

Coal mining on the Highveld and its implications for future water quality in the Vaal River system

T S McCarthy¹ and J P Pretorius²

1 School of Geosciences, University of the Witwatersrand, P O Box 3, Wits 2050; 2 P O Box 201, Belfast 1100.

Abstract

The Witbank region provides an opportunity to examine the longer term impacts of coal mining, as mining has been in operation there for over a100 years. The impacts include sterilization of land due to collapse and acidification of soils, but the most severe problem is water pollution, which high and rising. Water in the Middelburg Dam exceeds the quality limits for water for human consumption, and Witbank dam is trending in the same direction. The pollution levels are still rising, notwithstanding mitigation measures that have been taken. The upper Vaal River catchment is relatively unimpacted by mining, but if all the applications for mining permits in this catchment are granted, it is likely that the Vaal River will suffer a similar fate to rivers in the Witbank area, creating serious water supply problems for the industrial heartland of the country.

Introduction

The history of coal mining in South Africa is closely linked with the economic development of the country. Commercial coal mining commenced in 1864 in the eastern Cape near Molteno. The discovery of diamonds in the Kimberley area in the early 1870s and gold on the Witwatersrand in 1886 led to expansion of coal mining and the opening of mines in the Vereeniging, Springs, KwaZulu-Natal and Witbank areas. This industry has continued to grow as a consequence of the economic development of South Africa, especially following the Second Word War. In addition to meeting local needs, coal mining companies developed an export market, making South Africa a leading exporter of coal.

Given the long history coal mining, some deposits have been worked out and mines closed. With closure, numerous environmental problems emerged. Extensive research has been done on the causes and extent of these problems, 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.

The coalfields

South Africa's coal deposits occur as layers or seams in rock strata belonging to the Karoo Supergroup, a thick sequence of sedimentary rocks deposited between 300 and 180 million years ago. The coal deposits occur in an arc from Welkom in the Free State to Nongoma in KwaZulu-Natal, and in several smaller outlying remnants of the Karoo strata (**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 range from a few centimeters to over 6m.

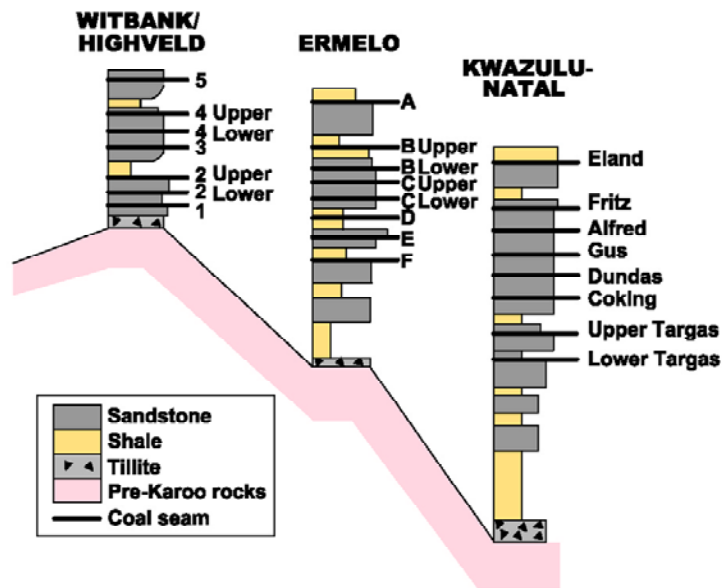


Figure 2. Diagrammatic representation of the coal seams in the main Karoo basin.

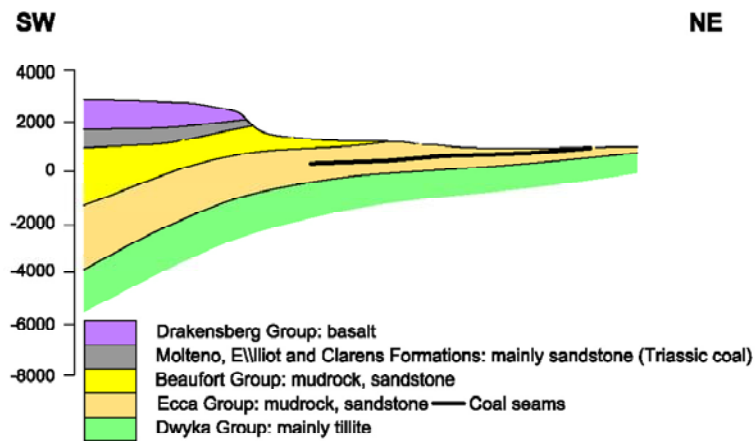


Figure 3. A diagrammatic cross section showing the progressive deepening of the coal seams from outcrop in the NE to their final pinch-out in the SE.

Mining methods

Coal mining methods have important environmental implications. Three different methods are used.

Bord and pillar: with this method only a portion of the coal is extracted, the rest being left in place as pillars to support the overlying rocks. A considerable amount of coal is left in the ground. If sufficient support is left, the roof rocks can remain stable, although in the long term the roof of the mine will collapse, rendering the land surface above the workings unsafe.

Longwall: with this method 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. The land may become unsafe.

Opencast: with this method, 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. Visually, restoration appears satisfactory.

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 used the bord and pillar method. The No 2 seam was a particularly important horizon and is between 5 and 6 m thick but only the lower 2 to 3 m was mined, leaving some 60% of the coal 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**).



Figure 4. A collapsed, burning coal mine



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

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 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. The acid water dissolves aluminium and heavy metals (iron, manganese and others) and is toxic to animal and most plant life (**fig 5; fig 6; fig 7**). Some rock types contain minerals that can neutralize the acidity (especially calcium carbonate), but this is not the case with most of the rocks that host the South African coal.

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**. It is evident that both the coal and host rock are net acid producers.

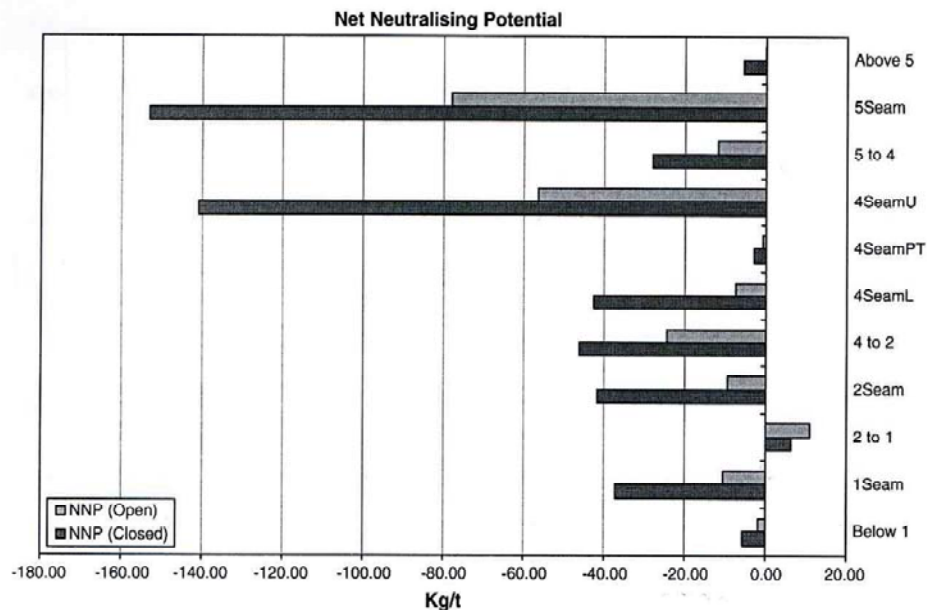


Figure 8. Diagram showing the acid-producing potential of coal seams and their host rocks in the Witbank area.

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. This water sterilizes soil that it comes into contact with (**fig. 6**) and acidifies rivers, reducing biodiversity to a few particularly hardy (generally alien) species. Aluminium in the water is toxic to fish and possibly other aquatic animals (**fig. 7**). Ultimately the acidity is neutralized, but the water remains sulphate-rich, typically containing 2000 to 3000 mg/l of sulphate (the recommended limit for water for human consumption is 200 mg/l).

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. This structure gives rise to two different groundwater aquifers: the first is formed by fractures in the bedrock; the second by the regolith. Rain water soaks into the ground in the rainy season, filling aquifers. The water slowly discharges via wetlands into streams through the dry season, thus sustaining stream flow throughout the year. 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.

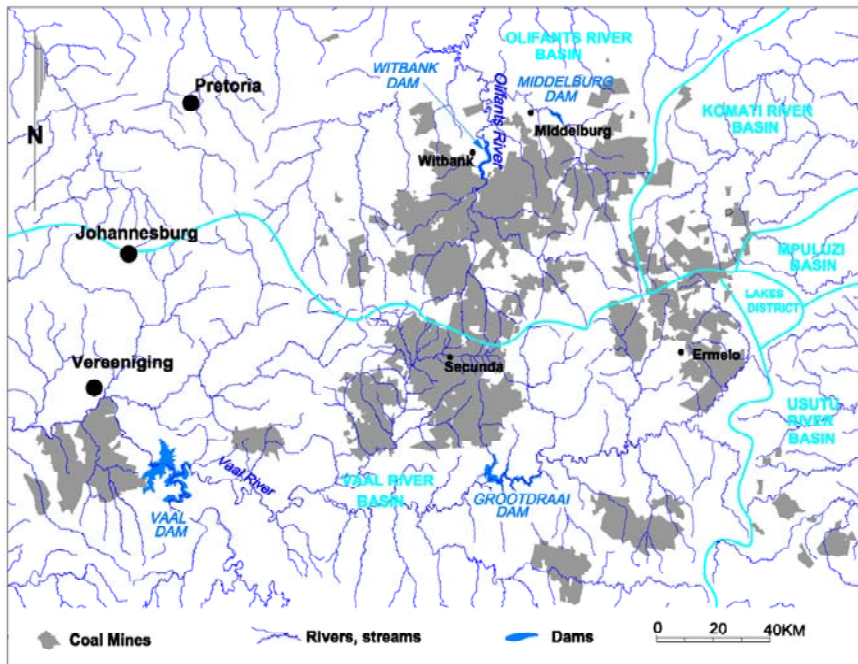


Figure 9. Map showing the distribution of coal mines in the Highveld region in relation to river catchments.

Mining disturbs the aquifer structure. Bord and pillar creates additional voids in the fractured rock aquifer, but the regolith aquifer remains intact provided there is no collapse of the workings. However, water filling the mine void is of extremely low quality. 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 and is usually very acidic. Longwall mining fractures the bedrock, creating additional void spaces and increases both inflow into the void and seepage. The water in the void is of low quality. Once an area has been mined and the mine void fills with water, 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 heavily contaminated, and releasing it into streams can have severe environmental consequences, often resulting in large-scale deaths of fish (due to aluminium poisoning; **fig. 7**) and other aquatic animals.

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, although many mines are still in production and are well maintained (**fig 9**). The water quality in Witbank and Middelburg dams over the last three decades is shown in **figs 10 and 11** respectively. The rather jagged appearance of the graphs is due to dilution during very wet periods. Both dams show a steady increase in total dissolved solids (TDS) and sulphate concentrations over the past 30 years. Bearing in mind that prior to mining the rivers concerned probably contained about 50 mg/l TDS, mining has resulted in a ten-fold increase. The sulphate concentration in the Middelburg Dam water now exceeds the maximum recommended concentration for water for human consumption, and is still rising.

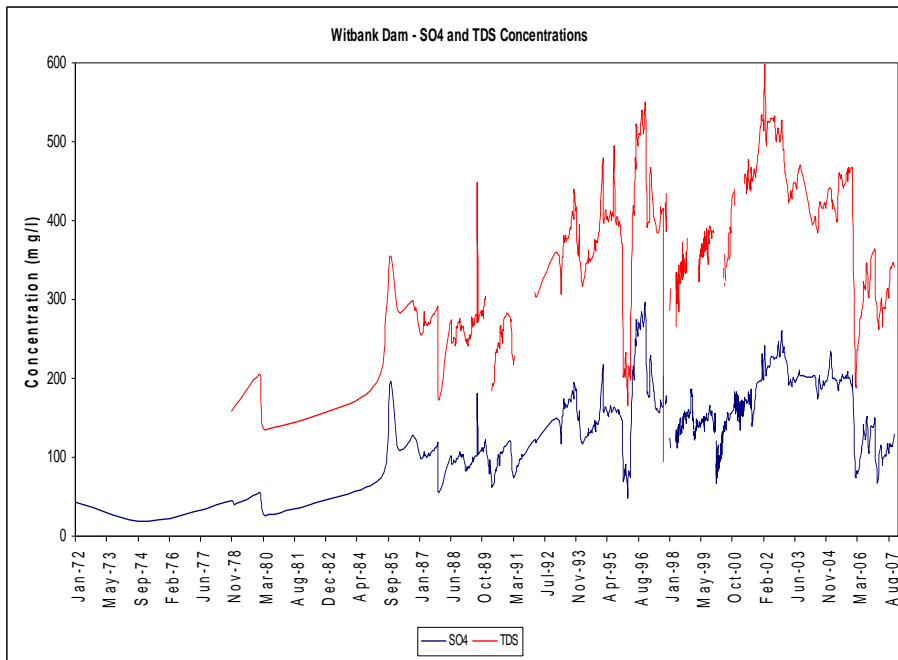


Figure 10. Total dissolved solid (TDS) and sulphate concentrations in Witbank Dam between 1972 and 2007.

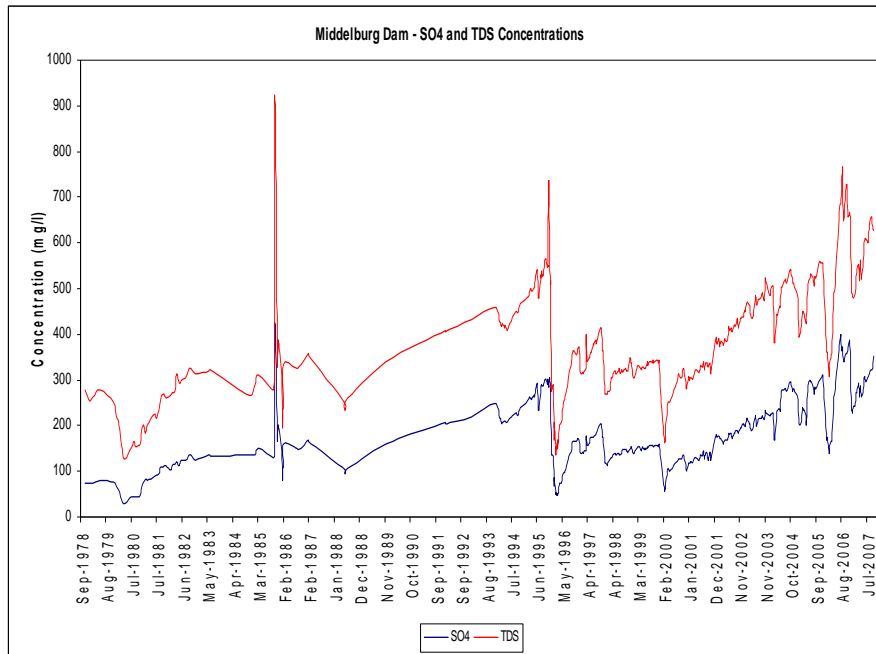


Figure 11. Total dissolved solid (TDS) and sulphate concentrations in Middelburg Dam between 1978 and 2007.

Mitigation

Various measures have and are being implemented to try to mitigate the deteriorating water quality in the Olifants River.

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. Such dams have to be completely sealed, requiring a strong plastic membrane liner, and are very expensive. 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 underway to examine the use of acid-neutralized, sulphate-polluted water for crop irrigation. 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 because the sulphate will accumulate in the soil forming hard gypsum 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, rapid flooding after closure will ensure consumption of the oxygen. Provided there is no additional inflow, acid production will cease and the water will stratify, with good water near surface and contaminated water at depth. Whether this situation is attainable in the coalfields has yet to be demonstrated. It is likely that after closure and flooding, water will emerge at surface via boreholes and fractures, thereby setting up groundwater circulation that will ensure a 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. 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, commissioned in 1997 at a cost of R26.5 million). This approach solved the acid problem, but the sulphate problem remains.

Water purification: Mining companies in the Witbank coalfield addressed the problem of disposing of polluted mine water by constructing a treatment plant to convert it into drinking quality water (the Emalaheni Water Reclamation Plant, commissioned in 2007 at a cost of R300 million). The plant produces 20Ml of water per day at a cost of R10 per cubic metre (in 2008 terms, including capital amortization; the design life is 20 years). For comparison, Vaal River water delivered to the area costs R3 per cubic metre.

Controlled release: Producing mines in the Olifants River catchment collectively manage the release of polluted water 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. 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 in an uncontrolled manner.

Soil protection: Ground water in back-filled opencast mines becomes acidic and may rise to surface by capillary action, causing sterilization of the soil (**fig. 6**). 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.

Records spanning the last 30 years indicate that the pollution level in the Olifants River is rising. The full effects of mining are yet to come, when the large opencast mines fill with water and begin 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 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.

In time, acid generation will decline as pyrite oxidation nears completion. It is unclear how long this will take, but acid and sulphate production are likely to persist for hundreds of years. 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 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 washed away. 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.

After mining, the surface of the mined area is generally rehabilitated and can, in principle be used for agriculture. However, the groundwater aquifers would have been disturbed, and the groundwater severely polluted, so that it will no longer be possible to obtain potable water from boreholes. Drinking water for livestock and humans in such areas will therefore have to be brought in from elsewhere. Streams draining these rehabilitated areas will also be unusable due to seepage of polluted groundwater.

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 increases progressively downstream (**fig 12**). The Klip River, which is heavily polluted by mining and industrial activity on the Witwatersrand, and the coal mines in the Vereeniging area, add significantly to the pollution load. Water quality in the lower Vaal is therefore relatively poor.

A disturbing development is the large number of applications that have been made to open new coal mines in Vaal River catchment (**fig. 13**). 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.

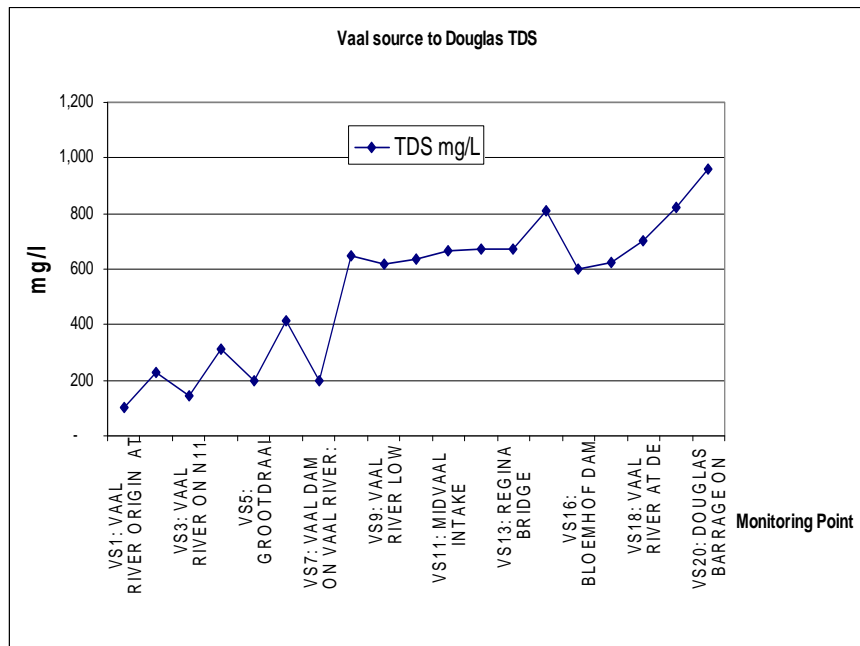


Figure 12. Diagram showing the changing total dissolved solid concentration in the Vaal River.

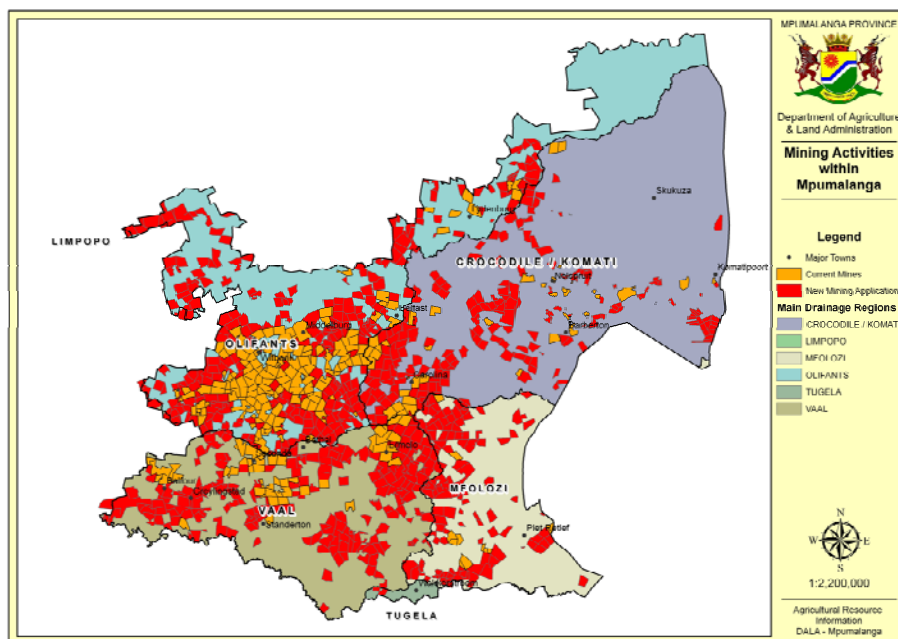


Figure 13. Map showing farms currently under application (red) for mining permits at the Department of Minerals and Energy.

Other catchments

Currently, the Mpuluzi 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.

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 by collapse and by acidification of soils, but by far the most severe problem is water pollution, which is still rising. Water quality will continue to deteriorate for the foreseeable future.

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. 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. 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? We believe they are not: there is no system either in place or planned to prevent this. 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. 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 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 basin, which provides water to the economic heartland of the country. Rivers rising on the escarpment, which 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, 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 mitigation can be guaranteed.