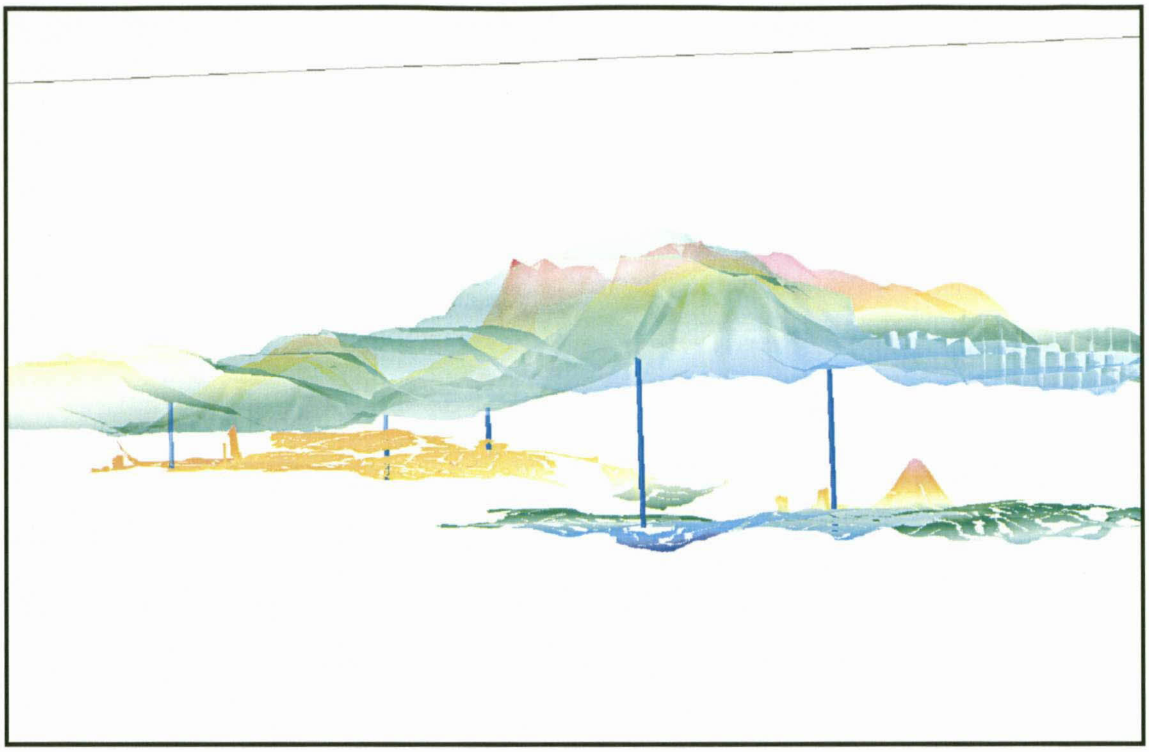


Figure 36: 3D combined surface and seam elevation with boreholes into the underground.

3.14 Ventilation seals

Barrier pillars between mines or compartments should be designed for the specific purpose of keeping water from transgressing through it; or to release water at a specific rate through controlled flow mechanisms. Only one of the mines has ever done permeability testing in a barrier pillar. It is essential that barrier pillars be tested and that monitoring systems be installed before intermine flow takes place in an uncontrolled fashion. Issues such as liability and accountability can only be addressed once this information is available Grobbelaar *et al.*, (2004).

In order for a mine to function properly, ventilation walls are needed to channel the fresh air away from those parts of the mine that were finished and directed the flow to the front of the mining operations. In the olden days these walls were built very solid and sealed corridors completely from bottom to roof.

The walls are so strong that they will function as "low pressure" seals resulting in a compartmentalized underground, withstanding huge pressures created by the recharged groundwater. These seal positions are important in the recharge and management calculations for a mine as well as for the water balance and mine dewatering. The seals in Usutu (also digitized from the old maps) are illustrated in Figure 37.

Also important is the barrier between different mines, which will determine mine interflow. The position of the Mooiplaats Colliery to the south of the southern mine is also illustrated in this figure. The shortest distance of the pillar between the collieries is 250 m.

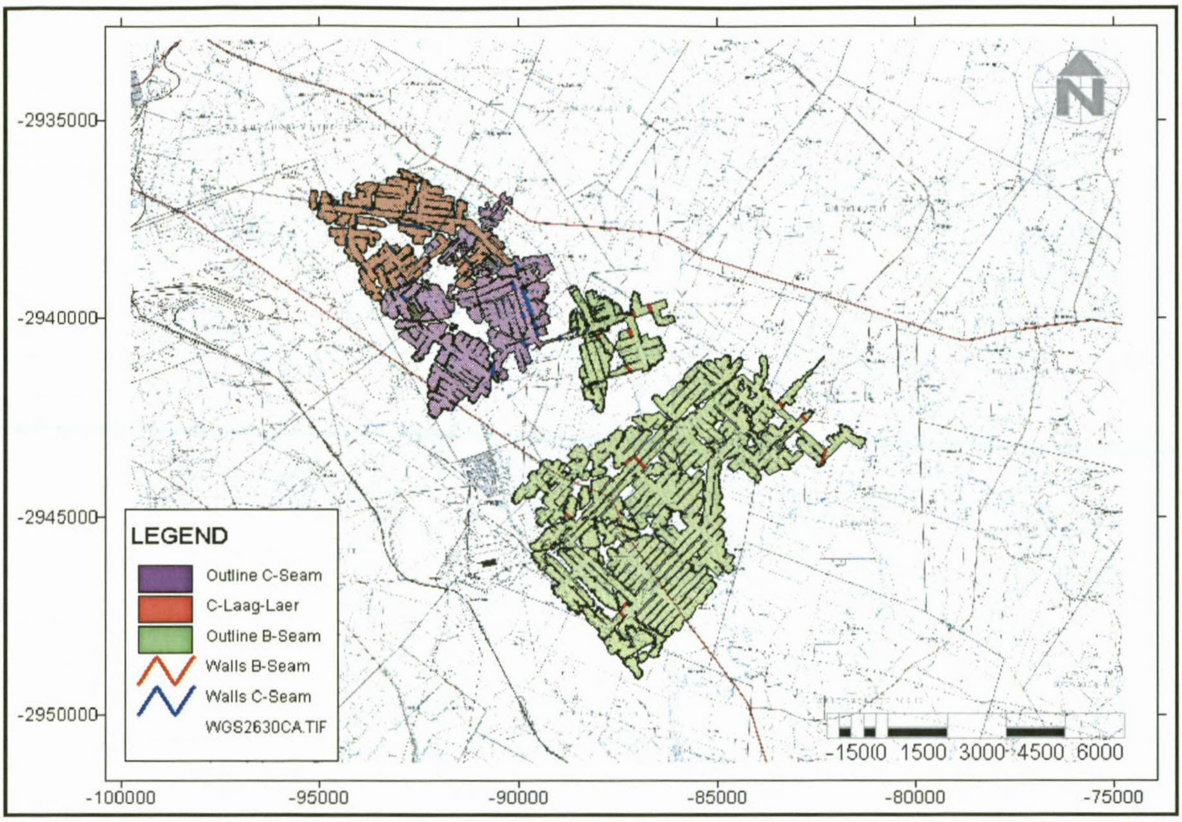


Figure 37: Layout of the B and C-seams illustrating the ventilation walls, as well as the position of the adjacent Mooiplaats Mine.

3.15 Faults

According to Grobbelaar *et al.*, (2004) dolerite intrusions in the form of dykes and sills are present in the Ecca Group. The sills usually precede the dykes, with the latter being emplaced during a later period of tensional forces within the earth's crust

The faults and dykes in the area were mapped using maps of the mine plans provided by Usutu (Figure 38) there are a few long faults cutting through the mine. This may have an influence on the water flow inside the mine. It can easily be seen that where a fault occurred the mining stopped and just continued on the other side of the fault. The faults and dykes also play a role in compartmenting the mine as it normally also displaced the coal seams vertically. The water will move along these faults in the underground.

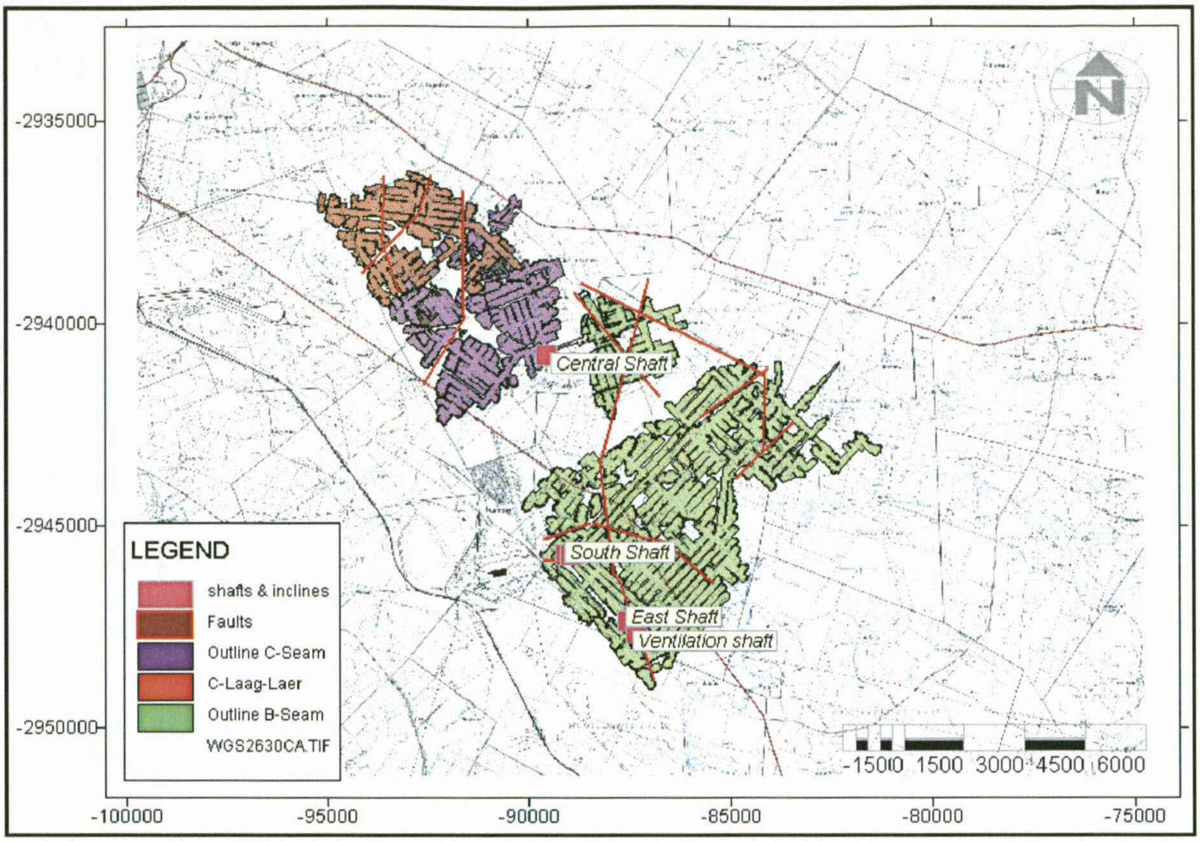


Figure 38: Faults and dykes identified inside the mine.

3.16 High extraction zones

According to Hodgson (2007) underground high extraction of coal has been performed for many years in South Africa. The impact that this has on groundwater and surface water resources has been investigated in most instances, and this information is available as part of their EMPR application.

Two mining methods for the underground high extraction of coal are generally used in South Africa. These are:

- Pillar extraction, also referred to as stooping.
- Long wall mining, with a short wall variation.

To date, stooping has been performed at many collieries. The extent of this may vary from experimentation in a single area to stooping over most of the mine.

Long wall and short wall mining, in view of its significant initial capital outlay has only been implemented at a few collieries. These are the Eskom tied mines, such as Coal brook, Matla, New Denmark and Arnot; the Sasol mines at Sasolburg and Secunda and Durnacol in KwaZulu-Natal (Hodgson, 2007).

Much of this information is of a historic kind, unable to predict with confidence the final geohydrological and hydrochemical outcome of such systems. This complicates matters when applying for closure of the mine, because of uncertainties associated with future water quantities and qualities.

Stooping is the process whereby pillars from bord-and-pillar mining areas are extracted. Continuous mining are generally used for this extraction process, cutting sections into pillars until most or all of the pillars have been removed from specific areas (Hodgson, 2007).

Pillar extraction usually commences at the furthest point, retreating to the entrance of an area. The roof in areas where pillars have been extracted is left to cave in, which it usually does. This caving often causes subsidence on the surface. Subsidence cracks may penetrate to the surface, allowing groundwater and surface water to drain into the collapsed mine workings (Hodgson, 2007).

The amount of subsidence at the surface and the severity of cracks depend on (Hodgson, 2007):

- The depth of mining and the nature of the overlying rock.
- The coal seam thickness mined.
- The area stooped and panel geometry.

The degree to which pillars have been left in the stooped area, thus still supports the coal roof.

- The following interpretation is relevant to water flow (Hodgson, 2007):
- The intensity of stooping varies tremendously from area to area.
- The stooping method applied also varies, removing anything from a small portion of a pillar to removing all of it.

Information on whether or not the roof in stooped areas has collapsed and, if so, whether the impact extends to surface, is not available.

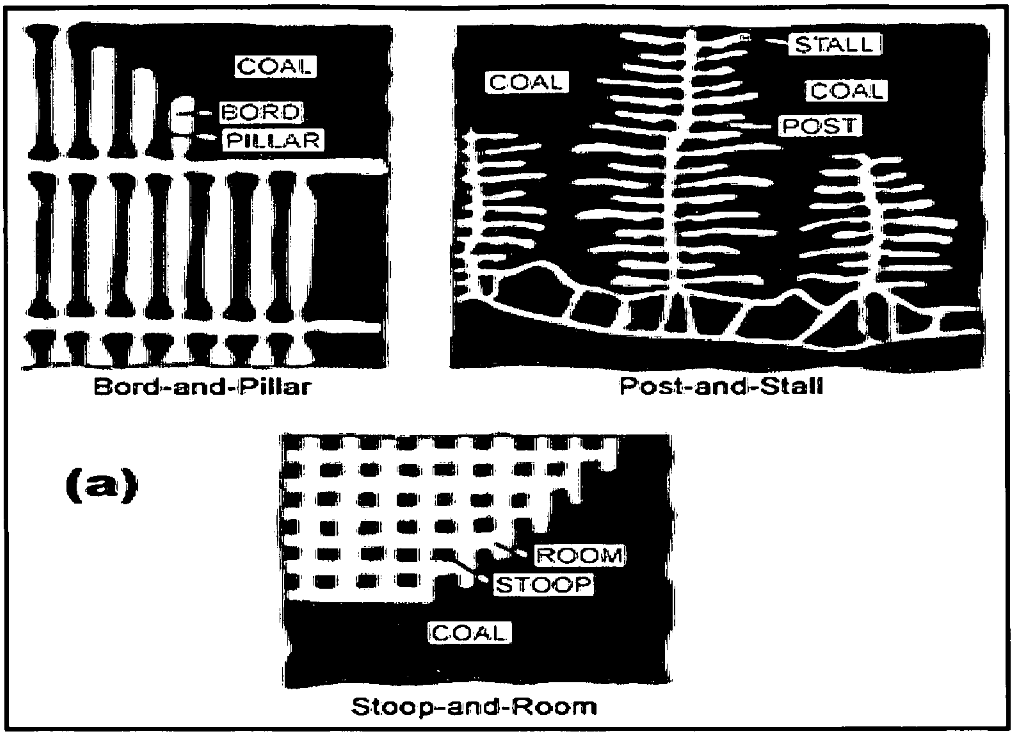


Figure 39: Different methods of mining (Hodgson, 2007).

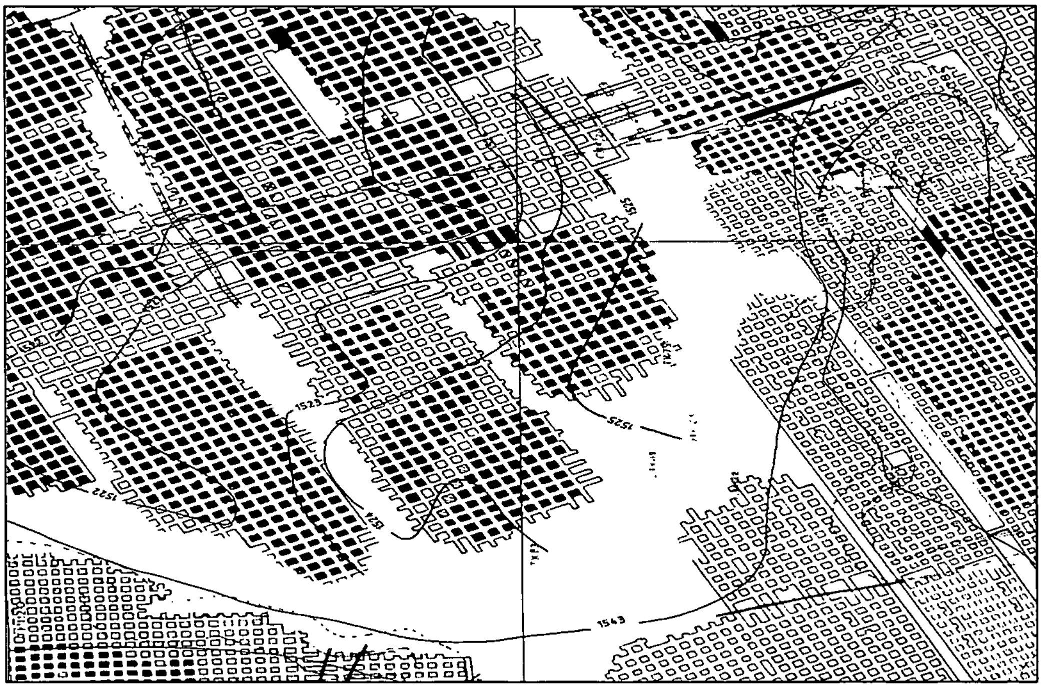


Figure 40: High extraction (stooping) example on an old mine map.

High extraction areas were also identified in the mine from the old maps of Usutu shown in Figure 40. High extraction was only done in the B-seam; the combined total high extraction percentage was 14% of total the mining area (stooping in the central area is 22% and in the southern area 13%). These areas are illustrated in Figure 41.

These areas may result in subsidence, increasing the recharge factor into the mine. The position of the shafts may also influence recharge if not properly sealed, and may also act as decant points if it is lower than the lowest point of mining).

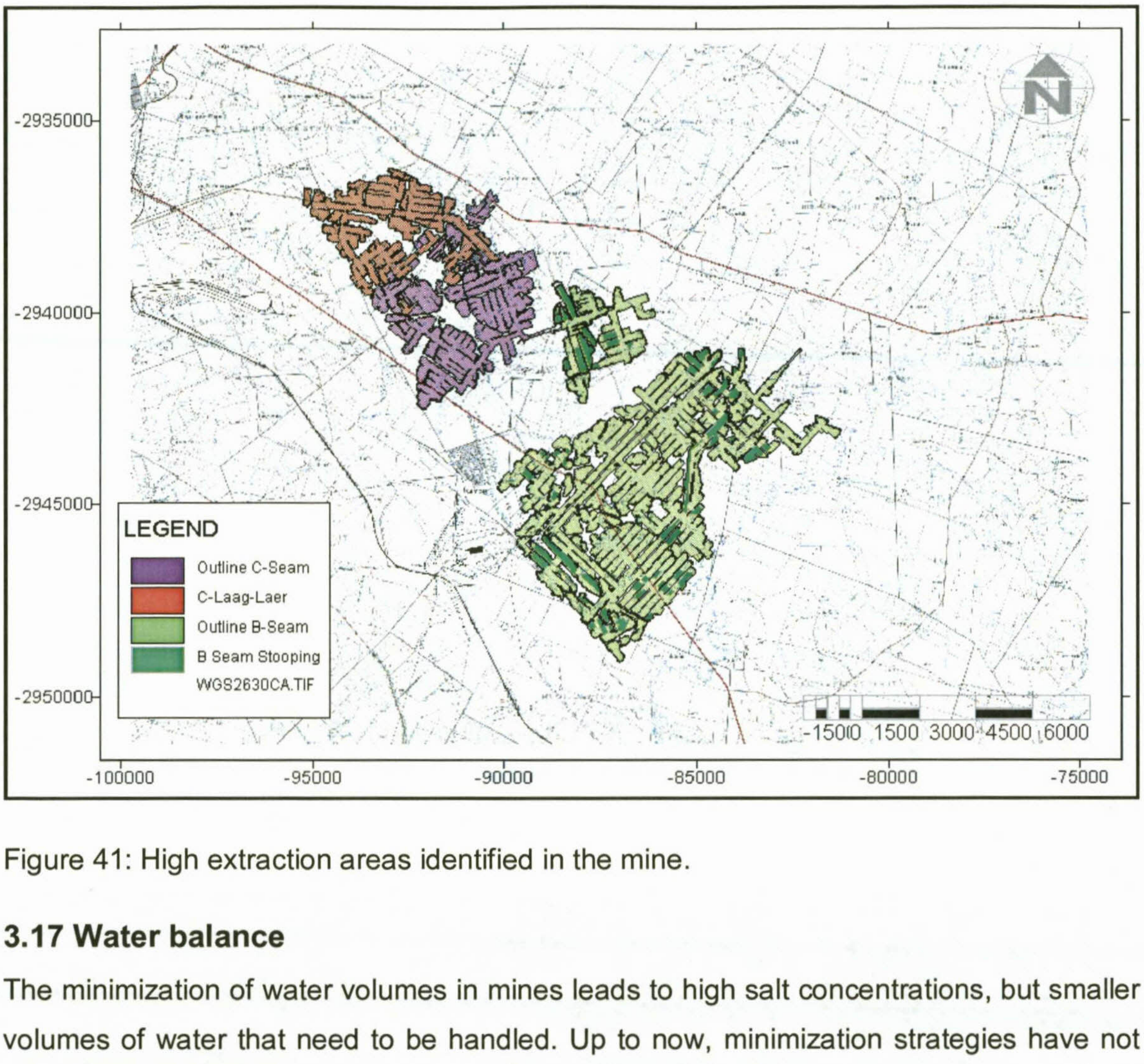


Figure 41: High extraction areas identified in the mine.

3.17 Water balance

The minimization of water volumes in mines leads to high salt concentrations, but smaller volumes of water that need to be handled. Up to now, minimization strategies have not been applied to a significant extent as a management tool. This is largely due to the vast scale of coal mining operations. It is almost impossible to change a mining strategy, for instance, from underground high extraction to bord-and-pillar, once mining has commenced. Other water minimization strategies include the artificial flooding of closed mines, improved rehabilitation of surface and the planting of trees. The conclusion is that water influx minimization should be considered carefully against the option of active flushing according, to Grobbelaar *et al.*, (2004).

The WISH/WACCMAN software was used to calculate the amount of water stored in the defunct mine. The software calculates the volume of water in the underground taking into consideration the current water level elevations and the geometry of the workings, including mining height, extraction factors and the position of the ventilation walls.

Due to the many compartments in the underground and only three water levels in the workings, a few compartments show up as being empty. It is highly unlikely that the compartments are empty but without water level information a water volume for a compartment cannot be calculated. This makes the management of a flooded mine with ventilation walls very difficult.

Mine compartments will fill themselves with water. The speed at which this happens is defined by the recharge rate which is depending on the geology, the depth, the type of mining and whether some form of high-extraction was performed.

Table 6: Anticipated recharge to bord-and-pillar mining in the Mpumalanga area (Hodgson et al., 2007).

Description	**Recharge as a % of annual rainfall**
Influx into bord and pillar,deep mining	1--4
Influx into bord and pillar,shallow mining	4--9
Influx into bord and pillar mining with stooping	4--12

Stooping has been done in some parts of the B-seam at Usutu colliery. Stooping, the process of removing pillars from the workings causes the overlying strata to collapse. Cracks will develop. If these cracks intersect with the surface, rainfall water and run-off may flow down directly into the mining cavity. From studies done at collieries where stooping was done (Hodgson *et al.,* 2007), it has been found that normally a recharge rate of 4 – 12% should be applied, depending on the depth of mining and ratio of stooping.

According to the data the B-seam is completely filled with water. This has happened over the last twenty years (this is the number of years since mining has ceased in the B-seam). From this can be concluded that there must be a recharge of at least 5%. Although the C-seam is shallower, no stooping has been done and the recharge is also considered to be 5%. The Ermelo region receives, according to Weather SA, an average rainfall of 705 mm per annum.

Table 7: Properties of the seams.

Seam	Avg Depth	Area not stooped	Area stooped	Recharge factor
	m	ha	ha	%
C Seam West	44	1560	0	5
C seam Central	125	108	0	0.1
B seam Central	97	333	96.5	5
B seam East	107	2125	315	5

The total water make for the B-seam is 2 687 m^3/day and for the C-Seam 1 612 m^3/day.

After the opencast mining activities ended there will be a rehabilitated open cast on top of the old workings (Figure 42). From the hydrology it is known that the average evapotranspiration is about 80% in terms of the rainfall, leaving 20% for recharge on a not fully rehabilitated pit. A pit that is badly rehabilitated and where all rainfall would run off towards the spoils may expect a maximum recharge of 20%. A very well rehabilitated pit with free draining from the spoils can expect a recharge of 10%.

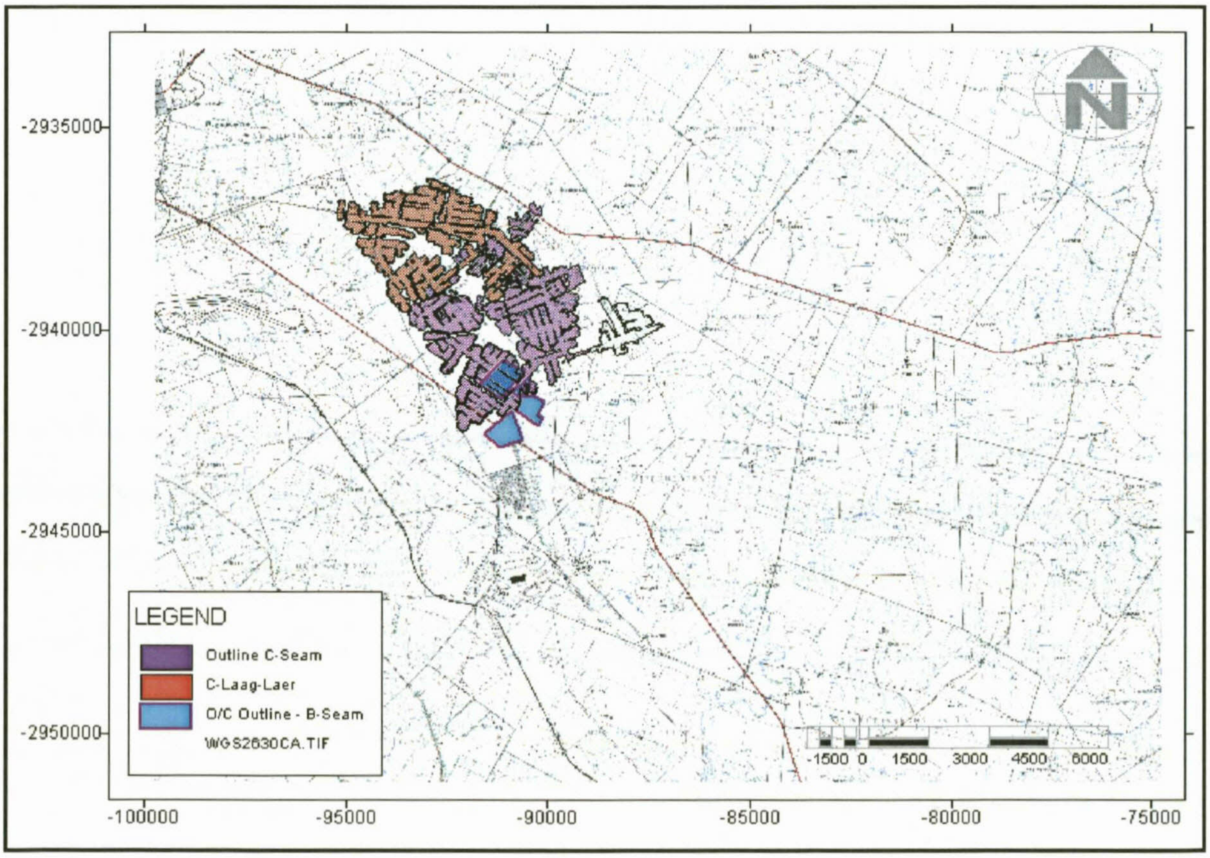


Figure 42: Position of the Vunene opencast pits in relation to the C-seam.

The pit is currently in use and is not rehabilitated. A recharge of 20% is assumed.

Only pit A and B are situated on top of the underground; the combined size of the two pits is almost 59 ha (588 000 m^2). The thickness of the layer between the C-seam underground and the floor of the opencast (B-seam) vary between 10 and 1.6 metres. With such a thin layer between the opencast and the underground cracks are imminent. All the water that recharges into the opencast will flow through the cracks into the underground. The amount of water anticipated from the two opencast pits is 588 000*0.705/365*0.20 = 227 m^3/day, resulting in a substantial higher water for the C-seam of 1612+227-22.7 = 1816 m^3/day.

The total water in the C-seam is currently 19.1 Mm^3. Some areas show no water (Figure 43), not because there is no water but no information is available on the existence of water!

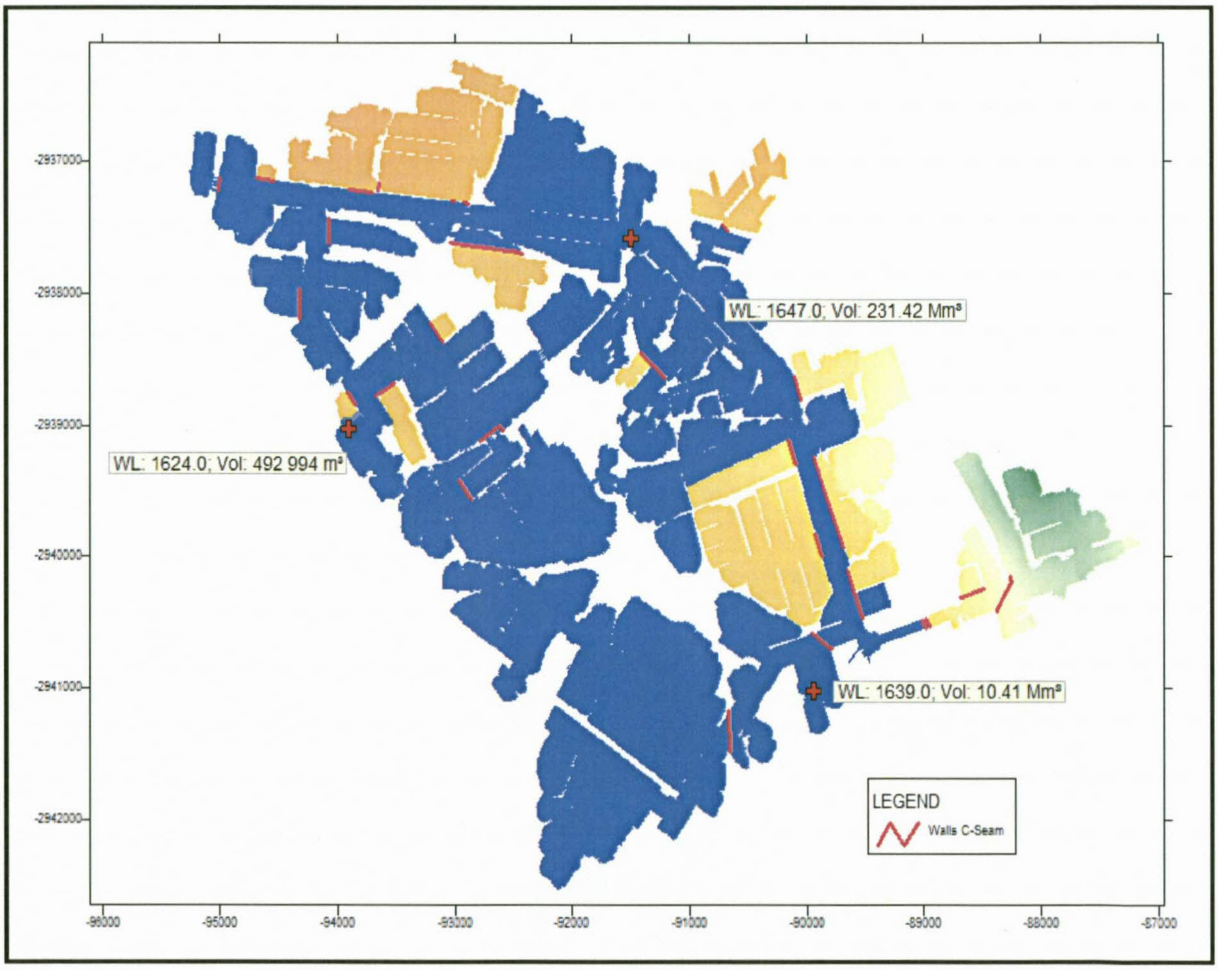


Figure 43: Water bodies in the C-seam.

A stage curve depicts the relationship between a stage height (the actual water level elevation) and the volume of water inside the underground.

This assumes that the water table is horizontal and continues over the entire mine. In Figure 44 the stage curve for the C-seam is illustrated, indicating that for a water level of 1647 mamsl (Usutu E water level elevation) the total water volume will be 17300 ML.

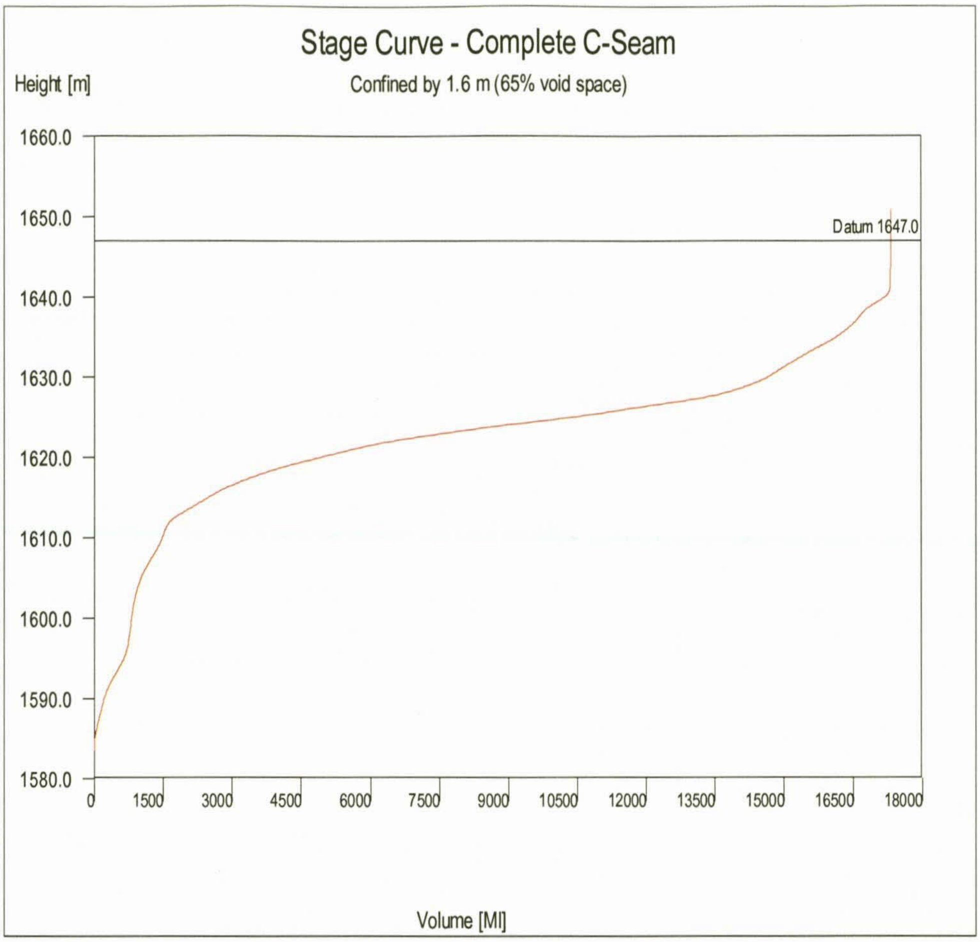


Figure 44: Stage curve for the C-seam.

For the B-Seam the total water volume is 22.88 Mm^3. The water bodies are illustrated in Figure 45. The dry areas are not necessarily dry; there is just no information available

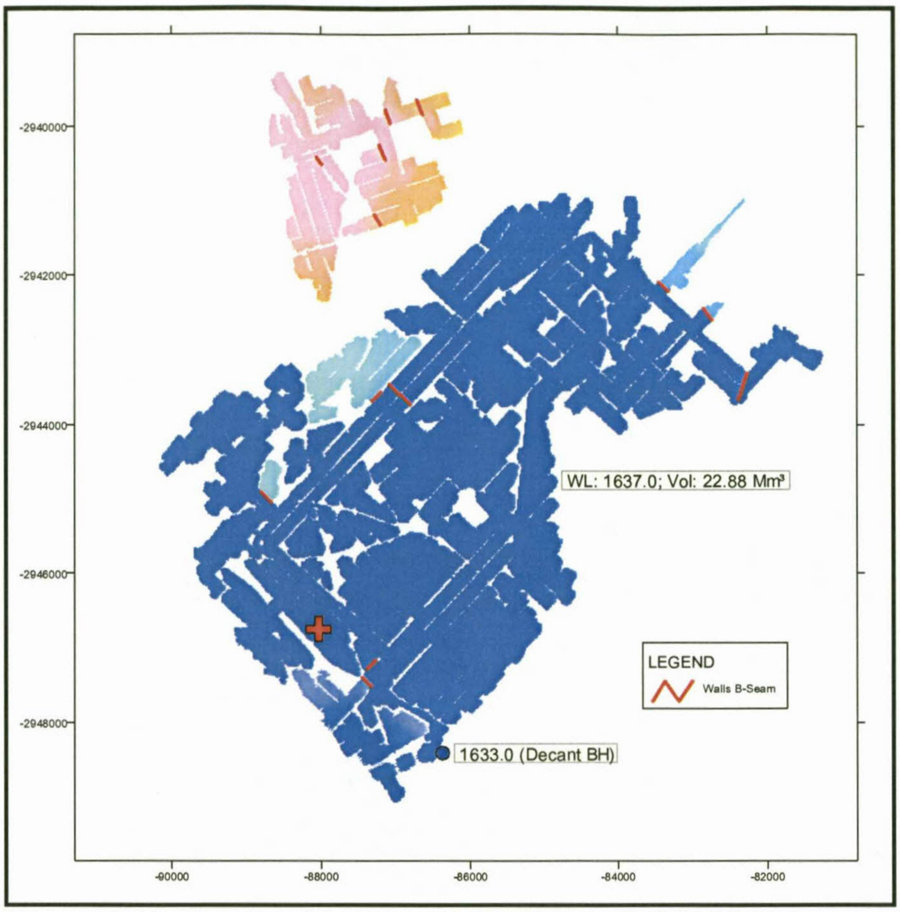


Figure 45: Water bodies in the B-seam.

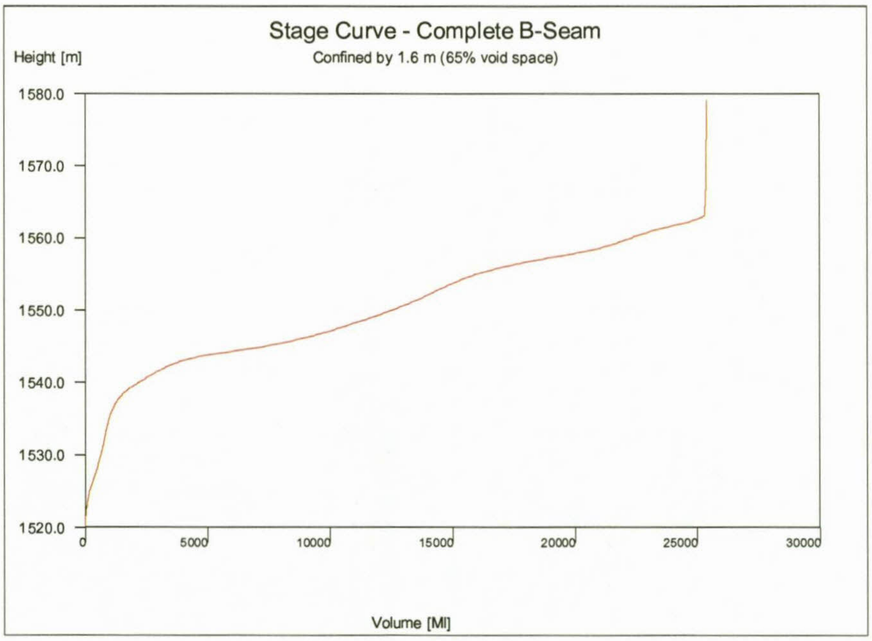


Figure 46: Stage curve for the B-seam.

In Figure 46 the stage curve for the B-seam is illustrated, indicating that the total water volume will be nearly 25 000 ML.

Decant:

It appears that there is a minimum stratification in the water columns in the two mines. As there are a number of ventilation seals in the mine, that reduce any change of pressure that can "push" the mine cavity water up to a decant level.

In 2010 there was a borehole decanting water at a supposed rate of 7 l/s (Figure 47). This borehole is situated in the far south of the B-seam (Figure 48) in a very isolated panel which (according to mine personnel) was completely sealed off during mining. One possible reason for this sudden decanting may be the collapse of a ventilation wall.

Figure 47: Photograph of decanting borehole.

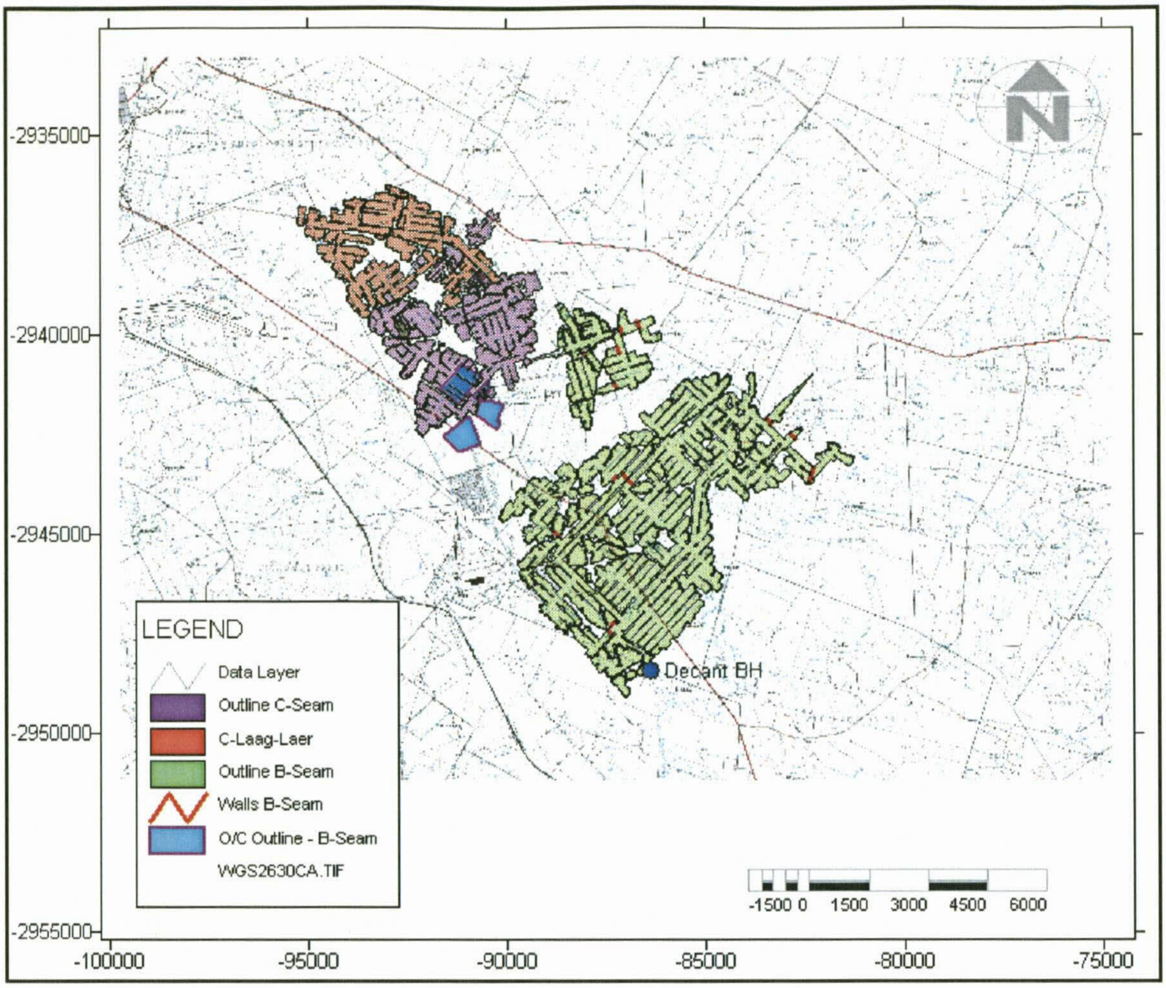


Figure 48: Position of the decant borehole in the far south of the B-seam.

The water level elevations of the two boreholes in the B-seam are illustrated against the background of the surface contours in Figure 49. A section was drawn through the mine on a line as indicated in Figure 49. The section (as illustrated in Figure 50) intersects both boreholes. The section illustrates the boreholes, their water level elevations, the position of the mining cavity and the surface in relation to each other. From this two things are clear:

- The water levels (not pressure levels) follow the topography (which is an accepted fact in geohydrology).
- At no point the mining cavity is close to the surface. Therefore no pressure can be created from the water in the mining cavity for mine water to decant. It is therefore unlikely that the borehole that decanted resulted from pressure that has been created from inside the mining cavity. The break of a ventilation seal, creating sudden pressure, may thus be a possibility.

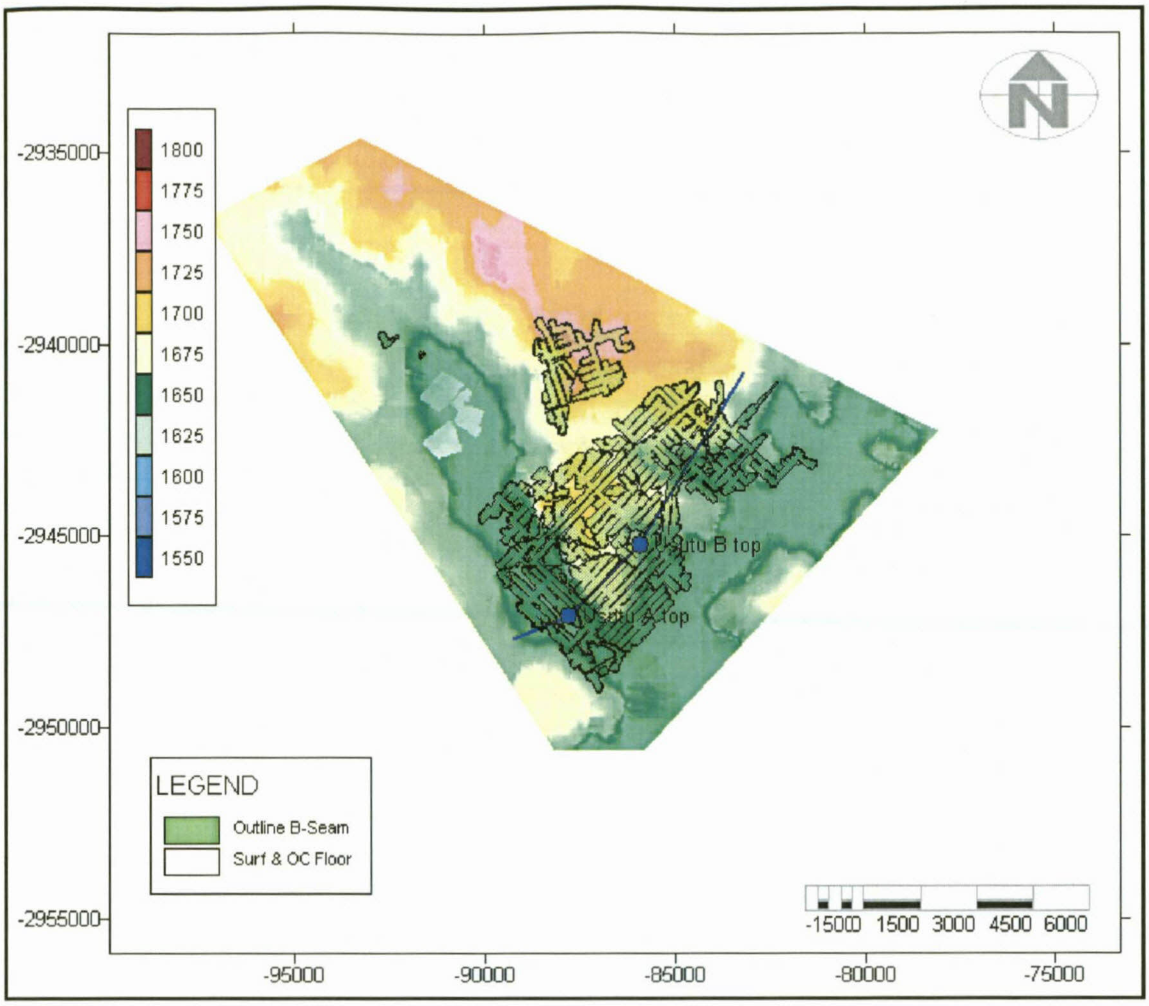


Figure 49: Water level elevations (mamsl) of Usutu A and B (with the blue cross-section line intersecting the two boreholes).

The general flow direction is from right to left (north-east to south-west) following the topography shown in Figure 50

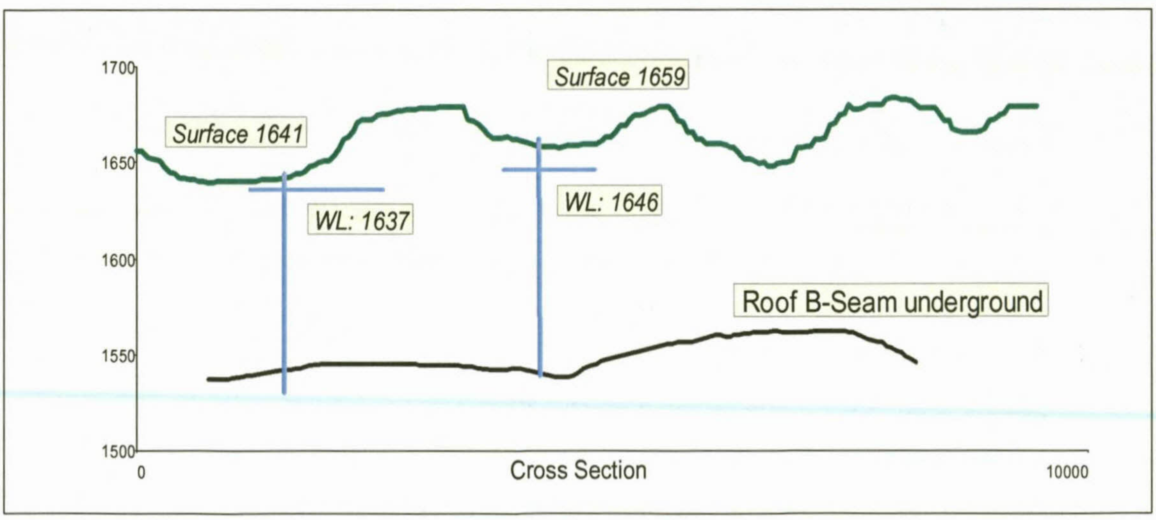


Figure 50: Cross-section of boreholes Usutu A and B.

3.18 Mine Interflow

Several mining operations are currently being conducted in the vicinity of Usutu Colliery. The next heading will deal with Mooiplaats as shown in Figure 51

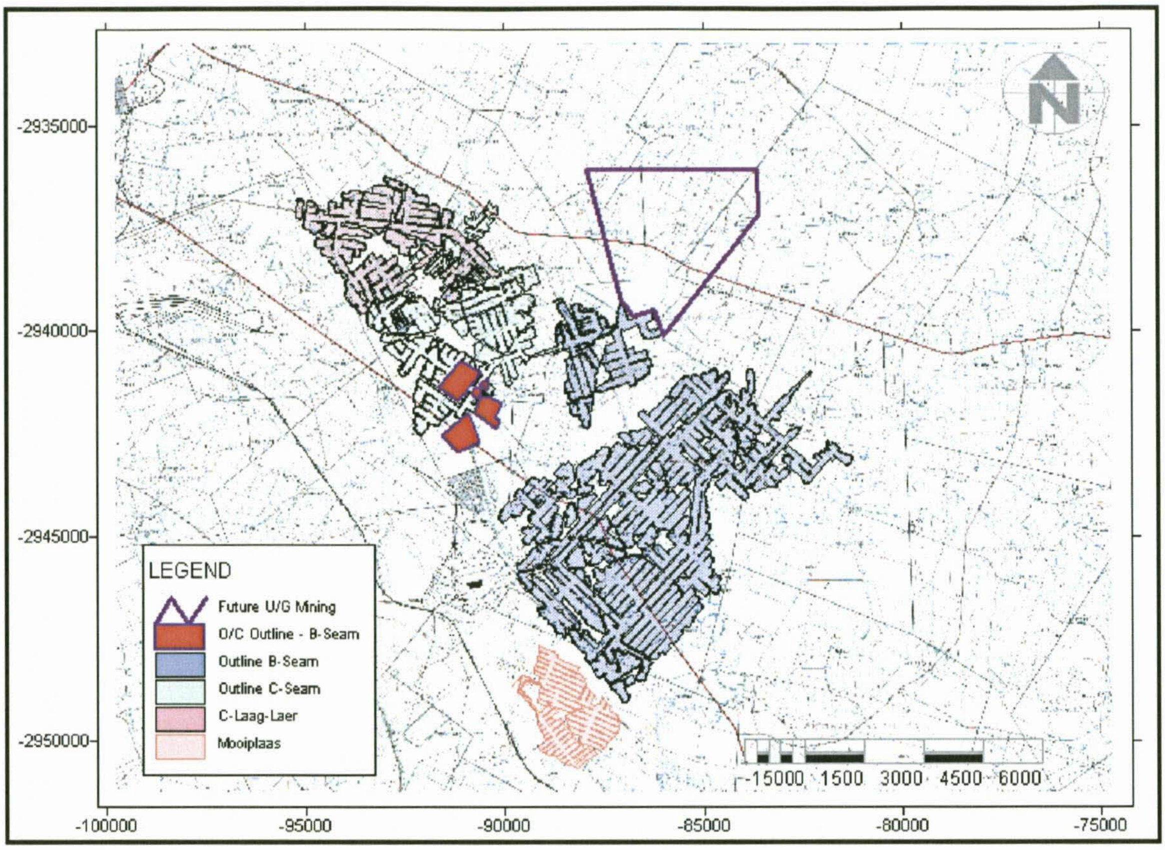


Figure 51: Planned future mining and mining adjacent to Usutu Colliery.

3.18.1 Mooiplaats

Mooiplaats Colliery operates to the south of the South Mine (B-seam). The two collieries are divided by a regional dyke. The barrier (pillar) between the two collieries is 250 m at the closest point between them. The level of mining also differs (according to Mooiplaats geohydrologists). It is highly unlikely that any mine interflow will thus occur between these mines, as a pillar of that width will result in an impregnable layer (which will even increase with the presence of the regional dyke that acts as a buffer).

Currently water is being pumped from the Usutu B-seam to provide Mooiplaats Colliery with water (Figure 52). Recharge into the Usutu South Colliery is 2 687 m^3/day; therefore pumping must be less than this to ensure that the water level does not drop below the roof of the mining cavity. Currently only 0.07 Mm^3 – 0.14 Mm^3 is used on average daily, according to figures obtained from the Mooiplaats geohydrologist.

Figure 52: Photograph of the extraction wells pumping water from Usutu South to Mooiplaats Colliery.

During an investigation, including EC profiling of the borehole (Figure 53), water could be heard running down the borehole. This is aquifer water draining directly into the mining cavity. These boreholes are situated on a topographic high and water from the high ground thus drains into the mine.

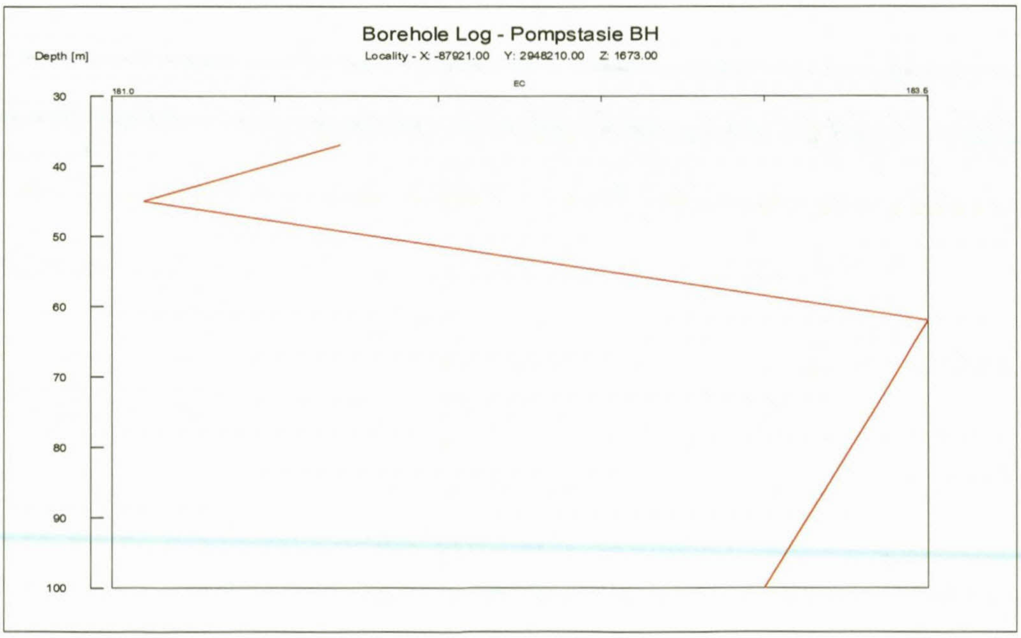


Figure 53: EC profiling of the pumping borehole.

The quality of the water being pumped is displayed in Table 8. From this it is clear that there is an improvement of the water quality. The measured quality corresponds with the profiling done during the field visit. Flushing is an accepted practice to improve the quality of mine water if the pumping rate (and thus the water levels) is managed properly, keeping the water level above the mining cavity.If the mine stays flooded then no additional oxygen ingress and pyrite oxidation will occur.

Table 8: EC quality over time of water being pumped to Mooiplaats Colliery.

Date	09/11/16	10/01/22	10/02/23	10/07/01	10/07/23	10/08/23	10/12/22	11/01/27	11/02/24	11/03/28
EC	353	344	340	338	352	333	261	223	116	5

The time series for the above tabel is shown in Figure 54

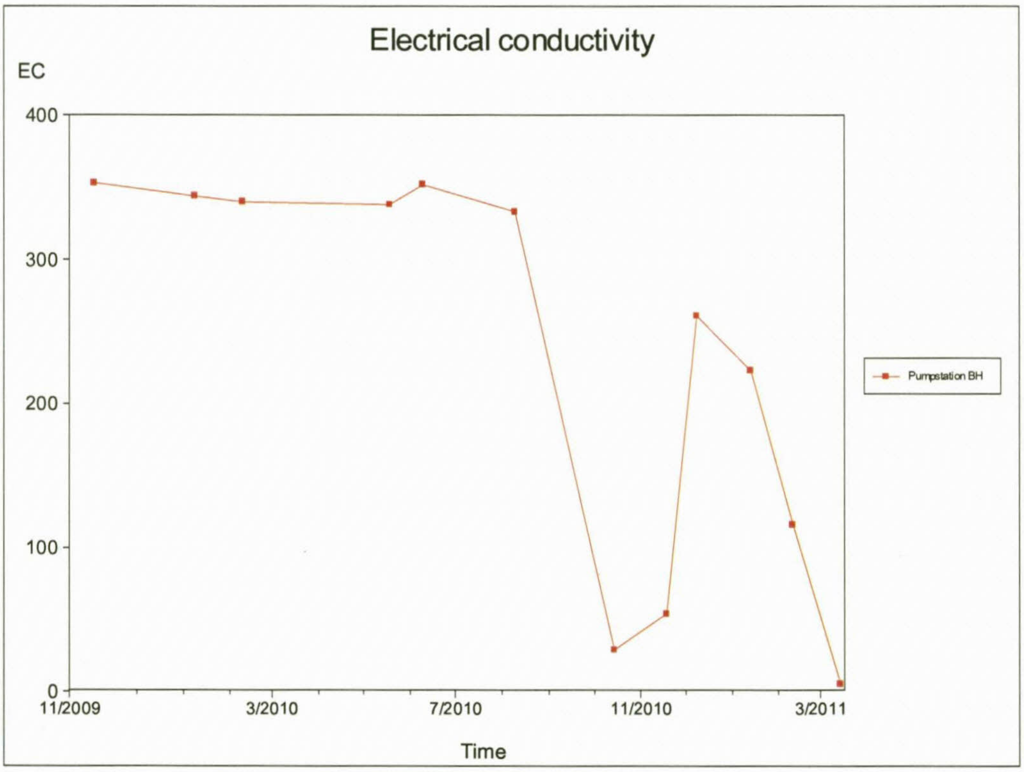


Figure 54: Time series of the EC quality over time of water being pumped to Mooiplaats Colliery

3.18.2 Vunene Mining

Underground:

The block in the north-east of the main dicates the planned future underground mining of Usutu. If this underground mining operation uses the central shaft of Usutu Colliery for entrance, it means that the mine has to be kept dry. This may result in a constant ingress of oxygen into the old mine workings, which may enhance acid rock drainage. No detailed data is available as yet.

Opencast:

The thickness of the layer between the C-seam underground (mined out) and the floor of the opencast (B-seam), currently mined by Vunene Mining, varies between 10 and 1.6 metres. With such a thin layer between the opencast and the underground cracks are imminent. All the water that recharges into the opencast will flow through the cracks into the underground. The amount of water anticipated from the two opencast pits is 588000*0.780/365*0.18 = 226 m^3/day, resulting in a substantial higher water make for the C-seam of 941 m^3/day. There is no water quality available due to the current mining operations, but such ingress through the opencast will result in poor quality water seeping into the underground workings, deteriorating the water currently in these workings. Hodgson *et al.*, (2003) indicate that sulphate generation in the flooded underground is less than 2 kg/ha/day [depending on the depth of mining and flooding rate and that of opencast mining 7 kg/ha/d).

3.19 Quality of the water

At most of the larger mines, the opportunity exists for mine water of different qualities to be mixed, thus improving the overall water quality. Typical benefits of doing this would lie in pH adjustment and iron precipitation. For the latter, retention of the mine water in a surface holding facility where aeration is possible, is necessary. Such a facility could also be used for the quick release of the water during flood discharge. Very few other chemical benefits would be forthcoming from mine water mixing, because most of the constituents are under saturated in this water (Grobbelaar *et al.*, 2004)

Water quality assessment is used to evaluate hydro-geochemical site conditions and the current state of aquifers. Sulphate, TDS and pH are the essential chemical components used for first-order pollution categorization in South African coal mines.

Mining at this locality has been in progress since the mid-eighties. Through accurate monitoring of water from different collapsed panels, it should have been possible to plot sodium and sulphate concentrations to determine:

- The possible lifespan of sodium neutralisation.
- The possible escalation of sulphate production due to the intervention of bacterial oxidation as the pH of the water drops.

Unfortunately, this kind of information is not available, since the importance of detailed and complete data sets is only realized by the mining community nowadays. Stream water quality in the coalfields deteriorated over the past 20 years, due to seepage and the discharge of mine water (Grobbelaar; et *al*, 2004)

Table 9 shows the chemistry data for the boreholes over time 2009-2011. All these boreholes were sampled at the top of the water column. During the hydrocensus the mine boreholes were sampled at the top as well as at the bottom in the mine.

The criteria used for inorganic sampling is the SANS 241:2006, and for organic analysis the USEPA Standards. Inorganic water samples are classified as:

- Class I – acceptable (Not color coded)
- Class II - allowable (color coded yellow)
- Above – not allowable (color coded red)

Table 9: Chemistry of the boreholes

BH number	Date	pH	EC	TDS	TCaCo3	Ca	Mg	Na	K	MAlk
			mS/m	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
Usutu A top	2011/02/17	7.4	194	<1	<1	24	17	461	3.3	919
Usutu A top	2009/07/03	7.08	55	356	128	28	14	75	1.9	302
Usutu A top	2009/10/06	8.18	283	1978	106	27	9	665	3.0	1300
Usutu A top	2010/03/26	8.2	323	2246	124	25	15	773	7.4	1527
Usutu A top	2010/06/01	8.39	318	1994	72	17	7	703	3.7	1308
Usutu A top	2010/07/23	8.13	303	2186	144	25	20	734	4.0	1514
Usutu B top	2011/02/17	7.21	32	<1	<1	29	13	18	1.8	121
Usutu B top	2009/07/03	7.03	34	196	124	26	15	21	1.1	133
Usutu B top	2009/10/06	7.12	39	262	153	35	16	26	1.0	156
Usutu B top	2010/03/26	7.29	34	212	124	26	14	24	1.3	132
Usutu B top	2010/03/19	7.47	23	148	71	16	8	18	4.4	79
Usutu B top	2010/06/01	7.47	33	198	117	25	13	23	1.1	126
Usutu B top	2010/07/23	7.22	35	226	125	26	14	26	1.2	142
Usutu E top	2009/07/03	7.37	33	202	130	26	16	18	1.3	258
Usutu E top	2011/02/17	7.07	50	<1	<1	35	11	57	2.8	106
Usutu E top	2010/06/01	7.55	33	206	125	26	15	18	1.3	91
Usutu E top	2010/07/23	7.39	32	212	130	27	16	18	1.4	140
Usutu F top	2011/02/17	6.66	169	<1	<1	176	75	85	5.5	90
Usutu F top	2009/10/06	7.54	44	290	142	34	14	39	2.7	123
Usutu F top	2010/07/23	7.76	40	268	125	29	13	42	2.8	135
Usutu D	2011/02/17	6.54	26	<1	<1	18	5	17	5.6	191
Usutu D	2009/07/03	7.01	25	158	65	18	5	27	1.7	136
Usutu D	2009/10/06	6.87	46	312	116	32	9	50	2.2	138
Usutu D	2010/03/26	6.91	80	608	192	51	16	96	3.5	267
Usutu D	2010/06/01	7.05	24	158	54	16	4	25	2.0	204
Usutu D	2010/07/23	7	28	172	73	21	5	28	1.6	210
Usutu I	2011/02/17	6.2	316			396	108	237	7.1	126

BH number	Date	F	Cl	NO3(N)	SO4	Al	Fe	Mn	NH4(N)
		mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
Usutu A top	2011/02/17	2.06	37	-0.50	154	0.001	0.033	2.67	1.802
Usutu A top	2009/07/03	0.36	6	0.34	10	0.030	2.42	1.09	<1
Usutu A top	2009/10/06	5.93	55	<0.1	310	0.020	0.54	0.39	<1
Usutu A top	2010/03/26	7.4	59	<0.1	360	0.110	0.2	0.4	<1
Usutu A top	2010/06/01	7.59	63	<0.1	338	<1	0.96	0.42	<1
Usutu A top	2010/07/23	6.93	58	<0.1	296	0.040	0.08	0.33	<1
Usutu B top	2011/02/17	0.05	15	0.64	21	0.040	0.050	0	0.181
Usutu B top	2009/07/03	<0.20	15	1.3	20	0.020	<0.01	0.01	<1
Usutu B top	2009/10/06	<0.20	17	1.1	44	<0.01	<0.01	<0.01	<1
Usutu B top	2010/03/26	<0.20	14	0.91	27	<0.01	<0.01	0.03	<1
Usutu B top	2010/03/19	0.43	19	<0.1	23	0.630	1.87	<0.01	<1
Usutu B top	2010/06/01	<0.20	15	0.94	26	<1	<0.01	0.02	<1
Usutu B top	2010/07/23	0.29	14	1.1	25	<0.01	<0.01	0.02	<1
Usutu D	2011/02/17	0.02	9	0.05	1	0.002	0.935	1.36	37.373
Usutu D	2009/07/03	<0.20	11	0.16	16	0.070	1.63	0.23	<1
Usutu D	2009/10/06	<0.20	19	<0.1	125	<0.01	2.68	0.27	<1
Usutu D	2010/03/26	0.36	23	<0.1	275	<0.01	3.55	0.33	<1
Usutu D	2010/06/01	<0.20	12	<0.1	22	<0.01	2.89	0.32	<1
Usutu D	2010/07/23	0.24	9	<0.1	13	<0.01	3.48	0.37	<1
Usutu E top	2009/07/03	<0.20	11	0.46	31	0.090	<0.01	0.01	<1
Usutu E top	2011/02/17	0.41	35	-0.05	9	0.000	0.150	0.20	2.068
Usutu E top	2010/06/01	<0.20	9	0.11	33	<0.01	<0.01	<0.01	<1
Usutu E top	2010/07/23	<0.20	10	0.18	33	<0.01	0.02	0.02	<1
Usutu F top	2011/02/17	0.52	22	0.35	669	-0.004	0.060	1.24	0.596
Usutu F top	2009/10/06	0.64	13	0.81	22	<0.01	<0.01	<0.01	<1
Usutu F top	2010/07/23	0.81	15	0.42	6	0.020	0.02	<0.01	<1
Usutu I	2011/02/17	0.22	26	-0.50	1942	-0.005	0.030	2.14	4.174

Table 10: Results of the chemical analyses for the boreholes sampled during the hydrocensus February 2011.

BH Number	pH	EC	Ca	Mg	Na	K	PAlk	MAlk	F	Cl
		mS/m	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
Usutu A-Bottom	8.05	295	17	7	776	4.2	0	1250	6.10	62
Usutu A-Top	7.4	194	24	17	461	3.3	0	919	2.06	37
Usutu B-Bottom	7.01	158	84	34	221	3.3	0	241	0.20	29
Usutu B-Top	7.21	32	29	13	18	1.8	0	121	0.05	15
Usutu D-Usutu	6.54	26	18	5	17	5.6	0	258	0.02	9
Usutu E-Bottom	7.04	49	33	11	59	2.7	0	189	0.39	35
Usutu E-Top	7.07	50	35	11	57	2.8	0	191	0.41	35
Usutu F-Bottom	6.61	192	223	95	97	6.6	0	296	0.28	26
Usutu F-Top	6.66	169	176	75	85	5.5	0	267	0.52	22
Usutu I-Usutu	6.2	316	396	108	237	7.1	0	126	0.22	26

BH Number	NO2(N)	Br	NO3(N)	PO4	SO4	Al	Fe	Mn	NH4(N)
	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
Usutu A-Bottom	<0.1	<0.4	<0.5	<1	385	0.005	0.08	0.06	2.85
Usutu A-Top	<0.1	<0.4	<0.5	<1	154	0.001	0.03	2.67	1.80
Usutu B-Bottom	<0.1	<0.4	0.22	<1	578	0.002	0.04	0.04	1.18
Usutu B-Top	<0.01	0.04	0.64	<0.1	21	0.040	0.05	0.00	0.18
Usutu D-Usutu	0.07	<0.04	0.05	<0.1	1	0.002	0.93	1.36	37.37
Usutu E-Bottom	<0.01	<0.04	<0.05	<0.1	9	0.002	0.23	0.28	0.96
Usutu E-Top	<0.01	<0.04	<0.05	0.10	9	0.000	0.15	0.20	2.07
Usutu F-Bottom	<0.1	0.14	0.20	0.39	905	<0.004	0.07	1.13	1.38
Usutu F-Top	<0.1	<0.4	0.35	0.34	669	<0.004	0.06	1.24	0.60
Usutu I-Usutu	<0.1	<0.4	<0.5	<1	1942	<0.004	0.03	2.14	4.17

It is clear from this table that there is a definite difference in water quality of the top and bottom samples of those boreholes drilled into the mining cavity.

- Usutu D is not drilled into the mine, as is clear from the water quality.
- Usutu A indicates high sodium and alkalinity with sulphate values slightly elevated but still within the drinking water standards. It appears as though the formation has an influence on the water quality in this borehole, even at the top (see also the Stiff diagram in Figure 58).
- Usutu B also differs top and bottom. Again the sodium is elevated in the bottom sample, with the difference that the sulphate is elevated and not the alkalinity; the coal seam has a definite influence on the sample in the mining cavity.
- Usutu E shows no influence from mining activities; it is not clear whether this borehole is drilled into the mining cavity or perhaps into a pillar.
- Usutu F and Usutu I show typical coal water reactions, with high sulphate, calcites and magnesium (see also the Stiff diagram in Figure 58). The mining depth in this area is shallow compared with the B-seam in the southern mine. It is likely that there is less buffering material, hence the acid rock drainage (ARD) reactions and the subsequent decrease in pH.

The expanded Durov diagram clearly indicates that Usutu F and I are mine water, while Usutu B top, Usutu E top and Usutu D are unpolluted (see Appendix for explanation of the Durov interpretation). Usutu A and Usutu E bottom are coal mine water.

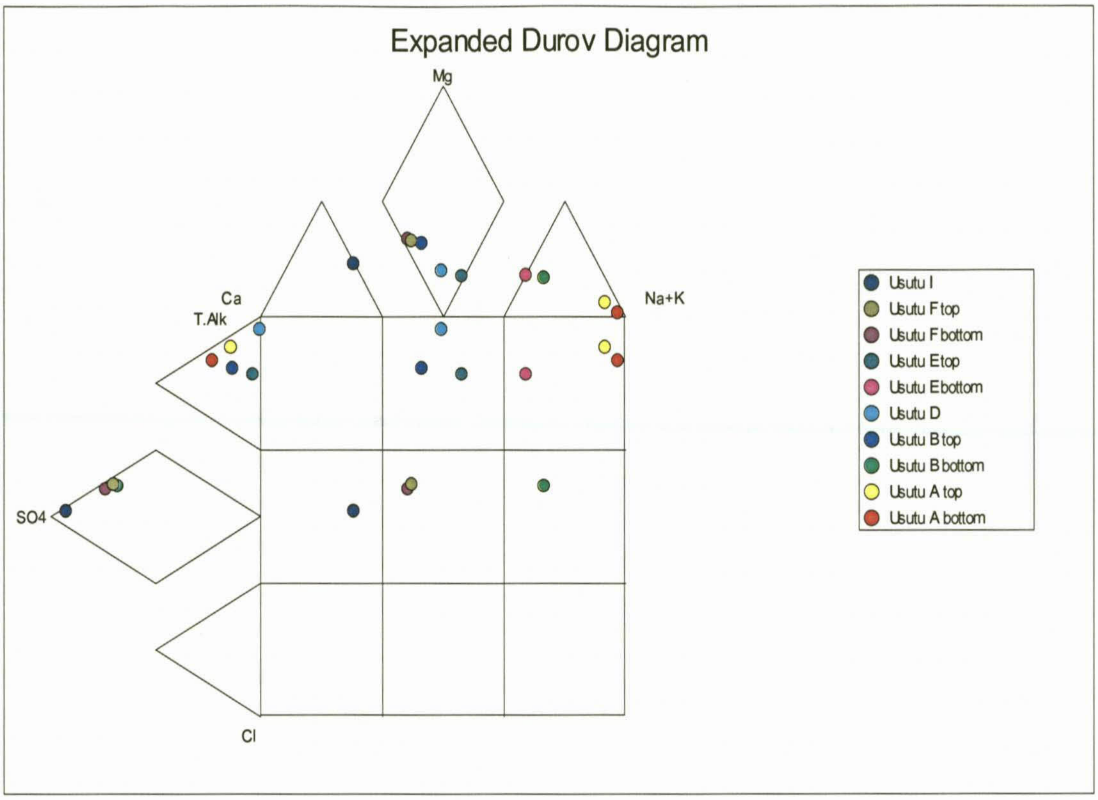


Figure 55: Expanded Durov diagram of the Usutu boreholes.

Two boreholes were profiled for EC. Usutu F (Figure 57) clearly illustrates the polluted water in the mining cavity compared with higher up in the water column. Usutu A also differs in depth, but the change happens halfway down the water column, strengthening the statement that the sodium bicarbonate water is geology-related.

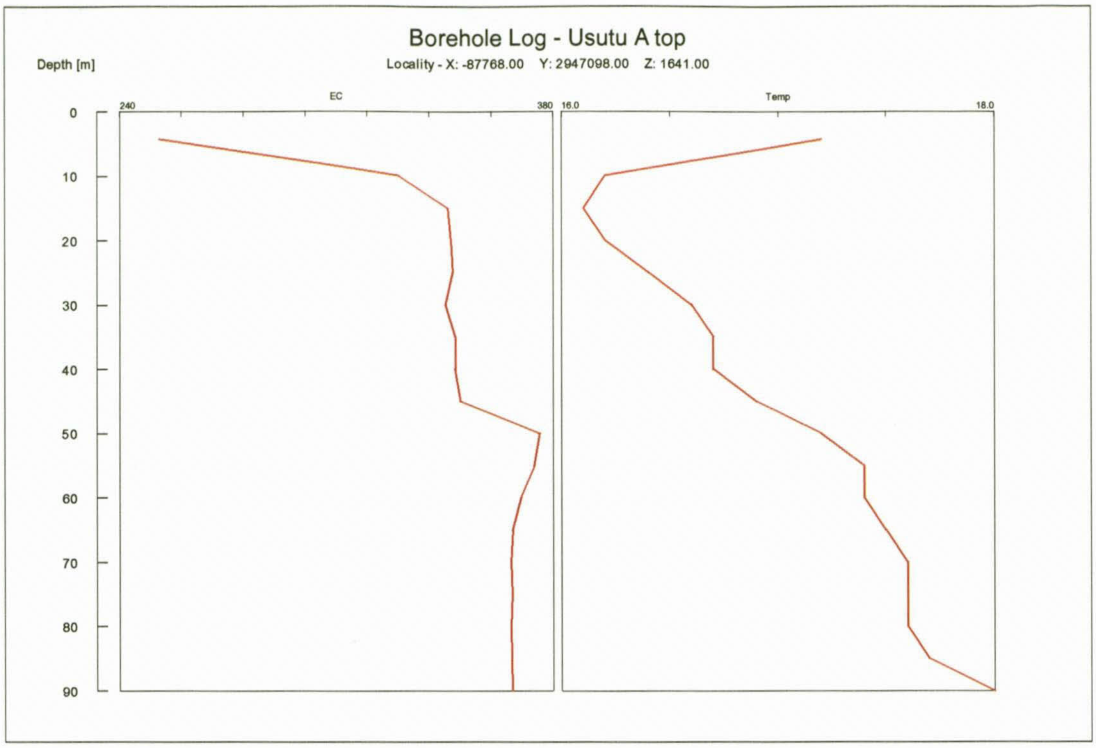


Figure 56: EC profiling for Usutu A.

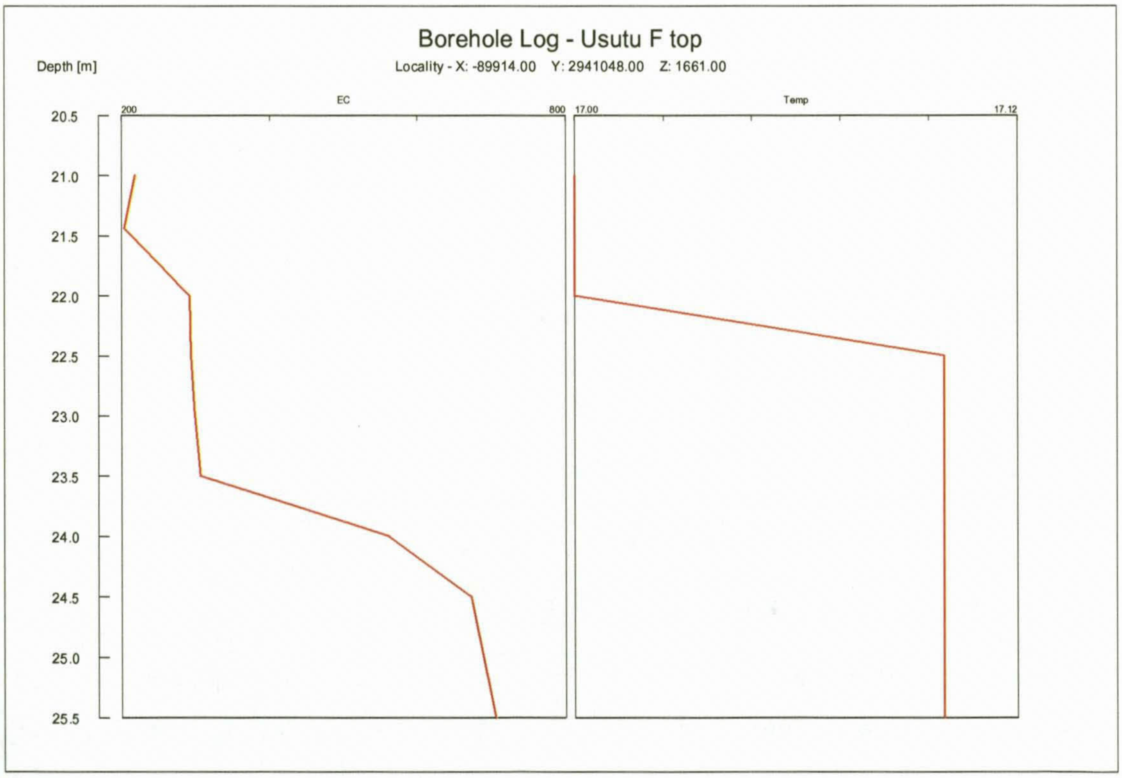


Figure 57: EC profiling for Usutu F.

Another interesting and conclusive way of comparing the different waters that emanate from the coalfields is using the so-called Stiff diagram as explained by Grobbelaar et *a.*, (2004). This allows comparison between six components for each site. The six components are usually calcium, magnesium, sodium + potassium, alkalinity, sulphate and chloride + nitrate. Each of these is plotted on horizontal axes, with cations to the left and anions to the right. The extremities of the points are connected and the inside is coloured, thus creating unique shapes that represent the overall chemistries for each site. While these diagrams may appear to be highly varied in shape, this is exactly the purpose of this plot. It characterizes water with a unique signature, clearly showing the dominant constituents at each of the sites.

The Stiff diagrams of the boreholes (which compare the water qualities in equivalents) also illustrate in Figure 58 that the bottom samples are more polluted than the top samples, with Usutu I and to a lesser degree Usutu F (bottom) very typical coal mine water.

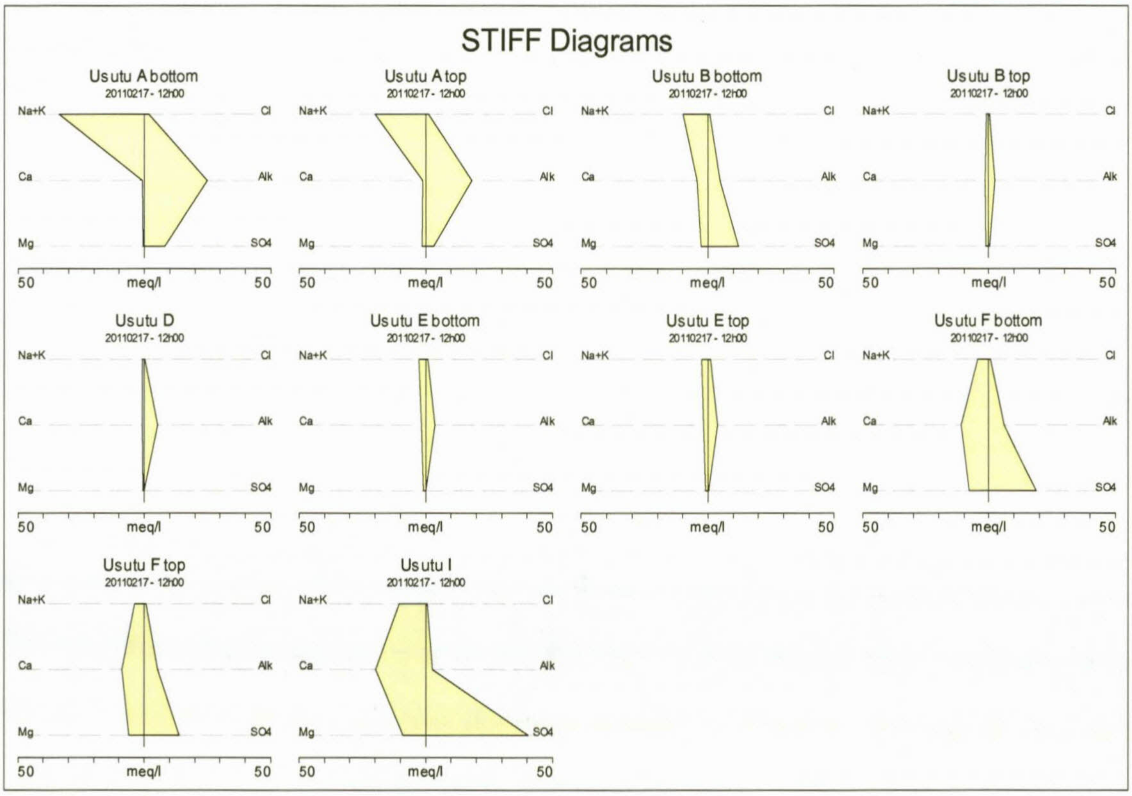


Figure 58: Stiff diagrams of the mine boreholes.

The time graph of the mine boreholes indicates that the water quality for the top boreholes did not deteriorate since 2009. The time graphs of all the macro-elements follow the same trend. Only Usutu F shows a different value, but this may be because the borehole was sampled at a different depth during the hydrocensus (the water in this borehole is only 6 m deep).

Figure 59 Usutu A shown in red shows typical mine water development where it increases, stabilizes and then decreases. The bottom sampled samples shows higher EC values than the top sampled. This is due to stratification and when sampling at the bottom the water sampled is located inside the mine.

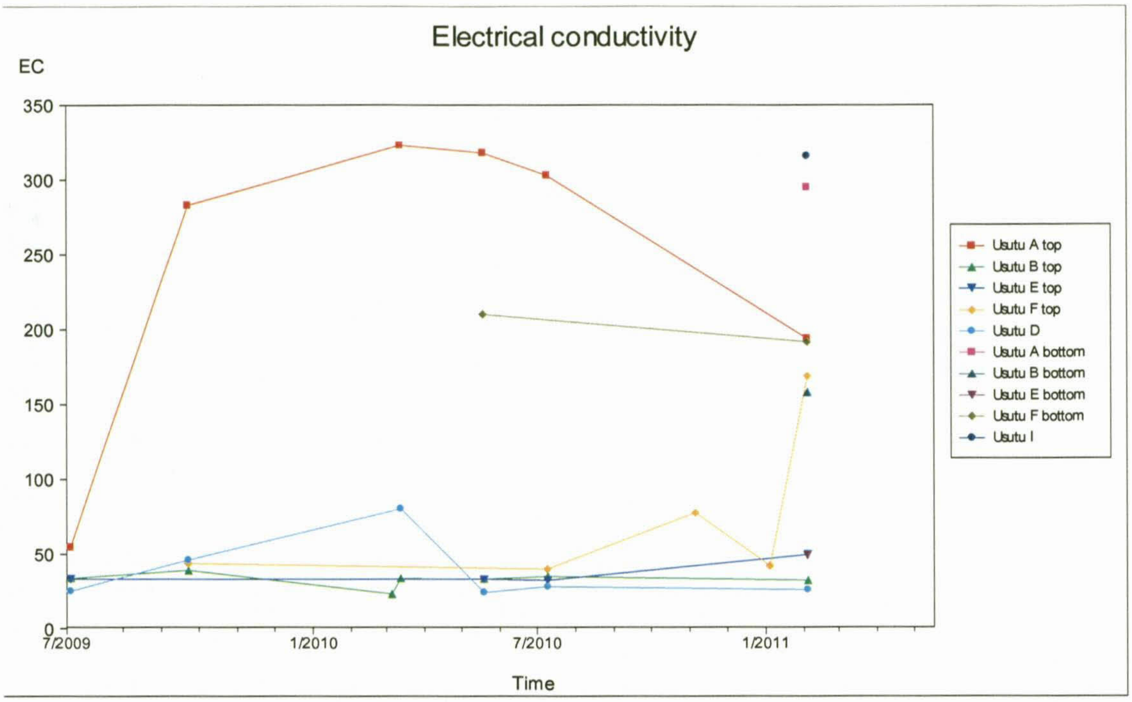


Figure 59: Time graph of the EC for the mine boreholes.

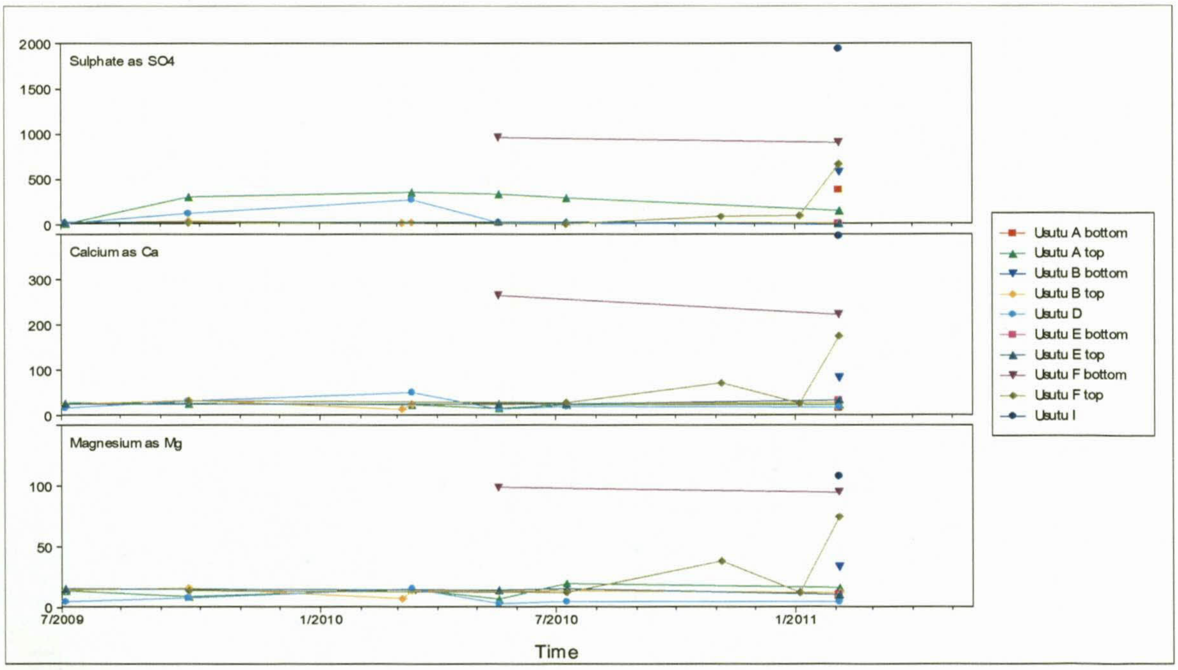


Figure 60: Time graph of sulphate, calcium and magnesium of the mine boreholes.

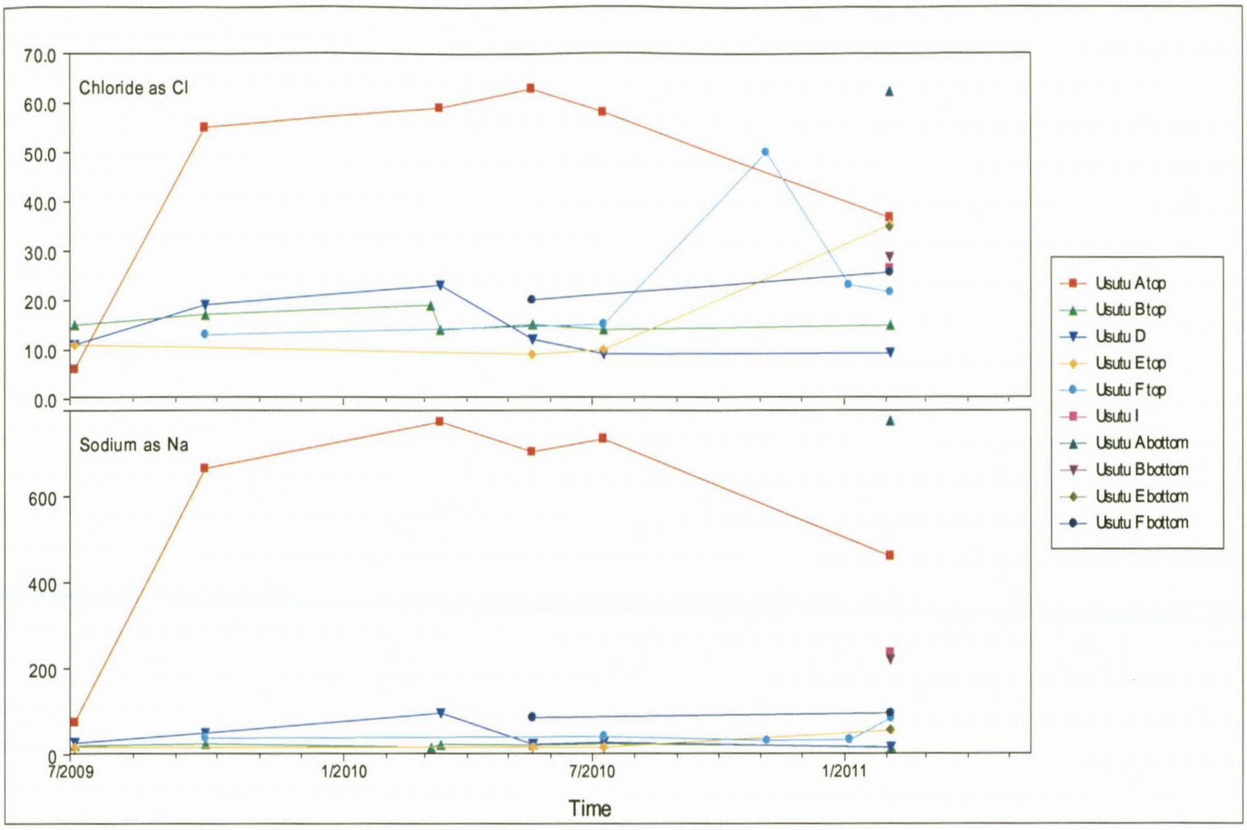


Figure 61: Time graph of sodium and chloride of the mine boreholes.

3.19.1 Regional water quality

The EC of only two farm boreholes is available, namely Farm 2 and Farm 6. These are depicted in Figure 62. From this it is clear that the regional aquifer water quality is similar to that of the "top" samples in the mine boreholes, indicating aquifer water for most areas above the mine; the exceptions are Usutu A, which has completely different sodium-bicarbonate water, and Usutu F which has only a few metres of water above the mining cavity. This is also clearly shown in the Stiff diagrams of the top mine samples and the farm samples (Figure 63). Usutu A top shows typical mine water characteristics with high levels of Na, K and Cl. Usutu F top shows high levels of pollution with high SO_4 values.

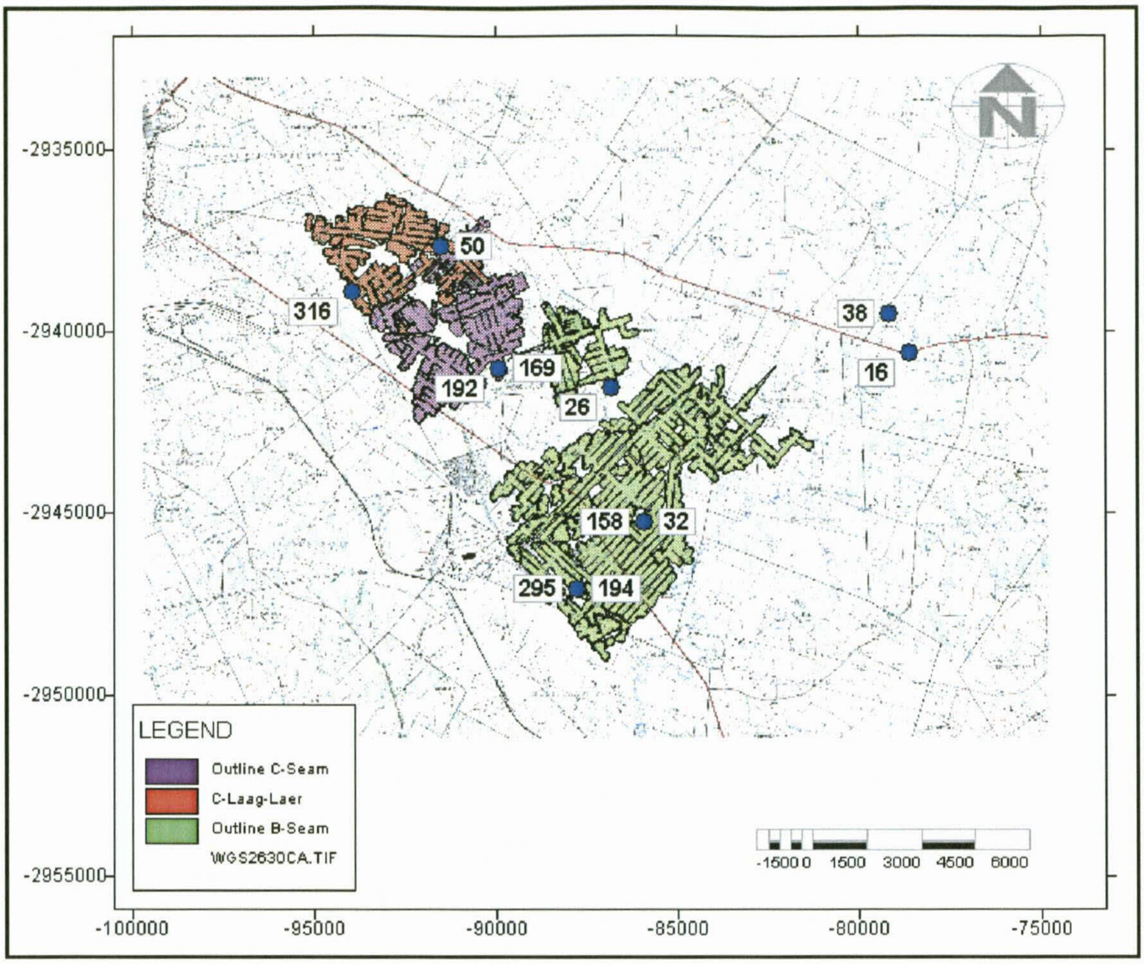


Figure 62: EC of all the boreholes measured during the hydrocensus in 2011.

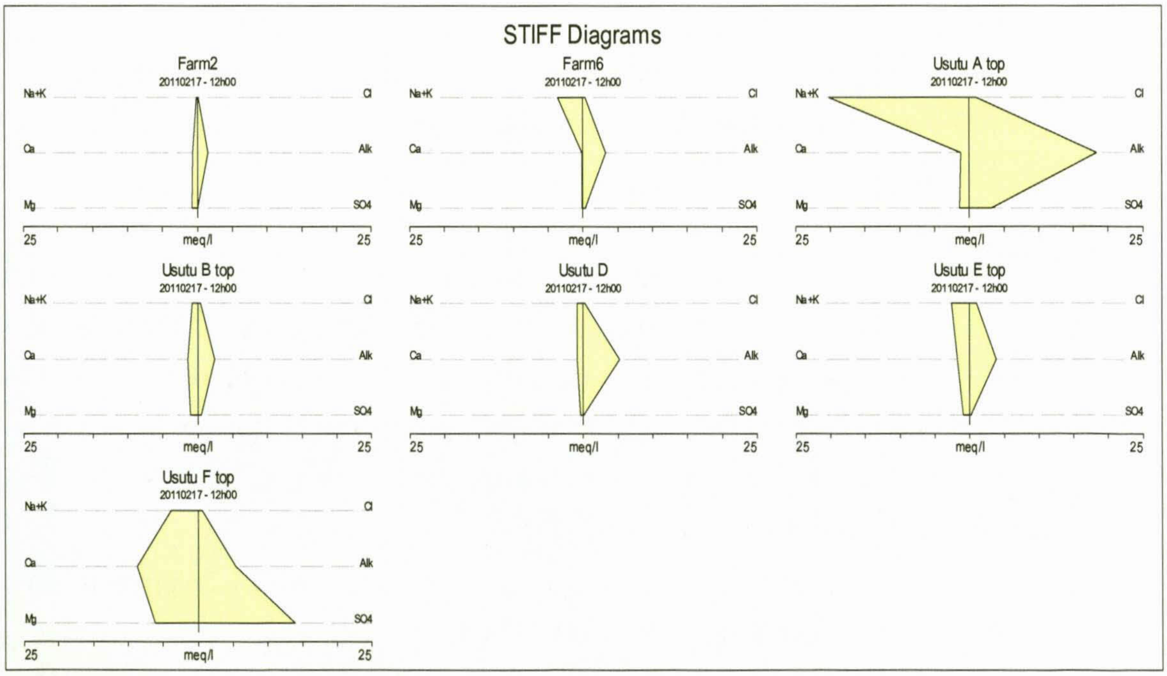


Figure 63: Stiff diagrams of the top mine samples and the farm samples.

3.20 Conclusions and recommendations

The following conclusions are drawn from this case study:

- The area topography slopes mostly away from the mining area to the south with an average slope of 3.2%, as the mining area is situated on a topographic high in the northern part.
- Non-perennial rivers exist in the area.

Water levels and quality:

- The average regional water level is currently less than 4 m. Some of the farm boreholes to the north of the mine are being pumped, resulting in water levels of deeper than 20 m. In the hydrocensus it was noted that usually one borehole was being pumped from at a farm.
- The water levels of the boreholes inside the mine differ for the two mines. The water levels in the southern mine is shallower than those in the northern mine. However, the water levels differ substantially in the different boreholes, most likely the result of compartmentalization due to the walls. This makes interpretation of the mine water levels very difficult, and a number of additional boreholes have to be drilled to get a clear indication of the exact water levels in the mine.
- The regional aquifer water quality is similar to that of the "top" samples in the mine boreholes, indicating aquifer water for most areas above the mine.
- The bottom samples are more polluted than the top samples, with Usutu I and to a lesser degree Usutu F (bottom) very typical coal mine water. The mine boreholes indicate that the water quality for the top boreholes did not deteriorate since 2009. It also appears that there is a minimum stratification in the water columns in the two mines. As there are a number of ventilation seals in the mine, they reduce any change of pressure that can "push" the mine cavity water up to a decant level. At no point is the mining cavity close to the surface. Therefore no pressure can be created from the water in the mining cavity for mine water to decant. It is therefore unlikely that the borehole that decanted resulted from pressure that has been created from inside the mining cavity.
- The regional recharge was calculated as 5.7% by using the Chloride method. Recharge into the mine was calculated as >5%.

Mining data:

- The average mining height of 1.6 m.
- The combined C-seam varied in depth from very shallow (5 m) to nearly 80 m in the north. The southern mine, where the B-seam was mined, varied between 75 m and 160 m.
- Also important is the barrier between different mines, which will determine mine interflow. The shortest distance of the pillar between the collieries is 250 m. The faults and dykes also play a role in compartmentalizing the mine as it normally also displaced the coal seams vertically.
- High extraction areas were also identified from the old maps. These areas may result in subsidence, increasing the recharge factor into the mine
- The total water make for the B-seam is 2 687 m^3/day and for the C-seam 1 612 m^3/day. The total water in the C-seam is currently 19.1 Mm^3. For the B-seam the total water volume is 22.88 Mm^3.

Recommendations

- It is recommended that the monitoring programme in the mine be executed properly with water being sampled in the mining cavity and higher up in the water column very quarter that is 4 times a year of all the Usutu boreholes. More boreholes into the mining cavity will also contribute to a better understanding of the current water volumes.
- It is further concluded that flooding is also influenced by factors occurring in and around the mine. Thus in looking at the influence of flooding the bigger picture is important. This makes the management of a flooded mine very complex. The compartmentalization of the mine makes it even more difficult to interpret the data.
- The final conclusion is that if flooding is well managed it is a very successful operation in managing a mine through preventing acid generation. This is done by depleting the oxygen component in acid generation.

CHAPTER 4

KILBARCHAN MINE, NEWCASTLE: CASE STUDY

4.1 Introduction

Kilbarchan is applying for partial closure and also needs to know what the current groundwater status of the mine water quality is. The coal mine has been flooded (recharged) with water as the production stopped between 1990 and 1992.

The coalmines in KwaZulu-Natal are another example of mining impact on water resources. The coal-mines are situated in a topographically dissected area, where coal seams outcrop above the valley bottoms. In most of the collieries, high extraction mining methods were used: bord-and-pillar followed by pillar extraction and long wall mining (at one mine). The result of the high extraction mining at all of these mines has been the collapse of the overlying strata

Rainwater easily moves through the mining-induced fractures in the collapsed strata. The water is contaminated (acidified) through the oxidation of pyrite in the rocks and loose material left in the mines. Because of the limited water retention in the mine openings, most of them decant water from sub-outcrop areas or shafts, into the valleys below. Coal discard dumps have been left on the surface at the coalmines in Natal, in different states of rehabilitation, adding an additional source of water pollution (Zeelie & Hodgson, n.d.).

As a result of this, the Department of Water Affairs and Forestry (DWA&F) had to review their catchment water quality standards for some of the catchments. Sulphate concentrations of up to 1 000 mg/L in the Black-Mfolozi and the Nkongolana Rivers are allowed (Zeelie & Hodgson, n.d.).

Some of the larger coalmines have closed or are in the process of applying for closure certificates. Many other mines have simply been abandoned and very little information is available regarding conditions in the mine or their possible impact on the water resources (Zeelie & Hodgson, n.d.).

Figure 64: Picture of the Kwazulu-Natal area (Zeelie & Hodgson, n.d.).

4.2 Locality

Kilbarchan colliery is located 10 km south of Newcastle in KwaZulu-Natal. It comprises two underground sections, called Roy Point and Kilbarchan. Figure 67 shows the location of Kilbarchan colliery with the two sections Kilbarchan and Roy Point. The Ingagane River runs along the eastern side of the colliery. The mine supplied coal to the Ingagane power station, to the east of the mine. To the south of Kilbarchan lays Natal Cambrian Colliery, which has also closed down.

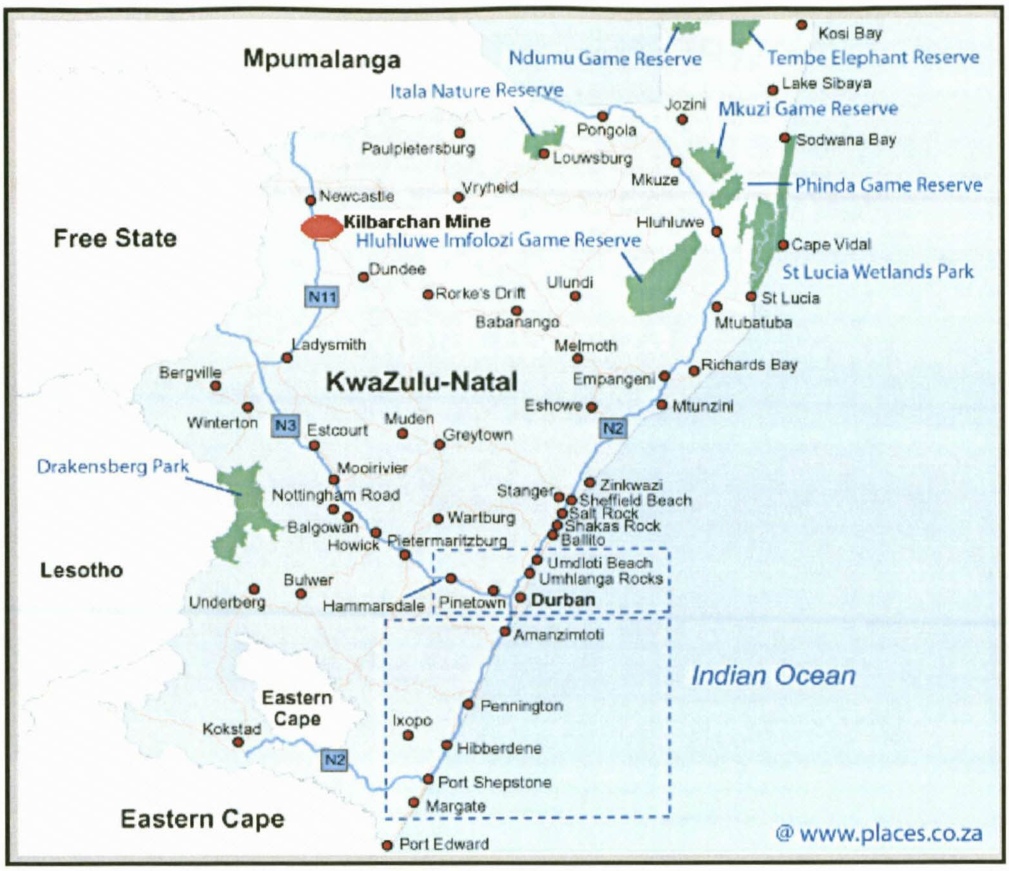


Figure 65: Location of Kilbarchan Mine in South Africa (www.places.co.za).

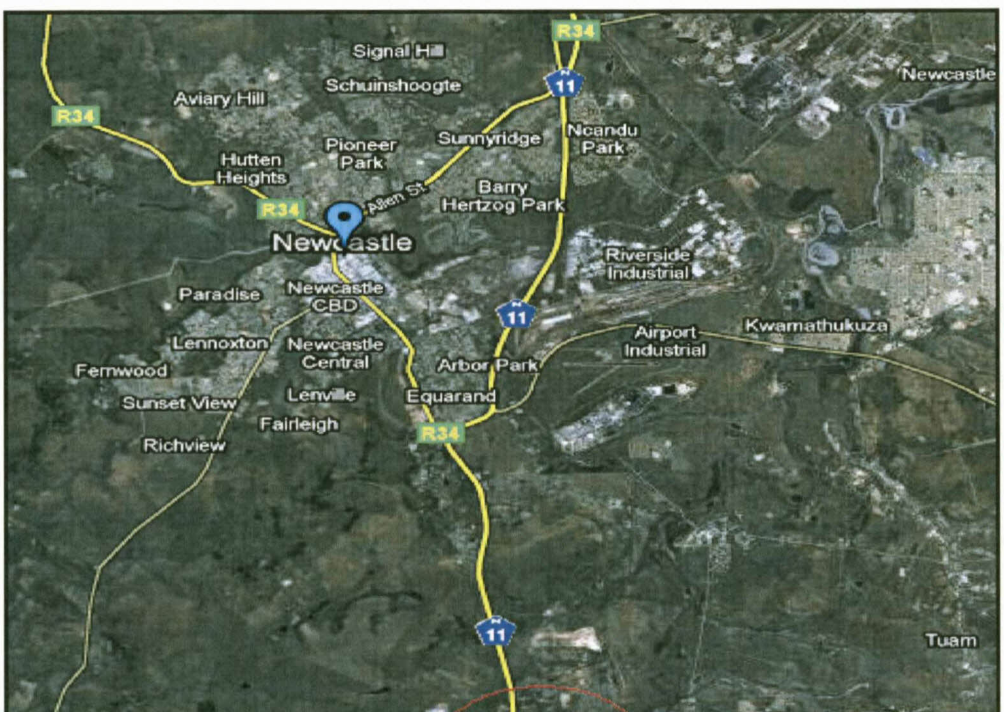


Figure 66: The location of Kilbarchan mine in Google earth image (Source: Google earth).

4.3 Topography

Significant topographic differences are present in the KwaZulu-Natal coalfields. Coal deposits have, in many instances, only been preserved within the mountains. Outcrops of coal are therefore plentiful along many of the mountain slopes. In these instances, the depth of the coal seams below surface typically ranges from 0 m to more than 100 m below surface. Access to these coal deposits has been gained by tunneling into the mountainside (Hodgson *et al.*, 2007).

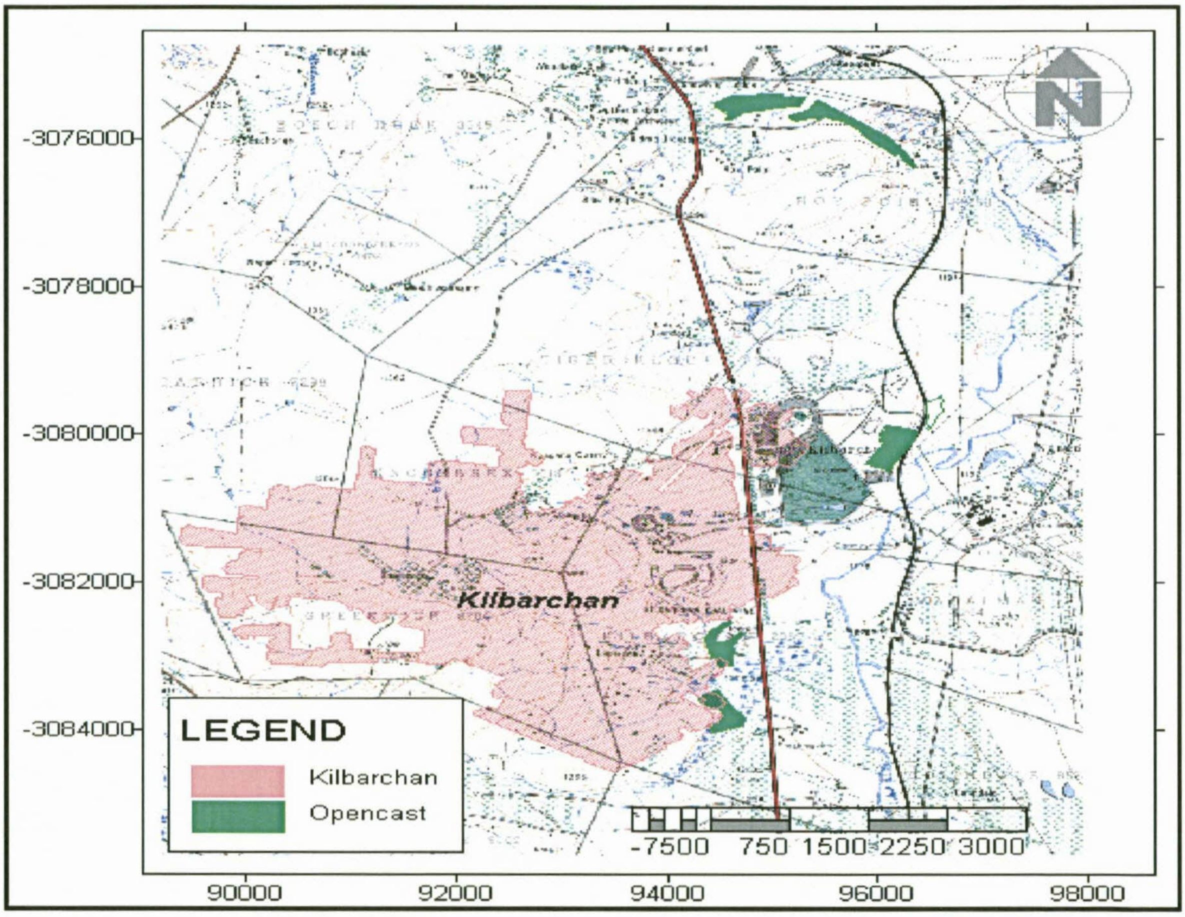


Figure 67: Location of Kilbarchan colliery in the investigation.

4.4 Land use

Most undermined land has been sold to commercial farmers or has been donated to local communities for carrying out farming activities. Former mining communities in KwaZulu-Natal have benefited from timber plantations facilitated by the closing mines through seasonal jobs to maintain plantations, as well as income generated from the sale of mature timber to milling companies. Taking into consideration land-use limitations imposed by previous mining activities, district and local municipalities of KwaZulu Natal are of the view that large-scale economic revival of former mining areas should include: tourism, through the marketing of former Zulu-English battlefields; the small-scale mining of previously mined areas; and further promotion of commercial agricultural activities in former mining areas (Nthabiseng, Molapo & Chunderdoojh, 2006)

4.5 Rainfall and climate

The annual rainfall (MAP) of the area is 864 mm (rainfall stations: Kilbarchan offices and Roy Point. Figure 68 shows a graph of the average rainfall for Kilbarchan area. The average temperature is high for most of the year, but the highest in December and January. High rainfall occurs from November to February and a low rainfall in the winter months from May-July.

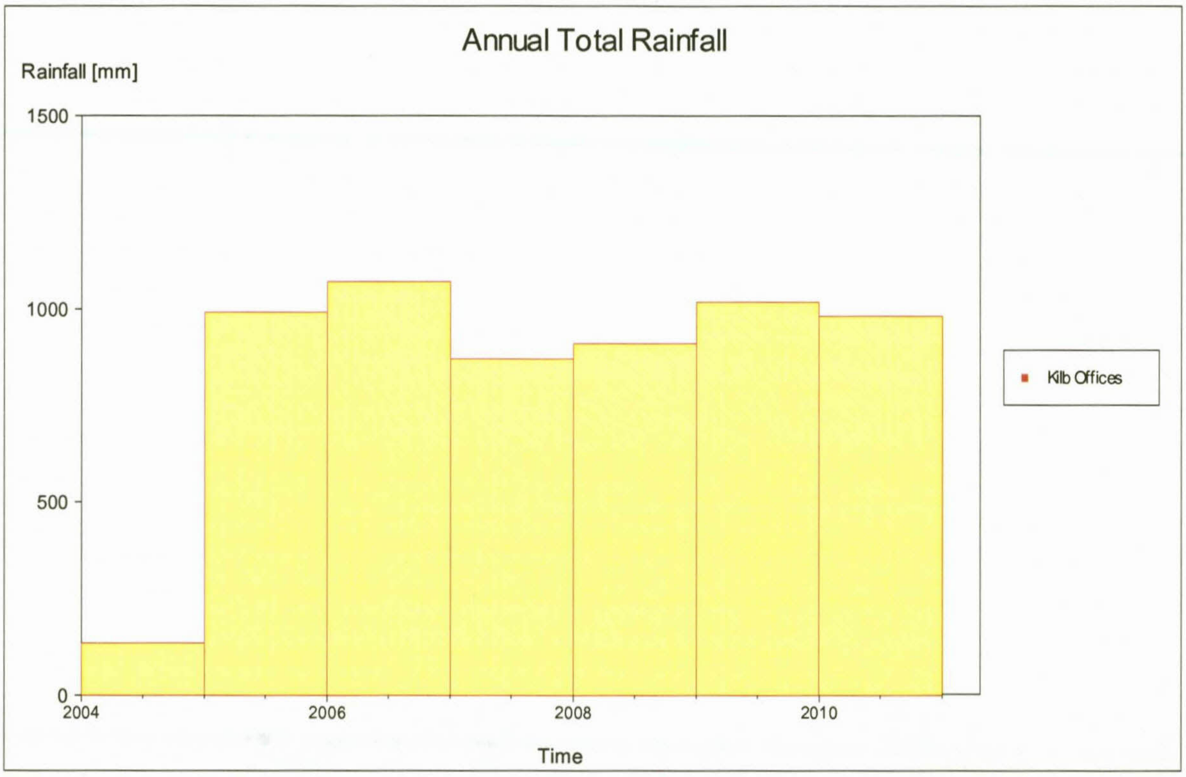


Figure 68: Rainfall graph for Newcastle.

4.6 Mine details

Mining activity ceased in 1992. Bord-and-pillar mining followed by stooping has been the main mining method. Extraction percentages are 50% at a height of 3.5 m (Figure 69). Floor contours are undulating and several low lying areas exist (Hodgson, 2006). The mining outline of the two mining areas Kilbarchan and Roy Point is shown in Figure 70.

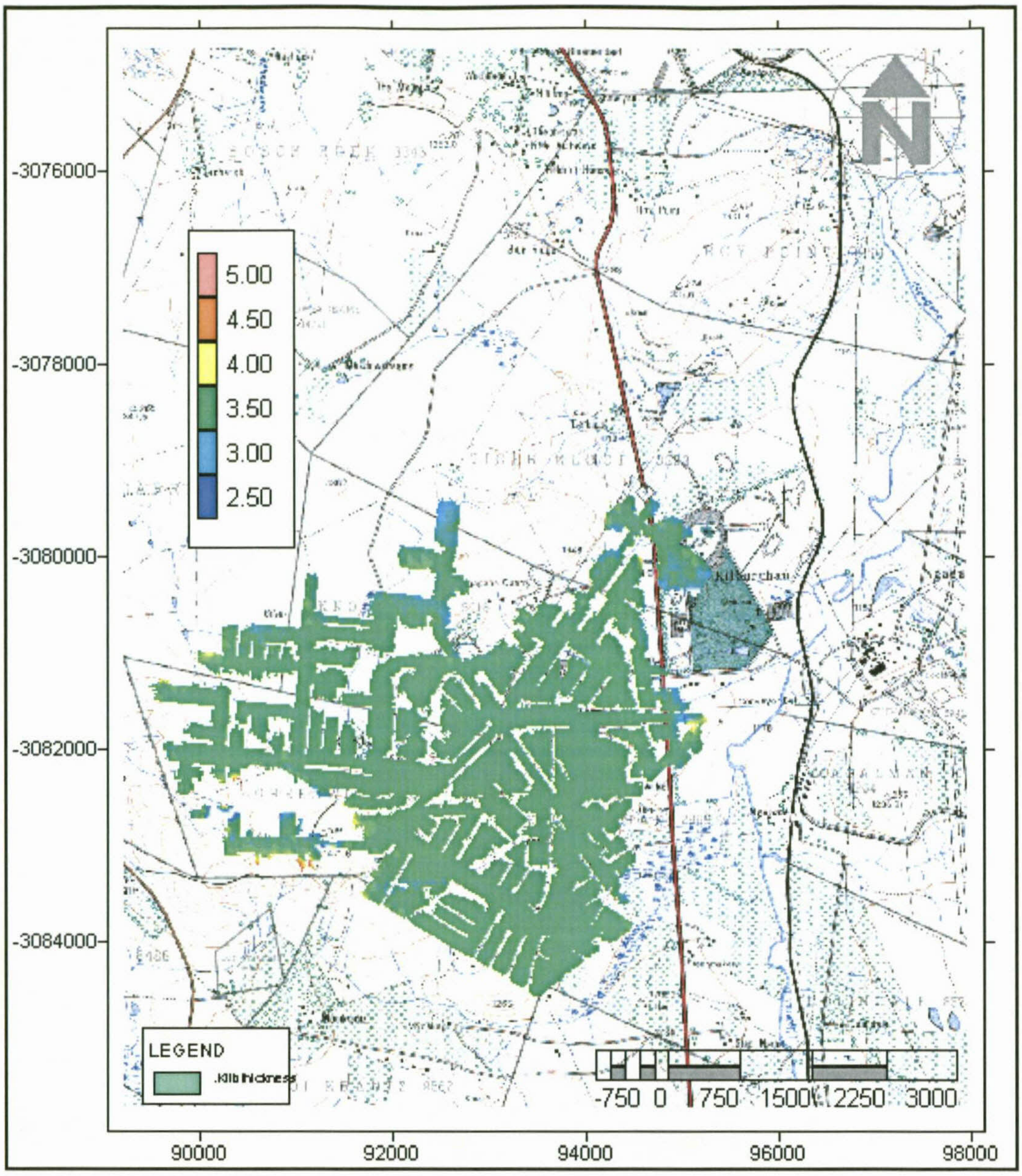


Figure 69: Extraction percentages are 50% at a height of 3, 5 m.

Opencast mining was performed to extend the life of the mine where the depth to the coal seam was less than 20 m. Five opencast sections have been mined. The average depth of mining was 11 m for opencast 1 and 15 m for the other areas. Of the opencast pits only 1A and 1B connect to the underground workings. These connections were sealed off with concrete plugs. In a previous report (Hodgson, 2006) it was indicated that the seals were destroyed by blasting in 1992. Thus water moved from the opencast into the underground workings. This will influence the water quality with the water seeping through, because the water from the opencast is rich in oxygen. This means oxygen will move into the system.

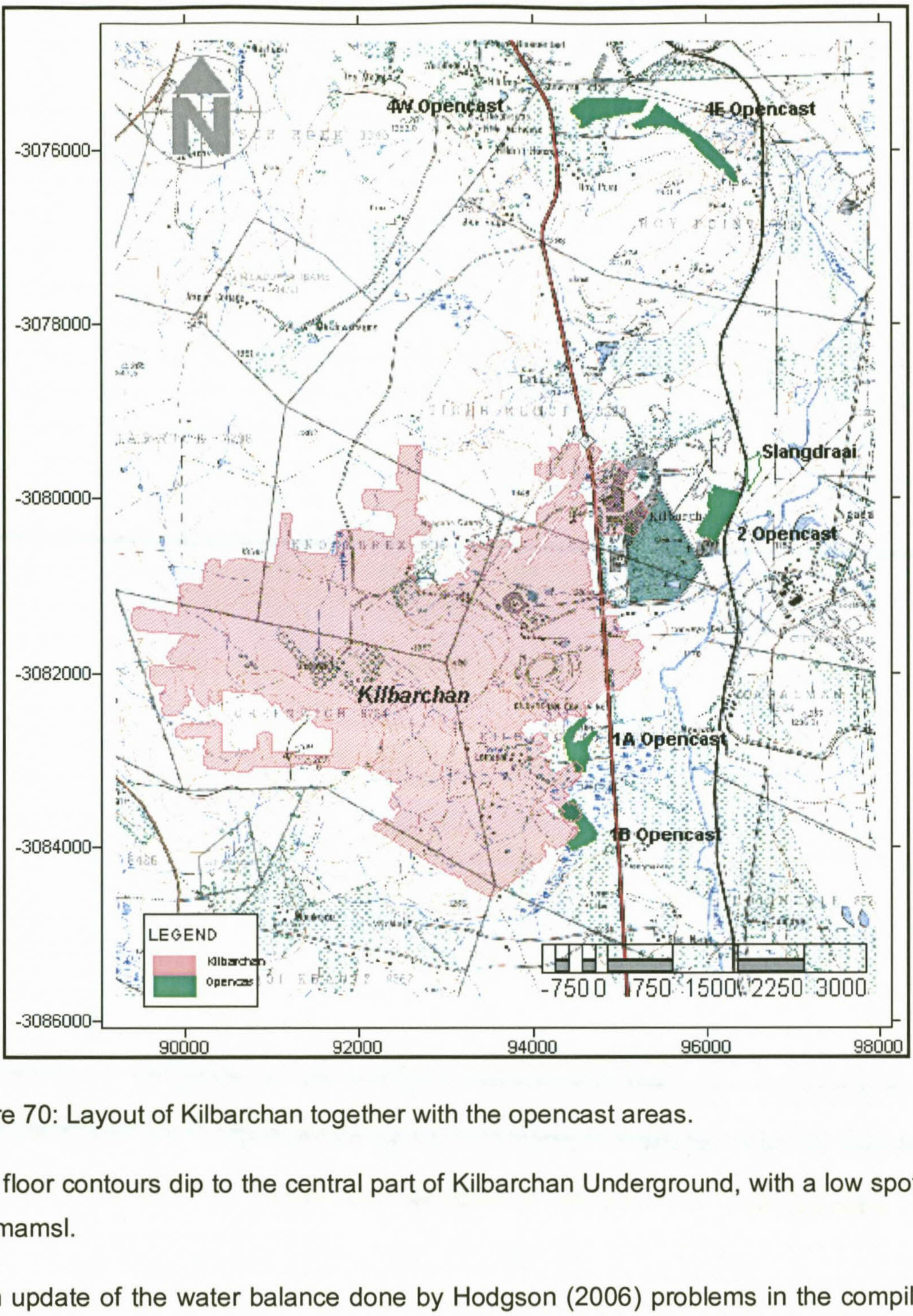


Figure 70: Layout of Kilbarchan together with the opencast areas.

Coal floor contours dip to the central part of Kilbarchan Underground, with a low spot at 1 144 mamsl.

In an update of the water balance done by Hodgson (2006) problems in the compilation of coal floor and roof contours were plentiful. Not only does the Kilbarchan section date back to the fifties, but the maps are in a coordinate system that is no longer in use. Converting the large maps into digital format presented a major challenge, hence only the outlines of the mines were digitized by hand (by Jones and Wagener). Scanning and vectorising of the detailed mine plans proved to be too costly.

Looking at the coal floor and surface contours we can clearly see that the mining depth was shallow. The depth of mining is in the range of 0 to 200m; in the eastern part the mining is much shallower than in the western part shown in Figure 72. In the eastern part the depth is between 0 to 120m and in the western part 120 to 200m.

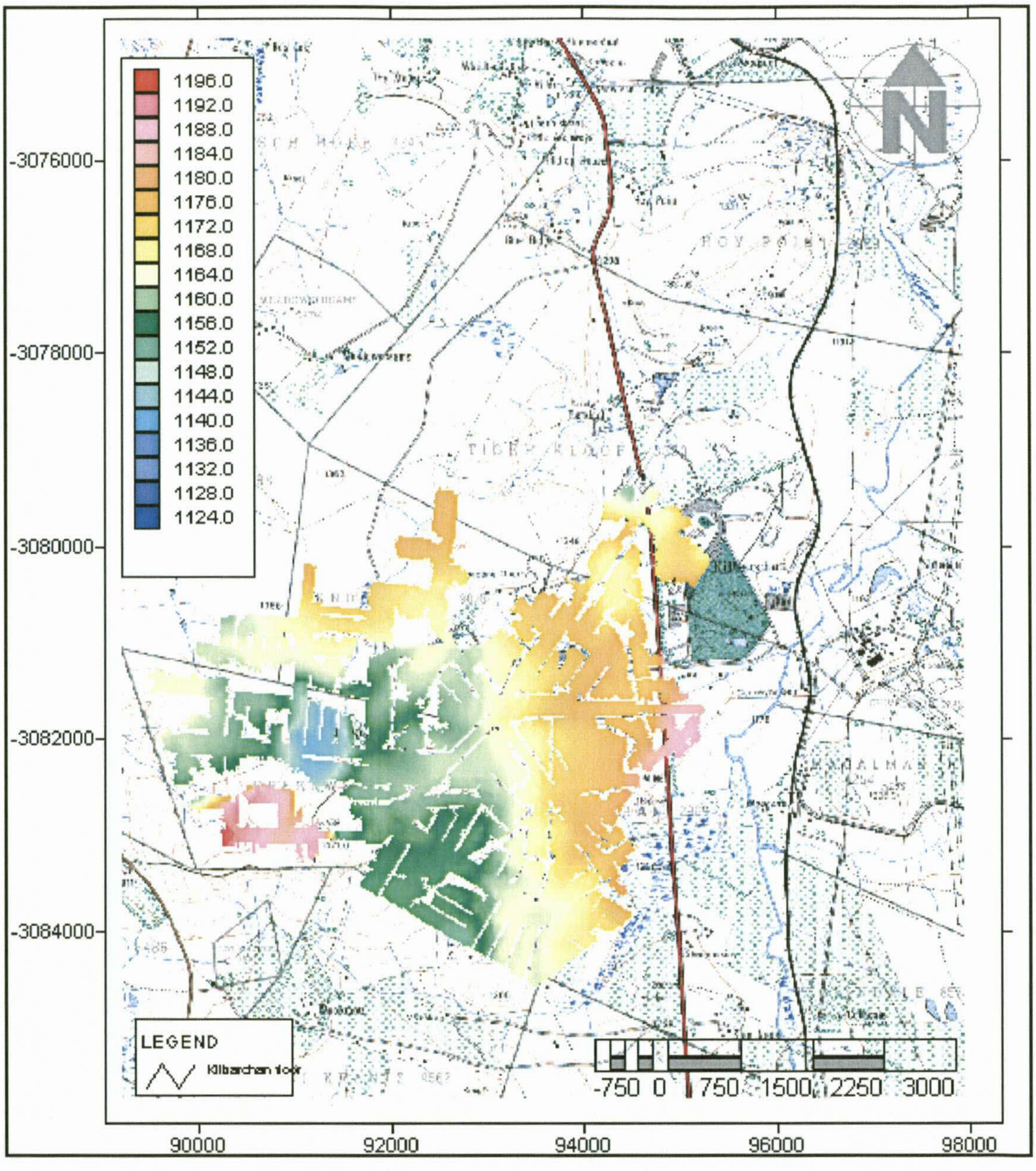


Figure 71: Kilbarchan coal floor contours (mamsl).

Figure 72 shows the depth of mining at Kilbarchan. The depth of mining is important, because it plays a role in the residence time of the water flow.

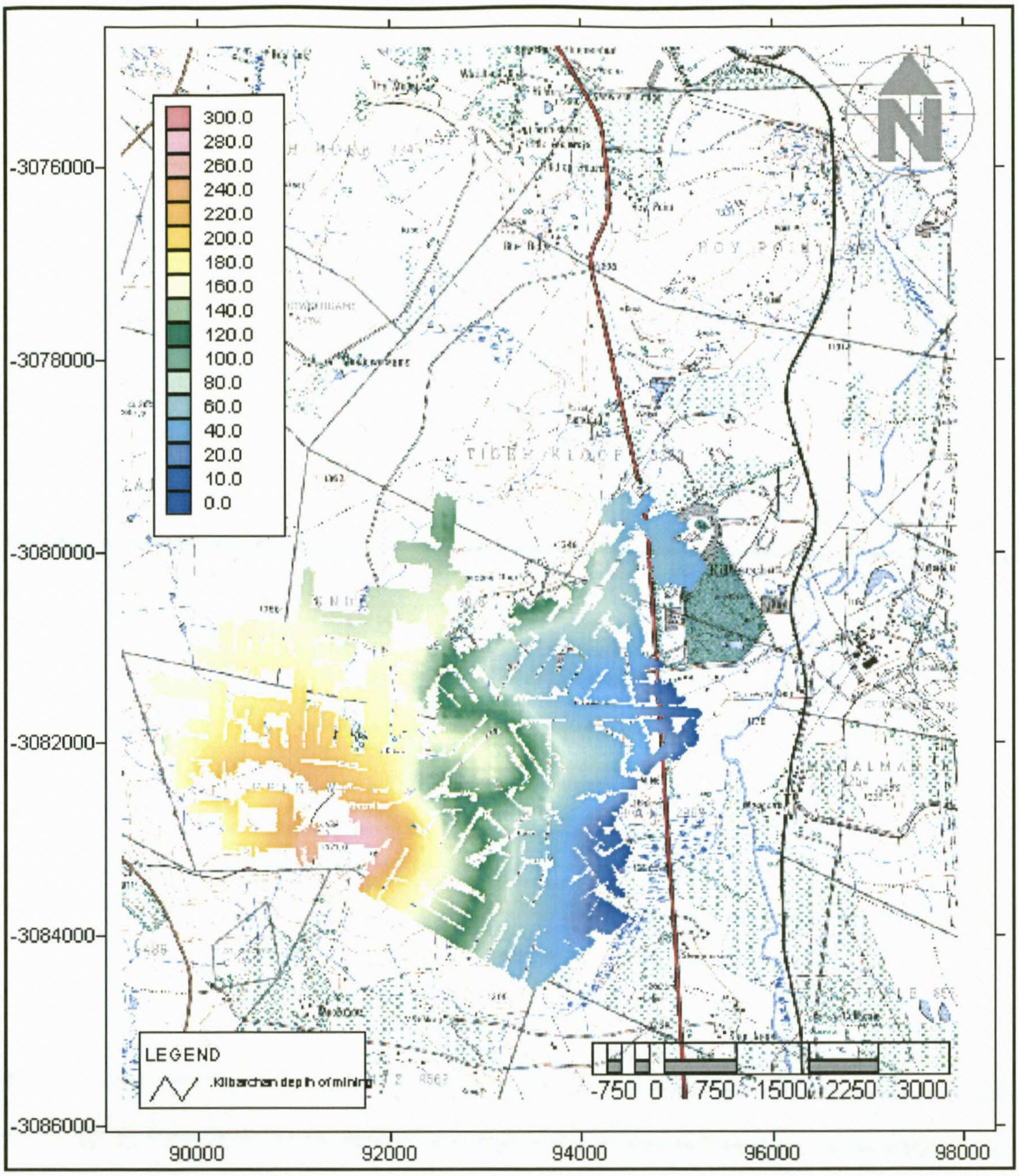


Figure 72: Depth of mining at Kilbarchan.

4.7 Geology

The Kilbarchan Colliery is situated within the Klip River Coal Field, comprising rocks of the coal bearing Vryheid Formation forming part of the Ecca Group of the Karoo Supergroup. Two economic coal seams can be distinguished (Bottom & Top Seams) within the Klip River Coal Field and is separated by 0.3 to 15 m of coarse-grained, pebbly sandstone which fines upwards to carbonaceous shale. The Bottom Seam has a thickness of 1.3 m in the north of the coal field, decreasing to 50 cm towards the southern area. The Top Seam has a thickness of 3.5 m in the north, decreasing to less than 0.5 m in the central area and then increasing to 1.5 m in the south (Wilson & Anhaeusser, 1998).

4.8 General Hydrogeology

Three groundwater systems are normally present in the mining areas of the Ecca formations. These are the shallow weathered aquifer, the intermediate unweathered fractured Karoo, and the coal seams (mining area).

The weathered groundwater system:

The top 5 - 15 m in the area consists of soil and weathered rock. The upper aquifer is associated with this weathered horizon. 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.

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 a 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.

Coal Seam (mine):

This system is mined out, with a much higher transmissivity value than the layers above and below it.

- The transmissivity (T)-value of the mined coal seam is very high (in the order of thousands) and the storativity (S) is also very high (50% in the mined out section as opposed to approximately 0.1% in typical Karoo aquifers).
- Once the mine has filled up with water, a horizontal piesometric level will occur (this piesometric level is also horizontal during the filling up process). If the piesometric level intersects the surface, decant could take place at the point of intersection if there is a link between this position and the mine (e.g. a borehole).

4.9 Recharge

The assumption necessary for the successful application of the chloride method to determine recharge is that there is no source of chloride in the soil water or groundwater other than that from precipitation. Chloride is conservative in the system. Steady-state conditions are maintained with respect to long-term precipitation and chloride concentration in that precipitation, and in the case of the unsaturated zone. However, this assumption may be invalidated if the flow through the unsaturated zone is along preferred pathways (Van Tonder & Xu, 2000).

In areas of extensive underground high extraction, it can be safely assumed that all recharged water will migrate downwards to enter into the collapsed mine workings. Under undisturbed conditions, 3% of the annual recharge would be an acceptable average value. Under disturbed conditions above long wall panels, recharge is likely to be greater and 5% of the annual rainfall would be a good first estimate (Hodgson, 2006).

General Equation: $R = (P\ Cl_p + D)/Cl$

[R = recharge (mm/a); P = mean annual precipitation (mm/a); Cl_p = chloride in rain (mg/l); D = dry chloride deposition (mg/m^2/a); $Cl_w = Cl_{sw}$ = chloride concentration (mg/l) in soil water below active root zone in unsaturated zone OR $Cl_w = Cl_{gw}$ = chloride concentration (mg/l) of groundwater where for many boreholes the Cl_{gw} = harmonic mean of the Cl content in the boreholes]

The regional recharge was calculated as 4% using the chloride method. The data from the chloride values from the boreholes is displayed in Table 11. Different recharge methods were used to compare with the Chloride method this included maps from Vegter, ACRU recharge by Roland Schulze, Geology, harvest potential and soil and vegetation maps. The average recharge percentage compared well with the findings in the chloride method of 4%. The EARTH model could be used for a single borehole with monthly rainfall and water levels used as parameters this also compared well with the recharge percentage.

Table 11 Different recharge methods were used to compare with the Chloride method this included maps from Vegter, ACRU recharge by Roland Schulze, Geology, harvest potential and soil and vegetation maps. The average recharge percentage compared well with the findings in the chloride method of 4%. The EARTH model could be used for a single borehole with monthly rainfall and water levels used as parameters this also compared well with the recharge percentage.

Table 11: Chloride method for recharge.

HARMEAN (mg/l)	CL- rainwater(mg/l)	Recharge (%)
25.56	1	4

The actual mine recharge was calculated using the water balance of the Kilbarchan mine. It was calculated at 11.3 %.

4.10 Monitoring

Kilbarchan colliery is currently experiencing problems regarding the handling of excess water. The underground and opencast workings have been filling up with water since mine closure in 1992. Active water management is required to prevent mine water from spilling onto the surface.

A study by Hodgson (2006) in updating the water balance shows Kilbarchan at the water levels of 1 160, 1 175, 1 183 and 1 190 mamsl (maximum fill level), representing:

- 1992 (1 160 mamsl) – When mining stopped.
- 1999 (1 175 mamsl) – Additional monitoring holes drilled.
- June 2002 (1 183 mamsl) – Water level before the sudden rise of 3.5 m.
- June 2004 (1 990 mamsl) – Mine full and decanting starts.

The conclusion is that, by 1992 when mining ceased, only about 20% of Kilbarchan was flooded. It took 12 years for the mine to fill.

Currently only three boreholes and a few surface water samples are being used as monitoring for Kilbarchan. The boreholes are KW1/98, KW1/99 and the VOID BH. The water levels of these boreholes are very well monitored, almost weekly. The surface water sampling positions with the position of the boreholes in the area are shown in Figure 73.

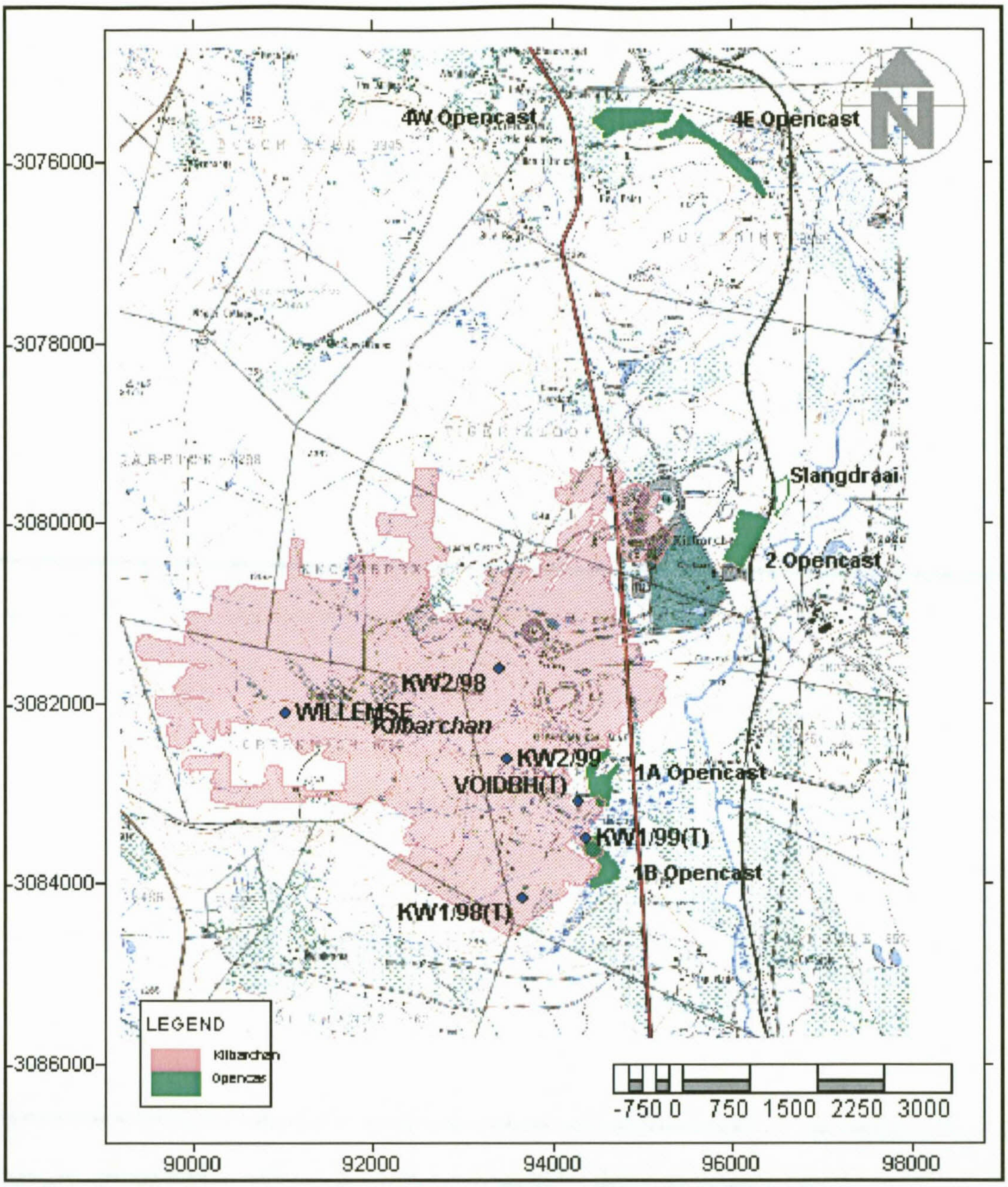


Figure 73: Position of the mine boreholes at Kilbarchan

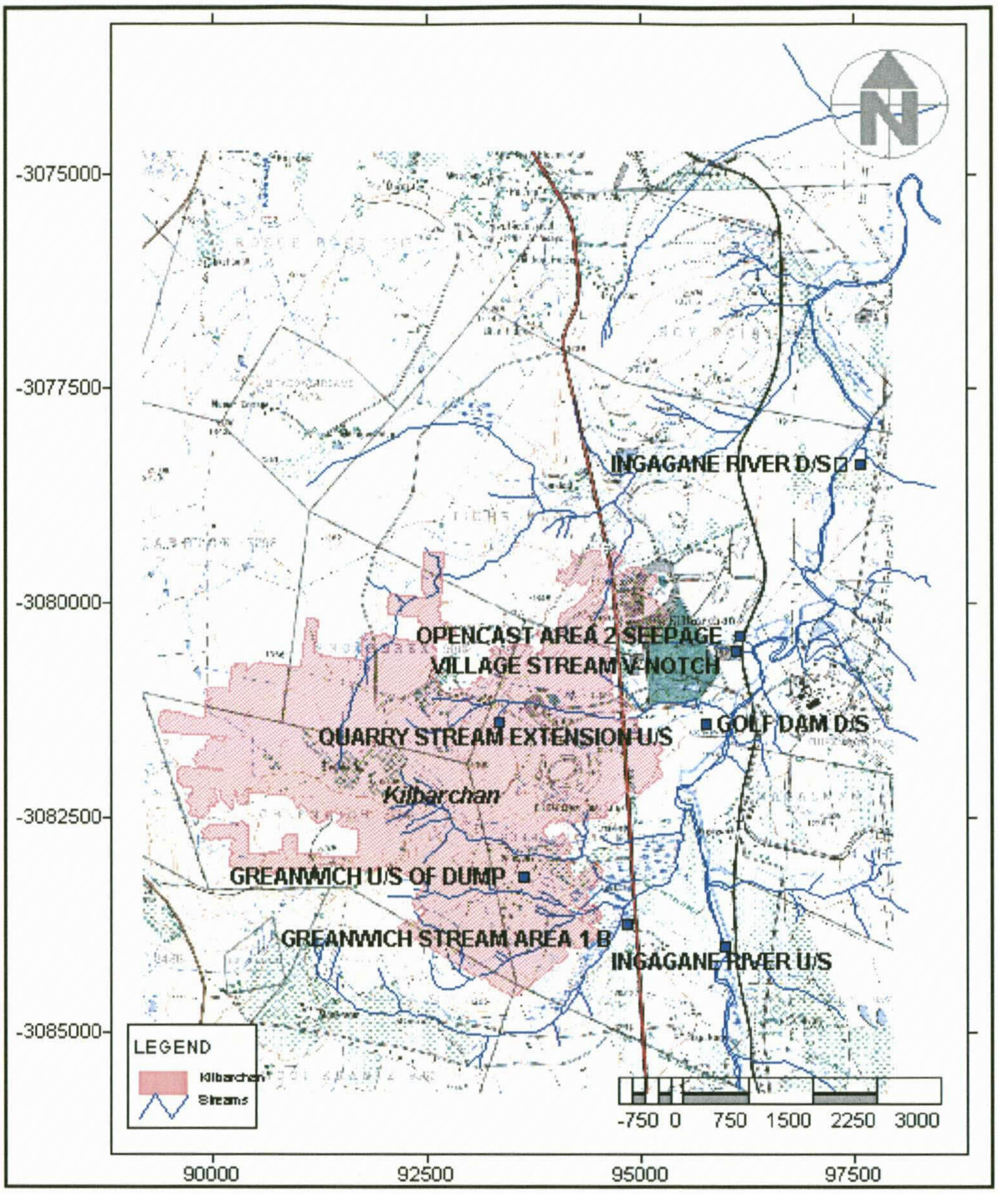


Figure 74: Surface streams monitoring positions at Kilbarchan colliery.

4.11 Borehole information

The information of the water levels after the previous site visit in April 2011 is shown in Table 12

Table 12: Information of the boreholes during April 2011.

Site Name	Water Level (m below surface)
KW1/98	21.16
KW1/99	7.49
VOID BH	16.50

Table 13 provides a summary of the information for each borehole that was sampled in the mine during April 2011. Sampling was done at two different depths at each borehole.

Table 13: Sample depth and depth of boreholes in the mine.

Site Name	Borehole depth	Sampling depth (T)	Sampling depth (B)
KW1/98	45.00	22	44
KW1/99	21.00	8	20
VOID BH	30.00	18	29

4.11.1 Detail of boreholes inside the mine

4.11.1.1 KW1/98

- This borehole is 45 m deep. The water level is 21.16 m deep.
- Borehole is drilled into the mine.
- Water levels are very well monitored.

4.11.1.2 KW1/99

- This borehole is 21 m deep. The water level is 7.49 m deep.
- Borehole is drilled into the mine.
- Water levels are very well monitored.

4.11.1.3 VOID BH

- This borehole is 30 m deep. The water level is at 16.5 m.
- No past chemistry data is available.
- First time sampled at previous visit April 2011.
- Water in the borehole is already acidic.

4.11.2 Details of surface water samples

4.11.2.1 Ingagane River upstream

- Water in the river is unpolluted.

4.11.2.2 Ingagane River downstream

- Water in the river is unpolluted.

4.11.2.3 Greenwich stream area 1B

- Sampled

4.11.2.4 Greenwich upstream of dump

- Monitoring water that is upstream of the dump.

4.12 Water levels

As discussed previously only three boreholes water levels are currently being monitored weekly. The three boreholes water levels KW1/98, KW1/99 (these boreholes are drilled into the mine) and the VOID BH are shown in Figure 75. Over time the boreholes have the same trend. The variations in water levels are only fully understood when looking at the water elevation figure. Over time the boreholes have shown the same trend.

The variations in water levels are fully understood when looking at the water elevation figure. Water level depth can easily fool people in this case. The water levels seem to differ in depth, but they actually lie on a flat line when plotted in metres above mean sea level (mamsl).

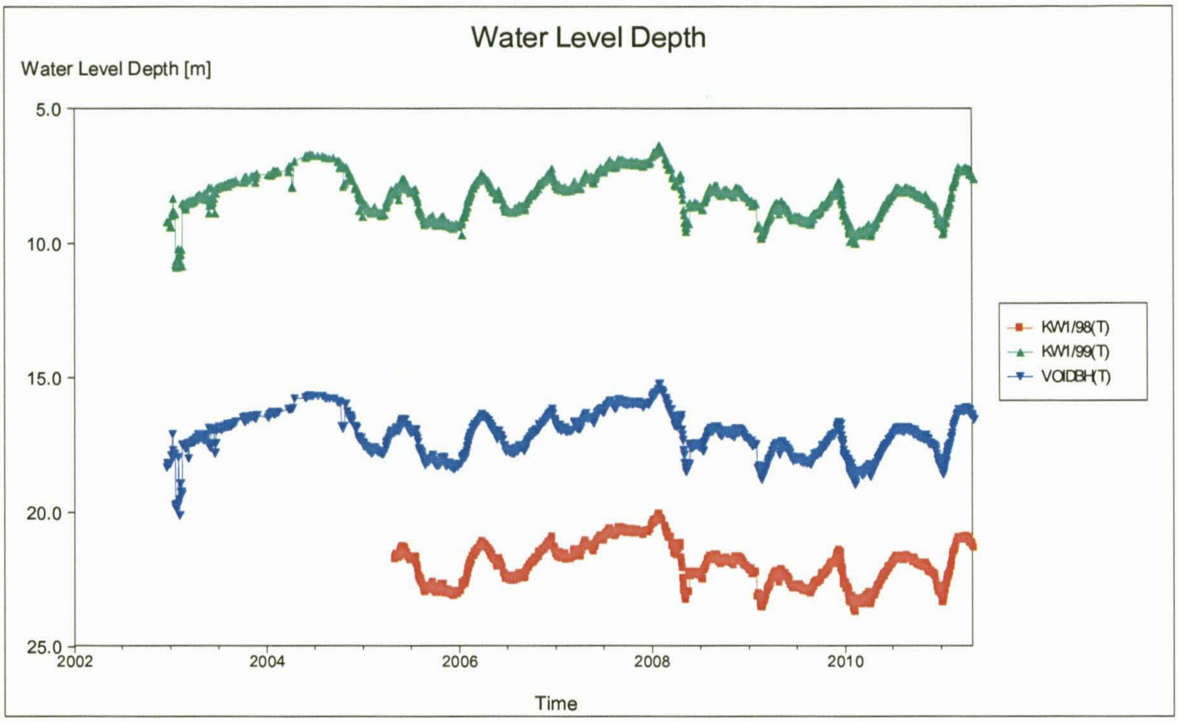


Figure 75: Water level time graph of the three boreholes measured since 2003.

- KW1/98 has the deepest water level over time, 20-25 m over the past 8 years.
- KW1/99 has the shallowest water levels over the same amount of time, 5-10 m
- VOID BH is in the middle, 15-20 m over time.

The fact that the water level elevations of the different boreholes are all the same shown in Figure 76, indicate that the water level is flat throughout the underground and connected opencast mine. Due to decant through the opencast, these mine water levels will not rise in the underground mine above the decant level.

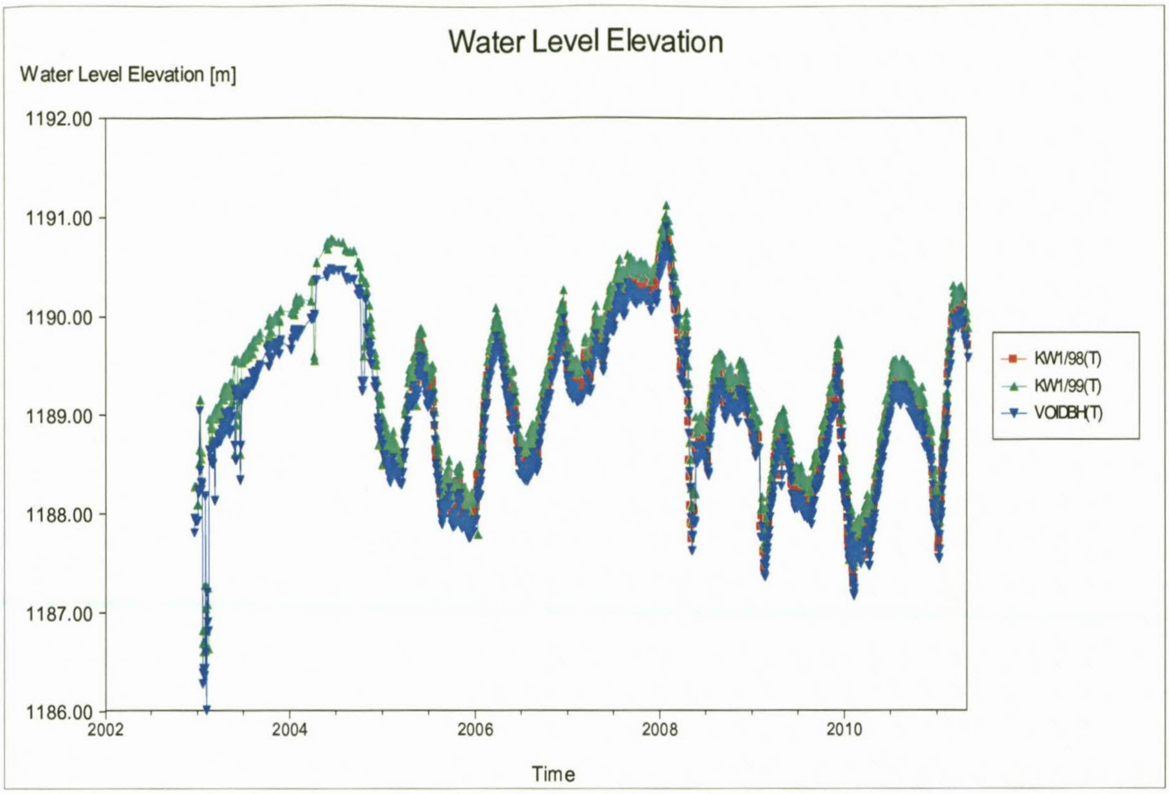


Figure 76: Water level elevation time graph of the three boreholes measured since 2003.

One of the most striking features (Figure 76) is the jump in water levels on a number of occasions in all the boreholes. In the 2006 report by Hodgson it was explained as a possible collapse of underground walls. Currently the explanation is that it is due to recharge and the resulted pumping from the underground, resulting in the 3 m variation in water level.

Coal Seam (mine)

This system is mined out, with a much higher transmissivity value than the layers above and below it.

- The transmissivity (T-value) of the mined coal seam is very high (in the order of thousands) and the storativity (S) is also very high (65% in the mined out section as opposed to approximately 0.1% in typical Karoo aquifers).
- Once the mine has filled up with water, a horizontal piesometric level will occur (this piesometric level is also horizontal during the filling up process). If the piesometric level intersects the surface, decant could take place at the point of intersection if there is a link between this position and the mine (e.g. a borehole).

The rate at which the piesometric level rises is dependent on the amount of influx from the top layers (or along subsidence areas) and the amount of lateral groundwater outflow.

Once the mine has filled up with water, the piesometric level of the mine will rise with the storage coefficient value of the mine (and not the specific yield) as conditions have changed from unconfined to confined. The flux from the overlying aquifers into the mine aquifer will decrease as the two water levels approach each other.

What is clear from the water levels is that the aquifers above the mining areas are not fully recharged yet, as these pressure levels differ from the regional water table aquifer water levels.

Two cross-sections (Figure 77 and Figure 79 indicates the position of the sections) were drawn through the three monitoring boreholes to indicate the water levels in relation to the surface and the mining void (Figure 78 and Figure 80). The water elevation indicated by the blue line. From this it is clear that boreholes KW1/99 is the closest to surface, but that all the water level elevations are the same.

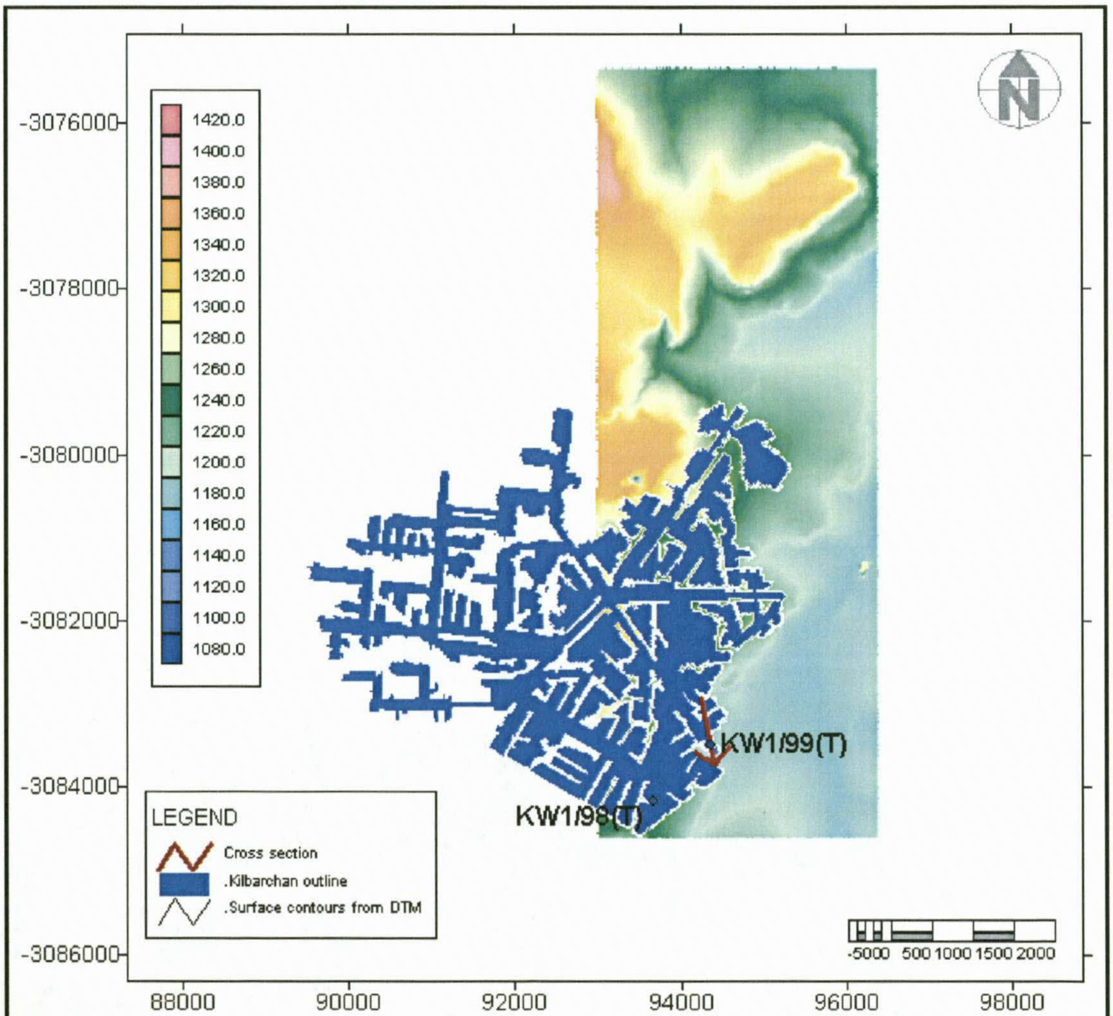


Figure 77: Cross section of boreholes VOID BH and KW1-99 (with the red line intersecting the two boreholes

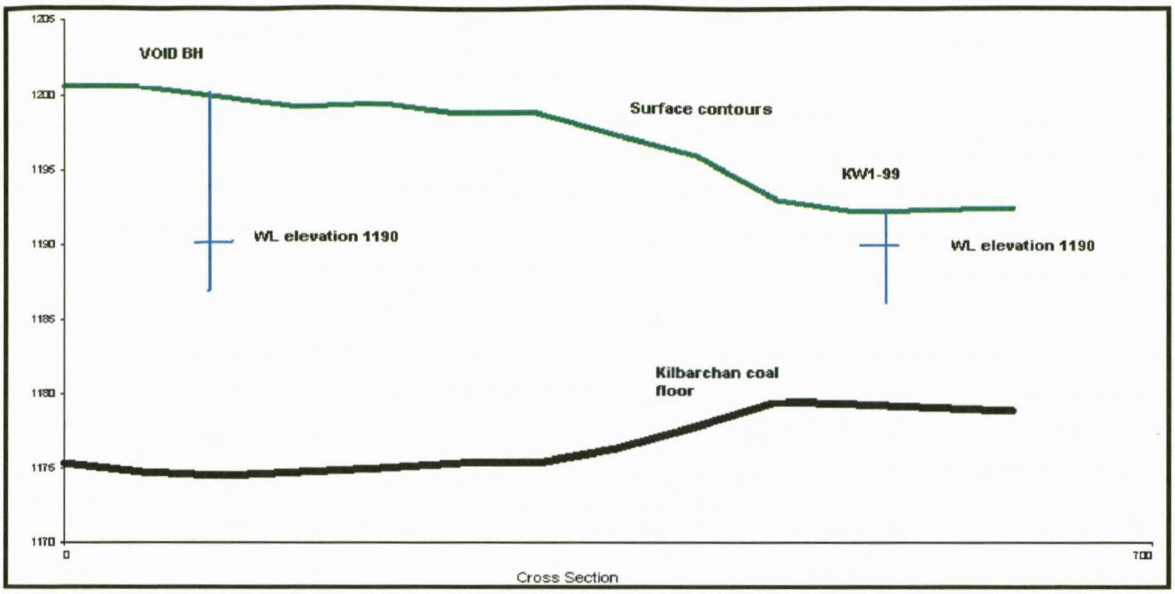


Figure 78: Cross-section of boreholes VOID BH and KW1-99.

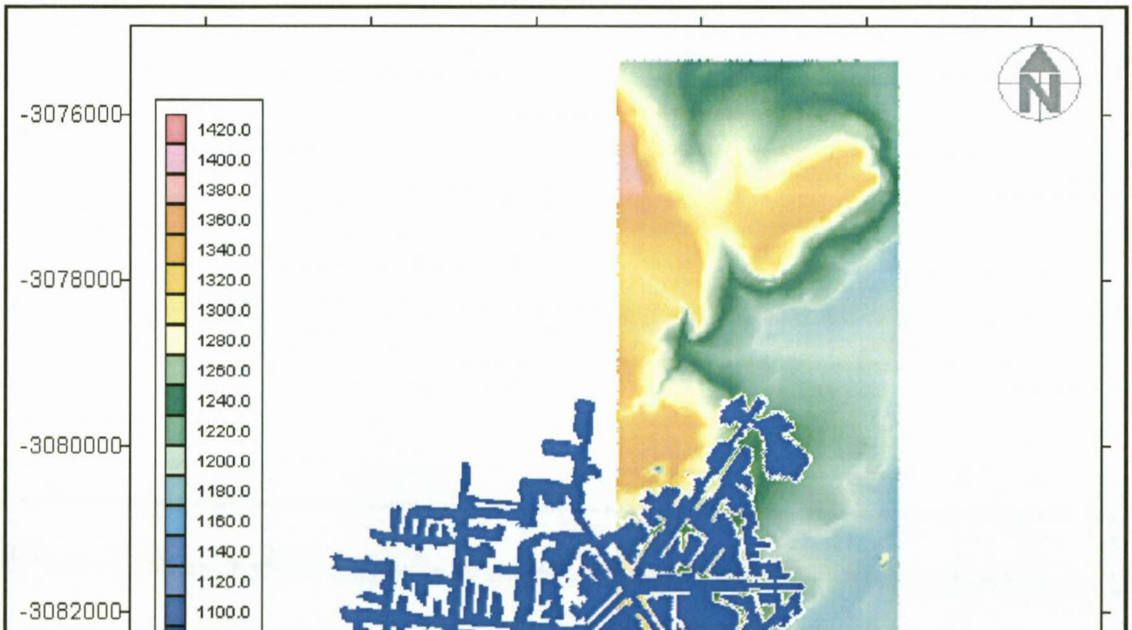


Figure 79: Cross-section of boreholes VOID BH and KW1-99 (with the red line intersecting the two boreholes).

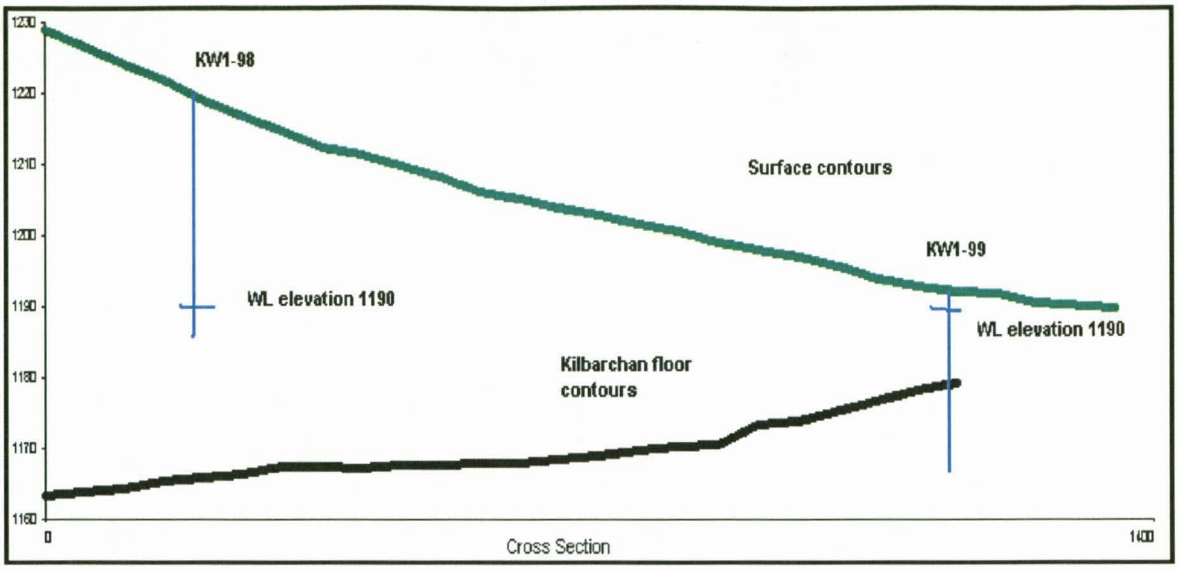


Figure 80: Cross-section of boreholes KW1-98 and KW1-99.

4.13 Mining methods

The colliery was mined by bord and pillar method and stooping was done in certain areas.

Table 14: Different areas of the Kilbarchan mine (Hodgson, 2006).

Decription	Area (ha)
Kilbarchan underground area	126.2
Stooped areas	11.84
Opencast areas interconnected with the underground	2.1
Ash-filled areas	10.1

Fly ash from Ingagane power station was introduced into the mine at different locations (Figure 81); the fly ash needs to be brought into consideration in the volume calculations of the area. Fly ash fills the voids and limited water gets recharged.

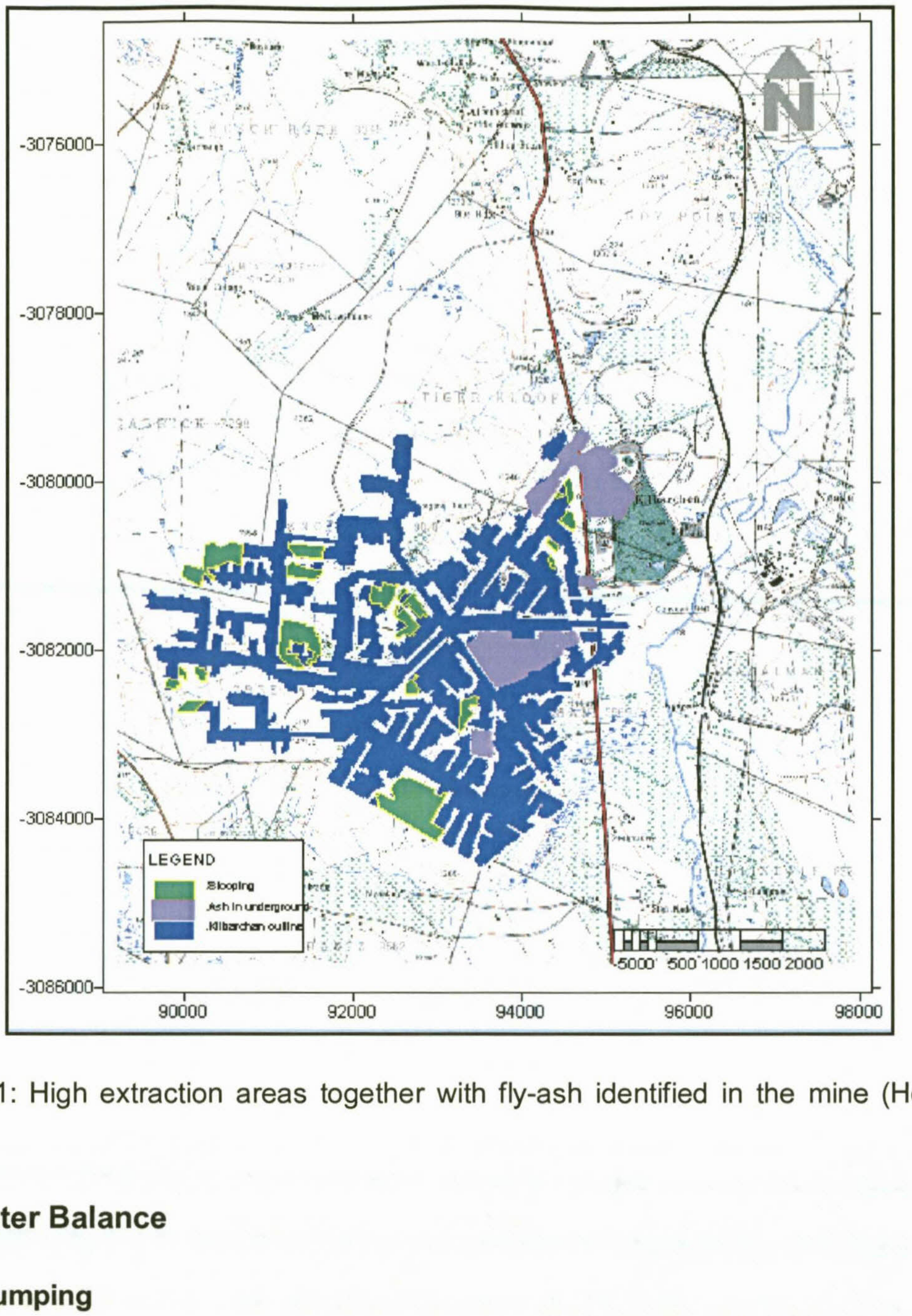


Figure 81: High extraction areas together with fly-ash identified in the mine (Hodgson, 2006)

4.14 Water Balance

4.14.1 Pumping

There are two transfer pipelines positioned at Roy Point (Figure 82). With these transfer pipelines water is currently being pumped from Kilbarchan to Roy Point, where water is stored for releases. This is done to create storage capacity at Kilbarchan in order to avoid uncontrolled mine decants.

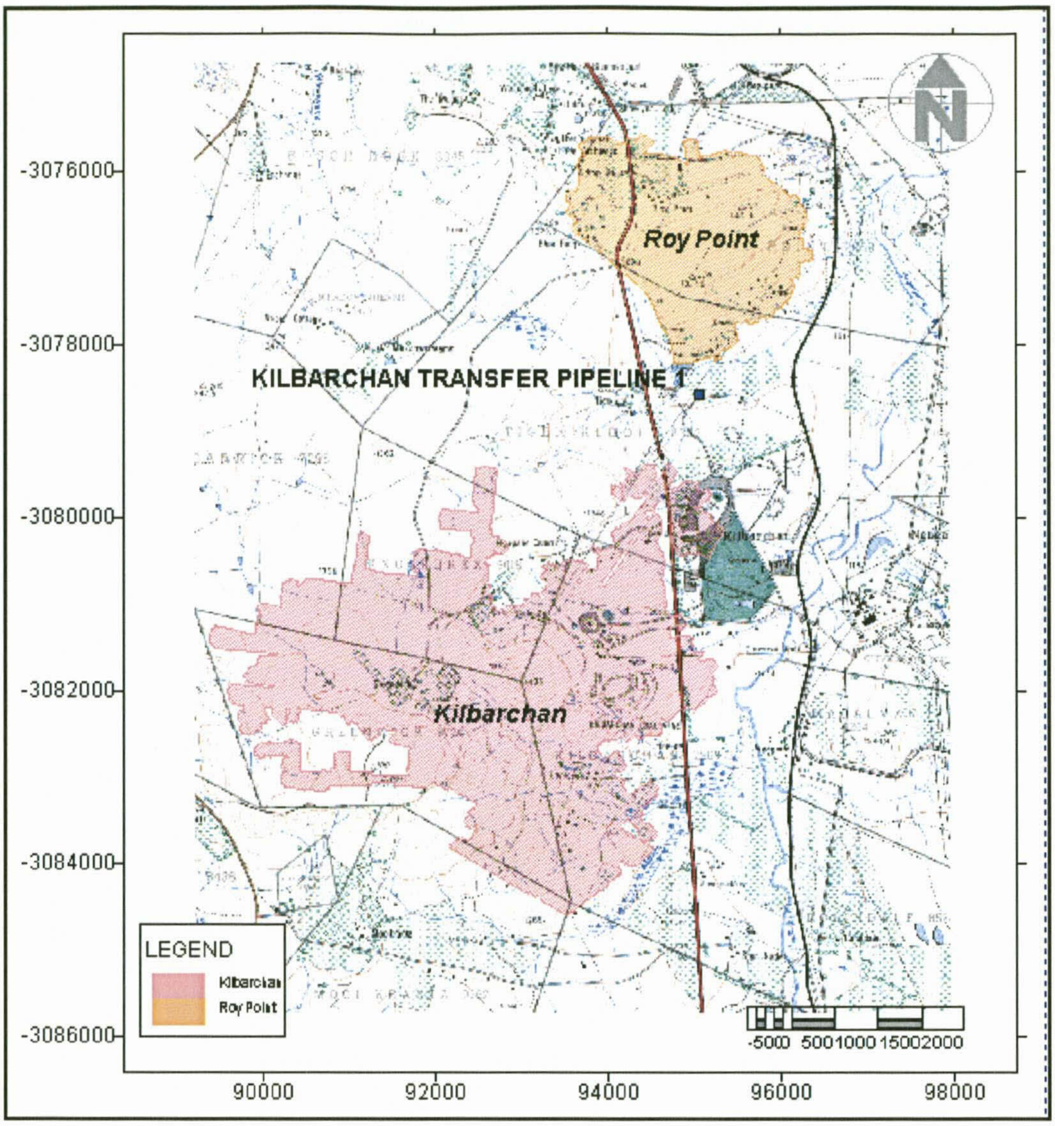


Figure 82: Pumping from Kilbarchan to Roy Point through transfer pipelines.

Table 15: Transfer pipelines volume of water released per annum.

Pumping [m3/day]	Pumping [m3/a]
2055	750000

The EC over time of the transfer pipeline does not improve as in the case at Usutu. At Usutu pumping improved the EC over time. The main reason for this is the fact that too much pumping is taking place at Kilbarchan.

Table 16: EC of the transfer pipelines over time.

Date	2005-02-17	2006-02-27	2007-03-23	2008-02-08	2009-01-20	2010-01-19	2011-02-16
EC	647.0	719.0	733.0	538.0	670.0	624.0	637.0

Water is also actively released from the Kilbarchan opencast areas via active pumping during the controlled / licensed releases by a big mobile pump.

Table 17 shows the volume of water released in the different seasons. The average pumping is 300 ML/a. This is equal to 300 ML*1000/365 = 822 m^3/d. This corresponds to 300 000 m^3/annum and 10 l/s.

Figure 83: Picture of the mobile pump.

Table 17: Volume water pumped by mobile pump.

Season	Big Mobile Pump Deutch (Ml)
2004/2005	0
2005/2006	0
2006/2007	0
2007/2008	375
2008/2009	307
2009/2010	292.384
2010/2011	168

4.14.2 Decant

Water is decanting at opencast area 1A and opencast area 1B. For the past 3 years water has not been decanting from opencast 2; thus it is not used in the calculations. The water decants from the underground at the opencast areas 1A and 1B which is connected to the underground.

The decant point is illustrated in Figure 84, and the v-notch where flow volumes are measured, in Figure 85.

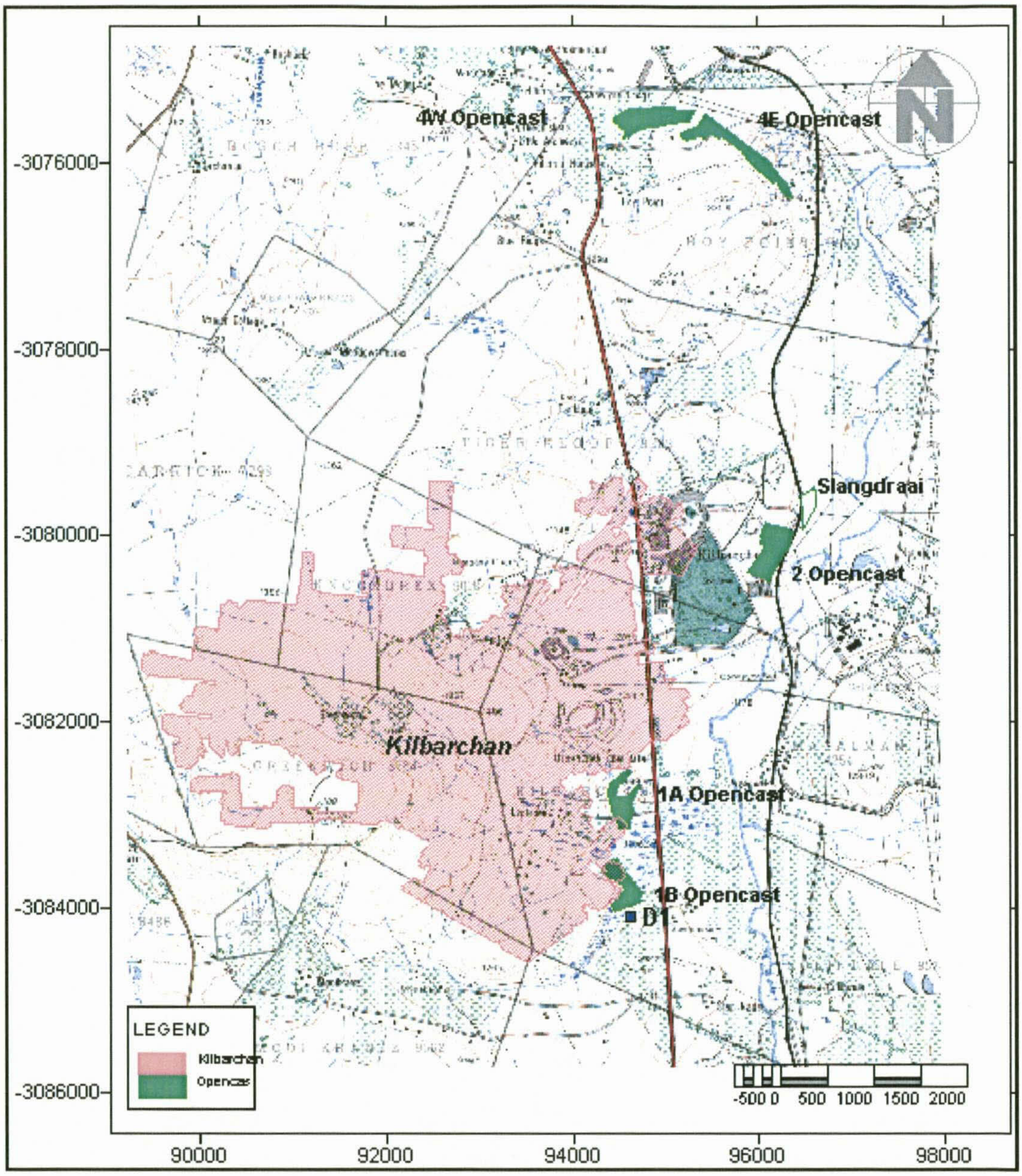


Figure 84: Position of D1, where decant is taking place.

Figure 85: Picture of the place where the water is decanting in opencast 1B.

Water decanting from the opencast areas according to data from Kilbarchan is measured at a total of 3.5 l/s as shown in Table 18.

Table 18: Approximate decant volumes of the opencast areas.

Opencasts	Decant [l/s]	Decant [m3/day]	Decant [m3/a]
1A	1	86	31536
1B	2.5	216	78840
Opencast area 2	0	0	0

Area 2: No decanting has taken place for the past 3 years.

1B: Average decanting is measured at 2.5 l/s = 216 m^3/Day*365 =78 840 m^3 /year

1A: Average decanting measured at 1 l/s = 86 m^3/Day*365= 31 536 m^3/year

Total decant for all the opencast areas are 110 376 m^3/year.

Figure 86: Picture of the V-notch of water decanting out of opencast 1B.

4.14.2 Water quality

The water decanting out of D1 has been decanting since 2004. Water qualities are not improving over time at D1. The water decanting out of opencast area 1B is of a poor quality. The quality of this water has been measured over time. Since 2004 until now the quality remained the same, as indicated in the time graphs of electrical conductivity and sulphate (Figure 87) and calcium, magnesium and sodium (Figure 88).

The background colors in the figures represent standards:

The criteria used for inorganic sampling is the SANS 241:2006, and for organic analysis the USEPA Standards. Inorganic water samples are classified as:

- Class I – acceptable (color coded green)
- Class II - allowable (color coded yellow)
- Above – not allowable (color coded red)

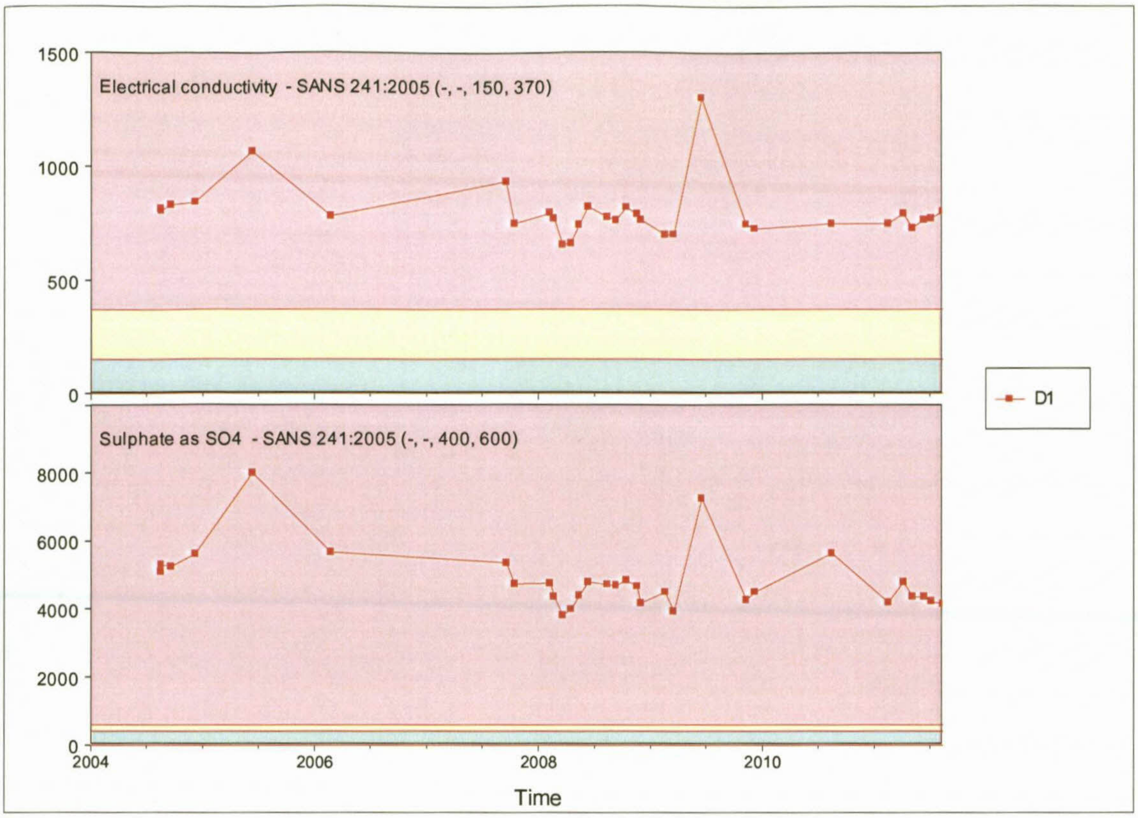


Figure 87 : Time graph of the EC and Sulphate over time at D1.

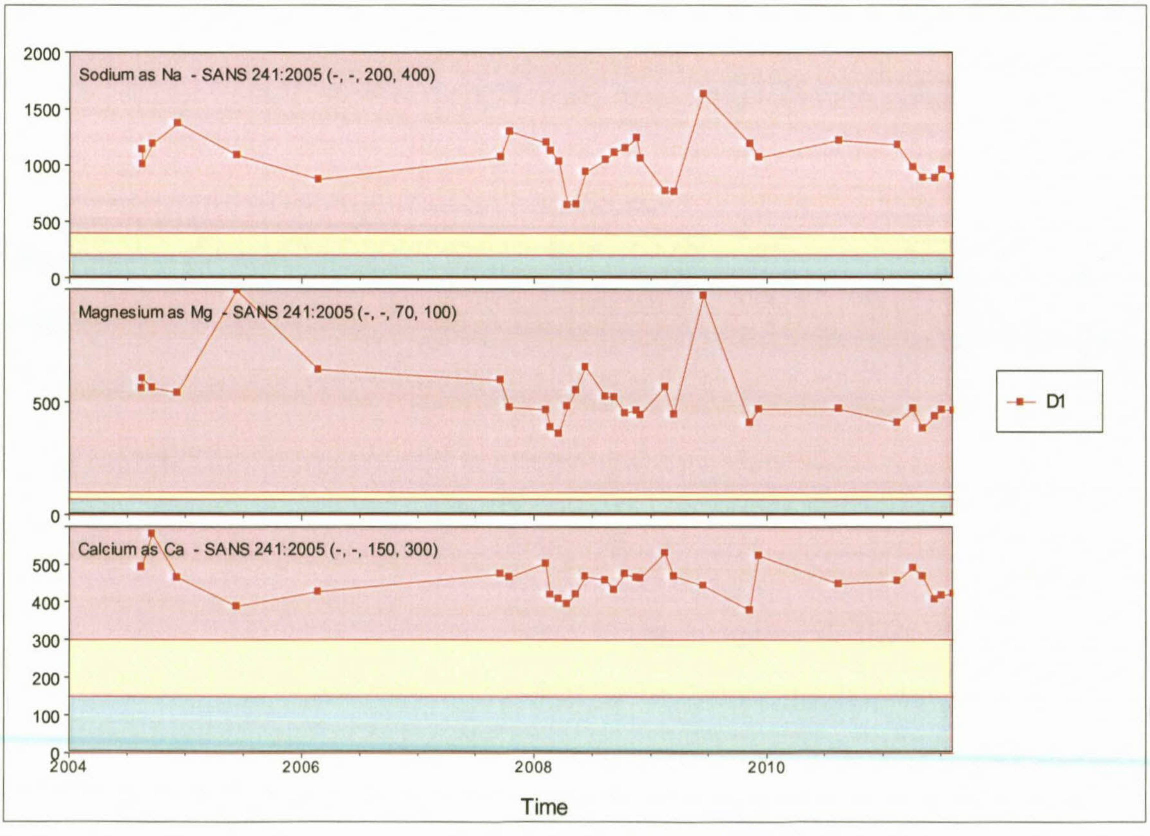


Figure 88 : Time graph of the Na, Mg and Ca over time.

4.14.3 Recharge

Recharge rate which depends on the geology, the depth, the type of mining and whether some form of high-extraction was performed. Stooping has been done in some parts of the B-seam at Usutu colliery. Stooping, the process of removing pillars from the workings causes the overlying strata to collapse. Cracks will develop. If these cracks intersect with the surface rainfall water, and run-off may flow down directly into the mining cavity. From studies done at collieries where stooping was done (Hodgson *et al.,* 2007), it was found that normally a recharge rate of 4 – 12% should be applied, depending on depth of mining and ratio of stooping. The Newcastle area receives, according to Weather SA, an average rainfall of 864 mm per annum

Table 19: Rainfall for the Kilbarchan underground area (excluding stooping and ash filling).

Area	Area	Rainfall	Rainfall
	[m2]	[m/a]	[m^3/a]
Underground	10424711	0.864	9006950

Table 20: Rainfall for the stooped areas at Kilbarchan.

Area	Area	Rainfall	Rainfall
	[m2]	[m/a]	[m3/a]
Stooped areas	1183775	0.864	1022782

Table 21: Rainfall for the opencast areas.

Opencasts	Area	Rainfall	Rainfall
	[m2]	[m/a]	[m^3/a]
1A+1B+ Area 2	319582	0.864	276119

Table 22: Recharge table for Total Kilbarchan.

Total Rainfall:	**Underground (B&P)**	**Stooped areas**	**Opencasts**	**Total**
(m^3/a)	9006950	1022782	276119	10305851
Total discharge:	**Total decant**	**Mobile pump**	**Transfer Pipelines**	**Total**
(m^3/a)	110376	300000	750000	1160376
			Recharge %	**11.3**

Show the recharge percentage taking into consideration the stooped areas, underground areas and opencasts. The value of the recharge is compared to the output of the system (decant, mobile pump and transfer pipelines).

A total of 10305851 m^3 of rainfall is deposited onto the mining area of Kilbarchan annually. Total extraction (decant plus pumping) of the colliery is 116376 m^3/a of water (or 3200 m^3/d). The mobile pump pumps out 300000m^3/a water per annum on average. The transfer pipelines pumps 750000 m^3/a water to Roy Point, and decant is estimated (from the V-notch flow gauge) as 110376 m^3/a (Vermeulen, P.D, 2011).

Recharge (%) = (Decant + Pumping)/Rainfall

The final conclusion is a recharge of 11.3 % in Kilbarchan.

Assumptions made when calculating the recharge is a closed system. No outside influences other than stated.

Significant external sources of mine water do not exist at the Kilbarchan Colliery. Water levels in Natal Cambrian Colliery, south of Kilbarchan, are 7 – 9 m below the level in Kilbarchan and can therefore not impact Kilbarchan (Hodgson, 2006).

A few scenarios in Table 23 were set up in changing the respective percentage of recharge at opencast and stooped areas. The effect on the water balance can be seen in the following tables. The influence different scenarios have on the underground is dependent on the size of the opencast and stooped areas. In this case stooped areas will have the biggest influence on the recharge in the underground followed by the opencast areas. The main purpose of the scenarios is to show how the recharge percentage is influenced by the different areas. Stooping, opencast en underground plays a vital role in understanding the recharge percentage.

Table 23: Different scenarios regarding recharge percentages.

Recharge	Underground	Stooped	Opencast
	[%]	[%]	[%]
	10.24	12	10
	10.1	12	15.00
	9.95	12	20.00
Recharge	Underground	Stooped	Opencast
	[%]	[%]	[%]
	10.778	4.00	20
	10.36	8.00	20
	9.95	12.00	20
Recharge	Underground	Stooped	Opencast
	[%]	[%]	[%]
	10.912	4.00	15
	10.496	8.00	15
	10.09	12.00	15

4.15 Chemical analyses

4.15.1 Chemistry of the boreholes

All three boreholes were profiled for EC. The profiling is done with an TLC meter (Temperature, water level and conductivity) the meter consists of a probe at the end the tape. This is lowered into the boreholes and readings are taken every 5m. This way the bore can be profiled with EC values.

- KW1/98 clearly illustrates the polluted water in the mining cavity compared with higher up in the water column. At about 42 m the EC value increases rapidly (Figure 89).
- KW1/99 also differs in depth, but there is a slight change halfway down the water column. At 19 m the EC increases, indicating the mining cavity (Figure 90).
- VOID BH is not drilled into the mine, but increases in EC at 22 m and then returns at 28 m. This may indicate a fracture where the water is seeping through into the borehole (Figure 91).

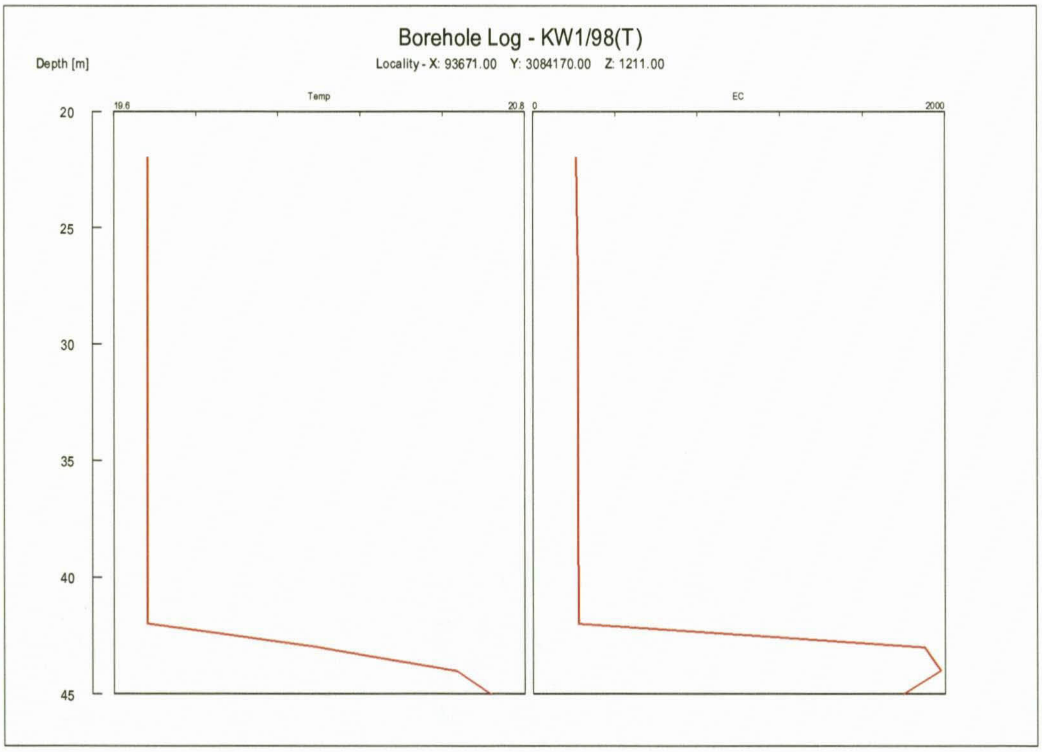


Figure 89: EC profiling for KW1/98.

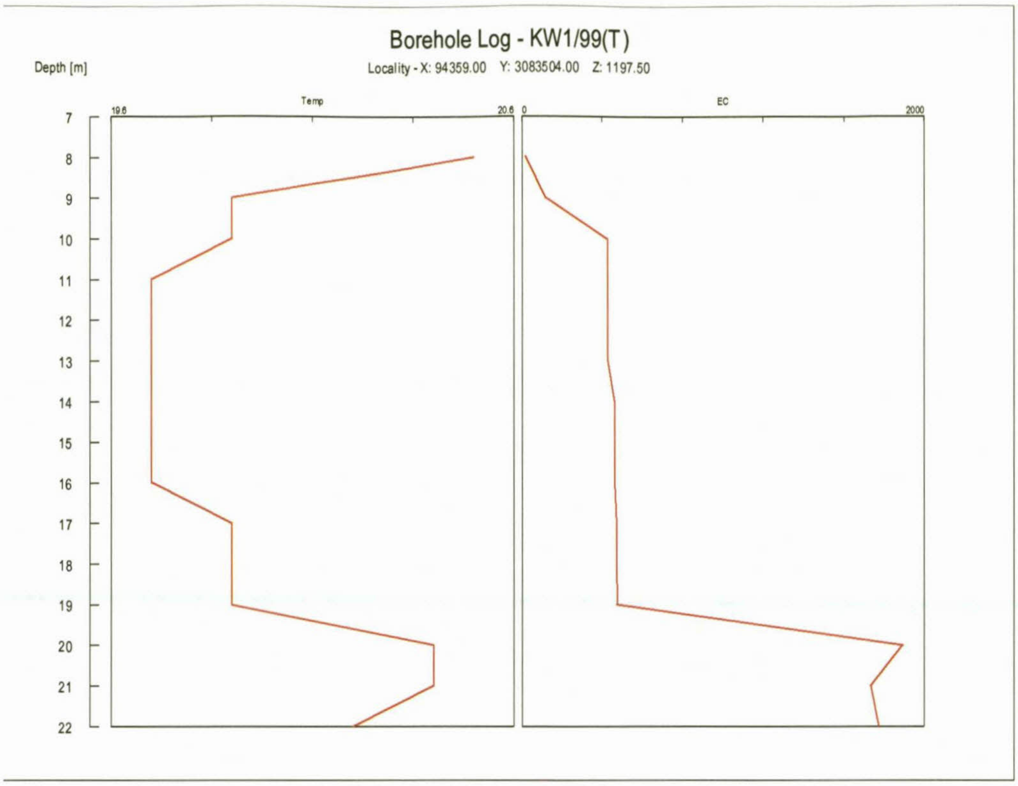


Figure 90: EC profiling for KW1/99.

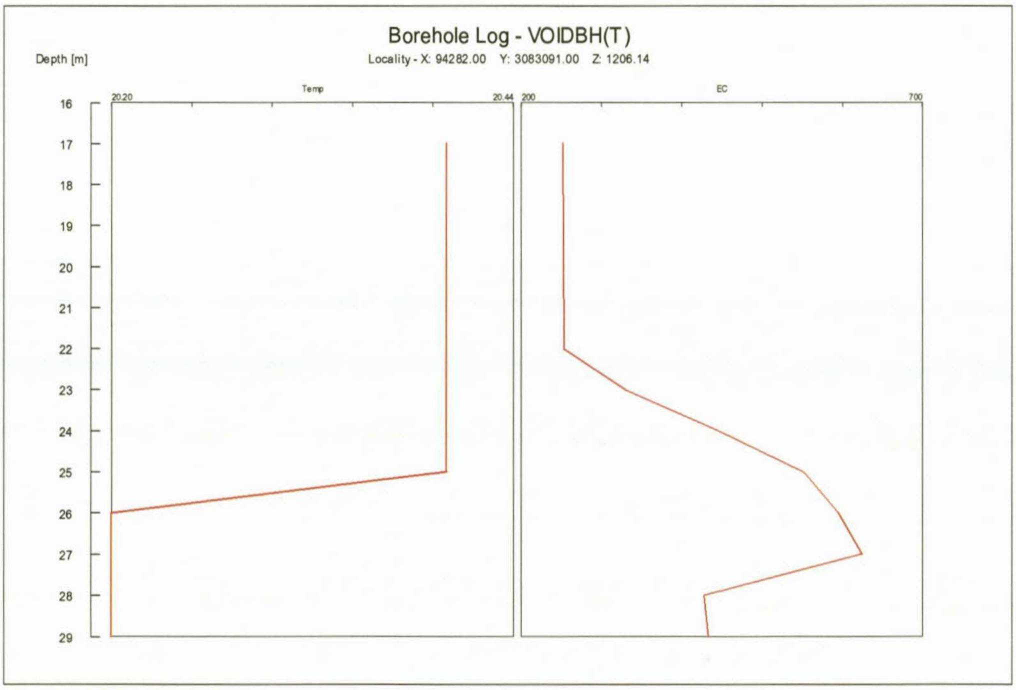


Figure 91: EC profiling for VOID BH.

The table below shows the chemistry data for the boreholes last measured in April 2011 (Table 24). All these boreholes were sampled at the top of the water column. During the last visit to the mine the three monitoring boreholes were sampled at the top as well as at the bottom in the mine.

The criteria used for inorganic sampling is the SANS 241:2006, and for organic analysis the USEPA Standards. Inorganic water samples are classified as:

- Class I – acceptable (not color coded)
- Class II - allowable (color coded yellow)
- Above – not allowable (color coded red)

See appendix B for class ranges.

Table 24: Results of the chemical analyses for the boreholes sampled during the last site visit April 2011.

BH number	pH	EC	Ca	Mg	Na	K	PAlk	MAlk	F
		mS/m	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l
KWI/99(T)	6.93	94	68	43	75	3.0	0	173	0.20
KWI/99(B)	6.85	395	182	110	604	8.4	0	365	0.54
KWI/98(T)	7.38	46	26	17	52	1.6	0	225	0.28
KWI/98(B)	6.86	413	187	105	677	8.9	0	341	0.22
VOID BH (T)	2.84	258	199	152	70	5.1	0	0	1.00
VOID BH (B)	5.65	497	391	210	532	21.4	0	50	0.09
BH number	**Cl**	**NO2(N)**	**Br**	**NO3(N)**	**PO4**	**SO4**	**Al**	**Fe**	**Mn**
	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l
KWI/99(T)	37.9	2.19	0.07	0.16	<1	252	0.023	0.159	0.344
KWI/99(B)	252.6	<1	<1	<1	<1	1545	0.040	0.460	0.396
KWI/98(T)	8.8	<1	<1	0.14	<1	8.89	0.024	0.063	0.012
KWI/98(B)	250.0	<1	<1	<1	<1	1725	0.031	0.190	0.314
VOID BH (T)	79.9	<1	<1	<1	<1	1402	15.255	26.751	1.793
VOID BH (B)	190.9	<1	<1	<1	<1	2917	0.025	26.040	6.430

From this table it is clear that there is a definite difference in the water quality of the top and bottom samples of those boreholes drilled into the mining cavity.

- KW1/99 differs from top to bottom. The chemistry of the top sampled water shows no problem according to the standards, but the bottom sample chemistry shows high electrical conductivity (EC) together with high sulphate. High levels of magnesium and sodium typical of coalmine waters were also found.
- KW1/98 was the same as KW1/99, with the bottom differing from the top, with exactly the same result with regard to the chemistry.
- VOID BH is not drilled into the mine. We have no other chemistry data on this borehole. It seems that the water is already acidic with a pH of 2.84. There are very high sulphate values together with high levels of the metals (Al, Fe and Mn), as well as high values of calcium, magnesium and sodium.

The expanded Durov diagram (Figure 92) clearly indicates that VOID BH top and bottom and KW1/99 top are mine water, while KW1/98 top is unpolluted. (See Appendix A for explanation of the Durov interpretation) KW1/98 bottom and KW1/99 bottom are coal mine water.

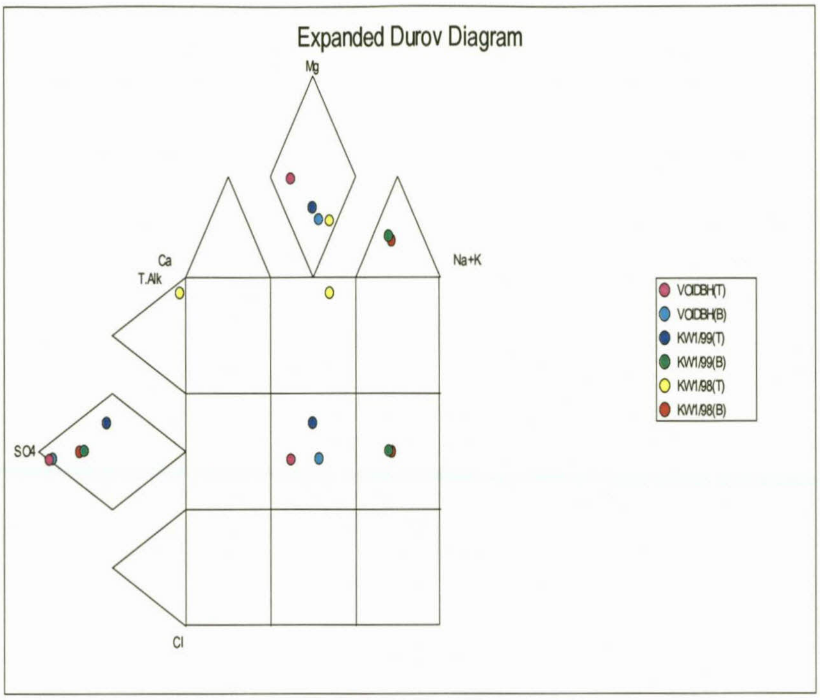


Figure 92: Expanded Durov diagram of the Kilbarchan boreholes.

The Stiff diagrams of the boreholes (Figure 93) (which compare the water qualities in equivalents) also illustrate that the bottom samples are more polluted than the top samples. This is clearly visible in the Stiff diagrams, but to a lesser extent in the VOID BH. The VOID BH seems to be the most polluted BH, as the stiff diagram shows with high sulphate values. The stiff diagrams show that the bottom samples show evidence of mine water mine while the top sampled samples are clean.

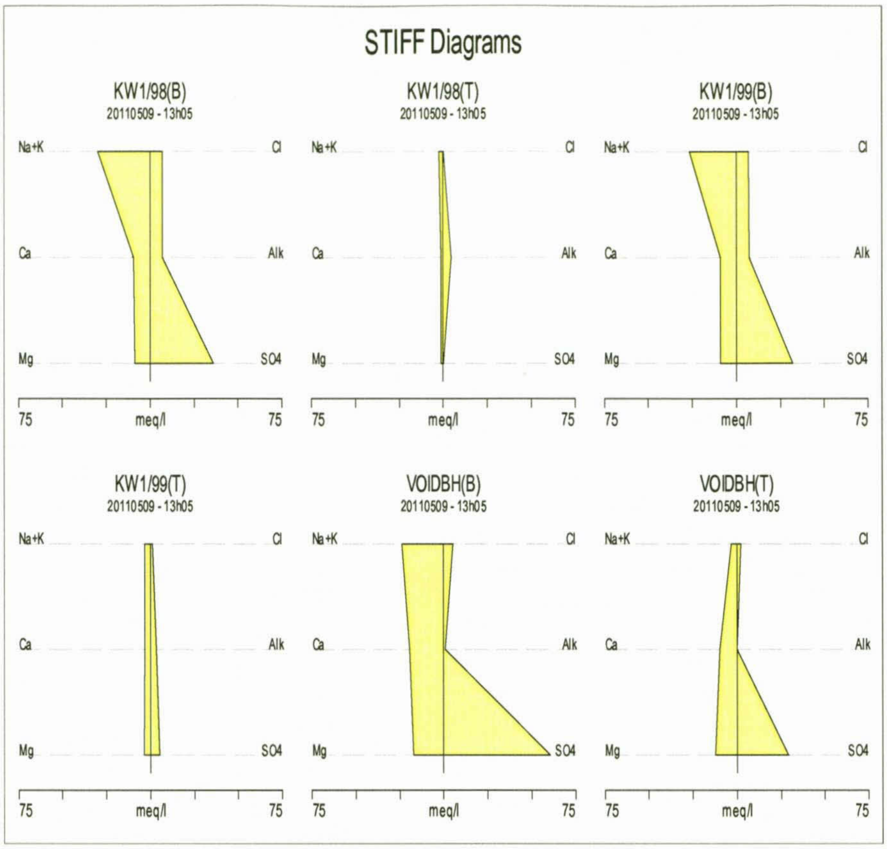


Figure 93: Stiff diagrams of the mine boreholes.

The time graph of the mine boreholes show that the water quality for the top boreholes did not deteriorate since 1999, except the VOID BH. As already stated, the bottom samples show high EC values (Figure 94). The high EC values indicate the water in the mine is still polluted compared to the top sampled.

The criteria used for inorganic sampling is the SANS 241:2006, and for organic analysis the USEPA Standards. Inorganic water samples are classified as:

- Class I – acceptable (not color coded)
- Class II - allowable (color coded yellow)
- Above – not allowable (color coded red)

See appendix B for class ranges.

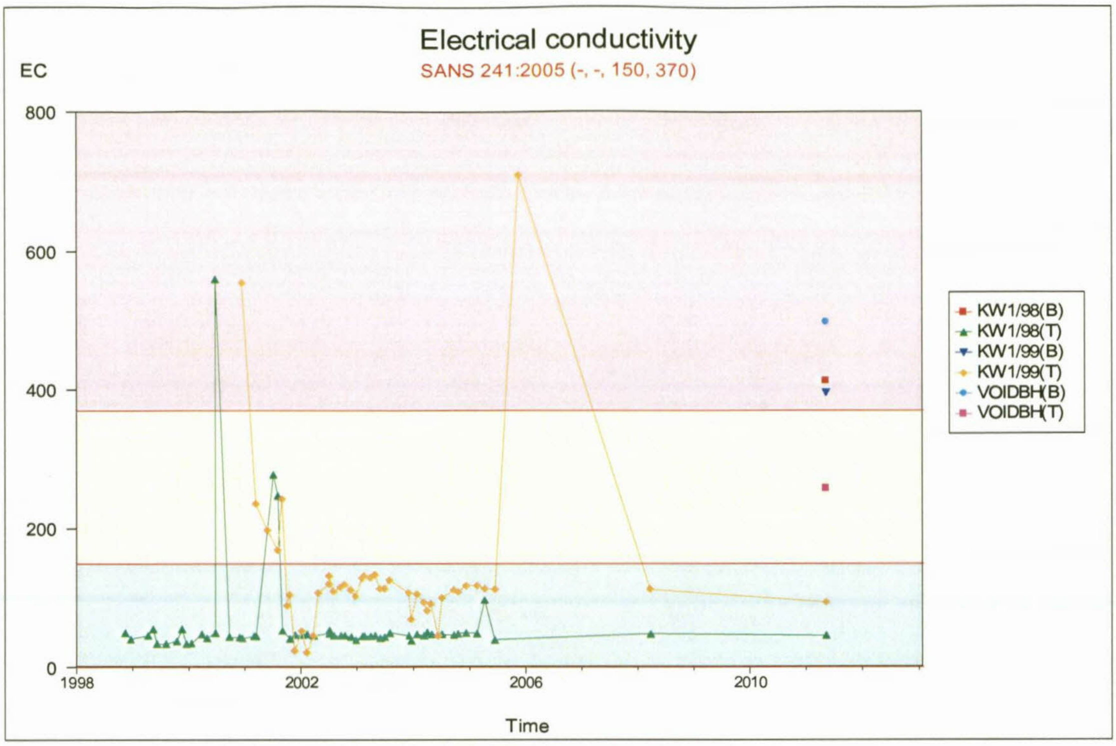


Figure 94: Time graph of the EC for the mine boreholes.

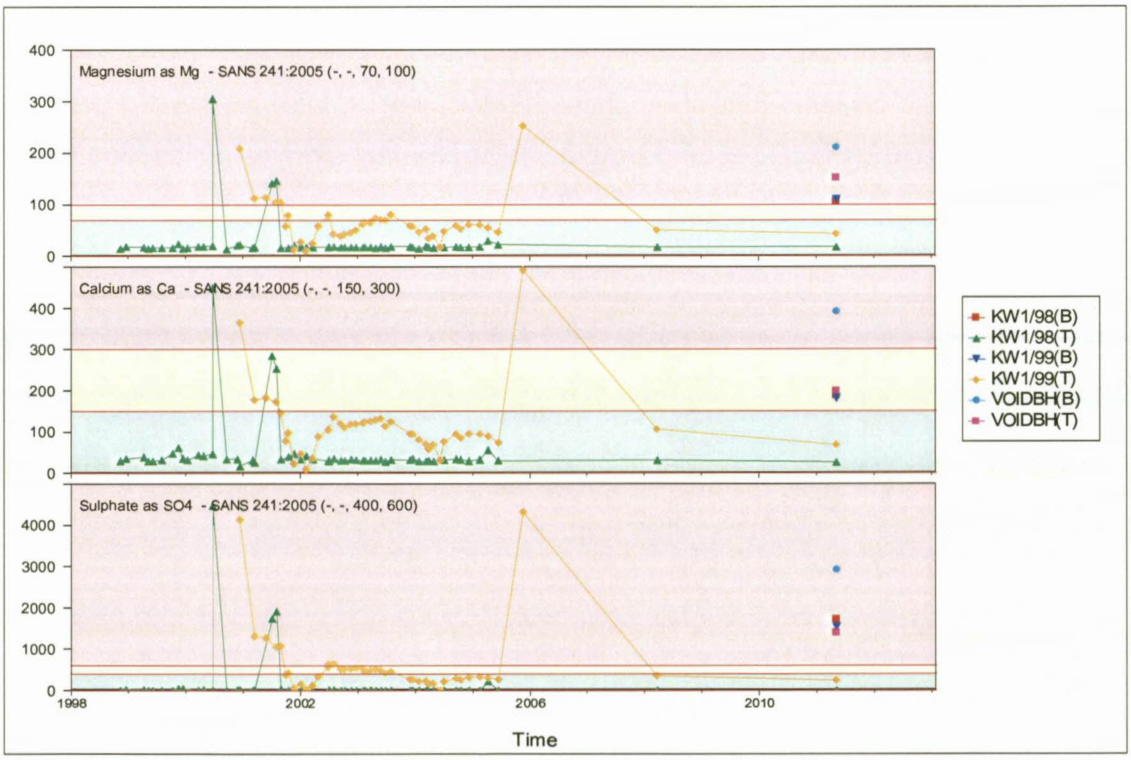


Figure 95: Time graph of sulphate, calcium and magnesium of the mine boreholes.

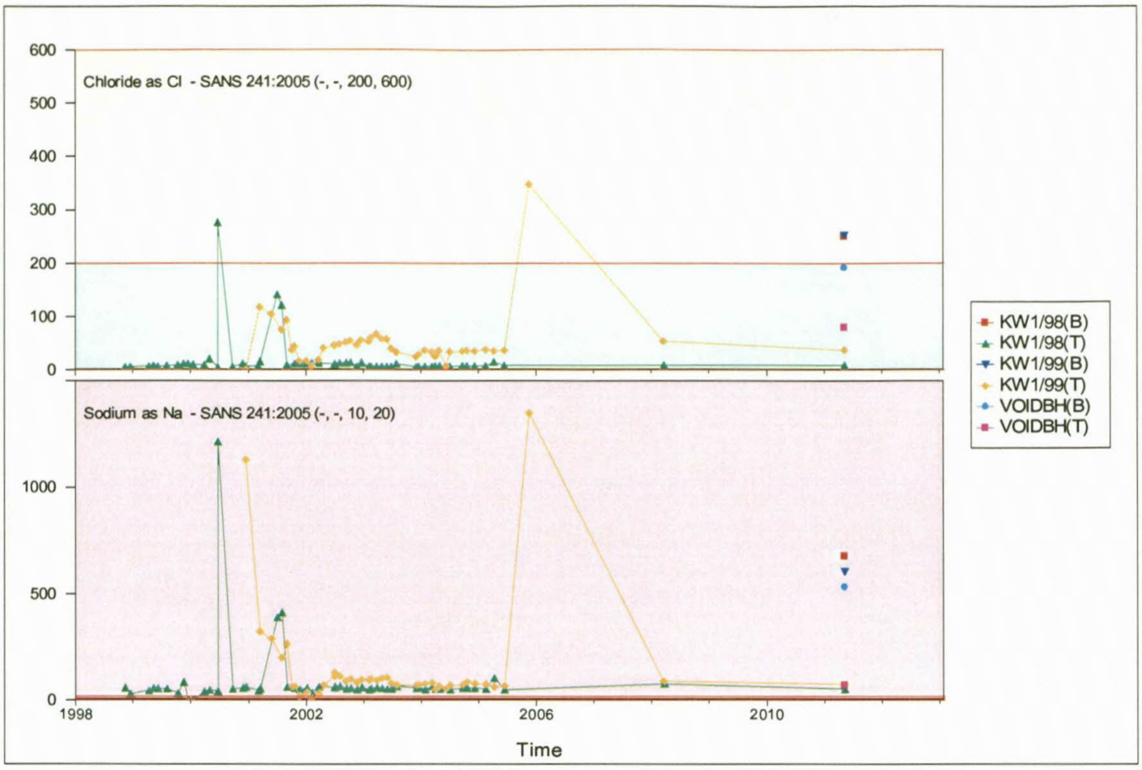


Figure 96: Time graph of sodium and chloride of the mine boreholes.

pH

The pH of the top sampled boreholes (Figure 97) KW1/98 and KW1/99 is still acceptable, but shows a slight decrease from 2006 till now, while it appears as if the VOID BH top sample is already acidic with, a pH of 2.84.

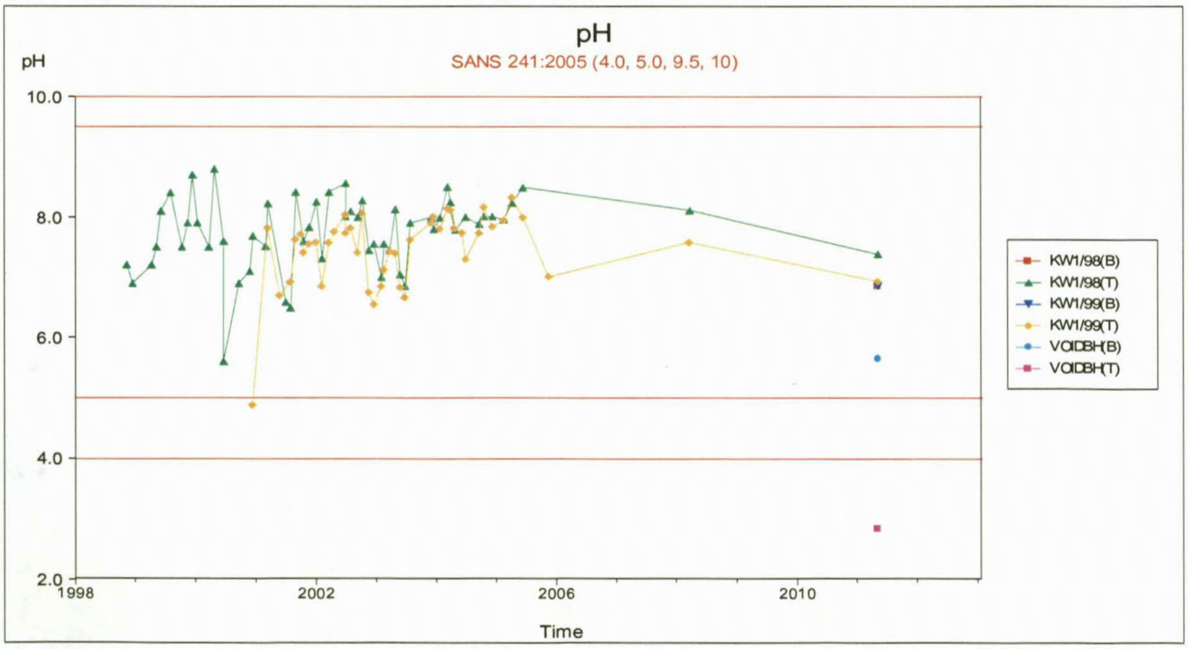


Figure 97: Time graph of the pH of the mine boreholes.

4.15.3 Opencast sampling points (Decant)

Water decants from position D1 (Figure 98). D2 ceased decanting since pumping started a few years ago. Borehole 26 and 30 are also drilled into the opencast, but is not part of the monitoring program. For this investigation they were profiled (Figure 99 and Figure 100). These profiles illustrate the polluted nature of these boreholes with BH26 indicating an EC of 7000mS/m at 7 m depth and BH30 an EC of 3000 mS/m at a depth of 15 m.

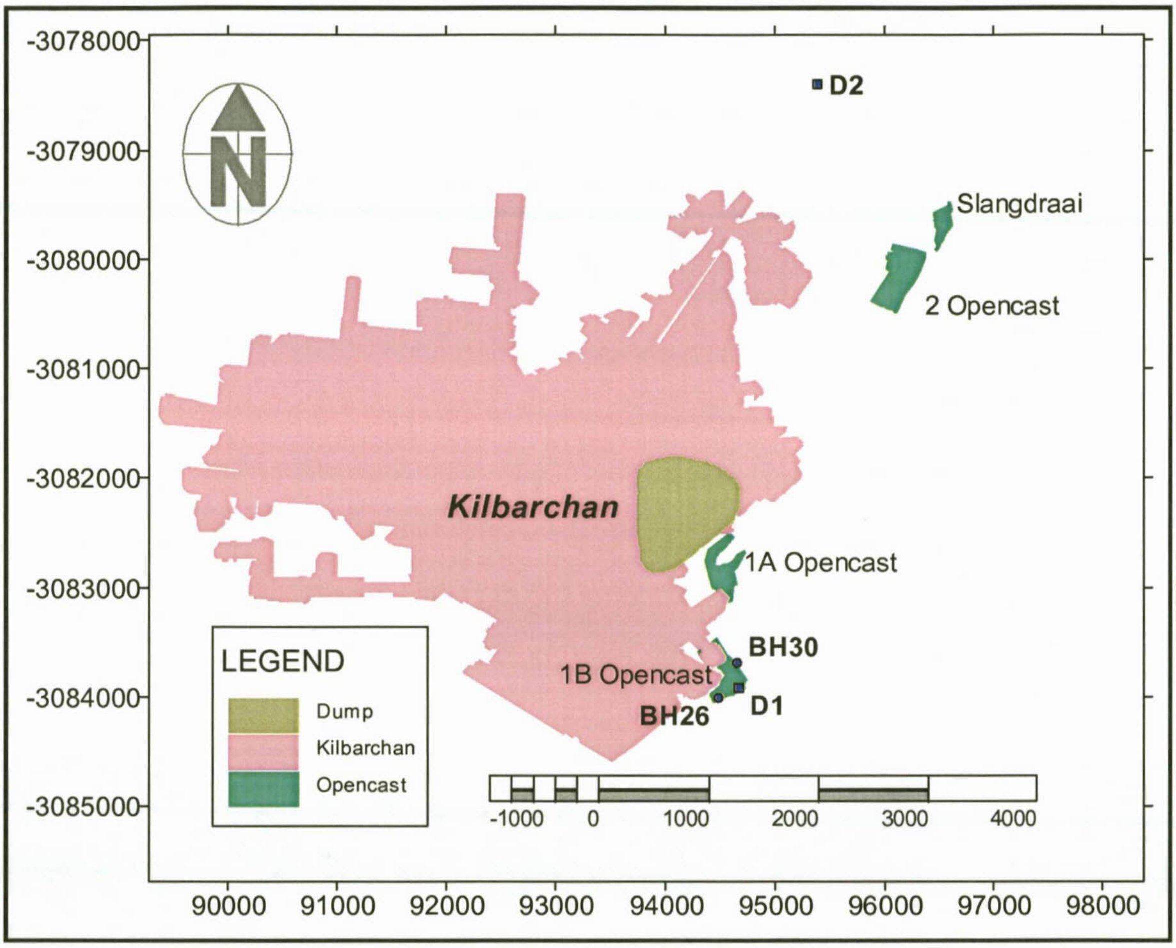


Figure 98: Opencast sampling points.

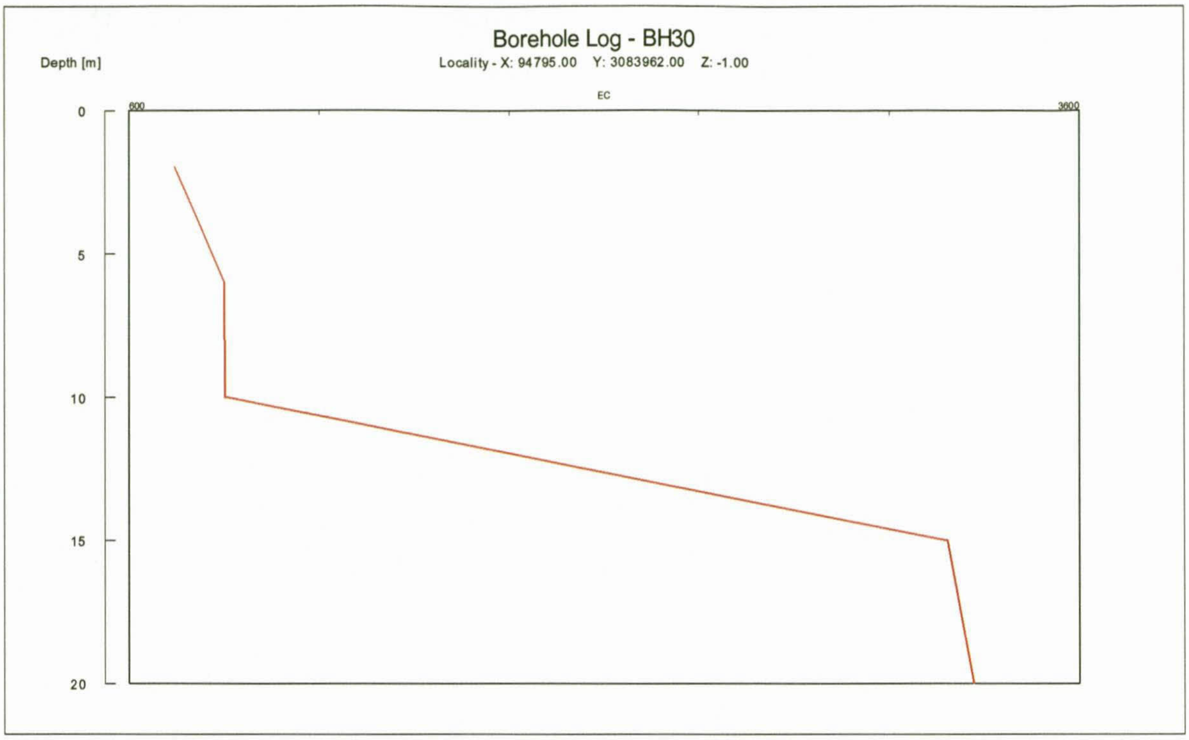


Figure 99: EC profiling for BH 30.

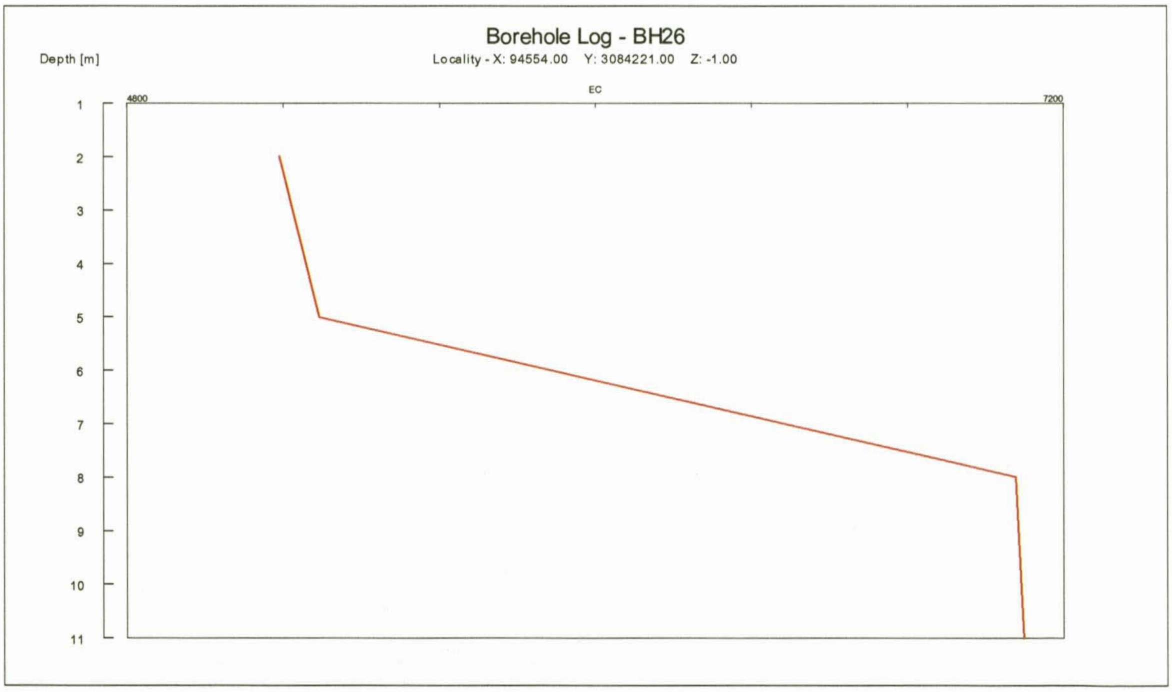


Figure 100: EC profiling for BH 26.

The water quality from the decant point as well as the water pumped with the transfer pipelines (directly out of the mining void) is illustrated in Table 25

These qualities indicate a very high sulphate (higher than the average of 2500mg/l in most of the mines in South Africa)and sodium character, with high calcium and magnesium values, implying a very dynamic system with a serious ARD problem. No buffer material (alkalinity) is present in the water from the opencast decant. The time graphs (Figure 101) of EC, sulphate, calcium and magnesium indicates that the water did not improve or deteriorate since 2004.

Table 25: Water quality of the decant point and the transfer lines.

SiteName	pH	EC	Ca	Mg	Na	K	Palk	MAlk	F
		mS/m	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l
D1	3.52	800	423	462	902	20.2	0.0	0	0.41
TRANSFER PIPELINE 1	6.98	668	279	155	1,220	17.8	-1.0	440	0.79
TRANSFER PIPELINE 2	6.97	600	258	108	932	13.5	-1.0	491	1.63
SiteName	**Cl**	**NO2(N)**	**Br**	**NO3**	**PO4**	**SO4**	**Al**	**Fe**	**Mn**
	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l
D1	352	-1	-1	0.18	-1	4161	4.15	13.0	45.6
TRANSFER PIPELINE 1	351	-1	-1	0.75	-1	3053	0.01	2.34	-
TRANSFER PIPELINE 2	343	-1	-1	0.21	-1	2340	0.035	10.3	-

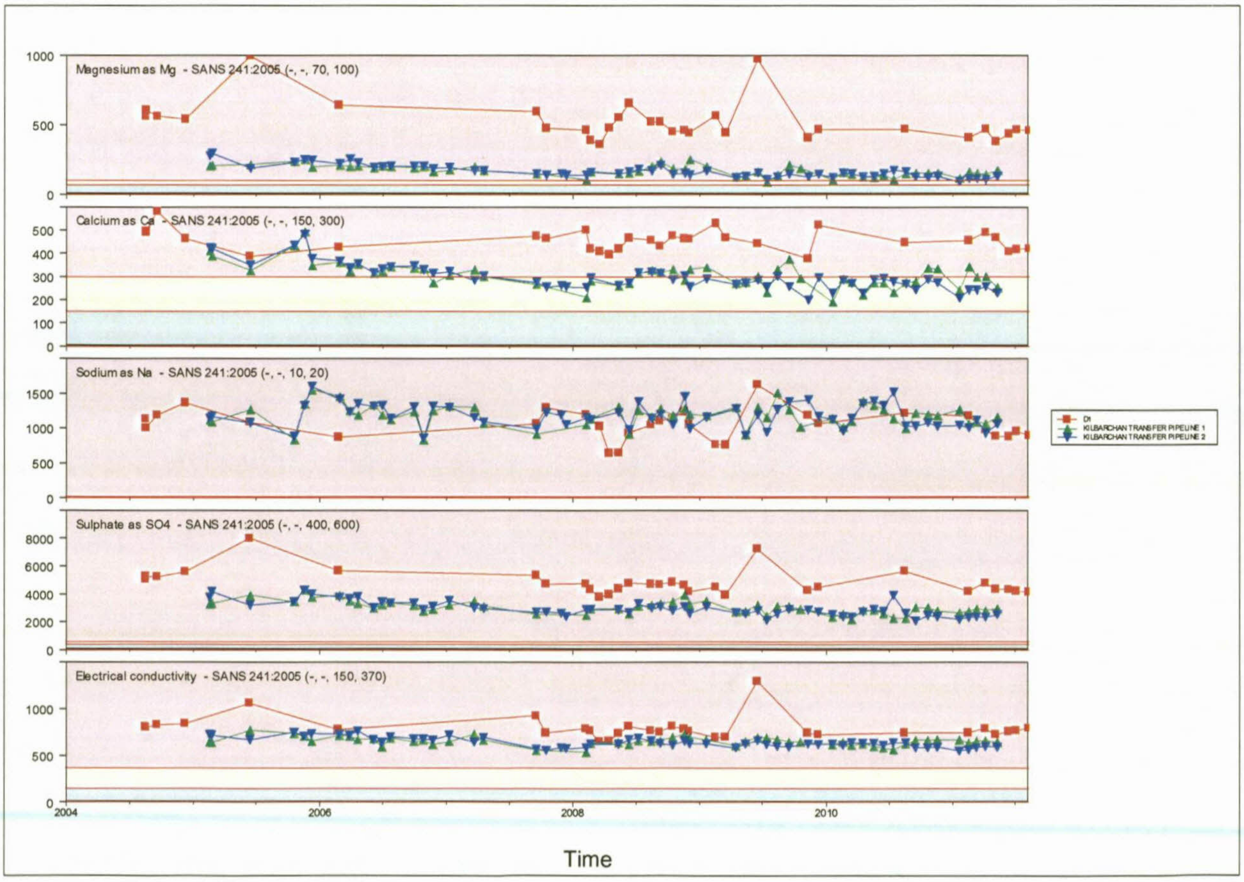


Figure 101: Time graph of EC, sulphate calcium and magnesium for the decant point and the transfer lines.

The Stiff diagrams in Figure 102 clearly illustrate the sodium sulphate character of the water originating from the opencast (D1) and the underground at Kilbarchan (transfer pipe lines) show mine water where sulphate has formed in the mine due to oxygen inside the mine.

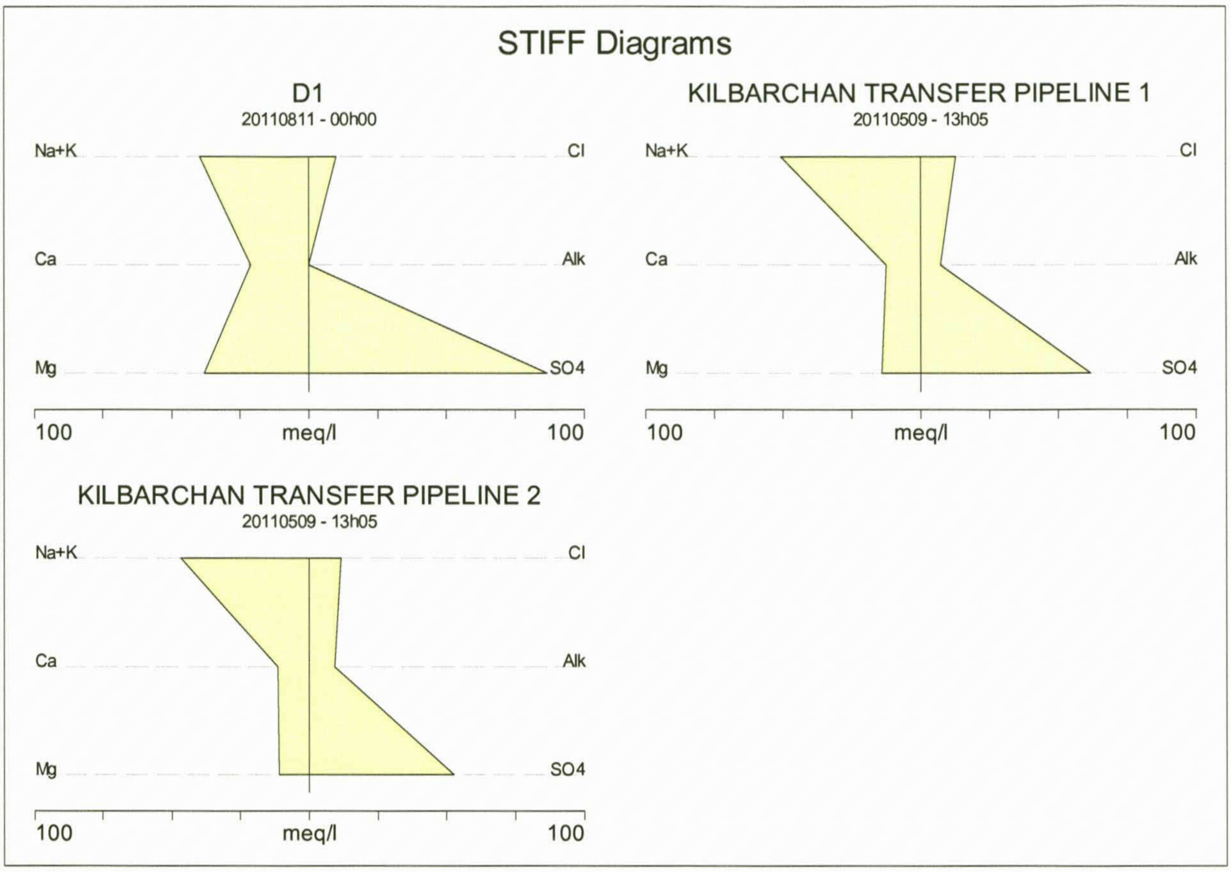


Figure 102: Stiff diagrams of the decant and transfer lines sampling points.

4.15.2 Chemistry of the surface water

In Figure 103 the position of all the surface sampling points sampled on a regular basis, together with shallow boreholes around the discard dump, is illustrated. In Figure 103 one of these discard boreholes is displayed.

Figure 103: Photograph of KMH3.

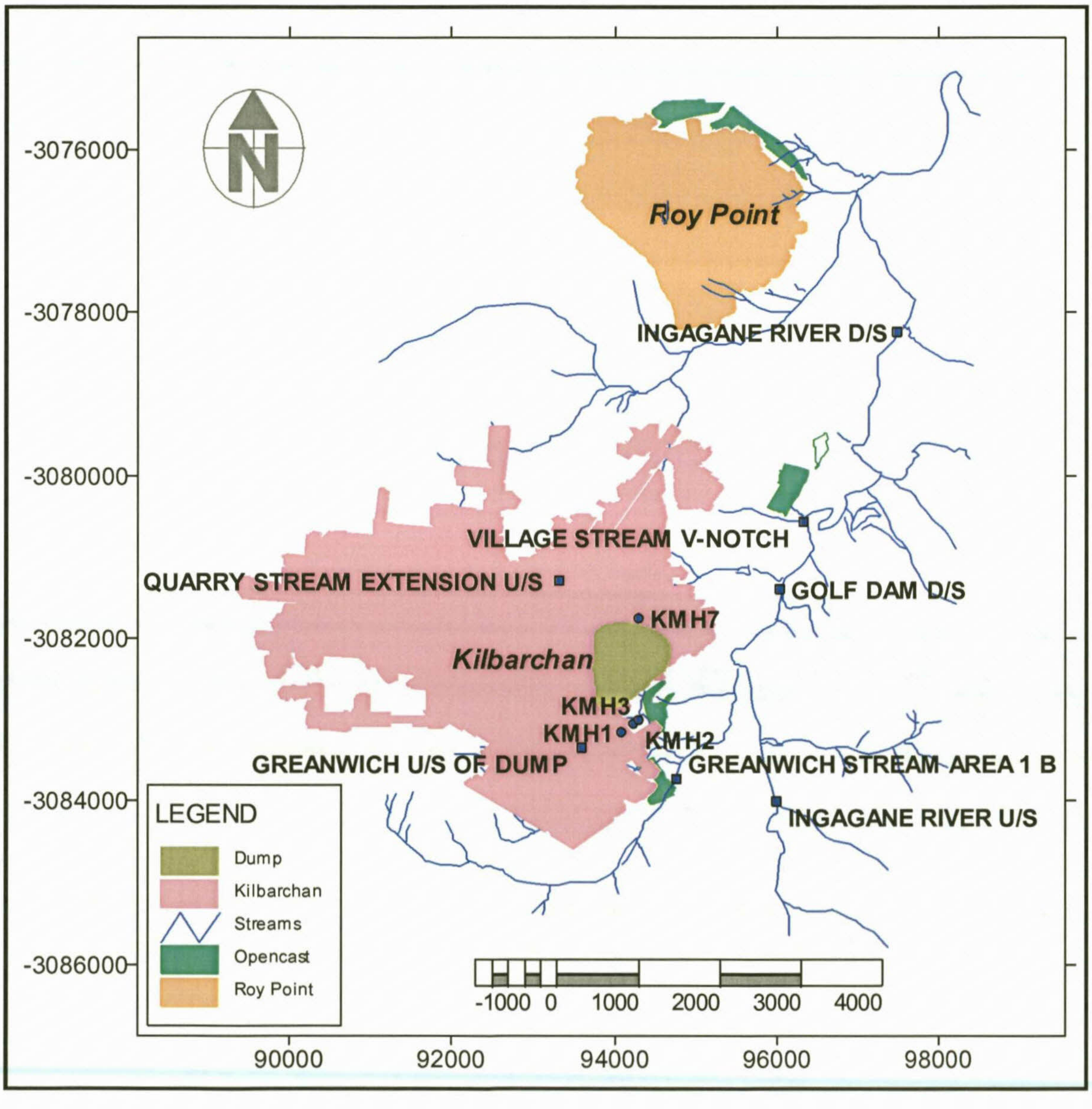


Figure 104: Position of the samples of the surface water.

The chemistry of the surface water samples and the boreholes monitoring the dump is shown in Table 26

The criteria used for inorganic sampling is the SANS 241:2006, and for organic analysis the USEPA Standards. Inorganic water samples are classified as:

- Class I – acceptable (color coded green)
- Class II - allowable (color coded yellow)
- Above – not allowable (color coded red)

Table 26: Results of the chemical analyses of the surface water sampled during the last site visit April 2011.

BH number	pH	EC	Ca	Mg	Na	K	PAlk	MAlk	F
		mS/m	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l
KMH1	5.5	450	409.7	228.4	414.8	15.3	0	26.5	0.47
KMH2	5.78	358	288.9	118.9	425.5	18.5	0	45.2	0.03
KMH3	5.13	476	404.2	64.6	616.1	41.4	0	10.5	0.02
KMH7	2.88	662	417.1	160.3	677.8	41.4	0	0	1.27
TransferPipeline 1	6.58	644	252.2	172.7	1160.7	14.6	0	359	0.78
TransferPipeline 2	7.02	592	228.9	133.2	1064.3	13.1	0	462	0.83
Golf Dam d/s	7.62	38.7	27.5	19.2	21.5	2.6	0	105	0.13
Ingagane rivier d/s	6.85	31.7	19.3	14.4	20.6	2.0	0	40.7	0.10
Village Stream V-Notch	7.18	144	90.4	116.9	55.8	7.6	0	112	0.22
Greenwich Stream extention	7.31	218	115.9	113.0	229.8	5.9	0	65.9	0.10
Quarry stream extension u/s	8.1	42.3	31.9	28.1	14.8	0.8	0	142	0.08
Greenwich u/s of dump	7.96	24.4	16.0	9.6	25.4	1.1	0	118	0.22
Opencast area 2	7.53	466	438.8	524.0	81.5	11.0	0	249	0.11
Ingagane rivier u/s	6.89	32.3	19.0	14.0	16.9	2.0	0	39.1	0.09
BH number	Cl	NO2(N)	Br	NO3(N)	PO4	SO4	Al	Fe	Mn
	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l
KMH1	134.38	<1	0.15	<1	<1	2841	0.069	2.769	12.338
KMH2	133.61	<1	<1	<1	<1	2001	0.075	0.139	6.146
KMH3	179.14	<1	<1	<1	<1	2607	0.071	13.086	6.396
KMH7	148.07	<1	<1	<1	6.41	4335	36.738	449.421	104.914
TransferPipeline 1	452.13	<1	<1	<1	5.68	2967	0.019	0.284	1.631
TransferPipeline 2	412.27	<1	<1	<1	<1	2533	<1	0.433	0.651
Golf Dam d/s	7.05	<1	<1	<1	<1	83.00	<1	0.056	0.017
Ingagane rivier d/s	5.67	<1	<1	<1	<1	111.00	0.130	0.278	0.023
Village Stream V- Notch	28.81	<1	<1	3.65	<1	713.00	0.017	0.085	0.668
Greenwich Stream extention	77.46	<1	<1	<1	<1	972	0.029	0.089	3.942
Quarry stream extension u/s	4.84	<1	<1	1.50	<1	72.00	0.021	0.106	0.017
Greenwich u/s of dump	2.06	<1	<1	<1	<1	11.67	0.144	0.418	0.014
Opencast area 2 seapage	4.32	<1	<1	<1	<1	3366	0.025	0.150	7.291
Ingagane rivier u/s	4.94	<1	0.05	0.11	<1	103.00	0.125	0.217	0.292

- From this data it is clear that the discard dump has an influence on the surrounding groundwater quality.
- The Greenwich stream extension downstream from the decant point indicates pollution. This is a result of the water decanting from the opencast.
- It is not clear if the affected water at the Village stream V-notch is a result of water flowing from the mine, as this is also down-gradient from the Ngagane power station.

The proportional size distribution of the electrical conductivity values of all these samples are displayed in Figure 105 the boreholes shown with circles and the surface water with squares, and the Stiff diagrams of the last values in Figure 106. The diagram of the discard boreholes clearly indicates the sodium-sulphate character of these waters, with elevated calcium and magnesium as well.

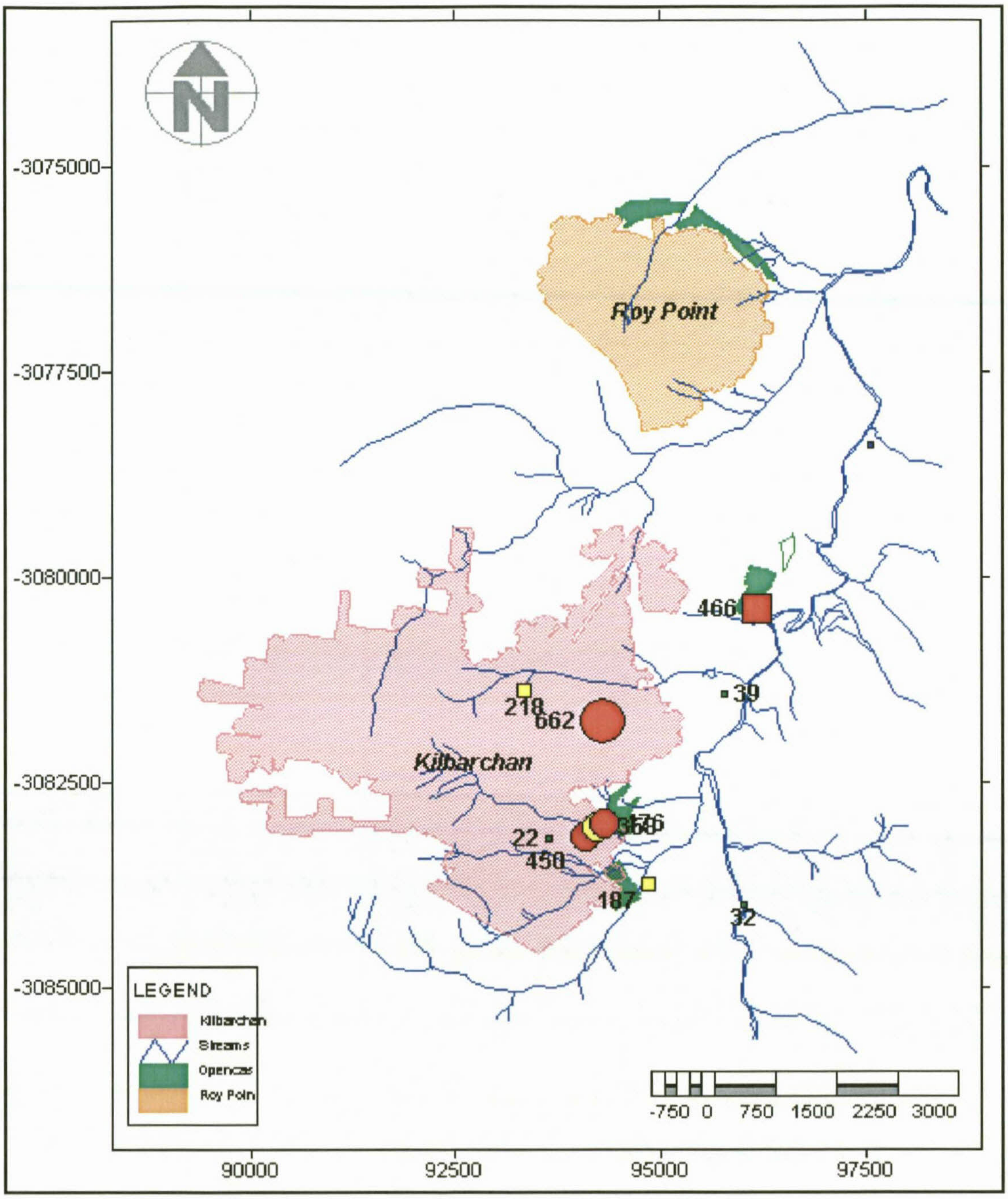


Figure 105: Proportional distribution of EC values of the surface samples and discard boreholes.

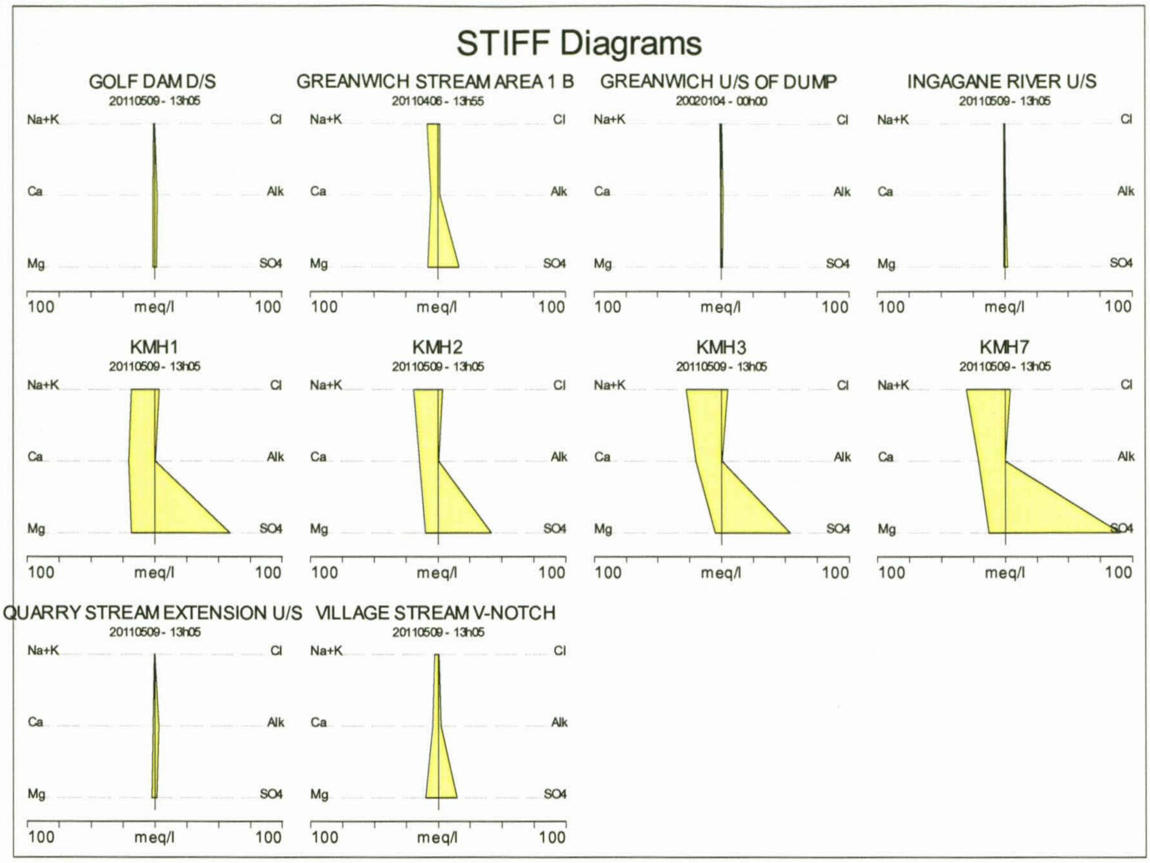


Figure 106: Stiff diagrams of the surface water and the discard dump.

The time graph of the surface water samples indicates that the two elevated samples discussed above (Greenwich stream extension and Village stream V-notch) have very erratic values and are definitely influenced by surface dilution (e.g. rainfall events), but the overall trend indicates the elevated values (SO_4) in relation to the other surface samples.

The EC values of the surface samples are in the standards for water quality show in Figure 107. The time series show that the surface waters are not polluted. The manholes around the discard dump shows EC values shown in Figure 108 that are not acceptable.

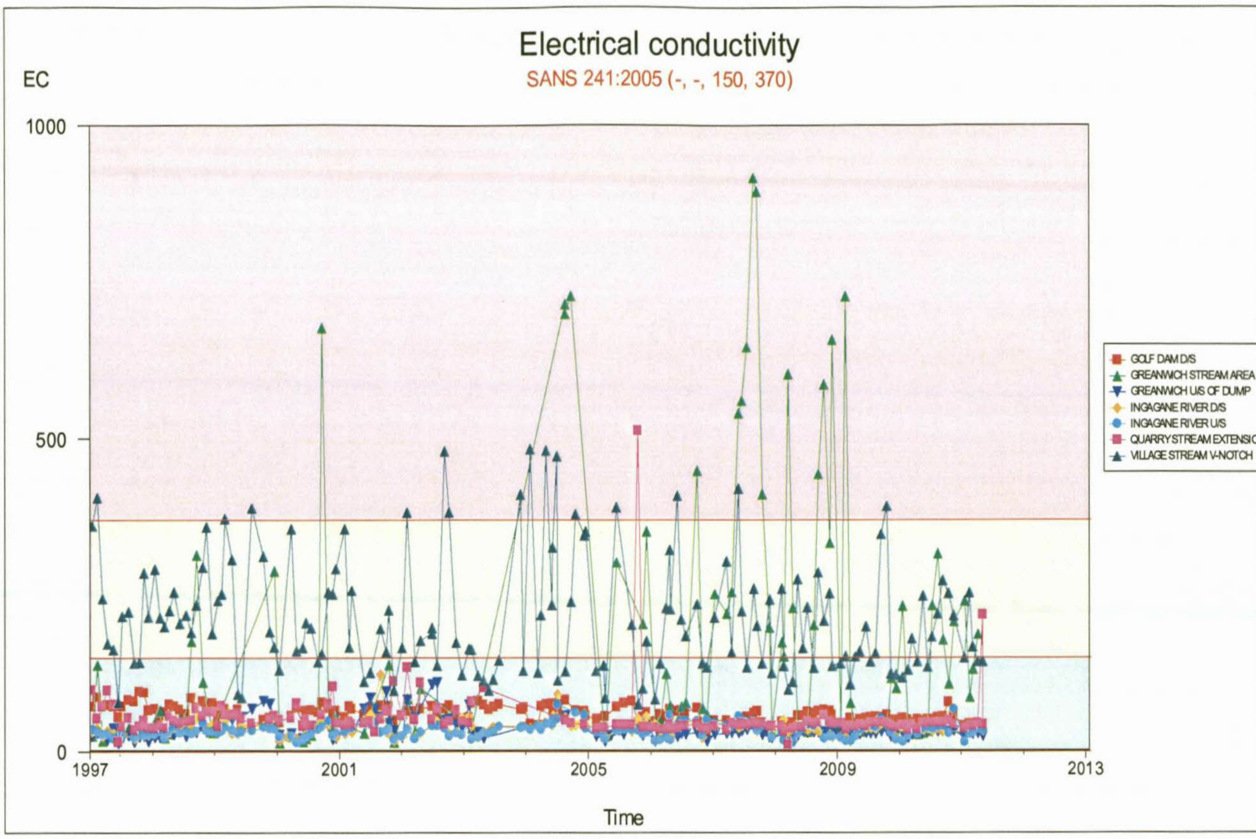


Figure 107: Time graph of the EC for the surface samples.

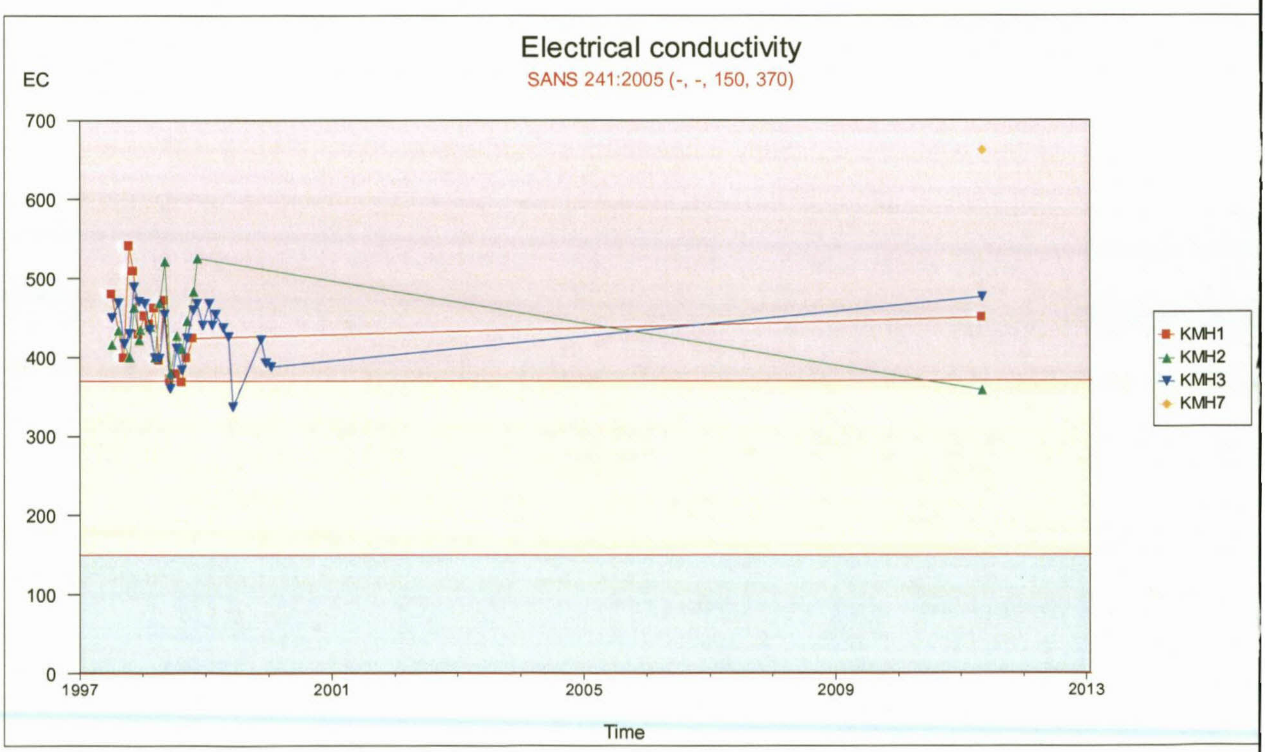


Figure 108: Time graph of the EC for the discard dump boreholes.

4.16 Conclusions and recommendations

The following is concluded from this study:

- The fact that the water level ***elevations*** of the different boreholes are all in the same order indicate that the water level is flat throughout the underground and connected opencast mine. Due to decant through the opencast, these mine water levels will not rise in the underground mine above the decant level. The variation in water level elevation is due to recharge and the resulted pumping from the underground, resulting in the 3 m variation in water level.

- Water is being pumped on a regular basis from Kilbarchan to Roy Point, and also controlled release pumping at the opencast.

- The mobile pump pumps out approximately 300000m^3/a of water per annum on average and the transfer pipelines pumps approx. 750000m^3/a. Decant of the opencast pits is at approximately 110000m^3/a of water.

- Taking the annual rainfall into account, the conclusion is that **recharge of 11.3 %** occurs into Kilbarchan.

- It is clear that there is a definite difference in water quality of the top and bottom samples of those boreholes drilled into the mining cavity, indicating stratification.

- VOID BH is drilled into the opencast void. The water is already acidic with a high sulphate value this results in a pH of 2.84, most probably due to the flow of water through the void, ingressing oxygen. High sulphate values together with high levels of Al, Fe and Mn, as well as calcium, magnesium and sodium are present. The water quality for the top boreholes did not deteriorate since 1999, except the VOID BH. The bottom samples show high EC values. ***This indicates that sampling is done at the incorrect depth, or that sampling should be done at least at different depths to have a clear indication of the mine water quality as well.***

- Water decants from the opencast. Two boreholes BH26 and BH30 are also drilled into the opencast, but is not part of the monitoring program. Profiling illustrates the polluted nature of these boreholes with BH26 indicating an EC of 7000mS/m at 7 m depth and BH30 an EC of 3000 mS/m at a depth of 15 m.

- The water quality decanting indicates a very high sulphate (higher than the average of 2500mg/l in most of the mines in South Africa)and sodium character, with high calcium and magnesium values, implying a very dynamic system. No buffer material (alkalinity) is present in the water from the opencast decant.

- The discard dump has an influence on the surrounding groundwater quality. The Greenwich stream extension downstream from the decant point indicates pollution. This is a result of the water decanting from the opencast. It is not clear if the affected water at the Village stream V-notch is a result of water flowing from the mine, as this is also down-gradient from the Ngagane power station. Greenwich stream extension and Village stream V-notch have very high SO_4 values and are definitely influenced by surface dilution (e.g. rainfall events), but the overall trend indicates the elevated values in relation to the other surface samples.

Recommendations

- It is recommended that the monitoring programme in the mine be executed properly with water being sampled in the mining cavity and higher up in the water column every quarter that is 4 times a year of all the Kilbarchan sites. More boreholes into the mining cavity will also contribute to a better understanding of the current water volumes. As only three boreholes are currently used for monitoring
- The water balance of the system needs be better understood to reduce the risk of oxygen flushing through the system. The water balanced needs to be balanced.
-

CHAPTER 5
CONCEPTUAL COMPARISON

5.1 Introduction

This chapter will focus on the differences between the two different collieries, Usutu and Kilbarchan. A comparison of the two studies will give a good indication of the influence of flooding at the different sites. This will show whether the depth of mining, topography, mining methods, water levels, exposure to oxygen, rainfall, recharge, residence time and pumping influence the effects of flooding at coal mines. The conclusion is that these factors do play a vital role in the management of flooded coal mines. There is a difference between the shallow underground mine and the deep underground mine. These differences will be discussed in the sections to follow.

The aim is to know what to expect when managing a deep underground or shallow underground colliery which have been flooded. Both mines have been flooded for more than 20 years. The effect of flooding is influenced by a number of factors

The differences between the two are with regard to:

- Water quality
- Topography
- Depth of mining
- Mining methods
- Rainfall
- Exposure to oxygen
- Residence time
- Decanting
- Recharge
- Pumping
- Management

Comparisons between the two studies include:

- Geology

- Mineralogy
- High extraction
- Coalmining
- Both fully flooded with water
- Production stopped
- Underground

5.2 Mining area

In general an underground coalmine that is mined by bord-and-pillar methods at a depth of 100 m below surface can be flooded with water after mining operations have ceased, without any danger to the adjacent environment. The mine is too deep to allow the ingress of oxygen into the workings and also too deep to allow water to flow from the mine after it has filled up (Zeelie & Hodgson, n.d).

The mining area between the two studies differs. At Kilbarchan very shallow mining took place in the mountains. Water has a shorter residence time in the system as the gradient is steeper. At Usutu the area is flatter and much deeper, water stays in the system much longer and the sensitivity to pollution is greater than at Kilbarchan.

The topography of Kilbarchan mine are more vivid than the flat surfaces at Usutu mine. At Usutu the topography is of a gentle rolling nature. Steeper slopes are present at sandstone outcrops. Significant topographic differences are present in the KwaZulu-Natal Coal-fields.

In contrast, in the case of the high underground extraction of coal, numerous cracks are created from the mining level all the way to the surface. Ingress of fresh water containing oxygen and also ingress of air are possible. The probability of the mine water becoming acidic over a period of time is therefore significantly greater for high underground extraction mining than for bord-and-pillar mining (Zeelie & Hodgson, n.d).

5.3 Depth of mining

Usutu mine is a deeper mine than Kilbarchan mine. The depth of water flow plays a role in the residence time of water. Therefore Kilbarchan mine will have a short residence time and a greater risk of pollution. This is one of the main reasons why the water quality at Kilbarchan is more polluted.

The rainfall of the two areas differs. There is about a 100 mm difference in the annual precipitation. Recharge will be greater at the shallow Kilbarchan mine 11.3 %, but by managing the releases the water balance could be solved. It is important to keep the mine flooded to stop oxygen interacting with water and sulphur rich minerals (pyrite) to cause acid mine drainage (AMD), but also to avoid decants. This is done by the water level remaining above the mining cavity.

Mining is taking place at a shallower depth at Kilbarchan. Water from rainfall is recharged and moves into the surface; this water is rich in oxygen. At Usutu mine the mining is deep and the oxygen-rich rainwater takes a long time to reach this level. Recharge differs significantly in both studies. The deeper Usutu mine is calculated at 5.7% and the shallower Kilbarchan mine at 11.3%. Shallow mines seem to be more susceptible to pollution than deeper mines. Based on the evidence that the mine is shallower, topographically more up and down and a shorter residence time.

5.4 Water levels

There are big differences in depth of the water levels at both areas. At Usutu mine the reason for the difference in water levels was the ventilation seals in the underground. On old maps ventilation walls show that the mine has been compartmentalized; water becomes trapped inside a compartment, in a sense creating its own water level. The measured water levels differ from one another. A different problem was encountered at Kilbarchan. The water levels also differed in depth, but the water level elevation are the same. It means that the overlying aquifer is not fully recharged as yet, because of decant. Mining is taking place at a hilly area very shallow, together with opencast areas. As the mine fills up with water the unconfined water level and the mine water level is moving towards each other. Decant then takes place before the aquifer gets fully recharged. Interpreting these water levels is a very difficult exercise. Water will sometimes decant at a borehole, caused by a break in these seals at Usutu. This is interpreted as the water level rising, which is not really the case. Finally it is concluded that when looking at water levels at flooded mines, water level elevation should be used rather than water level depth as it can be misleading.

5.5 Rainfall

Rainfall causes an increase in the recharge at a mine site. Kilbarchan is located in a higher rainfall area than Usutu. Kilbarchan is located in the KwaZulu-Natal province and Usutu in the province of Mpumalanga. Kilbarchan - 864 mm/a and Usutu - 710 mm/a. The rainfall at the different sites show that kilbarchan has an 20% higher rainfall than Usutu.

5.6 Recharge

The tempo at which this happens is defined by the recharge rate which depends on the geology, the depth, the type of mining and whether some form of high-extraction was performed. Under undisturbed conditions, 3% of the annual recharge would be an acceptable average value. Taking the annual rainfall into account, the conclusion is that recharge of 11.3 % occurs into Kilbarchan and 5.7 % at Usutu colliery. This difference in recharge is due to the opencast areas and stooped areas. At Kilbarchan colliery opencast mining took place, because of the shallow depth of the coal seams. The recharge at opencast areas is between 15-20 % and at stooped areas between 8-12 %.The depths of mining also influence the recharge, recharge is calculated easier at the shallow Kilbarchan mine than at Deeper Usutu. This changes the recharge in the underground as it influenced by these activities.

This work compared well with work previously done in this field of study in a WRC report.

A summary of the percentage influx to be expected for the various mining methods, as determined during this investigation, is as follows done by Hodgson & Vermeulen (2007):

- Deep bord-and-pillar with no subsidence 1-4% of the rainfall.
- Shallow bord-and-pillar 3 -10% of the rainfall.
- Stooping 4 -12% of the rainfall.
- Long wall 6 -15% of the rainfall.
- Opencast 14 - 20% of the rainfall

5.7 Pumping

Pumping is probably the main difference between these two sites. If the pumping is not managed properly, the mine water quality will not improve. This is clearly seen in the water level elevation, where water is being pumped more than is necessary for long periods at Kilbarchan. The shallowness of the mine causes oxygen to infiltrate into the underground workings as the water level drops from pumping. The EC over time at Kilbarchan is not improving because of the excessive pumping.

Pumping also takes place at Usutu, but it is managed well. The mine is kept full and the water levels stay steady over time. This prevents oxygen from infiltrating into the underground. The

EC over time has improved. Finally, in pumping a flooded mine management is vitally important. Care should be given at shallow underground mines to an understanding of the water balance. Flushing is an accepted practice to improve the quality of mine water if the pumping rate (and thus the water levels) is managed properly, keeping the water level above the mining cavity. If the mine stays flooded then no additional oxygen ingress and pyrite oxidation will occur. This is seen at the pumping station BH at Usutu. A large proportion of the collieries will eventually decant. The flushing of mines is inevitable once they are flooded. This could improve the water quality in the mine, but reduces the available base potential of the mine as a whole. Plans to manage this must be in place.

5.8 Decant

Decant is taking place at the shallow underground Kilbarchan colliery. The water is decanting from opencasts at 2.5 l/s. The EC of the decant water over time is not improving, measured at 637 mg/l. Decant then takes place in the opencast before the aquifer gets fully recharged, because of the gradient at which mining is taking place. This is an important concept in understanding the reason for decant. At the deep underground mine Usutu no decanting is taking place. The area is flat and the water levels are monitored to prevent the water level to drop under the mining cavity, thus preventing oxygen from moving into the system.

5.9 Sampling

Sampling is such an important management tool at flooded coal mines. Sampling at the different sites was done at the incorrectly depths, it should be done at different depths to have a clear indication of the mine water quality. The water needs to be sampled at the bottom of the boreholes sampling inside the mine, sampling was done at the top of the boreholes. This is not a representable sample of the mine water At Usutu the water were sampled just beneath the water level, results of the hydrocensus concluded that the water quality sampled was exactly the same as the farmer's boreholes around the mine. This means that the water of the regional aquifer was sampled and not the actual mine water inside the mine. The sampling for this study was done at the top and the bottom of the boreholes inside the mining cavity. Results indicated a substantial difference in qualities at depth. If you can't measure it you can't manage it.

5.10 Residence time

Groundwater sensitivity to pollution is best understood in relation to travel time, which is the approximate time that elapses from when a drop of water infiltrates the land surface until it enters an aquifer or reaches a specific target such as a spring. This is also called residence time. The pollution sensitivity of an aquifer is assumed to be inversely proportional to the time of travel. In addition, contaminants are assumed to travel at the same rate as water. Very high sensitivity indicates that water moving downward from the surface may reach the groundwater system within hours to months. In these areas, there is little time to respond to and prevent aquifer contamination. Conversely, low sensitivity indicates there is time for a surface contamination source to be investigated, and possibly corrected, before serious ground-water pollution develops (Alexander &Alexander, 1989)

The residence time of the two sites differs. Kilbarchan has a short residence time, because of the shallow depth and excessive pumping. This makes it more sensitive to contamination. On the other hand, Usutu has a longer residence time, because of the deeper depth and controlled pumping. The sensitivity to pollution is less the longer the residence time. The opencast area 1A and 1B that is connected to the underground causes more oxygen rich rainwater to enter into the workings

The residence time is influenced by the depth of mining:

- The shallower, the shorter the residence time and the more chance for a poor water quality. Higher sensitivity.
- The deeper, the longer the residence time and a better chance for good water quality. Lower sensitivity.

5.11 Water quality

The SO_4 values / sulphate generation comparison compared shows a very large difference in the values. The SO_4 values at Usutu range between 300 and 900 mg/l, while at Kilbarchan the range is between 1500 and 3000 mg/l. The reason for this is that Kilbarchan is more exposed to oxygen, because of the shallow depth and excessive uncontrolled pumping. Sulphate generation occurs when sulphate minerals (pyrite) combine with water and oxygen. At Usutu VOID BH is drilled into the opencast void. The water is already acidic with a pH of 2.84, most probably due to the flow of water through the void, ingressing oxygen. This result in very high sulphate values together with high levels of Al, Fe and Mn, as well as calcium, magnesium and sodium are present. The two Durov figures clearly show the differences in water quality between the two sites. Firstly Kilbarchan samples plot more in the 4 and 5 fields. The Usutu samples plots in the 2 and 3 fields (See Appendix). All the samples that have data were used to draw up an Expanded Durov diagram. This can also be used to see the differences in water quality.

5.12 Recommendations

The following actions are recommended:

- Much can be done to improve mine-water planning at all collieries. It is essential that as much mine water as possible be kept underground during and after mining. Mining should be done from low-lying areas to higher ground.

- Compartments should be created that could fill up with water while mining continues in other sections of the mine. This should ensure the minimization of water treatment.

- The recommendation from these results is to flood the mines as quickly as possible. This can be achieved by the selection of mining method, the mining sequence and flooding. Mining methods and mining geometry play a decisive role in the amount of water to be managed during and after mining.

- Mine scheduling is one of the most important water management tools to be considered from the outset of mining, throughout the life of the mine. The filling up of mines with water is inevitable after closure. Seepage of water away from the mines will occur once they approach the full mark.

- EC profiles should be done at depth, to see whether stratification keeps on occurring. Sampling for water quality at the "top" and "bottom" of a borehole. This means sampling just below the water level and in the mining cavity. This will give us a better understanding of the qualities inside the mine itself.

- Water pumped from the Kilbarchan mine should be treated. The water quality of the water pumped to the transfer pipelines at Roy point is below standard.

- Water levels, pumping yields, discharge, rainfall and chemistries should be monitored as frequently as possible. Weekly water levels and quarterly water samples should be taken. Anomalies should be identified and checked as soon as they occur. The information should be interpreted on an ongoing basis.

BIBLIOGRAPHY

Alexander, S.C., and Alexander, E.C., Jr. (1989). Residence times of Minnesota ground waters: Minnesota Academy of Sciences Journal, 55(1):48-52.

Aryafar, A, Doulati, F, Ardejani, Singh, R and Shokri, B.J. (2007). Prediction of groundwater inflow and height of the seepage face in the deep mine pit using numerical finite element model and analytical solutions. In: IMWA Symposium 2007: Water in Mining, 27th - 31st May 2007, Cagliari, Italy.

Balkau, F. (1999). Abandoned mine sites In: Natural Resources Management Unit Division, Protection of the environment and Natural Resources: Report on the International Round Table on Mining and the Environment (Berlin 11 Declaration). pp 40-43; Kohn (Carl Duisberg, Gesellschaft).

Bedient, P.B., Rifai, H.S. & Newell, C.J. (1994). Groundwater Contamination; Transport and Remediation. 541 pp, Prentice Hall, New Jersey. Cited in Minerals Council of Australia (1997). Chapter 8: Open Cut Mines, In: Mine site Water Management Handbook, edited by Minerals Council of Australia, First Edition.

Brawne, C.O. (1982). Control of groundwater in surface mining. International Journal of Mine Water, **1**:1-16.

Carter, P. (1992). Chapter 11 Dewatering. In: Drainage design, by Smart, P. and Herbertson, J.G, http://bestcoaltrading.blogspot.com/2010/09/mine-dewatering.html (accessed September 2010).

Chen, M, Soulsby, C and Younger, P, L. (1999). Modeling the evolution of mine water pollution at Polkemmet Colliery, Almond catchment, Scotland, The Quarterly Journal of Engineering Geology, 32(4):351-362. Cited in: J.J Donovan, B R Leavitt and E Werner. (2003). Long-Term Changes in Water Chemistry as a Result of Mine Flooding in Closed Mines of the Pittsburgh Coal Basin, USA In: 6th ICARD, Cairns, QLD, 12 - 18 July 2003, pp 869-874.

Connelly, R.J, Gibson, R. (1985). Dewatering of The Open Pits at Lethakane and Orapa Diamond Mines, Botswana. *International Journal of mine water*, 4:pp 25-41, Madrid, Spain.

5.13 Comparative flow diagram

Figure 109: Comparative flow diagram.

BIBLIOGRAPHY

Alexander, S.C., and Alexander, E.C., Jr. (1989). Residence times of Minnesota ground waters: Minnesota Academy of Sciences Journal, 55(1):48-52.

Aryafar, A, Doulati, F, Ardejani, Singh, R and Shokri, B.J. (2007). Prediction of groundwater inflow and height of the seepage face in the deep mine pit using numerical finite element model and analytical solutions. In: IMWA Symposium 2007: Water in Mining, 27th - 31st May 2007, Cagliari, Italy.

Balkau, F. (1999). Abandoned mine sites In: Natural Resources Management Unit Division, Protection of the environment and Natural Resources: Report on the International Round Table on Mining and the Environment (Berlin 11 Declaration). pp 40-43; Kohn (Carl Duisberg, Gesellschaft).

Bedient, P.B., Rifai, H.S. & Newell, C.J. (1994). Groundwater Contamination; Transport and Remediation. 541 pp, Prentice Hall, New Jersey. Cited in Minerals Council of Australia (1997). Chapter 8: Open Cut Mines, In: Mine site Water Management Handbook, edited by Minerals Council of Australia, First Edition.

Brawne, C.O. (1982). Control of groundwater in surface mining. International Journal of Mine Water, **1**:1-16.

Carter, P. (1992). Chapter 11 Dewatering. In: Drainage design, by Smart, P. and Herbertson, J.G, http://bestcoaltrading.blogspot.com/2010/09/mine-dewatering.html (accessed September 2010).

Chen, M, Soulsby, C and Younger, P, L. (1999). Modeling the evolution of mine water pollution at Polkemmet Colliery, Almond catchment, Scotland, The Quarterly Journal of Engineering Geology, 32(4):351-362. Cited in: J.J Donovan, B R Leavitt and E Werner. (2003). Long-Term Changes in Water Chemistry as a Result of Mine Flooding in Closed Mines of the Pittsburgh Coal Basin, USA In: 6th ICARD, Cairns, QLD, 12 - 18 July 2003, pp 869-874.

Connelly, R.J, Gibson, R. (1985). Dewatering of The Open Pits at Lethakane and Orapa Diamond Mines, Botswana. *International Journal of mine water*, 4:pp 25-41, Madrid, Spain.

Connelly, R.J. (1982). A Case History of The Open Pits mine dewatering at Letlhakana Mines in Groundwater 82. Groundwater division of the Geological Society of South Africa, University of the Witwatersrand.

Donovan, J.J, B. Leavitt, R and Werner, E. (2003). Long-Term Changes in Water Chemistry as a Result of Mine Flooding in Closed Mines of the Pittsburgh Coal Basin, USA In: *6th ICARD, Cairns, QLD, 12 - 18 July 2003, pp 869-874.*

Fuji, S. (2002), Modern Trends in Computer-Integrated Technologies in Minerals Industry, IV International Symposium on the Occasion of the 40 Years of Ex is tence of the Department for Machinery in Mining, *Proceedings*, Mechanization and Automation in Mining and Energy Sources, Faculty of Mining and Geology, University of Belgrade, Belgrade, 2002.

Fuji, S. *et al* (2004), Adapt able Computer-Supported Monitoring-Management Model of the System for Dewatering of the "Drmno" Coal Open Pit Mine (Phase I) (in Serbian), Project 102-154A, Internal Report, Faculty of Mining and Geology, University of Belgrade, Belgrade, Serbia and Montenegro.

Grobbelaar, R. Usher, B, Cruywagen, L-M, de Necker, E. Hodgson, F.D.I. (2004). Long Term Impact of Intermine Flow from collieries in the Mpumalanga coalfields, WRC Report No 1056/1/04. Institute for Groundwater Studies, University of the Orange Free State, Bloemfontein.

Hodgson, F.D.I, Vermeulen, P.D, Cruywagen, L-M and de Necker, E. (2007). Investigation of water decant from the underground collieries in Mpumalanga WRC Report No: 1263/1/07, University of the Free State, Bloemfontein.

Hodgson, F.D.I. (2006). Kilbarchan Colliery: Update of the Water Balance for Kilbarchan and Roypoint Sections, Institute for Groundwater Studies, Report no: 2006/02/Kilbarchan, University of the Free State, Bloemfontein .

Hodgson, F.D.I. and Krantz, R.M. (1998). Groundwater Quality Deterioration in the Olifants River Catchment above the Loskop Dam with Specialized Investigation in the Witbank Dam Sub-Catchment. Report to the WRC, Report291/1/98, Water Research Commission, Pretoria.

Hodgson, F.D.I., Cruywagen, L-M and de Necker, E. (1997). Chapter 4 Coal mining in outcrop areas of KwaZulu-Natal. In: Coal Mining in the Vryheid Area – Geohydrology and Hydrochemistry, Institute for Groundwater Studies, University of the Free State, Bloemfontein.

Hoek, E. and Pentz, D.L. (1968). The Stability of Open Pit Mines Two-dimensional Flow Net Illustrating Seepage Forces in a Slope, Imperial College Rock Mechanics, Research Report no 5. Cited in: Brawne. C.O. (1982). Control of groundwater in surface mining. *International Journal of Mine Water*, 1: 1-16.

Hustrulid, W. A. (2000). Slope stability in surface mining. Hydrogeological model approach for dewatering mining, SRK Consulting. Citing Internet Resources. http://www.srk.com/files/File/papers/Numerical%20Groundwater10WIM_Chapter06_17.pdf.

Jeffrey L.S. (2005). Characterization of the Coal Resources of South Africa. Journal of the South African Institute of Mining and Metallurgy, 95-102.

Libicki, J. (1993). Proposal of Criteria for The Selection of Dewatering Methods in Surface Mining. International Mine Water Symposium, Zambia, pp53-332. Poltegor Engineering ltd.

Mccarthy T. S. and Pretoruis, K. (2009). Coal Mining on the Highveld and Its implications for Future Water Quality in the Vaal River System, In: Abstracts of the International Mine Water Conference, Pretoria, South Africa, 19 – 23 October 2009, pp 56-65.

Minerals Council of Australia. (1997). Chapter 8: Open Cut Mines, In: Mine Site Water Management Handbook, edited by Minerals Council of Australia.vol 1.

Morton, K.L and van Miekerk F.A. (1993). A Phase Approach to Mine Dewatering. Mine Water and the Environment, 12: 27-34.

Morton, K.L. (2009). Comparison of Designs for the Dewatering of Coal, Gold and Diamonds. KLM Consulting Services. Lanseria, Gauteng, South Africa.

Naise, E.J. (1993). Dewatering Concepts at Zambian Copper Belt Mines, Mine water and the Environment, 11(3):35-45, September 1993.

Nthabiseng, M, Molapo, M and Chunderdoojh, B. (2006). Task 7.8.5 Socio-economically Sustainable Communities Post-mine Closure, Phase I: Situational Analysis, Coaltech 2020.

Parra, G, Merz, S.K. (2009). Modeling Dewatering Effects on Groundwater Dependent Ecosystems at Raymond Terrace, Newcastle. Presented at the Intemational Association of Hydrogeologists, Groundwater in the Sydney Basin Symposium, August 4-5.

Rasul, M.G. and P.J. Vermeulen. (2007). Improvement Strategies for Mine Dewatering Process. Proceedings of the 4th WSEAS International Conference on Fluid Mechanics, Gold Coast, Queensland, Australia, January 17-19: pp137-142. Faculty of Sciences, Engineering and Health, Central Queensland University, Rockhampton, Queensland 4702, Australia.

SA Weather Service - Rainfall Figures.

Stoertz, M.W., Hughes, M. L., Wanner, N. S. and Farley, M .E. (2001). Long-term Water Quality trends at a Sealed Partially Flooded Underground Mine. Environmental and Engineering Geoscience, 7(1):51-65. Cited in: Donovan J.J, Leavitt B.R. and Werner. E. (2003). Long-Term Changes in Water Chemistry as a Result of Mine Flooding in Closed Mines of the Pittsburgh Coal Basin, USA. In: 6th ICARD, Cairns, QLD, 12 - 18 July 2003, pp 869-874.

Stoertz, M. W. Hughes, M. L, Wanner N. S., and Farley, M. E. (2001). Long-term water quality trends at a sealed partially flooded underground mine. *Environmental & Engineering Geoscience*; February 2001; 7(1): 51-65.

Thomas, L. (2002). *Coal Geology*. West Sussex, England. Wiley, J & Sons LTD, The Artruim, Southern Gate, Chichester, West Sussex, PO19 8SQ, England.

Van Tonder, G. and Xu, Y. (2000). A Guide for the Estimation of Groundwater Recharge in South Africa. Project conducted for DWAF under the supervision of Eddie van Wyk, June 2000.

Visit-South-Africa. (2011). Citing Internet Resources. http://www.visit-south africa.co.za/Ermelo.html (accessed 27 June 2011).

WeatherSA (2011). *Citing Internet Resources*. http://www.weatherSA.com/we atheraverages.aspx?q=Ermelo,%20South%20Africa (accessed 19th July 2011).

White, S.P., Creighton, A.L., Bixley, P.F, Kissling, W.M. (2003). Modeling the Dewatering and Depressurization of the Lihir Open Pit Gold Mine. Lawrence Berkley National Laboratory, Berkeley, California, May 12-14.

Whitworth, K.R. (2002). The Monitoring and Modeling of Mine Water Recovery in UK Coalfields. IMC Consulting Engineers, PO Box 18, Hutkwaite, Sutton-in-Ashfield, Nottinghamshire, NG17 2NS, UK.

Wilson, M.G.C. & Anhaeusser,C.R., Editors (1998). The Mineral Resources of South Africa. Handbook, Council for Geoscience.

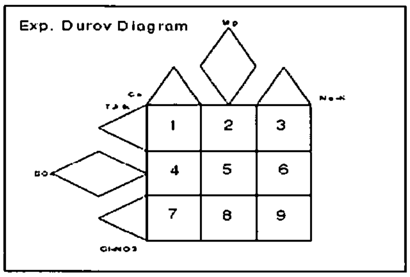
Wolkersdorfer, C. (2008). Water Management at Abandoned Flooded Underground Mines, Series: Mining and the Environment, pp456, Freiberg.

Woodford, A.C and Chevallier, L. (2002). Hydrogeology of the Main Karoo Basin: Current Knowledge and Future Research Needs, WRC Report No. TT 179/02, Gezina, Pretoria.

Younger, P. L., (2000). Predicting Temporal Changes in total Iron Concentrations in Groundwaters Flowing from Abandoned Deep Mines. A First Approximation. *Journal of Contaminant Hydrology*, 44(1):47-69. Cited in: J.J Donovan, B. R. Leavitt and E. Werner. 2003. Long-Term Changes in Water Chemistry as a Result of Mine Flooding in Closed Mines of the Pittsburgh Coal Basin. USA. In: 6th ICARD, Cairns, QLD, 12 - 18 July, pp869-874.

Zeelie, S. and Hodgson, F.D.I. (n.d.). Risk Assessment for Groundwater Pollution from Mines in South Africa. In: *Post Mining Impacts*. Institute for Groundwater Studies, University of the Free State, Bloemfontein.

APPENDIX A: Mine water classification



- Field 1: Fresh, very clean recently recharged groundwater with HCO_{3-} and CO_3 dominated ions.
- Field 2: Field 2 represents fresh, clean, relatively young groundwater that has started to undergo Mg ion-exchange, often found in dolomitic terrain.
- Field 3: This field indicates fresh, clean, relatively young groundwater that has undergone Na ion-exchange (sometimes in Na-rich granites or other felsic rocks), or because of contamination effects from a source rich in Na.
- Field 4: Fresh, recently recharged groundwater with HCO_{3-} and CO_3 dominated ions that has been in contact with a source of SO_4 contamination, or that has moved through SO_4 enriched bedrock.
- Field 5: Groundwater that is usually a mix of different types – either clean water from Fields 1 and 2 that has undergone SO_4 and NaCl mixing/contamination, or old stagnant NaCl dominated water that has mixed with clean water.
- Field 6: Groundwater from Field 5 that has been in contact with a source rich in Na, or old stagnant NaCl dominated water that resides in Na-rich host rock / material.
- Field 7: Water rarely plots in this field that indicates NO_3 or Cl enrichment, or dissolution.
- Field 8: Groundwater that is usually a mix of different types - either clean water from Fields 1 and 2 that has undergone SO_4, but especially Cl mixing / contamination, or old stagnant NaCl dominated water that has mixed with water richer in Mg.
- Field 9: Very old, stagnant water that has reached the end of the geohydrological cycle (deserts, salty pans, etc.) or water that has moved a long time and/or distance through the aquifer and has undergone significant ion-exchange.

Figure A: Interpretation of the Expanded Durov.

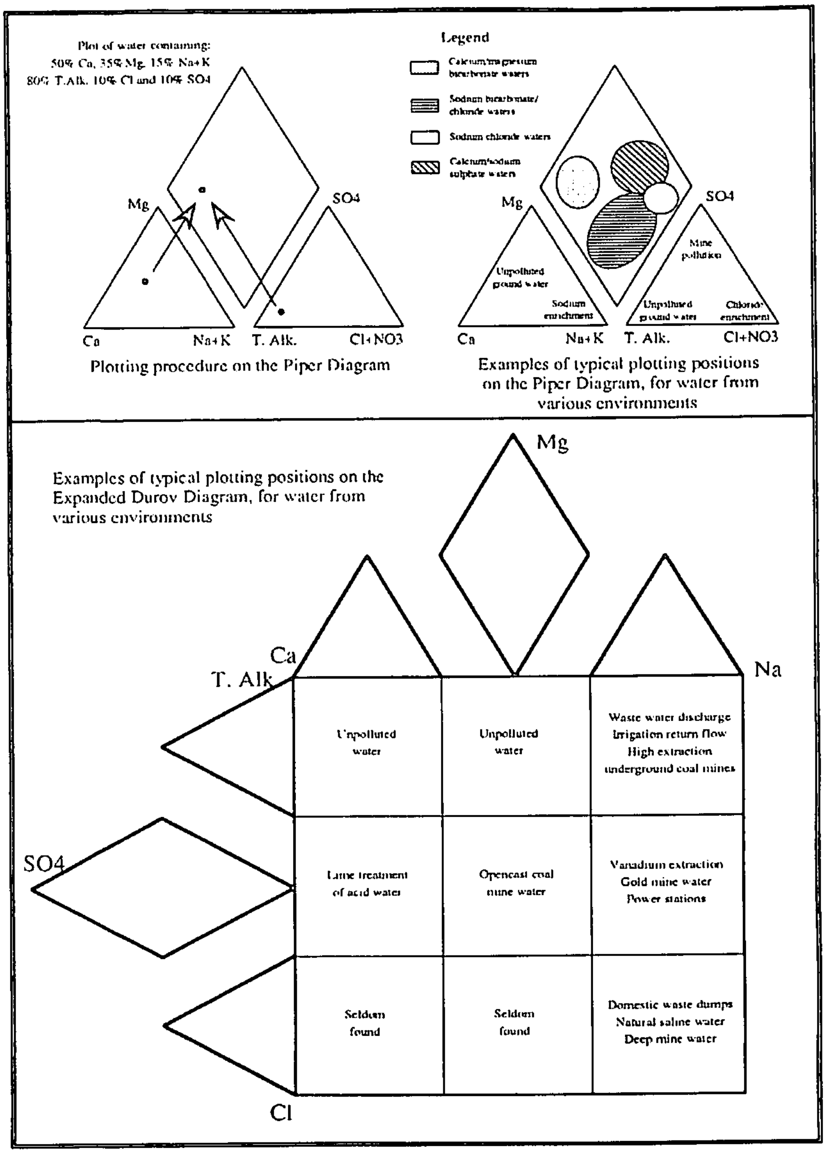


Figure B: Piper interpretation and classes in the expanded durov.

APPENDIX B: Water standards

				Water Standards SANS241:2006								
			EC	pH	pH	Ca	Mg	Na	K	PAlk	MAlk	F
			mS/m	min	max	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
Class 0&1	Ideal to ac	Green	70	6	9	80	30	100	25			0.7
Class 2	Allowable	Yellow	150	5	9.5	150	70	200	50			1
Class3	Not allowa	Red	370	4	10	300	100	400	100			1.5
			Cl	NO3(N)	PO4	SO4	Al	Fe	Mn	B	Si	TDS
			mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L			mg/L
Class 0&1	Ideal to ac	Green	100	6		200	0.15	0.01	0.05	0.5		450
Class 2	Allowable	Yellow	200	10		400	0.3	0.2	0.1	2		1000
Class3	Not allowa	Red	600	20		600	0.5	2	1	4		2400
			NH4(N)	COD	CN(Free)	t. Coliform Co	Coli Type	Cr6+	As	Cd	Co	Cr(total)
			mg/L	mg/L	mg/L	per 100ml	per 100ml	mg/L	mg/L	mg/L	mg/L	mg/L
Class 0&1	Ideal to ac	Green	0.2	10	0.2	0	0	0.05	0.01	0.003	0.25	0.05
Class 2	Allowable	Yellow	1	30	0.2	2	0	1	0.05	0.005	0.5	0.1
Class3	Not allowa	Red	2	50	0.2	5	0	5	0.2	0.02	1	0.5
			Cu	Hg	Li	Ni	Pb	Se	U	V	Zn	
			mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	
Class 0&1	Ideal to ac	Green	0.5	0.001	2.5	0.05	0.01	0.01	1	0.1	3	
Class 2	Allowable	Yellow	1	0.002		0.15	0.05	0.02	4	0.2	5	
Class3	Not allowa	Red	2	0.005	5	0.35	0.1	0.05	8	0.5	10	

Figure C: Water standards

APPENDIX C: Example of maps and subsidence

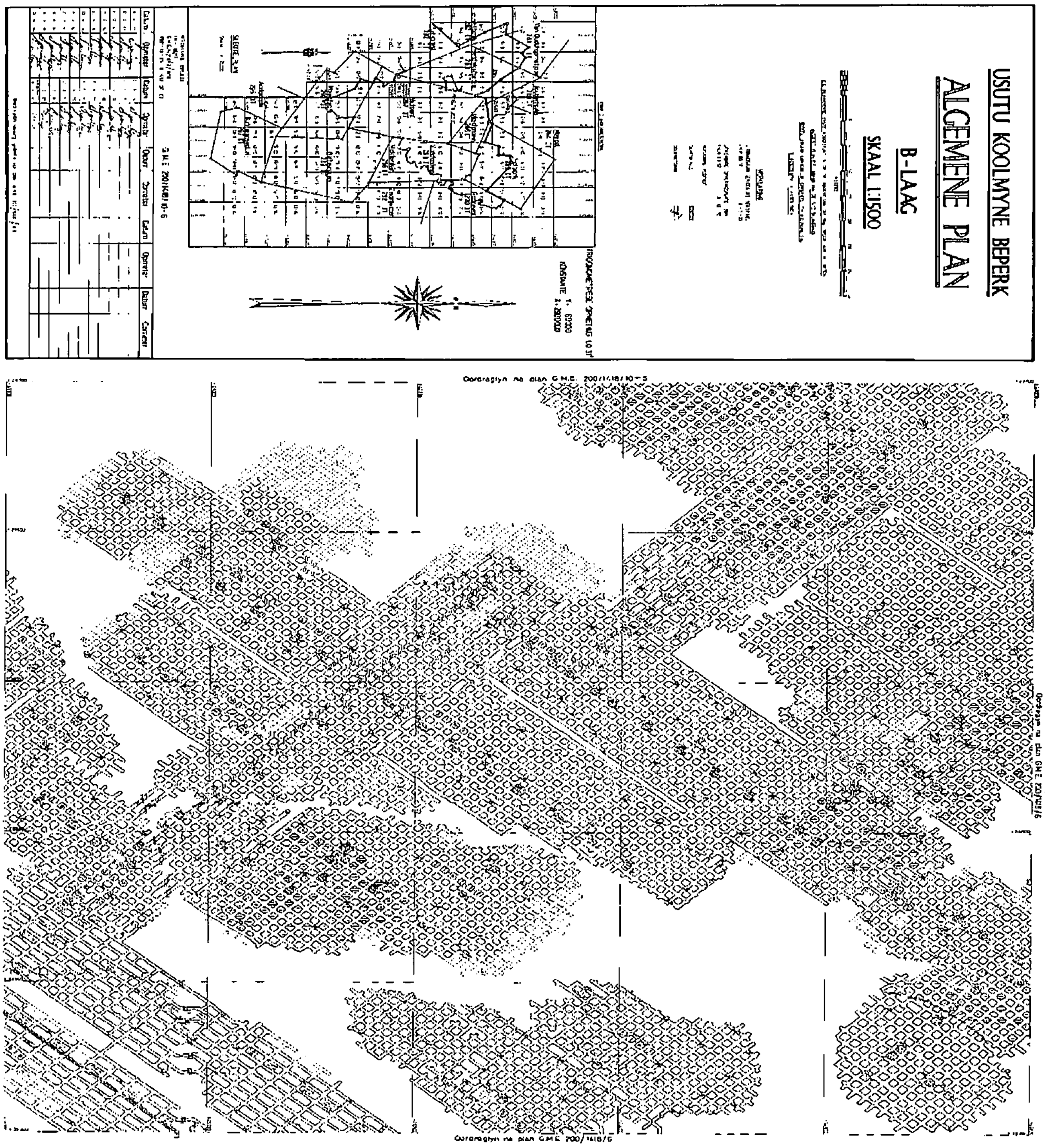


Figure D: Example of the maps that had to be digitize

Figure F: Surface subsidence and prior rehabilitation above a stooped area

APPENDIX D: Water qualities

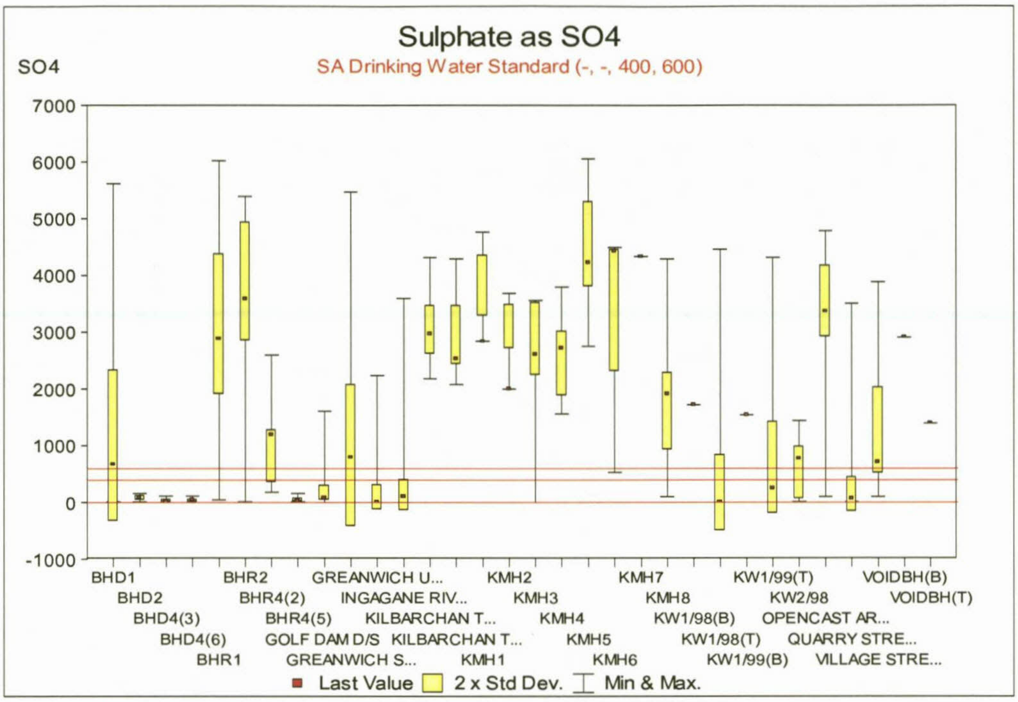


Figure G: Kilbarchan standard deviation graph for Sulphate

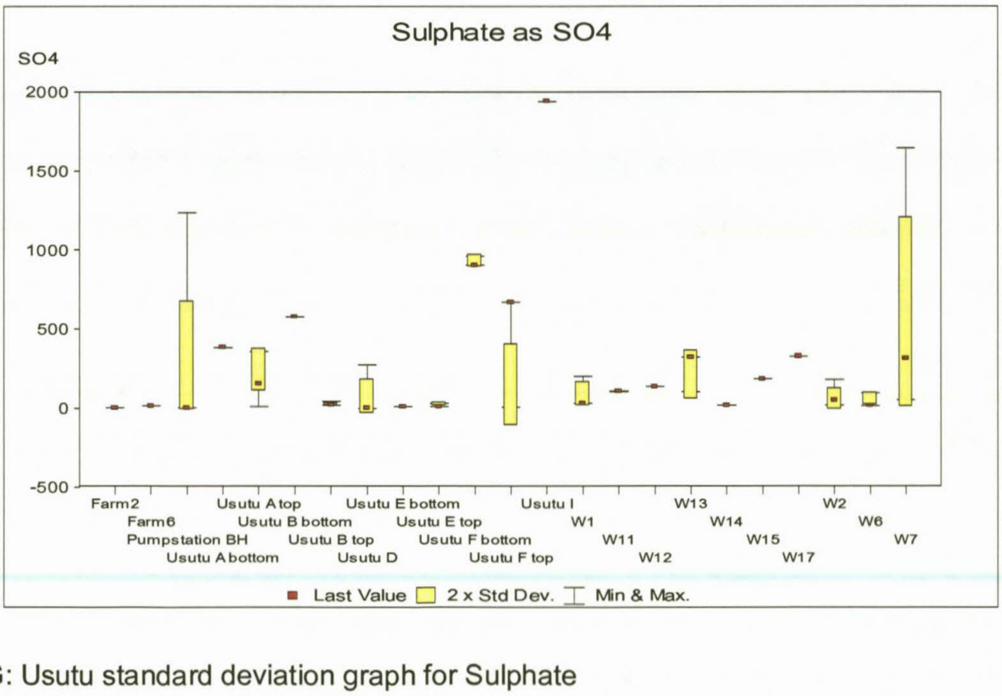


Figure G: Usutu standard deviation graph for Sulphate

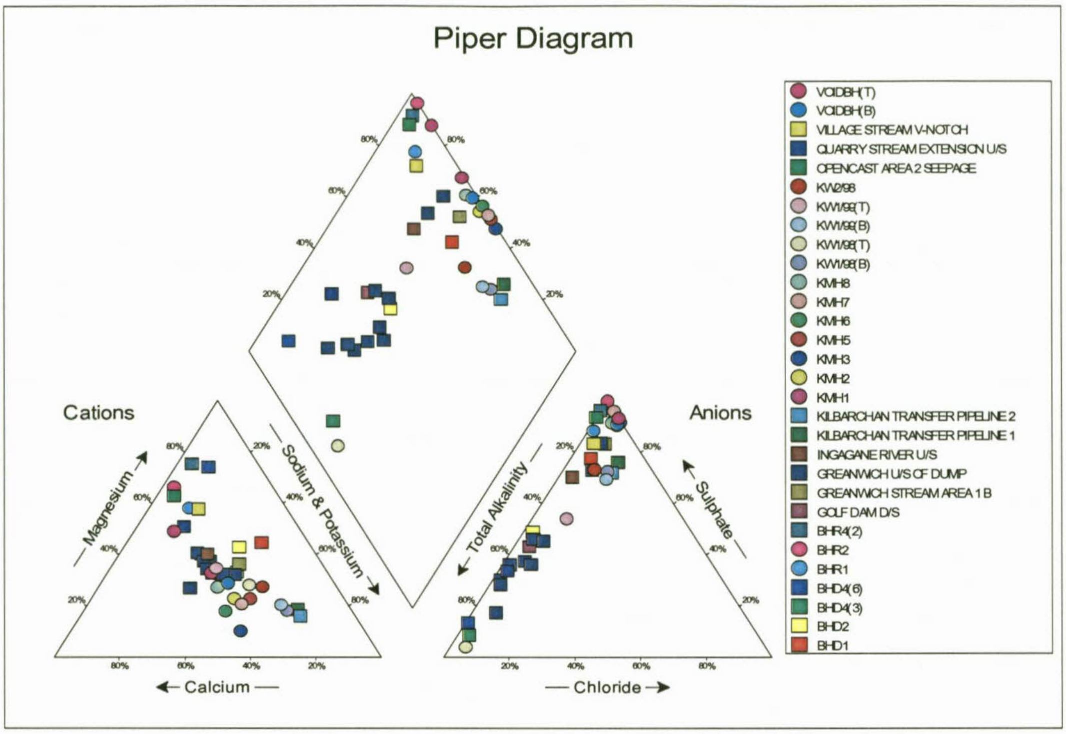


Figure G: Kilbarchan piper

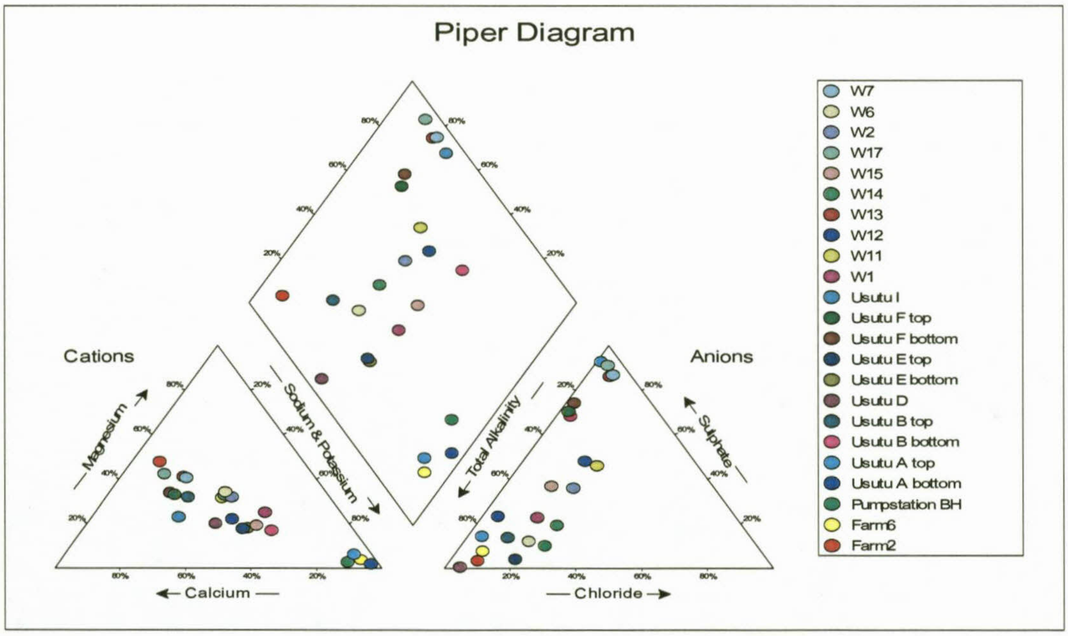


Figure H: Usutu piper

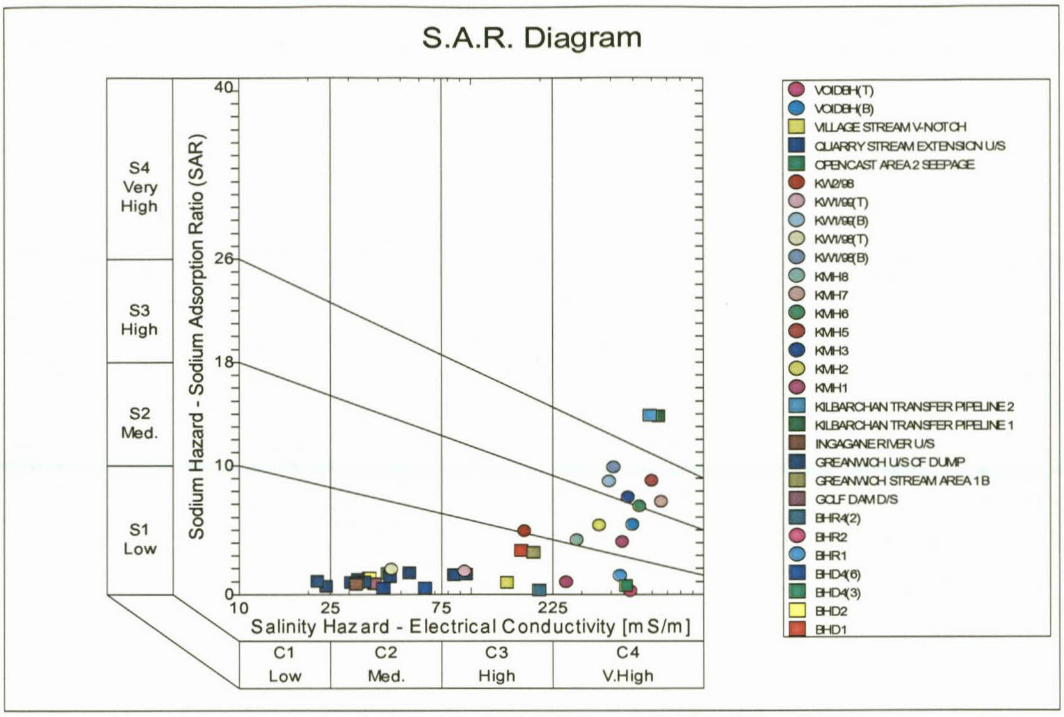


Figure I: Kilbarchan

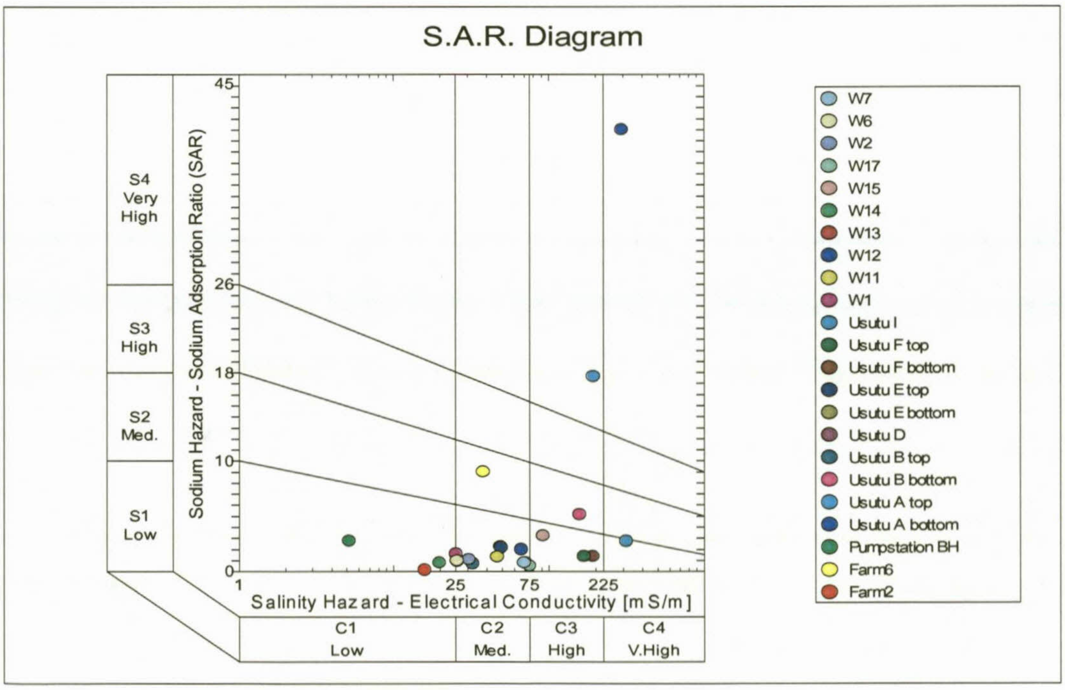


Figure J: Usutu.

APPENDIX E: Cl values of boreholes

Cl values			
11	63	36	20
35.26	58	45.0	31
9	28.68	14	34
10	14.89	17	20
25.60	15	23.0	13.0
21.56	17	34.0	15
13	14	41	15
15	19	40	25
20	15	21.0	20
26.41	14	18	21
5.12	9.18	19	22.0
11.19	11	54	62.38
34.89	19	12	36.65
23	29.0	6	
12	27	55	
9	14	59.0	
		HARMEAN	17.54301988
		Cl rainwater	1
		% recharge	5.7

APPENDIX F: Pictures of the Usutu boreholes

Usutu A

Usutu B

Usutu D

Usutu E

Usutu F

Usutu I

APPENDIX G: Pictures of the Kilbarchan boreholes

KW1/98.

KW1/99

VOID BH

Ingagane river upstream

Ingagane river downstream

Greenwich stream area

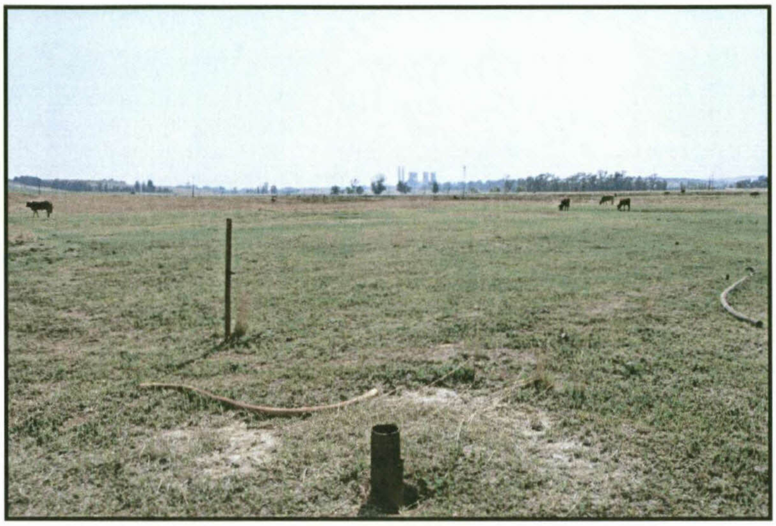
Greenwich upstream of dump

Quarry stream extension upstream

Village stream V-notch

Golf dam downstream.

APPENDIX H: Pictures of the opencast boreholes at Kilbarchan



BH26

BH30

SUMMARY / OPSOMMING

The purpose of the study is to investigate the influence of flooding on underground coal mines. Two case studies were investigated the shallow underground Klibarchan coal mine and the deep underground Usutu mine. Kilbarchan colliery is located 10 km south of Newcastle in KwaZulu/Natal. It comprises two underground sections, called Roy Point and Kilbarchan. Usutu colliery is situated just 8 km outside the town of Ermelo in Mpumalanga, close to Camden power station on the N2 road to Piet Retief. The geology of both studies lies within the Karoo Group, Ecca subgroup in the Vryheid formation. Higher precipitation at Usutu and Kilbarchan occurs in the summer months, while Kilbarchan has a higher annual rainfall of 864 mm/a compared to Usutu's 705 mm/a.

The water levels at both mines yielded interesting findings. Usutu mine is compartmentalized with walls in the underground. These walls are so strong that they function as “low pressure” seals resulting in compartmentalized underground, withstanding the huge pressures created by the recharged groundwater. This causes water levels to differ in the underground. Water levels at Kilbarchan mine vary in depth, but when plotted in metres above mean sea level (mamsl) they plot in a straight line. Regional recharge at Usutu was calculated as 5.7 % and 11.3 % at Kilbarchan. Recharge is influenced by what type of mining activity was practised in that specific area. It was concluded that recharge on opencast is between 15 to 20%, the stooped area between 10-15% and in an underground shallow mine it could be as high as 10%.

Mining activity ceased in 1992 at Kilbarchan. Pumping is a common practice at flooded underground mines, because the mine needs to be filled with water on an ongoing basis. This prevents sulphate generation and the water quality from deteriorating. Pumping at Usutu is well managed and flushing started to occur in the underground with the electric conductivity improving over time. Pumping at Kilbarchan is poorly managed and over pumped. The electric conductivity over time, is not improving indicating that oxygen infiltrates the system when too much pumping occurs. Bord-and-pillar mining followed by stooping has been the main mining method. At Usutu mining activity ceased in the late 1980 and then the mine was flooded.

It is finally there is concluded that an underground should be flooded as quickly as possible and then managed well. Shallow underground mines have a higher potential of contamination, because of a shorter residence time. The depth of mining, topography, mining methods, water levels, exposure to oxygen, rainfall, recharge, residence time and pumping have an influence on the effects of a flooded coal mine.

OPSOMMING

Die doel van die studie is om ondersoek intestel op die invloed wat n gevloede myn het op die ondergrond. Die twee studies wat ondersoek was is die vlak ondergrondse myn Kilbarchan en die diep ondergrondse myn Usutu. Kilbarchan myn is geleë 10 km suid van Newcastle in KwaZulu-Natal. Dit word opgedeel in twee ondergrond seksies, naamlik Roy Point en Kilbarchan. Usutu myn is geleë 8 km buite die dorp van Ermelo, naby die Camden kragstasie op die N2 pad na Piet Retief. Die gelogie van beide die studies val binne die Karoo Groep, Ecca subgroup in die Vryheid formasie. Hoe reënfal vind plaas by Usutu met n somer reënval, terwyl Kilbarchan n hoer jaarlikse reenval het van 864 mm/a in vergelyking met die 705 mm/a van Usutu.

Water vlakke van beide studies het interresante bevindinge opgelewer. Usutu myn is gekomparlimentaliseerd met mure in die ondergrond. Hierdie mure is so sterk dat hulle as lae druk seels funksioneer en so die ondergrond comparlimentaliseer, die mure kan hoe druk van aanvulling weerstaan. Dit veroorsaak dat watervlakke verskil in die ondergrond. Water vlakke by Kilbarchan mag verkil in diepte, maar as dit in meter bo seespiëel getrek word le dit op n reguit lyn. Die regionale aanvulling was bereken as 5.7 % by Usutu en 11.3 % by Kilbarchan. Aanvulling word beinvloed deur waste tipe myn aktiviteit in daardie area plaasgevind het. Die gevolgtrekking is dat aanvulling op oopgroef areas tussen 15-20 % is en hoë ekstraksie areas tot 10 % kan wees.

Myn aktiwiteit is gestaak in 1992 by Kilbarchan en in 1980 by Usutu. Om water tepomp by ondergrondse gevloede myne is baie algemeen, want n myn moet gevloed bly die myn goed the bestuur. Dit voorkom sulfaat generasie en die kwaliteit van die water om te verswak. By Usutu word die myn goed bestuur en daar het reeds spoeling in die ondergrond begin plaasvind deur dat die EC oor tyd verbeter. By Kilbarchan word die myn teveel gepomp and swak bestuur. Die EC oor tyd verbeter nie, die rede hiervoor is dat suurstof deur die myn getrek word oor daar teveel gepomp word.

Laastens is daar opgesom dat n ondergrondse myn so vinnig as moontlik gevloed moet word and bestuur word. Vlak ondergrondse myne het n hoër potensiële risiko vir contaminasie, oor dit 'n korter akkomodasie tyd het. Die myn diepte,topografie, myn metode,water vlakke, blootstelling tot suurstof, reënval, aanvulling, akkomodasie tyd en die pomp het n invloed op die effek van n gevloede steenkool myn.

KEYWORDS

- Flooding
- Decant
- Pumping
- Recharge
- Rainfall
- Sampling
- Chemistry
- Depth
- Opencast
- Mining