

COAL MINING ON THE HIGHVELD AND ITS IMPLICATIONS FOR FUTURE WATER QUALITY IN THE VAAL RIVER SYSTEM

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INTRODUCTION

The history of coal mining in South Africa is closely linked with the economic development of the country. Commercial coal mining commenced in the eastern Cape near Molteno in 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.

Given the long history coal mining, some deposits have been worked out and mines closed. With the closure of mines numerous environmental problems emerged. Extensive research has been done on the causes and extent of the problem, especially under the auspices of the Water Research Commission. In this paper, we draw on the experiences from the Witbank area and particularly the impact mining has had on the quality of water in the Olifants River in order to assess future scenarios in other Highveld river catchments, and especially the Vaal River.

1. THE COALFIELDS

South Africa's coal deposits occur in rocks of the Karoo Supergroup, a thick sequence of sedimentary rocks deposited between 300 and 180 million years ago. The coal seams occur in a division of the Supergroup known as the Ecca Subgroup, which consists of sandstones and mudstones, together with coal seams, which were deposited in large river deltas that entered the ancient Karoo Sea. Although rocks of the Ecca Subgroup are very widespread around the country, conditions suitable for the formation of coal did not occur everywhere, and the coal deposits are fairly restricted, occurring in the main Karoo basin in an arc from Welkom in Free State Province to Nongoma in KwaZulu-Natal, and in several smaller outlying remnants of the Karoo Supergroup (**fig. 1**). This paper will focus on the Witbank, Ermelo and Highveld coal fields, which contain an estimated 50% of the nation's recoverable coal reserves.



Figure 1. Map showing the distribution of the rocks of the Karoo Supergroup and its coal-bearing regions. Up to eight coal seams are developed in the main Karoo basin (**fig. 2**). The seams outcrop along the northern, northeastern and eastern portions of the Witbank and Ermelo coalfields. They dip gently to the southwest and become thinner so that towards the southwest they become progressively deeper and eventually pinch out (**fig. 3**). The thicknesses of the seams are very variable both within and between coalfields, and range from a few centimeters to over 6m.

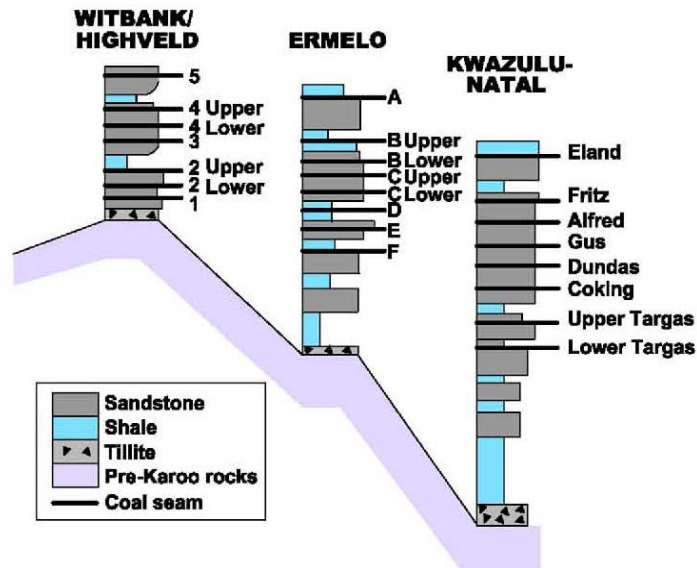


Figure 2. Diagrammatic representation of the coal seams in the main Karoo basin.

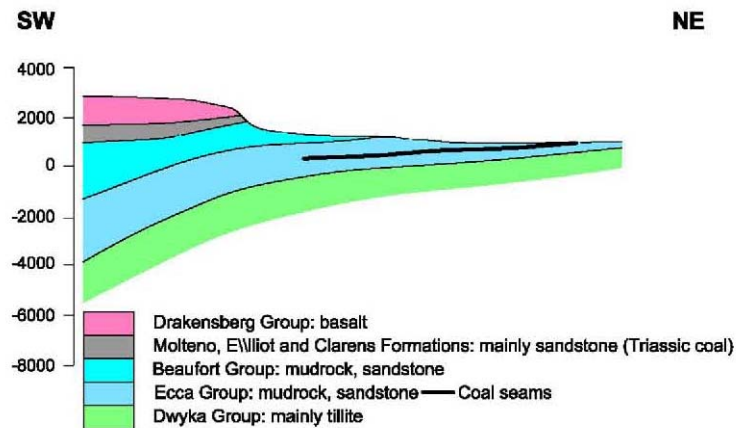


Figure 3. A diagrammatic cross section showing the progressive deepening of the coal seams from outcrop in the NE to their final pinch-out in the SE.

2. MINING METHODS

Coal mining methods are briefly discussed as they have important environmental implications. There are three different methods used to extract coal: bord and pillar mining (or room and pillar), longwall mining and opencast mining.

Bord and pillar: in this form of mining only a portion of the coal is extracted, the rest being left in place as pillars to support the overlying rocks. Towards the end of mining, pillars may be partially extracted (pillar robbing) to recover additional coal, but a considerable amount of coal is left in the ground. If sufficient support is left, the roof rocks can remain stable.

Longwall: in this form of mining, the coal is removed entirely and the roof allowed to collapse into the mined out void. The mining face is protected by supports which are moved forward as mining progresses. Collapse causes fracturing of the overlying rocks and can cause subsidence of the surface if mining is shallower than about 200 m depth. In such cases, fractures will extend through to surface. *Opencast:* in this form of mining, the soil cover is scraped off and stockpiled, the rocks overlying the coal seam are blasted and removed to one side, and the coal is then extracted. Next, the broken rock is returned to the pit, the site is landscaped, the soil is returned and grass is planted.

3. ENVIRONMENTAL PROBLEMS

A number of environmental problems have emerged as a result of coal mining. These are best exemplified by the Witbank field, which has experienced a long history of mining. *Underground fires, collapsing ground:* Early mines in the Witbank field were shallow and were mined by the bord and pillar method. The coal seams came to outcrop although the actual coal seam outcrop was generally covered by soil. The No 2 seam was a particularly important horizon and is between 5 and 6 m thick. Only the lower 2 to 3 m was mined as the rest was considered of too low quality. Thus, some 60% of the seam was left in the ground. After closure, the remaining coal in many of the mines caught fire and as the fires burned, the roof rocks collapsed, creating dangerous ground conditions and making the surface unusable (**fig 4** collapsed, burning mine).



Figure 4. A collapsed, burning coal mine.

Acid mine drainage: The most serious environmental problem arising from coal mining is the generation of sulphuric acid as a result of a chemical reaction between an iron sulphide mineral (pyrite) present in the coal and its host rocks and oxygen-bearing water (infiltrated rain water). Under natural conditions, the Karoo rocks have a very low permeability and although acid is generated, the process is extremely slow and other equally slow reactions completely neutralize the acid. However, mining breaks up the rock mass allowing free access of water and the acid-producing chemical reactions proceed faster than the acid can be neutralized. Consequently, the water becomes acidic and toxic to animal and most plant life. The acid water dissolves aluminium and heavy metals (iron, manganese and others), increasing its toxicity (**fig 5**. red water with dead trees; **fig 6**. barren soil; **fig 7**. blue water). Some rock types contain minerals (especially calcium carbonate) that can neutralize such acidity even when produced rapidly, but this is not the case with most of the rocks that host the South African coal.



Figure 5. Acidic, iron-rich water filling a collapsed coal mine.



Figure 6. Barren, sulphate-encrusted soil caused by seepage of acidic water from a flooded coal mine.



Figure 7. The Wilge River in during a coal mine-related pollution event in June 2007.

The blue colour is believed to be due to the precipitation of aluminium compounds. Methods have been developed to measure the acid-generating capacity of coal and its associated rocks (generally known as acid-base accounting). The results are expressed as the amount of calcium carbonate (in kg) needed to neutralize the acid produced by one tonne of rock (the Net Neutralizing Potential). Positive values indicate that sufficient carbonate is present in the rock to neutralize the acid (i.e. no acid will be produced), and negative values mean calcium carbonate needs to be added. Results of these tests on Witbank coals and their host rocks are shown in **fig. 8** (ABA diagram). It is evident that both the coal and host rock are net acid producers.

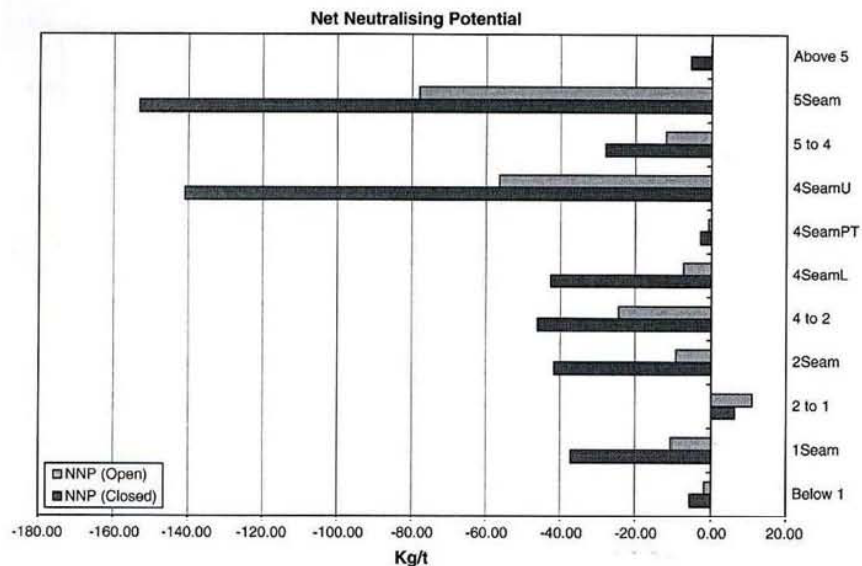


Figure 8. Diagram showing the acid-producing potential of coal seams and their host rocks in the Witbank area.

The mining method used has a significant impact on the acid generated. In bord and pillar mining, only the pillars come into contact with water, and hence acid generation is limited. Collapse of the roof increases the contact area and also facilitates the ingress of rain water, thus increasing acid generation. Consequently, longwall mining results in more acid generation than bord and pillar mining. In opencast mining the rock mass is completely fragmented, maximizing the contact between water and rock, and is therefore the most acid producing mining method. Acid water produced in the mines may seep out at surface, where further reactions with oxygen occur, precipitating iron and generating yet more acid. This water sterilizes soil that it comes into contact with (fig. 6). The water enters rivers, which become acidified, reducing biodiversity to a few particularly hardy species. Neutralization reactions occur as a result of mixing with other neutral water sources, and may result in the precipitation of aluminium (fig. 7), which is toxic to fish and possibly other aquatic animals.

Ultimately the acidity is neutralized, but the water remains sulphate-rich, typically containing 2000 to 3000 ppm (parts per million) sulphate (the recommended limit for water for human consumption is 200 ppm).

Destruction of groundwater reservoirs: The rolling hills of the Highveld are characterized by abundant seasonal wetlands, perennial and seasonal streams and many fresh to mildly saline pans. This diversity arises because of the unique nature of the groundwater aquifers. The Karoo bedrock strata are generally massive, with very low porosity, except for that provided by occasional fractures. Overlying the bedrock is a weathered zone (termed regolith) in which the rocks are partially or completely decomposed, creating a porous mass. Near the surface of the regolith there is often a hard, impermeable layer (called plinthite) formed by precipitation of material (mainly iron and/or silica compounds). This structure gives rise to three different groundwater aquifers: the first is formed by fractures in the bedrock; the second by the deeper regolith, and the third by the zone above the plinthite layer (perched aquifer). Water is supplied to the aquifers by rainfall, and soaks into the ground to supply the aquifers. Water flowing laterally in the perched aquifer may emerge on surface to form wetlands high on the hill sides. Infiltrating rain and water seeping from these wetlands supplies the deeper weathered rock aquifer. The aquifers fill with water in the rainy season, and slowly discharge water into streams through the dry season, thus sustaining stream flow throughout the dry season. Fractures in the bedrock also provide some surface water by seepage, but this aquifer appears to be of lesser importance than the regolith aquifers because of its more limited storage capacity. Water quality differs in the different aquifers, being highest in the perched aquifer (<20 ppm dissolved solids), and lowest in the fractured rock aquifer, where the dissolved solid concentration is in the order of hundreds of parts per million.

Mining disturbs the aquifer structure. Bord and pillar creates additional voids in the fractured rock aquifer, but the regolith aquifers remain intact provided there is no collapse of the workings. However, water filling the mine void is of extremely low quality and is detrimental to the environment should it leak out. At the other extreme, opencast mining completely destroys the groundwater aquifers and creates a single, massive aquifer in the mine void. After mine closure, water fills this aquifer to the lowest elevation of the bedrock rim, and additional water entering the void decants over the rim. This water is of extremely low quality. Longwall mining fractures the bedrock, creating additional void spaces and increases both inflow into the void and seepage. The water is of low quality. Once an area has been mined, borehole water from that site will generally no longer be usable for agricultural or domestic use due to its low quality. *Disposal of excess water during mining:* The coal mines are not particularly water-rich, and mining activities do consume some water. However, from time to time, operating mines find themselves with an excess of water, often as a result of heavy rains. The water is usually severely contaminated by acid mine drainage, and releasing it into streams can have severe environmental consequences, often resulting in large-scale deaths of fish (due to aluminium poisoning) and other aquatic animals.

4. CONSEQUENCES OF MINING ON WATER QUALITY IN THE WITBANK AREA

Coal mining has been taking place in the Witbank area for more than a century, and the area is replete with examples of the negative aspects of mining listed above. Many mines are still in production (**fig 9**). Routine analysis of water samples in the Olifants River system which drains the coalfield began long after mining commenced in the area, so there is no record of the quality of river water prior to mining. However, the upper Olifants tributaries that lie outside the mining areas have total dissolved solid (TDS) concentrations in the order of 50 ppm, and probably reflect the pre-mining condition.

The water quality in Witbank and Middelburg dams over the last three decades is shown in **figs 10 and 11** respectively. Both show a steady increase in TDS and sulphate concentrations over the past 30 years. Bearing in mind that prior to mining the rivers concerned probably contained about 50 parts per million TDS, mining has resulted in a ten-fold increase. Of greater concern is the fact that the sulphate concentration in the Middelburg Dam now exceeds the maximum recommended concentration for water for human consumption, and is still rising.

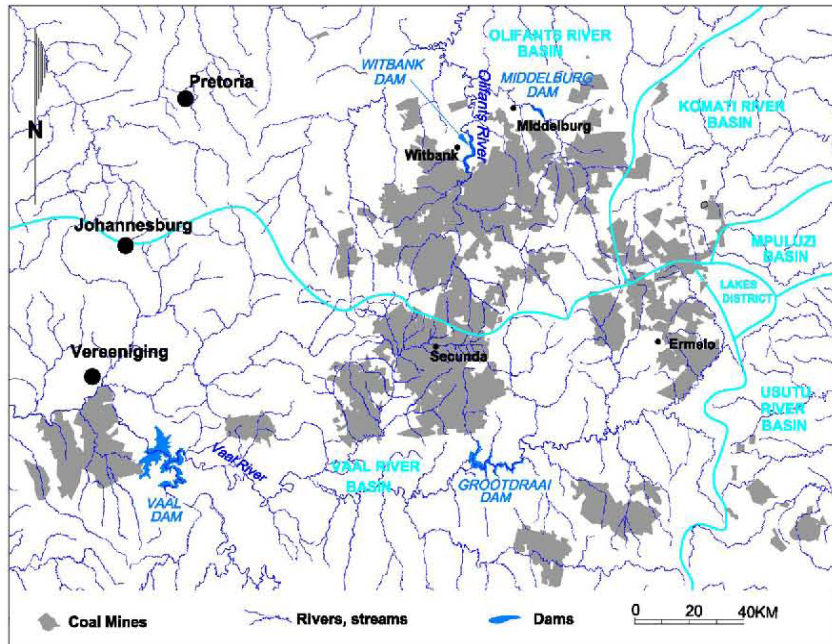


Figure 9. Map showing the distribution of coal mines in the Highveld region in relation to river catchments.
WitbankDam-SO4andTDSConcentrations

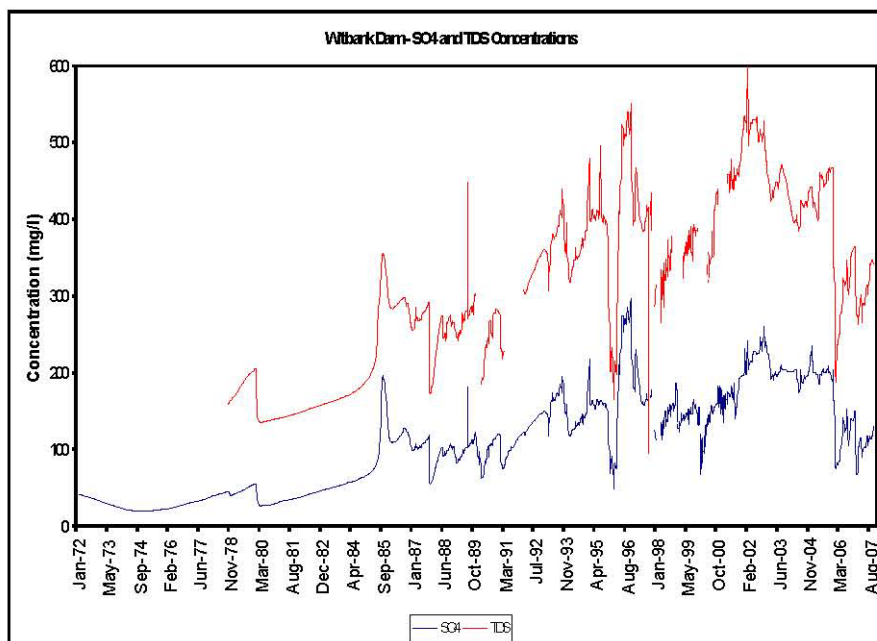


Figure 10. Total dissolved solid (TDS) and sulphate concentrations in Witbank Dam between 1972 and 2007.

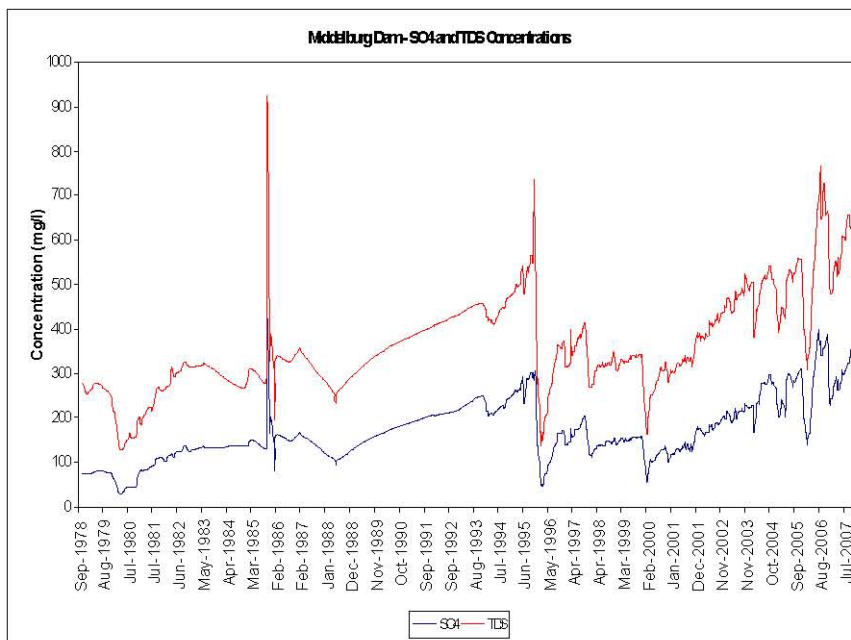


Figure 11. Total dissolved solid (TDS) and sulphate concentrations in Middelburg Dam between 1978 and 2007.

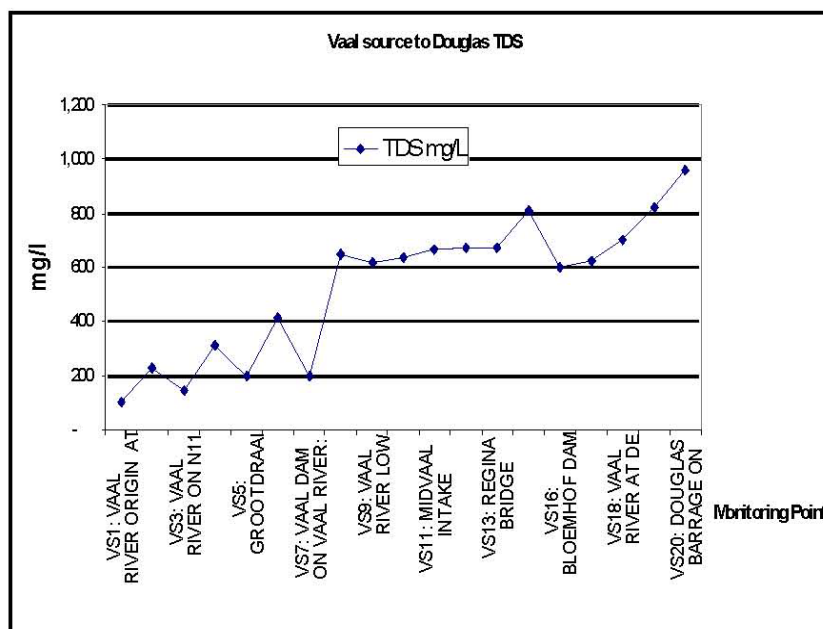


Figure 12. Diagram showing the changing total dissolved solid concentration in the Vaal River. Water quality in the dams partly obscures the extent of the quality problem because dams tend to improve water quality compared to their inflow. This is because short duration flood events are stored and dilute the dam water, and possibly also because of biological remediation processes operating in dams such as sulphate fixation by anaerobic bacteria in dam sediment. The dilution effect is reflected in the rather jagged appearance of the graphs in **figs. 10 and 11**. Nevertheless, water quality in both dams shows a trend of deterioration over the data period.

5. MITIGATION

Various measures have and are being implemented to try to mitigate the deteriorating water quality in the Oilfants River. In considering the various mitigation options, it is necessary to distinguish between those that are used whilst mines are still operating, and those that will be used after closure. In the latter instance, it is important to bear in mind that the effects of mining, and especially the production of acid mine drainage, is likely to persist for centuries after closure.

Evaporation dams: Some mines faced with the problem of getting rid of severely polluted excess water have resorted to constructing shallow dams where the water is allowed to evaporate. This has also been proposed as a potential solution to the problem of getting rid of polluted water seeping from flooded mines after closure. Such dams have to be completely sealed, requiring a strong plastic membrane liner, and hence the cost of construction of is very high. It is unclear how long such dams will survive after mine closure and what the long term maintenance costs will be (for

removal and disposal of accumulated salts, repairing of leaks, protection from vandalism and theft, etc). *Using contaminated water for irrigation:* There is currently a research programme in operation examining the use of sulphate-polluted water for crop irrigation. It should be noted that polluted water has to be neutralized before it can be used in this way. Results have been promising, although investigations have shown that the sulphate is accumulating in the soil. This method of mitigation is unlikely to succeed in the long term: either the sulphate will be leached from the soil and will contaminate the ground water, or more likely, given the high evaporation rate over the Highveld, the sulphate will accumulate in the soil forming hard gypcrete cement and severely impacting long term agricultural productivity.

Limiting oxygen ingress into closed mine workings: The continued production of acid mine water depends of a steady supply of oxygen. If the oxygen can be excluded, acid generation will eventually cease. In the case of deeper mines, especially bord and pillar and to a certain extent longwall operations, rapid flooding after closure will ensure rapid consumption of the oxygen. Provided there is no additional inflow, acid production will cease and the water will stratify. Deep groundwater will thereby remain isolated and will not contaminate surface water resources and the near-surface aquifers will continue to function more or less as normal. Whether this situation is attainable in the coalfields has yet to be demonstrated. Mining depth is less than 200 m below surface and the rocks are heavily punctured by exploration boreholes and fractures, and it is likely that after closure and flooding, water will emerge at surface via these openings (when the Randfontein Gold Mine compartment on the West Rand flooded in 2005, polluted water began discharging from a borehole and from natural springs), thereby setting up groundwater circulation that will ensure continued oxygen supply and acid generation in the deeper mining levels.

Acid neutralization: Acidic water seeping from abandoned mines northwest of Witbank was severely polluting the Brugspruit, a tributary of the Olifants River. To address this problem, a system was installed to collect the water and channel it to a treatment plant where the acid was neutralized with sodium hydroxide (the Brugspruit Water Pollution Control Works). This approach could solve the acid problem, but the sulphate problem remains, and is possibly exacerbated by the addition of sodium to the water. There have, however, been maintenance problems with the plant, including theft of essential components, and the plant has been non-functional for extended periods.

Water purification: A consortium of mining companies operating in the Witbank coalfield has addressed the problem of disposing of polluted mine water by constructing a treatment plant to convert it into drinking quality water (the Emalahleni Water Reclamation Plant). The plant utilizes reverse osmosis technology to process 20MI of water per day. It is operating as designed, but the cost of the water is R10 per cubic metre (including capital amortization), which is R7 more than charged by Rand Water for bulk water. The plant's design life is 20 years, after which it will have to be replaced (construction cost of the plant was R300 million in 2006).

Controlled release: Producing mines in the Olifants River catchment are participating in a programme of collectively managing the release of polluted water in such a way as to keep pollution levels to a minimum. Polluted water is stored on the mines and released in controlled manner at times when there is sufficient runoff to dilute pollutants to acceptable levels. This programme is working successfully, although its efficacy in years of drought has yet to be tested. Managing discharge is only possible while mines are in production, and this approach will not work in the case of closed mines that are leaking polluted water.

Soil protection: Ground water in back-filled opencast mines becomes acidic. Some of this water rises up into the restored soil layer by capillary action and can cause sterilization of the soil. To protect the soil, calcium carbonate is added to the lower part of the replaced soil layer, which neutralizes the acidity. The quantity of calcium carbonate added is nowhere near sufficient to neutralize all of the acid that will be produced in the backfill, as it is assumed that only a small proportion of the acidity will move up into the overlying soil layer. There are many closed and abandoned mines in the Olifants River catchment which have been polluting the river for decades. The records spanning the last 30 years indicate that the pollution level is still rising. The full effects of mining are yet to come, when the current generation of large opencast mines fills with water and begins to decant. Of the mitigation strategies listed above, only water purification is capable of producing water of a quality equivalent to that which existed prior to mining. The cost of treatment is high, however. It is estimated that water from current mining operations entering the Witbank and Middelburg Dams amounts to 30 million cubic metres per annum and this will rise to 44 million cubic metres by 2030. To treat this water to pre-mining standards would cost R300 million Rands per annum currently, rising to R440 million per annum in 2030 (at present Rand value). What the final discharge of polluted water will be is uncertain but one estimate places it at around 200 million cubic metres per annum, which will cost R2000 million per annum to treat at current Rand value. It is unclear for how long acid generation will continue, but it is likely to persist for hundreds of years. In time, acid generation will decline as pyrite oxidation nears completion. What is also uncertain is how effective the protective calcium carbonate layer in the restored soil will be in the long term. Should this carbonate be consumed or become ineffective (e.g. by carbonate grains becoming coated in calcium sulphate or iron compounds), the soil could become acidified and sterilized, making it highly susceptible to erosion. Rivers and dams downstream of the mining areas could become choked with sediment as the soil and opencast backfill is eroded. Such sterilization of restored soil has already been observed in sections of older opencast operations where insufficient carbonate was added, although the scale of the problem appears to be limited at present.

6. THE VAAL RIVER CATCHMENT

Although mining is taking place in the Vaal River catchment (**fig 9**), much of the coal is deep. Many of the mines are still in production and water management is good so pollution levels from coal mining in the catchment generally are low. The total dissolved solid concentration in the Vaal River rises progressively downstream (**fig 12**). The Klip River, which is heavily polluted by mining and industrial activity on the Witwatersrand, adds significantly to the pollution load. For reasons mentioned above, dams along the river (Grootdraai, Vaal and Bloemhof) have a moderating effect on the pollution levels, but insufficient to prevent the downstream increase in TDS. Water quality in the lower Vaal is relatively poor, and has caused soil salinity problems in the Vaal-Harts irrigation scheme. A disturbing development is the large number of applications that have been made to open new coal mines in Vaal River catchment. If all of the coal resources of the upper Vaal River basin are exploited, it will result in the undermining of the entire basin from the headwaters to a position downstream of the Vaal dam. In the future, once these mines are closed and commence decanting, it is likely that the water quality in the upper Vaal River will suffer the same problems as the Olifants River system. It can be expected that water quality in the Grootdraai and Vaal Dams will come to resemble that in the Middelburg and Witbank Dams (**figs. 10 and 11**), and the water could ultimately become unfit for human consumption. The effects on downstream users of Vaal River water will be even more serious, as TDS in the lower Vaal River is already very high, even though it rises from a presently low initial base. Pollution in the upper regions will result in extremely high TDS levels in the lower reaches of the river.

7. OTHER CATCHMENTS

Currently, the Mpupuzi and Lakes District catchments are free of mining (**fig. 9**) and the aquatic systems are pristine. Only a few mining permits have been granted in the Usutu Basin, and water quality in this catchment is generally good. However, a large number of applications have been submitted in these areas (**fig. 13**). Should these be granted, these presently pristine river systems will suffer the same fate as the Olifants River catchment.

8. CONCLUSIONS

The South African economy has benefited greatly by the abundant coal resources in the country, but the environmental cost is only beginning to emerge. Experience in the Witbank area, which has seen more than a century of sustained coal mining, provides some insight into what the future consequences might hold. Problems that have emerged include the sterilization of land due to underground fires, unsuccessful rehabilitation procedures and surface collapse, and by acidification of soils. By far the most severe problem is water pollution, which is still rising, and the water in the Middelburg Dam is now no longer fit for human consumption for 40% of the time. It will continue to deteriorate for the foreseeable future and the Witbank Dam is likely to experience a similar fate.

What does the future hold for the Witbank coalfield? We would like to sketch out a scenario for the future of the coalfield once the coal reserves have been fully exploited and mining has ceased. At this time, perhaps a century from now, all of the mines will be flooded and leaking acid water. In their upper reaches, the rivers will run red (**fig. 5**), and both river and ground water will be undrinkable. Aquatic animal life will be minimal, and only very hardy aquatic vegetation will survive. The rivers will also be choked with sediment. Extensive areas of the region will have become devoid of vegetation due to acidification of the soil (**fig. 6**), setting in motion severe erosion which will strip the soil cover and eat into the backfill of the old opencast workings. The eroded sediment will choke the rivers and all dams will be filled with sediment. In short, the region could become a total wasteland.

This scenario might seem melodramatic and emotive, but are the currently employed mitigation procedures adequate to prevent such a scenario from arising? We believe they are not. Acid water will be generated by the closed mines, making the ground water in the region unpotable. Uncontrollable seeps of this water will become widespread, seriously degrading surface water resources. There is no large scaled master plan either in place or planned to prevent this based on knowledge of the impact and within a decision making framework taking all of the impacts into account. Applications are dealt with on a single application basis without a larger development framework context being in place.

Systems such as the Brugspruit Pollution Control Works will not solve the problem. Water resources in the area are currently degrading notwithstanding efforts by the industry to control the problem. The scale of the problem is going to increase enormously in the future as the mines close and water management becomes more difficult. The future costs of water purification will be massive, far greater than any mitigation fund could cover, and will have to be borne by the state in the absence of the closure cost provisions of the DME also catering for water rehabilitation. There is also likely to be major loss of future revenue from reduced agricultural potential of mined land, partly due to the loss of ground water resources, but also because of the threat to the soil itself. Whether the current procedures are adequate to protect the soil cover over former opencast mines remains to be seen – the current experience seems to suggest it is not. The Olifants River catchment is in trouble, but the most serious long term threat that coal mining poses is to the water resources of the Vaal River, Usuthu and Komati basins, which provides drinking water to possibly a third of the country's population and supplies Eskom with water for its power stations. The Komati and other rivers from the

escarpment also supply the lowveld as well as neighbouring southern Mocambique and Swaziland, are also under threat. In the absence of adequate, fail-safe environmental protection procedures which include passive and active treatment systems that are sustainable over the long term, we believe that a moratorium should be declared on new mining applications in all of these catchments until such time as cumulative impact of mining is fully understood and adequate sustainable mitigation measures can be guaranteed. In addition, there should be a concerted research programme to assess the future impact of current and past mines, to find ways of reducing acid discharge from mines and of passively treating sulphate-rich mine water. If adequate, low cost mitigation procedures cannot be discovered, then no further mining should be permitted in sensitive catchments.