WATER QUALITY CONSIDERATIONS FOR OPENCAST MINING OF THE MOLTENO COAL FIELD, INDWE, EASTERN CAPE

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ABSTRACT

In 2008 the Molteno Coal Field was re-opened for commercial production with a small scale open cast mine at Indwe, Eastern Cape. This mine is situated on 5 hectares of land within a headwater catchment of the White Kei River, a tributary of the Great Kei River. The Molteno coal seam was one of the first to be exploited in South Africa, where mining commenced in 1877, rising to an average peak production of 176 000 tonnes per annum by 1904. Production gradually fell when higher grades of coal were discovered in Gauteng and KwaZulu-Natal, and the mines were abandoned, unrehabilitated, by 1948. The abandoned workings have continued to be mined by informal coal miners for over 100 years. The historic effects of the unrehabilitated works and the ongoing informal mining on the water quality of receiving water resources have been found to be relatively minor, with evidence of high alkalinity in downstream rivers and dams (pH median > 8). With the development of high efficiency circulating fluidized-bed (CFB) technology, the low grade Molteno coal seam has become commercially attractive for a range of industrial and power generation applications. Production of up to 100 000 – 240 000 tonnes per annum of the estimated 100 million tonnes of measured coal is now planned for the first phase of the project. The potential for acid mine drainage due to the scheduled increase in production has been addressed through a combination of environmentally sustainable practices on site including the ongoing rehabilitation of pits prior to blasting of new areas, minimization of on-site stockpiling, and the establishment of settling ponds for stormwater runoff interception. In addition the geochemistry of the coal seam and buffering capacity of the soils and receiving water resources is the subject of a further research initiative.

1. INTRODUCTION

The production of coal in South Africa is located primarily in the coalfields of Mpumalanga. The Molteno-Indwe coalfield in the Eastern Cape is generally of a low grade and has not been regarded as economically viable for commercial development, after the initial mine works were abandoned in the early 1900's. Informal mining has continued to take place in the area for over 100 years. With the development of circulating fluidized-bed (CFB) technology, the coal is now regarded as commercially attractive and an extensive exploration phase has been completed to quantify the resource. A preliminary assessment of the impacts of the historical mining activities on surface water resources draining the mining area has been carried out, as a basis for further research into the potential for Acid Mine Drainage, the buffering capacity of the water resources and long term sustainable management of the mine related activities in the catchment.

History of Coal Mining in Indwe

According to Peatfield (2002) the earliest recorded exploitation of coal in South Africa was in the Molteno-Indwe field in 1864. It is probable that the indigenous inhabitants of the area exploited some of the exposed coal within the Machubeni District before the arrival of European settlers, but little evidence of this has been documented. Full scale commercial mining for coal began in 1895 and the town of Indwe was formally laid out in 1896. Later, better quality coal was discovered in Gauteng and Mpumalanga and the mines in Molteno-Indwe closed down leaving abandoned mine workings and unused railroads.

Over time, informal miners have continued to collect and use the easily accessible coal and gradually as this became scarce, the miners started to tunnel into the coal seam. These tunnels may be several meters deep into the hillside and most are unsupported. It is reported that some of the caves stretch up to 200 meters into the hillside without proper reinforcement supports, ventilation shafts or safety measures.

With the development of CFB technology, Elitheni Coal has established a commercial coal mine within the Macubeni 3 Allotment Area, part of the Chris Hani District Municipality of the Eastern Cape Province. The mine is situated on State Land approximately 10 km south-west of the town Indwe. The project aims to provide a safe mining practice for the group of illegal miners, through a community partnership of shareholding and profit sharing. The mining plan entails two phases. Phase One is an open cast operation during which the training and recruitment processes will commence, the infrastructure for sorting and transporting the coal will be developed and contracts with the local market will be negotiated to generate capital for the next phase. Phase 2 entails an underground mining operation to a maximum depth of approximately 80 meters with initial production of 300-400 000 tonnes per annum, increasing to an estimated 1 million tonnes per annum by 2012 and 3 million tonnes per annum by 2015.

2. GEOLOGY

Figure 1 shows the major coalfields of South Africa. The majority of coal produced currently comes from the Witbank Coalfield, and at present mining rates this source will be exhausted in the next 50-100 years (Exxaro, 2008). In the Eastern Cape, the Molteno-Indwe coal field is currently undeveloped. The Molteno formation hosts the coal within the Eastern Cape Region. It is bounded by the Elliot formation at the top and the Beaufort formation at the base. It occupies an area of some 4 400 km2. The Molteno formation reaches a maximum thickness in the southern portion, close to the town of Indwe, and thins out towards the north (Thamm, 1998). The formation consists of sandstone layers interbedded with dark greenish grey, dark greyish red and maroon mudstone and subordinate siltstone, which is volumetrically equal in abundance to the sandstone. Calcareous nodules and layers are common in the mudstone and sparse sandstone-filled desiccation cracks are present. The reddish colours indicate oxidation of the mud during subaerial exposure and the calcareous nodules and layers have been interpreted as pedogenic calcrete that formed in a semi-arid environment (Smith, 1990; Cobban and Weaver, 1993).

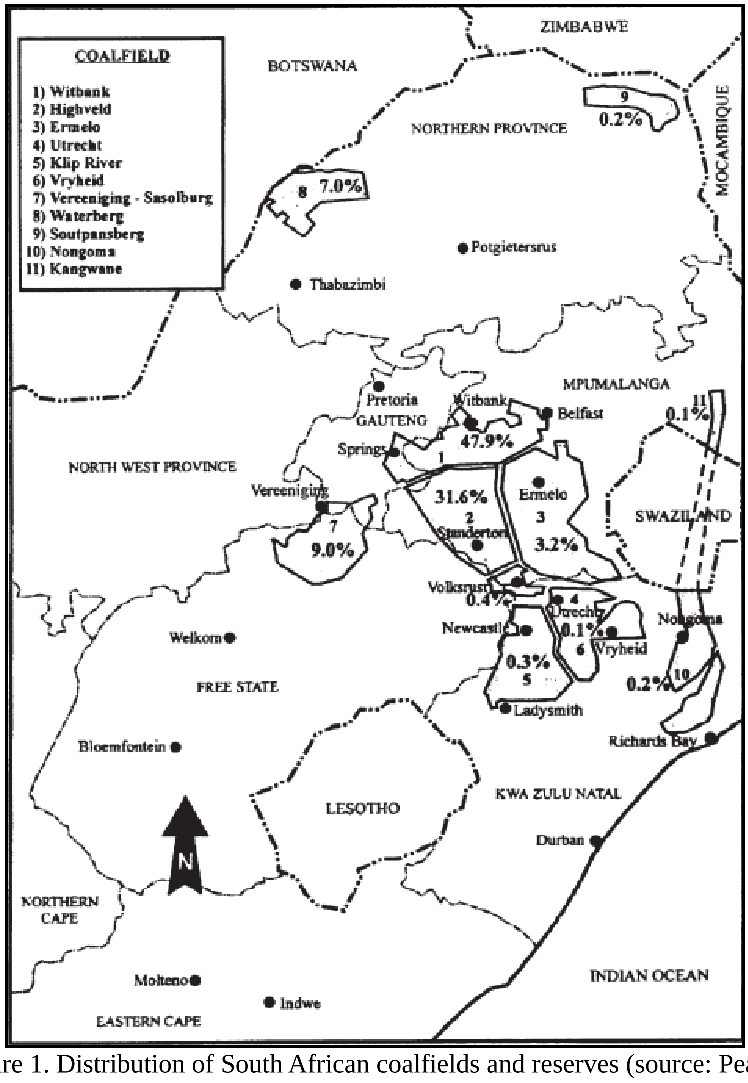

Figure 1. Distribution of South African coalfields and reserves (source: Peatfield, 2002)

Dolerite intrusives are common throughout the area, forming approximately 30% of the surface area in the Molteno - Dordrecht - Indwe region (Thamm, 1998). Dykes are typically 5-10 metres (m) in width and up to 10 km along strike. Dolerite sills and sheets are extensive up to 200 m in thickness. The rank of coals in the Molteno coalfield generally increases from west to east and also fluctuates on a local scale according to proximity to igneous intrusions. High volatile bituminous coals are present but sparse in the west, and the coals are more common but mostly low volatile bituminous to anthracitic in the east.

There are four coal seams identified within the Molteno Formation, which are named from the base as: Indwe, Guba, Molteno and Gubenxa seams (Smith, 1990; Thamm, 1998). All seams cap upward-fining fluvial sequences of sandstone and mudstone:

Indwe Coal Seam

The Indwe coal seam is the largest seam in the succession and is widely, but sporadically, distributed throughout the western and southern part of the Molteno coal field. It varies in thickness up to 4.3 m north of Indwe, and consists of alternating coal and shale. There are also interspersed mudrock partings.

Guba Coal Seam

The Guba coal seam lies about 20 – 30 m above the Indwe seam and tends to be discontinuous. The Guba seam is generally of better quality with a higher coal to shale ratio than the Indwe seam and the coal quality tends to be better in the lower portions of the seam. The Guba seam is particularly well developed south-west of Indwe in the Guba Valley where as much as 1.8 m of clean coal occurs. The higher quality coal is located in the lower part of the seam (Thamm, 1998). This is the site for the initial open cast phase of the Elitheni mining operation. The Guba coal seam is exposed as a dark horizontal layer running mid-way along the hillsides in the Guba Valley. The coal is eroding under natural weathering processes and can be seen as loose rocks on the hill slopes and valley bottoms, and in stream beds of watercourses which have incised through the coal seam.

Molteno Coal Seam

The Molteno coal seam is variable in thickness but generally less than 0.6 m and lies 30 – 50 m above the Indwe and Guba seams. It may contain up to 50% shale.

Gubenxa Coal Seam

The Gubenxa seam is most predominant about 30 km southeast of Elliot, with a maximum thickness of about 1.8 m. It lies some 30-40 m above the Molteno seam and is shaly, containing no more than 40% of clean coal at most localities (Thamm, 1998).

According to Peatfield (2002) the Indwe, Guba and Molteno seams have economic potential in places although they are mainly of poor quality. The Gubenxa has no economic potential under present technology. Analyses show that the Indwe and Guba seams have high ash content of 31–51% unwashed and between 26–27% when washed, high moisture content of 7–11% and low volatile matter of 7 to 12% (Prevost, 2002). The coal resources in the Eastern Cape province are indicated in Table 1. Nel (2008) reports that exploration on less than 10% of the prospecting area of the Guba seam has found over 25 Million Tonnes (Mt) measured resource and 40 Mt inferred resource. Based on these findings, the expected measured resource is around 200 Mt, of which extractable is 130 Mt, which supports the commercial potential for development of the coalfield.

Table 1. Coal resources of the Molteno Formation (after Thamm, 1998)

UNIT	**RAW DEMONSTRATED (Million Tonnes)**	**SALEABLE RESERVES (Million Tonnes)**
Molteno	68.9	8,0
Guba	180.2	24,0
Indwe	112.7	13,3
TOTAL	**361,8**	**45,3**

3. ACID MINE DRAINAGE

Robinson (2003) defines Acid Mine Drainage (AMD) as the accepted term for a polluted effluent from mining activities including base metal, coal and gold mines. The effluent contains sulphuric acid and toxic metals leached out from the ore and wastes. The sulphuric acid and toxic metals are formed by oxidation of sulphide minerals such as pyrite. Even if a mine has ceased operating, the formation of AMD continues underground and on surface. If a mine ceases operations, the AMD might flow into an adjacent operating mine or can overflow into shallower fresh water springs and rivers. AMD is one of the most severe causes of impacts on water resources in South Africa, in particular due to the uncontrolled decanting of acidic underground water from abandoned mine works.

The Indwe/Molteno coal field is the only coal field in the Eastern Cape with potential for commercial development under presently available technology, but it has not been investigated for AMD potential. Development of commercial coal mining may therefore impose major risks on the surrounding environment and specifically the water quality. In a recent ongoing study by Malaza and Zhao (2009), the Indwe/Molteno coal field is under investigation with respect to potentially high concentrations of sodium salts and sulphide.

Preliminary results show that sulphur levels are generally low, as can be seen in the Acid Base Accounting analyses which were carried out by Labuschagne (2008) on a limited set of samples collected from the roof, coal and floor material of an existing mine works within the Guba seam.

Table 2 shows the results of the analyses, with neutralization potential ratios ranging respectively from 3.56, 1.33 to 23.

Table 2. Acid Base Accounting Analyses for Guba Seam, near Indwe (after Labuschagne, 2008)

	Sample		
	Roof	**Coal**	**Floor**
Paste pH	6.4	7.1	7.0
Total Sulphur (%)	0.009	0.096	0.008
Acid generation potential (AP) $CaCO_3$ (kg/t)	0.28	3.00	0.25
Neutralisation potential (NP) $CaCO_3$ (kg/t)	1.00	4.00	5.75
Net neutralisation potential (NNP) $CaCO_3$ (kg/t)	0.72	1.00	5.50
NP:AP ratio	3.56	1.33	23

Findings reported by Thamm (1998) in Table 3 on the general characteristics of samples taken from the Molento, Dordrecht and Indwe coal districts, show sulphur levels around 6 times higher than in Table 2. The variation in sulphur levels can be attributed to a lack of empirical data, which is required to quantify the geochemistry of the coal seams in more detail.

Table 3. Generalised coal characteristics of the Molteno Formation, washed at relative density of 1.8 (air dry) (after Thamm, 1998)

Seam	**CV(%)**	**H_2O(%)**	**Ash(%)**	**Volatile Matter(%)**	**F.C.(%)**	**Sulphur(%)**
Gubenxa	22.7	1.46	40.03	18.46	56.44	0.56
Indwe	23.25	1.65	30.06	14.89	53.40	0.45
Guba	21.25	2.22	32.45	8.87	40.03	0.64

4. STUDY AREA

The area under investigation is the drainage basin within which most of the informal mines are operating, and where the current prospecting area on the Guba coal seam is situated (Figure 2). The study focuses on the drainage occurring downstream and/or down-gradient of the historical mining activities which are located predominately within in the Guba Valley, where communities are exploiting the exposed outcrop of the Guba coal seam. The Guba River enters the Indwe River between the relatively small Doringrivier Dam to the north with a full storage capacity of 17.9 million cubic meters, and the larger Lubisi Dam to the south with a full storage capacity of 158 million cubic meters.

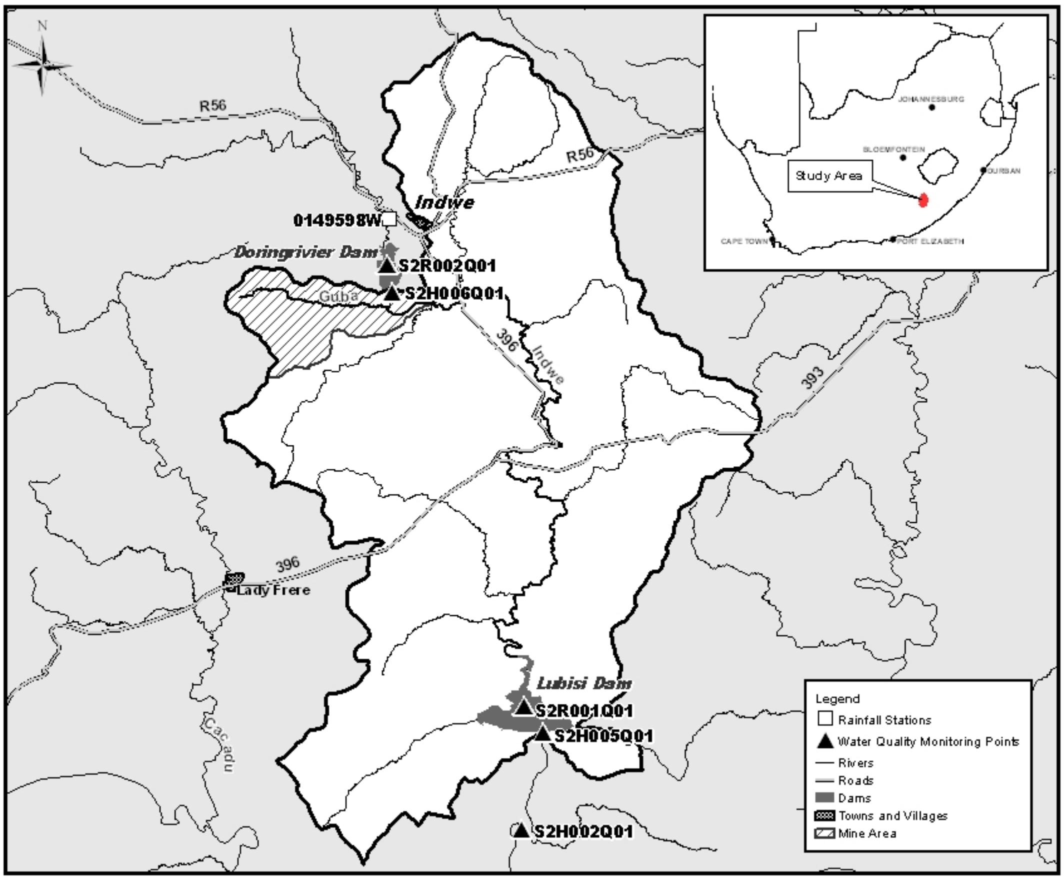

Figure 2. Catchment area of the coal mining activities

Topography

The catchment uplands are formed from the gently undulating Msenge plateau, with incised stream and river valleys which are mostly unnamed and ephemeral in the upper reaches. There is widespread gully erosion throughout the Machubeni District, usually occurring within alluvial fans at the foot of the steeper slopes (Cobban and Weaver, 1993) and also associated with mining of mud from river banks for brick making by the local communities. Over-grazing and erosion has been cited as a factor in the moderately impacted status of riparian vegetation and in-stream ecosystems (Scherman *et. al*., 2008). The valleys are bounded by steep sides, where the exposed Molteno Formation outcrop is clearly visible with horizontal sandstones, mudstones and coal seams of varying thickness.

The greatest apparent number of illegal and abandoned coal mines fall within the immediate catchment of an unnamed tributary of the Nomaguwana River, which later becomes the Little Guba River and then the Guba River. A seep zone (wetland) is located on the northern bank of the Guba river. The Guba River joins the Indwe River approximately 5km downstream of the dam wall of the Doringrivier Dam, which is the main water supply to the town of Indwe. A further 25 km downstream on the Indwe River is the Lubisi Dam, with a full storage capacity of 158 million cubic meters. There are no significant allocations for water use out of the Lubisi Dam at present, although the need for safe water supply to villages in the area may result in an allocation for domestic water use to the Chris Hani District Municipality in the near future.

Downstream of the Lubisi Dam, the Indwe River has its confluence with the White Kei River, which is one of the larger river systems of the Eastern Cape. Several riparian villages utilize the White Kei directly for domestic water supply as well as subsistence irrigation and stock watering. The Lubisi Dam is regarded as the cumulative lowest point draining the current mining area, consequently the water chemistry within the Lubisi Dam is expected to reflect the long term impacts of the mining activities.

Rainfall

Mean Annual Precipitation (MAP) for the tertiary catchment S20 peaks in October and April and ranges from 500-650mm. Rainfall data records were taken from the nearest measuring station situated at Indwe in the upper catchment (Station Number 0149598), where the records date from 1906 to present with just 6.15% missing data and over which period the recorded MAP was 592.8mm (see Figure 2).

Geohydrology

Groundwater in this catchment is mostly associated with fractured intrusive dolerite contacts and, to a lesser extent, fractured Karoo Sequence lithology. The aquifers in the area can generally be classified as unconfined to semi-confined secondary hardrock aquifers (Labuschagne, 2008). The groundwater in these systems is contained in voids, fractures, bedding planes and joints. Some minor shallow localised aquifer systems may also be associated with superficial alluvial deposits found along rivers and streams and overlying the Karoo rocks.

The mining sites are situated on low to medium yielding aquifers with good water quality. These aquifers have no to low potential in terms of development. The aquifers are of minor regional importance in terms of community water supply and have been classified by Labuschagne (2008) as a Minor Aquifer System, according to the Parsons Classification methods.

5. WATER QUALITY

The water quality across the mine area and regionally is considered to be of good quality. This is of particular significance given the extensive and long term exposure and weathering of coal deposits, as well as the widespread informal mining of coal which has been ongoing for more than 100 years. The water has a sodium and bi-carbonate dominant character. The pH is in the order of 8.3 to 8.6, which is relatively high and indicates alkaline conditions. The characteristics of the coal seam are low sulphur and iron content, which is unlikely to lead to acid drainage.

Water quality samples have been collected by the Department of Water Affairs (DWA) at 11 gauging sites within the study catchment, with data records ranging in length from 1 to 176 (Table 4). For statistical significance, sites with less than 30 data records were excluded from the analyses.

Table 4. Water quality monitoring sites within the study area

STATION	START DATE	END DATE	NO. RECORDS
STIL FONTEIN	06/08/1993	06/08/1993	1
S2H001Q01 INDWE RIVER AT NCAPA FARM	05/07/1995	17/05/1999	4
S2H002Q01 INDWE RIVER AT NTLONZE 29/LANTE 16	23/01/1980	10/10/2007	11
S2H005Q01 LUBISI DAM ON INDWE RIVER: DOWN STREAM WEIR	07/08/1996	03/12/2007	81
S2H006Q01 DORINGRIVIER DAM: DOWN STREAM WEIR	01/03/1978	25/04/2007	50
S2R001Q01 LUBISI DAM	04/06/1980	02/01/2008	86
S2R002Q01 DOORN RIVER DAM	06/02/1978	19/07/2007	176
KUMNGQANGA	29/09/1993	29/09/1993	1
DOORN KOP	06/08/1993	06/08/1993	1
LADY FRERE BILATYE LOCATION (DUP NAME 30476)	26/03/1996	26/03/1996	1
LADY FRERE BILATYE LOCATION (DUP NAME 30477)	28/03/1996	28/03/1996	1

Surface Water Chemistry

Key acid-related water quality parameters were plotted for selected monitoring stations, to assess if there have been any statistically significant changes in the chemistry of water in receiving water resources downstream of where the mining is taking place. The water quality data record commences in 1978 for the Doringriver Dam (upstream of the mining area) and in 1980 for the Lubisi Dam (downstream of the mining area). In-stream surface water samples from upstream and downstream of the mining catchment are compared and the reservoir water quality from upstream and downstream are also compared for emerging trends and for evidence of acidification in the system.

S2H005: Downstream Site

This site is situated on the downstream weir below Lubisi Dam. Electrical conductivity (Figure 3a) and total alkalinity (Figure 3b) trends are statistically insignificant. Figure 3c shows there is a net increase in sulphate during the sample period, although it must be pointed out that the trend is weak (R^2=0.3) and concentration rises less than 10mg/l which falls within laboratory measurement error boundaries. Figure 3d shows a corresponding drop in pH, however the margin is less than 0.4 pH units. The trend is even weaker than that of sulphate at R^2 = 0.2, which can be regarded as insignificant.

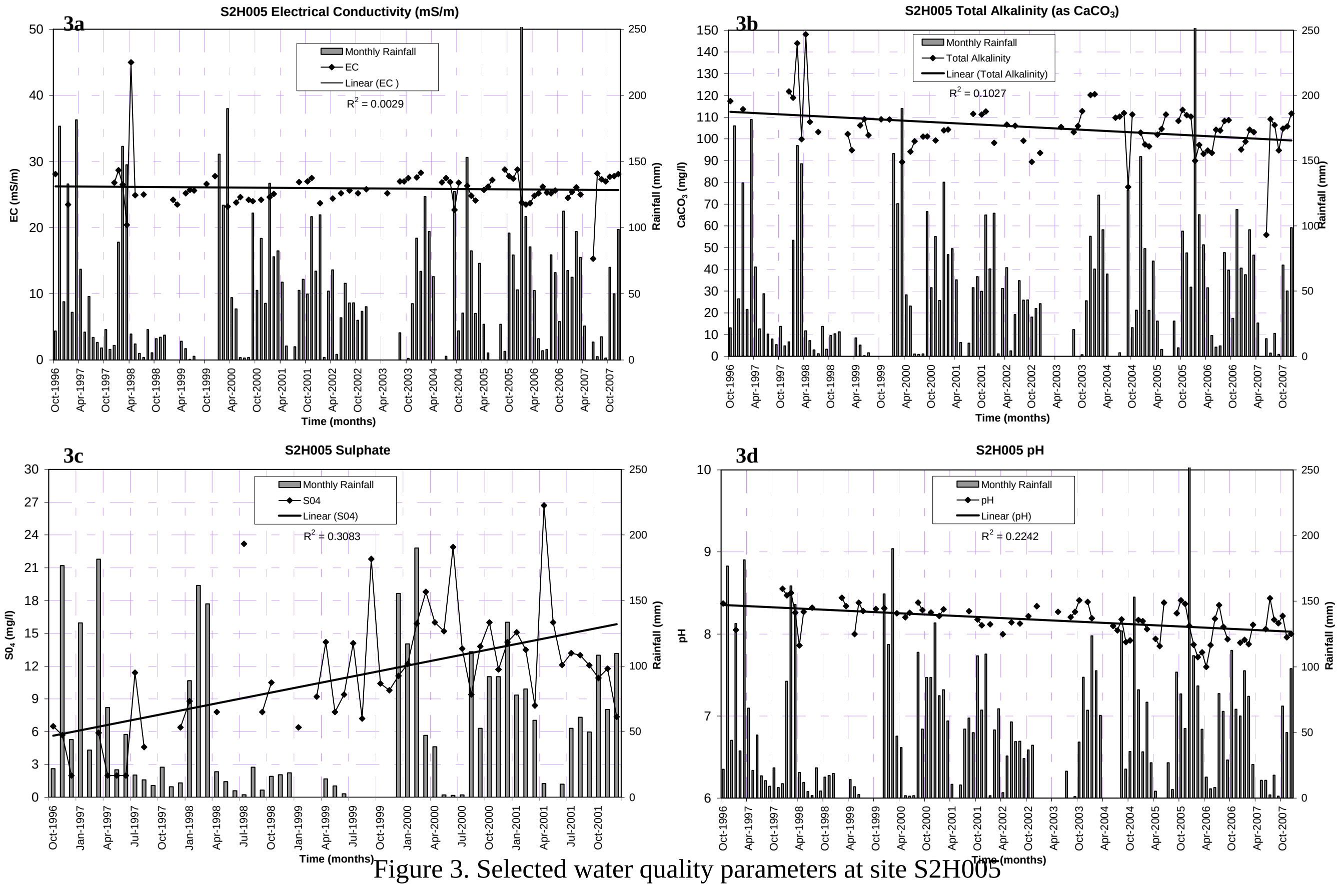

Figure 3. Selected water quality parameters at site S2H005

S2R001: Downstream Site

The water quality results taken from within the Lubisi Dam at site S2R001 show similar concentrations to those found in the data from site S2H005, just downstream of the dam wall. Within the dam, the net pH shown in Figure 4d has a weak increasing trend (R^2=0.2) while all other variables show no significant trend for the sample period.

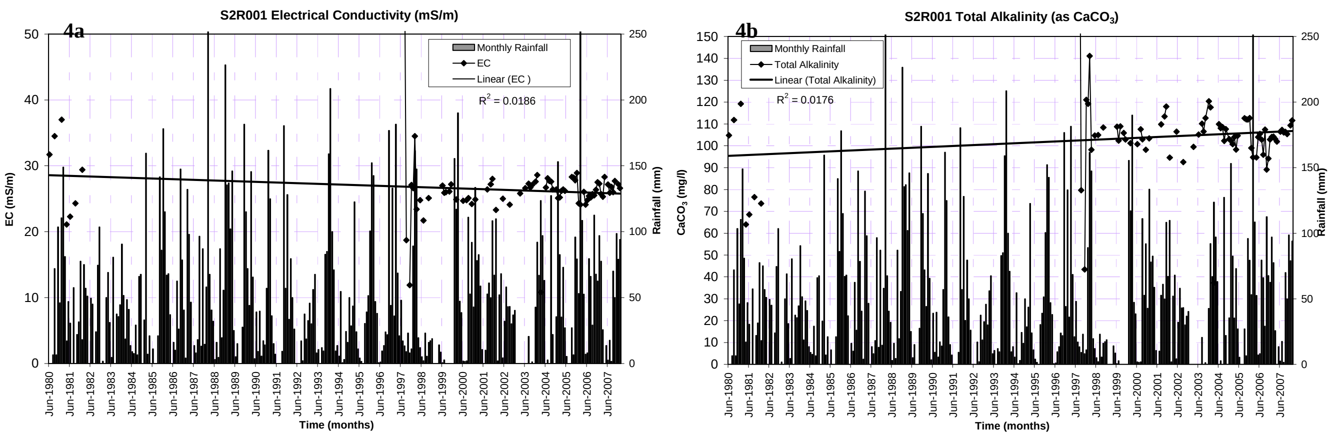

Figure 4. Selected water quality parameters at site S2R001

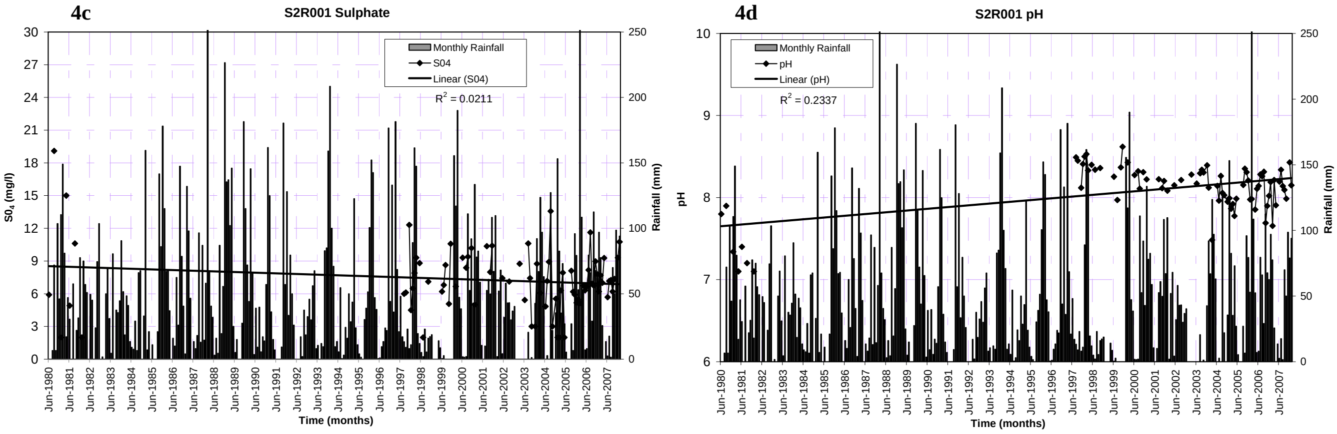

Figure 4. (contd.): Selected water quality parameters at site S2R001

S2H006: Upstream Site

No clear trends emerge for the concentrations in water samples taken from the weir downstream of Doringrivier Dam (Figure 5), with the exception of a moderate positive trend (R^2 = 0.47) in pH (Figure 5d). The pH increases over the sample period by just under 1 pH unit, which can be regarded as moderately significant. The trend is reflected in the pH of samples taken from within the dam (Figure 6d) although to a lesser extent (R^2 = 0.3). It must be noted that while the pH increases, the sulphate concentrations show no trend (R^2 = 0.19). The alkaline character of the river is therefore unrelated to sulphate concentrations, and an explanation for the processes affecting the pH would require investigation of other water quality variables.

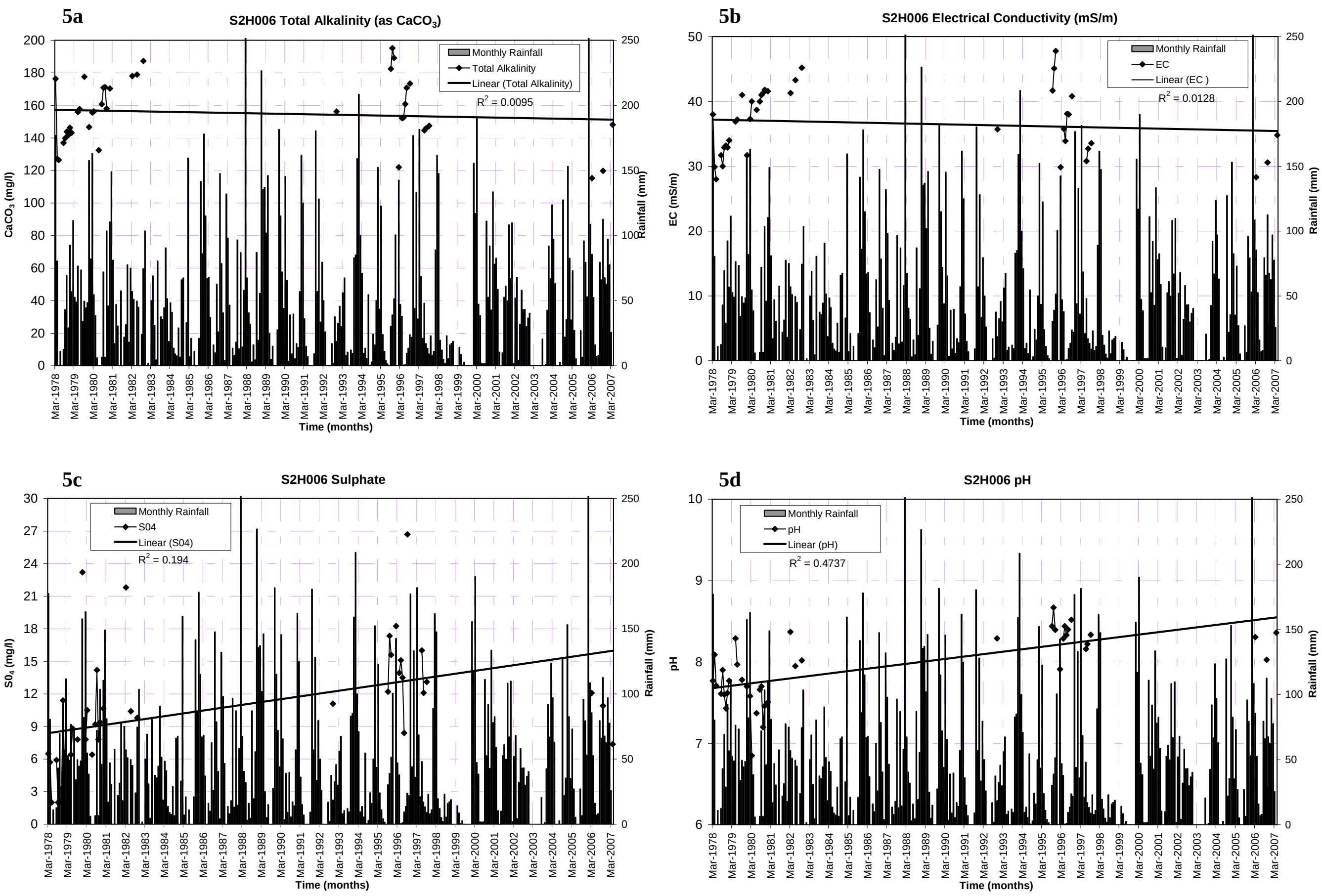

Figure 5. Selected water quality parameters at site S2H006

S2R002: Upstream Site

The water quality results taken from within the Doringrivier Dam at site S2R002 show no significant trends for any of the variables, with the exception of pH where a weak positive trend ($R^2 = 0.3$) can be seen (Figure 6d). This corresponds with the pH readings taken from S2H006 at the outlet of the Dam.

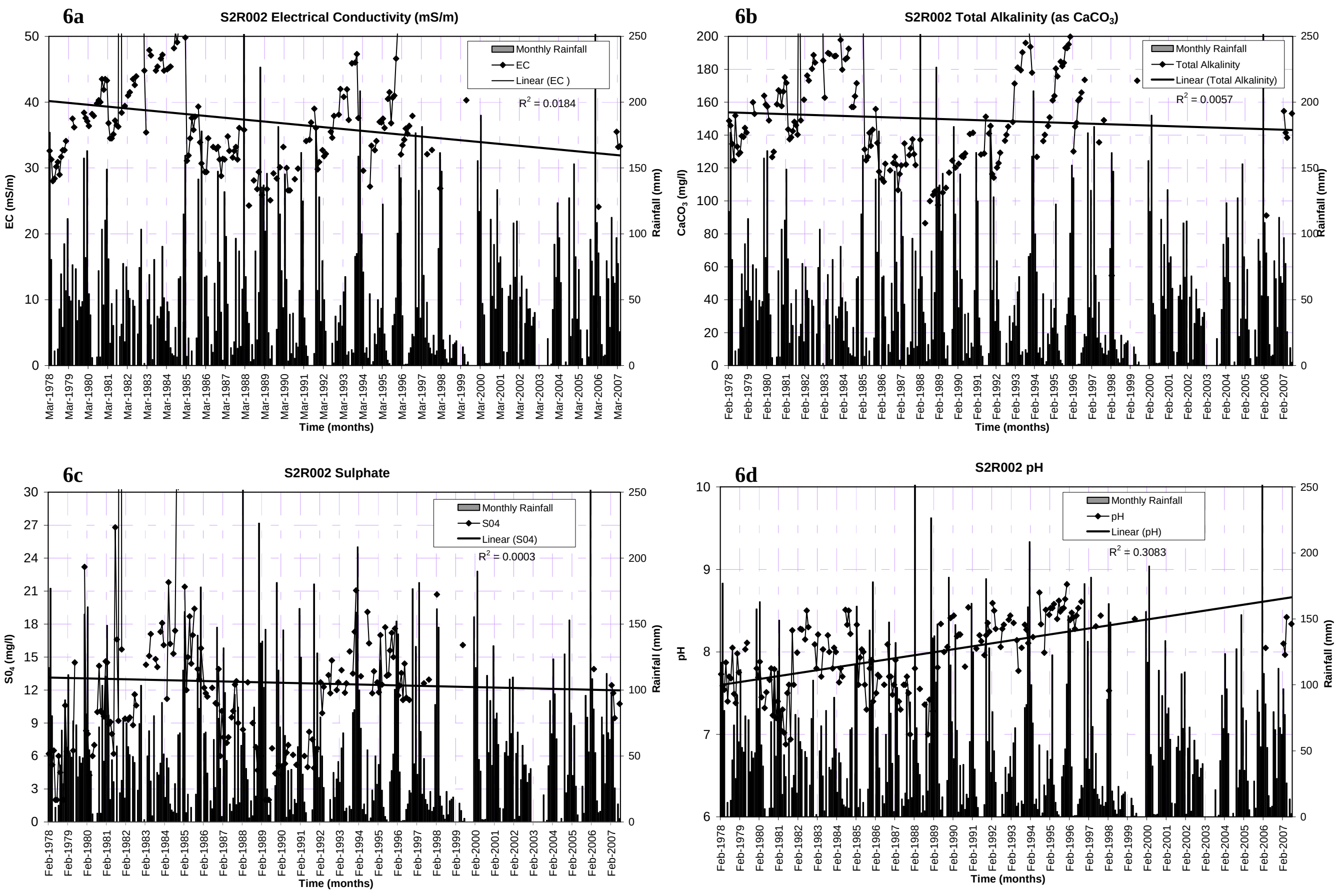

Figure 6. Selected water quality parameters at site S2R002

Water Quality in Reservoirs

Selected water quality variables for the Doringriver Dam and Lubisi Dam were assessed (Table 5). It can be seen that concentrations in the upstream dam are consistently higher than the downstream concentrations for all variables. This can be attributed to the effects of dilution in the larger Lubisi Dam. The pH is virtually identical in both dams, although falling to 6.7 minimum in the upstream Doringrivier Dam. There is no evidence of AMD in the Lubisi Dam, which has maintained alkaline characteristics over the sample period of 28 years.

Table 5. Water quality data for Indwe River: reservoir sampling upstream and downstream of mining area

	Mean	Maximum	Minimum	Std. Dev.
Electrical Conductivity (mS/m)				
S2R002 (upstream)	37.1	190.6	24.1	13.3
S2R001 (downstream)	26.4	60.8	10.8	5.1
Total Alkalinity (Ca CO_3 mg/l)				
S2R002 (upstream)	150.0	304.3	54.7	31.2
S2R001 (downstream)	104.2	246.2	37.3	21.3
Total Sulphate (SO_4 mg/l)				
S2R002 (upstream)	12.7	191.3	2.0	14.5
S2R001 (downstream)	7.2	19.1	2.0	3.0
pH				
S2R002 (upstream)	8.0	8.8	6.7	0.4
S2R001 (downstream)	8.1	8.6	7.1	0.3

The Mann–Whitney U (two-tailed) test was used to determine if there is any significant difference between the water quality in the Doringrivier Dam (n=186) and the Lubisi Dam (n=86). Results in Table 6 show that the distributions in the two data sets have no significant difference at the 0.95 confidence interval for the constituent concentrations, and at the 0.90 confidence interval for pH.

Table 6. Results of probability distribution in sample sets (WQStat Plus v1.5, 1998)

	Z	**Table**	**Significant**
T. Alkalinity ($CaCO_3$)	-11.62	2.326	No (0.01)
Sulphate	-7.277	2.326	No (0.01)
Electrical Conductivity	-11.56	2.326	No (0.01)
pH	1.61	1.645	No (0.05)

In-Stream Water Quality

Table 7 summarises the water quality of key variables measured within the Indwe River. Generally, the mean concentrations measured at the weir below Doringriver Dam (upstream site) are higher than the concentrations downstream at the weir below the Lubisi Dam. This may be explained as due to the greater dilution effects of the larger Lubisi Dam.

The pH can be regarded as the same at both sites, with the exception of the upstream site minimum reading which falls to 6.9, whereas downstream the minimum reached was in the alkaline range at 7.6. The upstream site is located above the mining area and so this pH value cannot be attributed to the effects of mining. From the preliminary assessment there is no evidence of impacts due to the coal mining activities on the concentrations of key variables, or on the pH.

A non-parametric test could not be applied to the in-stream water quality due to the small sample size at S2H006 (n=50).

Table 7. Water quality data for Indwe River: instream sampling upstream and downstream of mining area

	Mean	**Maximum**	**Minimum**	**Std. Dev.**
Electrical Conductivity (mS/m)				
S2H006 (upstream)	36.7	51.2	25.3	5.4
S2H005 (downstream)	26.3	67.9	12.8	5.7
Total Alkalinity (Ca CO_3 mg/l)				
S2H006 (upstream)	155	198.3	99.4	21.5
S2H005 (downstream)	106.0	240.6	42.5	22.5
Total Sulphate (SO_4 mg/l)				
S2H006 (upstream)	11.3	26.7	2.0	5.5
S2H005 (downstream)	7.9	17.3	2.0	3.2
pH				
S2H006 (upstream)	8.0	8.9	6.9	0.4
S2H005 (downstream)	8.1	8.7	7.6	0.3

6. DISCUSSION AND CONCLUSIONS

There is no conclusive evidence from the water quality records available that the present and historical mining activities have had any significant impact upon the acidification of the downstream water resources in the Indwe River catchment draining into the Lubisi Dam. Conversely, the water quality data shows that the system is becoming increasingly alkaline in both dams where the pH shows a positive trend, although the correlations are weak. Should there be AMD emanating from the mining area, it would be expected to result in a trend of decreasing pH. One explanation which can be considered is that the coal resource has a relatively low sulphur content and will not lead to acid-forming weathering and drainage. The naturally alkaline conditions prevalent in the surface water resources of the catchment represent a buffering capacity within the aquatic environment. The extent to which the environment would be able to maintain alkaline conditions, should AMD increase under commercial mining and possible dewatering of the underground works, is indicated for further investigation in order to enable appropriate mitigation measures to be put into place.

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