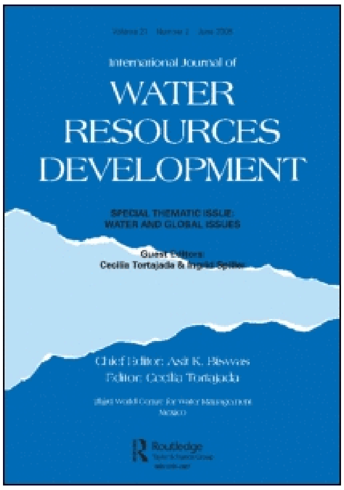

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Management of Environmental Impacts from Coal Mining in the Upper Olifants River Catchment as a Function of Age and Scale

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ABSTRACT *Effective water resource governance in a water scarce environment such as South Africa is a strategic issue in national sustainable development priorities. Acid mine drainage (AMD) is one of the largest liabilities of the mining industry due to its inherent threat to water resources, human health and the environment. Against the background of evolving water governance in South Africa, three examples are explored to reflect the management of AMD in the upper Olifants River catchment. The Brugspruit Water Pollution Control Works shows the scale of historic liabilities faced by the state, as well as the challenge of effectively addressing AMD within a resource-poor environment. The Controlled Discharge Scheme takes advantage of the natural assimilative capacity of the upper Olifants River system during high flow conditions to effect the controlled discharge of AMD. The Emalahleni Water Reclamation Plant exemplifies the successful initiative by large and well-resourced mining houses to achieve engineered sustainable mine water management.*

Introduction

In a water constrained country such as South Africa (Brown, 1875; Conley, 1996; Turton *et al.*, 2006), the quality of water determines its suitability for use. Surface and groundwater pollution is the most common environmental issue coal mines must deal with (van Zyl, 2002). This is exemplified in the upper reaches of the Olifants Water Management Area (Figures 1 and 2), where extensive coal mining has resulted in poor quality acidic water (Basson *et al.*, 1997; Hodgson & Krantz, 1998). The situation is exacerbated by several factors, including, amongst others, a historic lack of policy to address AMD, especially at mine closure. As a consequence, AMD from several derelict and ownerless coal mines in the catchment creates tremendous long-term environmental liabilities for government (Adler *et al.*, 2007).

Although it is challenging to differentiate between the consequences unique to AMD and those that are more generally related to mine closure (Adler & Rascher, 2007), the government recently implemented new policy and legislation to address mine water management. This has forced the mining industry to adopt practices to conform to these new regulations but, almost 10 years later, it is clear that several vulnerabilities remain (Adler & Rascher, 2007). One of these is government's management of the liabilities

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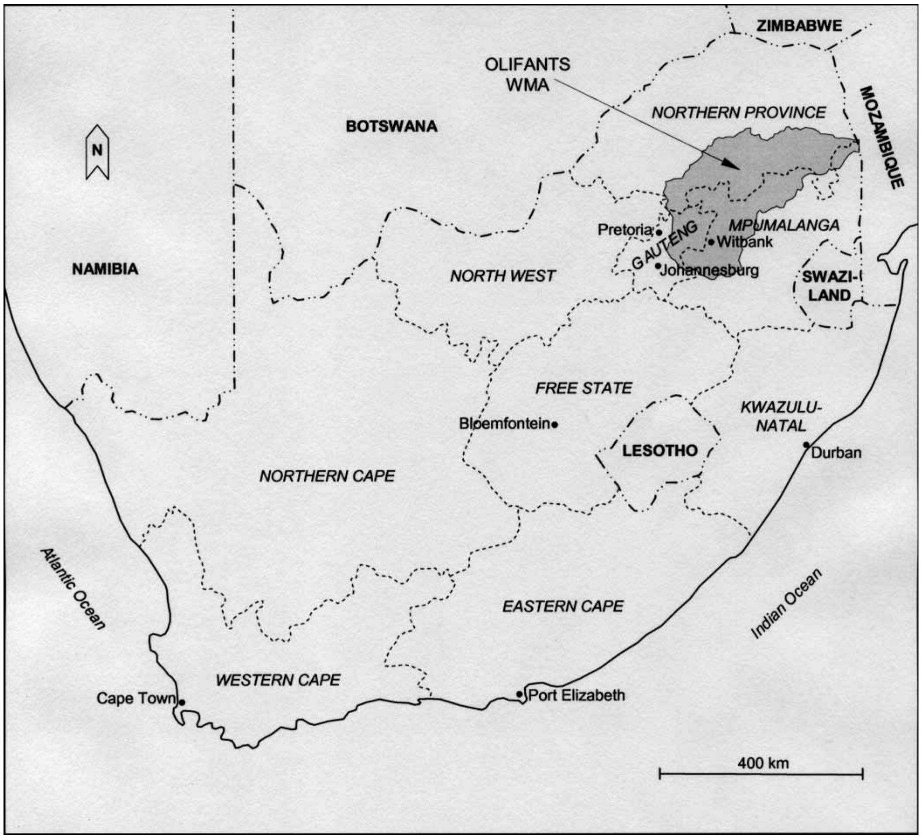

Figure 1. Map showing the position of the Olifants Water Management Area (WMA) in South Africa.

associated with derelict and ownerless mines. At the same time industry, applying technological innovation to manage AMD, plays an important role in the prevention of environmental and socio-economic degradation through its contribution to sustainable mine water management (Adler & Rascher, 2007). However, this technological innovation has not yet become part of policy to govern AMD in South Africa.

This paper provides a broad overview of coal mining, water resources and AMD in the upper Olifants River catchment. The evolution of water governance related to AMD in South Africa is discussed against this background, and three examples of AMD-related water management are explored. These examples are analysed to understand the current situation, and to identify the challenges that government and the coal mining industry face in the management of AMD and its related impacts.

The Upper Olifants River Catchment

Coal Mining

South Africa's coal mining industry is the second largest mining sector after gold, with sales contributing 16% of export revenue in 2003 (R20 billion in 2000, equivalent to €1.98

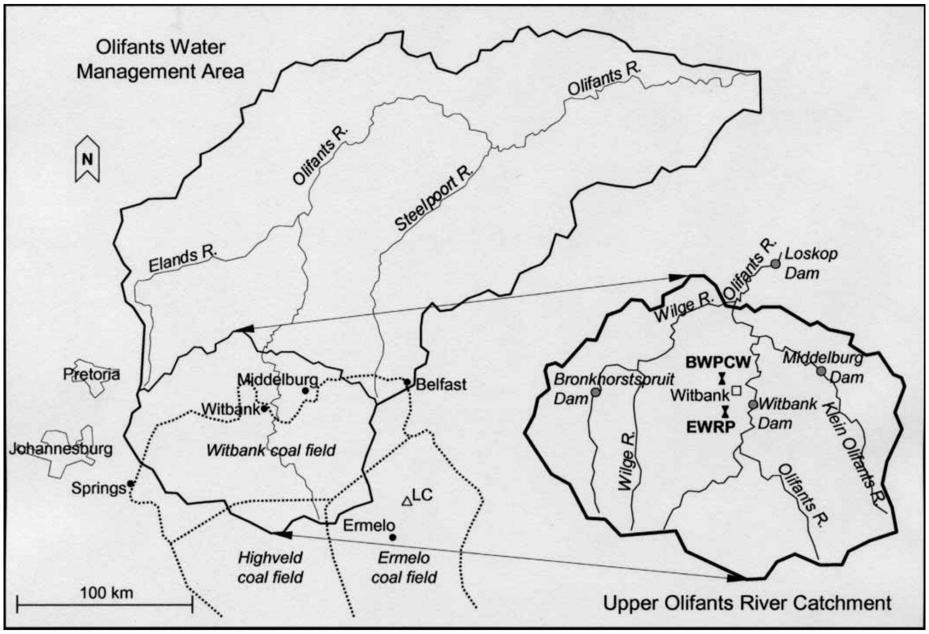

Figure 2. Map showing the main drainages and coal fields in the Olifants Water Management Area (WMA), and the locations of the Brugspruit Water Pollution Control Works (BWPCW) and the Emalahleni Water Reclamation Plant (EWRP) in the upper Olifants River catchment, as well as Lake Chrissie (LC) in the Ermelo coal field.

billion in December 2007). Together with the Highveld and Ermelo coalfields (Figure 2), the Witbank coalfield represents the largest conterminous area of active coal mining in South Africa. These coalfields produce coal for power generation—the region supports 48% of the country's total power generating capacity (Tshwete *et al.*, 2006)—for export and for domestic consumption.

Located mainly in Mpumalanga Province, the Witbank coalfield spans ~190 km from Springs in the southwest to Belfast in the northeast (Figure 2), with an average north-south extent of ~60 km. The northern margin of the Witbank coalfield also marks the northern limit of the Permian Karoo Supergroup sediments represented locally by the basal coal-bearing Vryheid Formation of the Ecca Group. These circumstances explain the very shallow position of the coal seams along the northern margin of this coalfield, their depth increasing southward in congruence with a slight southerly dip. Up to five separate bituminous coal seams are present, of which all but the lower two are potentially acid generating (Pinetown *et al.*, 2007).

Mining in the Witbank coalfield, the most productive in South Africa (Figure 3), commenced in 1895 (Snyman, 1998). Despite the large number of producing mines, this coalfield has not yet reached its production peak (Prévost & Msibi, 2005). Almost 90% of the saleable coal production in 2005 was supplied by mines managed by the six largest mining groups, namely Anglo Coal, Ingwe Collieries Limited, Sasol, Eyesizwe, Kumba Resources and Xstrata (Prévost, 2006). Opencast mines provided 53% of the run of mine (ROM) production in 2005. The balance of the ROM production came from bord-and-pillar (37%), stoping (7%) and longwall (3%) mining techniques. The eight largest

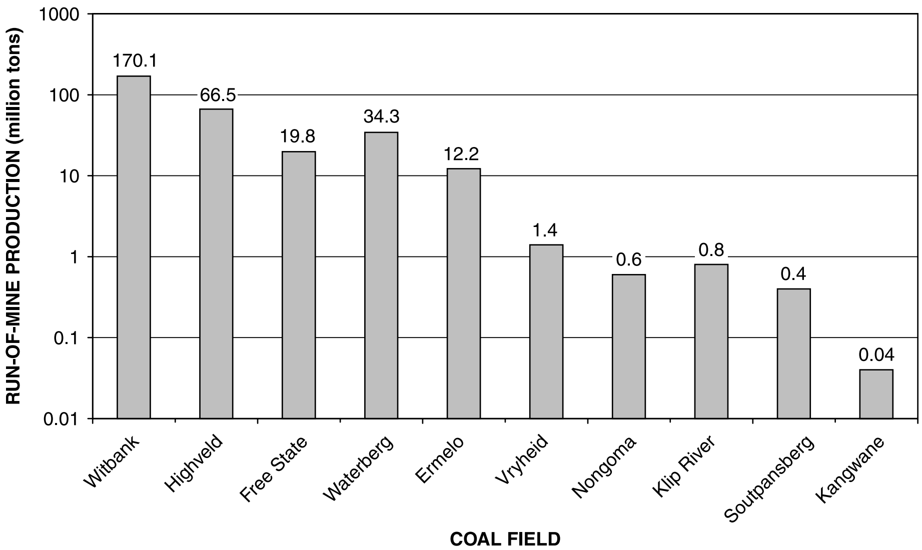

Figure 3. Coal field run-of-mine production in 2005 (modified after Prévost, 2006).

collieries, with an individual output of >12 million tons per annum (MT/a) produced 152 MT in 2005. A further 21 medium-sized mines (output >2 MT/a) produced 67 MT, and 38 small mines (output <2 MT/a) produced 27 MT (Prévost, 2006). The total saleable production of 246 MT represents a 2.5-fold increase over the 100 MT reported for 1995 (Snyman, 1998) in only 10 years. Opencast coal mining operations in the region were already underway in the early 1970s, and disturbance of the land is massive compared to the earlier underground workings (Cochrane, 2002).

Water Resources

The upper Olifants River catchment covers an area of $\sim 11\,464\,km^2$ in the headwaters of the Olifants Water Management Area (WMA). The mean annual precipitation is 683 mm, the mean annual runoff $\sim$10 780 million cubic metres, and the mean annual evaporation $\sim$1 580 mm (Midgley *et al.*, 1994). Land use is characterized mainly by coal mining, mineral processing and agricultural activities. Surface runoff is regulated by several large dams, notably the Bronkhorstspruit, Witbank and Middelburg dams (Figure 2) and, further downstream, the Loskop Dam (Basson *et al.*, 1997).

As mining and other industries in the region expand, water demand is growing rapidly. The Witbank/Middelburg area has experienced an increase in water demand of 3.5% per annum on average over the past six years (Günther *et al.*, 2006). The Emalahleni Local Municipality, the statutory local water service authority for Witbank, already exceeds its licensed abstraction of 90 ML/d from Witbank Dam by $\sim$11 ML/d (Günther *et al.*, 2006). The neighbouring Steve Tshwete Local Municipality serving the town of Middelburg faces similar challenges from its primary water source, the Middelburg Dam. Current and future platinum-group mining development on the eastern limb of the Bushveld Complex in the lower reaches of the Olifants River catchment places an additional burden on the water resources of the region. Shortfalls in water supply in the upper reaches for the many water-cooled power stations in the region are augmented from the Vaal and Komati rivers (Basson *et al.*, 1997). There is very little scope to further develop the surface water resources in the upper Olifants sub-area (DWAF, 2004). Further requirements for water will have to be met by transferred water (DWAF, 2004), or the treatment of AMD for re-use. These circumstances unlock the potential for the "... alternative institutional concepts for water services operation", referred to by Wall (2006, p. 266).

Impacts of Acid Mine Drainage

In the order of 50 ML/d of mine water discharges into the Olifants River catchment (Maree *et al.*, 2004). The Department of Water Affairs and Forestry (DWAF) estimates the post-closure decant from defunct coal mines at ~62 ML/d (DWAF, 2004). The management of these volumes is being addressed by the mining industry with a number of projects assessing treatment and irrigation management options (Hodgson & Krantz, 1998; DWAF, 2004; Annandale *et al.*, 2006; Vermeulen *et al.*, 2007). The water quality in the Loskop Dam has deteriorated over time, and groundwater quality is being threatened by mining activities (DWAF, 2004). The average sulphate load in Witbank Dam in 1993 was estimated at 33 T/d (WMB, 1993). A later study (Hodgson & Krantz, 1998) suggested a total average sulphate production of 70 T/d, and a possible future projected load of 120 T/d.

The various negative impacts associated with AMD-related pollution loads include environmental, socio-economic, political and financial risks (Adler & Rascher, 2007). Environmental risks include surface and groundwater pollution in the form of heavy metal uptake in the environment, the degradation of soil quality and the harming of aquatic fauna (Pulles *et al.*, 2005; Adler & Rascher, 2007; Oelofse *et al.*, 2007). AMD has been linked with several health related consequences. Groundwater contaminated with AMD might unwittingly be consumed by individuals, with treatment often ineffective by the time that the effects materialize (USEPA, 1994; Warhurst & Noronha, 2000; Oelofse *et al.*, 2007).

Mine closure and AMD also have severe socio-economic consequences for surrounding communities, since the mining industry plays an important role in providing employment and income to individuals (Warhurst & Norhona, 2000; Claassen, 2006). Following closure, these employment opportunities disappear, and communities struggle to survive (Oelofse *et al.*, 2007). In addition, AMD may cause population displacement, which has numerous different socio-economic consequences of its own (Warhurst & Noronha, 2000; Limpitlaw, 2004). These circumstances inform the need for a 'social and labour plan' (Dixon, 2005) as part of mine closure strategy in accordance with requirements of the Mineral and Petroleum Resources Development Act (Act 28 of 2002).

Acid mine drainage also has enormous direct and indirect financial implications for government and the mining industry, and can raise constitutional issues under certain circumstances. According to a recent Australian report, the total costs of AMD in Australia were expected to reach approximately $80 million annually with an estimated cost > $1 000 million over ~15 years. Similar expenses were also reported in Canada, the United States and others (Mudder & Harvey, 1998). The South African Department of Water Affairs and Forestry has spent more than R120 million over the last decade to investigate and clean up the historic pollution caused by abandoned or liquidated mines. This amount is only a fraction of the total amount that may ultimately be required (Schwab, 2002). Mining operations substantially alter the hydrological and topographical characteristics of mining areas and subsequently affect surface runoff, soil moisture, evapotranspiration and groundwater behaviour (DWAF, 2007). Further, the interconnectedness of underground mine workings associated with different mining companies increases the liabilities associated with AMD, especially for those companies last in operation, since "the cumulative impact resulting from all the mines in a region could be imposed upon the last mine in the region to cease operations" (Pulles *et al.*, 2005, p. 5.16). The removal of highly acidic water from active mine workings may also have large cost implications, as the replacement of infrastructure such as pumps and pipelines due to excessive corrosion is extremely expensive and could reduce mine productivity over time (Günther, 2007).[1]

A recent news article titled 'High stakes battle between mining and environment' reports that "Environmentalists and tour operators appear to be losing the battle against mining companies in Mpumalanga" (Lang, 2007a). Further, that "This confrontation—which also pits two ministries against each other—will determine the future of hundreds of lakes and rivers, and has implications for the economic sustainability of the province" (Lang, 2007a). Similarly, serious concern has recently been expressed (Lang, 2007b) about the impacts of mining on the future of the freshwater Lake Chrissie and its surrounding wetlands in the Ermelo coalfield (Figure 2). The concerns relate to the numerous licence applications by small and medium operators for opencast coal mining ventures in the region, and especially in regard to the rigour of their requisite environmental management programmes and the sufficiency of financial provisions for remediation.

Evolution of Water Governance and AMD Management

Understanding the evolution of water governance and AMD management in South Africa facilitates appreciation for the dilemma faced by the state in managing liabilities and successfully implementing new legislation. It also assists in understanding weaknesses within existing frameworks and recognizes the need for coherent legislation.

Legislation dating back to 1903 placed full responsibility for mining impacts on the owner of a mine until such time as a certificate releasing him/her from such responsibilities was obtained (Schwab, 2002). Many mines became defunct and ownerless, while environmental impacts continued. In 1975 negotiations between the Minister of Water Affairs and the Chamber of Mines on sharing responsibility for derelict and ownerless mines culminated in the Fanie Botha Accord. It was agreed the state would take full responsibility for all mines up to 1976. Mines closed from 1976 to 1986 would be 50% state responsibility and 50% owner responsibility. All mines worked after 1986 would be 100% the responsibility of the owners (Cochrane, 2002).

The Minerals Act (Act 50 of 1991) was the first South African law that forced mining operations to include sustainable land management in mine closure (Cochrane, 2002). The responsibility to manage the effect of mining on the environment was, according to this Act, vested in the owner of a mine and regulated through an environmental management programme (EMP). In addition, the owner of a mine remained responsible for the mine until a closure certificate was issued by the Department of Minerals and Energy (DME). Various guidelines, most notably the *Policy and Strategy for Management of Water Quality Regarding the Mining Industry in the RSA* (DWAF, 1995) and the *Aide-Mémoire for the Preparation of Environment Management Programme Report for Prospecting and Mining* (DME, 1992), were developed to assist mines in meeting their environmental responsibilities.

Following the change of government in 1994, a new Constitution (RSA, 1996) was adopted and South African law underwent major reform to align legislation with new Constitutional imperatives. Government became the custodian of South Africa's natural resources, the collective property of the people (Funke *et al.*, 2007). The National Water Act (NWA) (Act 36 of 1998) was promulgated and regulations (Regulation GN 704 of 1999) passed on the use of water for mining and related activities aimed at the protection of water resources. Three major pieces of legislation with some bearing on AMD resulted, namely:

- the National Water Act (NWA) (Act 36 of 1998);
- the National Environmental Management Act (NEMA) (Act 107 of 1998); and
- the Minerals and Petroleum Resources Development Act (MPRDA) (Act 28 of 2002).

The NWA, administered by the DWAF, is the principal Act governing water resource management in South Africa. The 'Polluter Pays Principle' supported by this Act has direct implication for the mining industry specifically relating to AMD. This principle requires that those responsible for producing, allowing or causing pollution should be held liable for the costs of clean up and legal enforcement (DWAF, 1998; Taviv *et al.*, 1999).

The NEMA is administered by the Department of Environmental Affairs and Tourism (DEAT), and addresses AMD and mining impacts through statutory requirements for Environmental Impact Assessments (EIA's) and Environmental Management Programmes (EMP's). The act further requires that pollution or degradation of the environment must be prevented or rectified. If the landowner or person responsible for the pollution fails to take the required action, DEAT may take such actions and recover the costs from the polluter (Section 28).

The MPRDA administered by DME regulates mining, including transformation of the minerals and mining industry, promotion of equitable access to the mineral resources of the country and environmental sustainability of the mining industry. Ownership of minerals rights was previously vested in the state or the private sector. The new objective of government is for all mineral rights to be vested in the state, with due regard to constitutional ownership rights and security of tenure (Mwape *et al.*, 2005). In this regard, the socio-economic Empowerment Charter, which calls for historically disadvantaged South Africans to control 15% of mines, was promulgated in 2004 (Mwape *et al.*, 2005). Rapid transformation of the coal mine industry resulted, with Black Economic Empowerment (BEE) coal mining companies expanding in number and contributing 16% of the country's coal production in 2005 (Prévost & Msibi, 2005).

Examples of AMD Management

Brugspruit Water Pollution Control Works

A number of defunct and flooded underground coal mines such as the Middelburg Colliery to the west and northwest of Witbank commenced decanting in the mid-1990s, contributing to pollution of the water resources in the upper Olifants River catchment. The location of these mines along the northern margin of the Witbank coalfield (Figure 2) very near the outcrop of the coal seams also explains their shallow (typically < 30 m deep) position in the landscape. In line with the Fanie Botha Accord, DWAF took responsibility for these mines and constructed the Brugspruit Water Pollution Control Works (BWPCW) in 1997 at a cost of R26.5 million (€2.62 million at the time of writing) (DWAF, 1997). The BWPCW (Figures 2 and 4) sought to protect the Loskop Dam from the impacts of AMD (DWAF, 1997). As such, its design function is to treat undesirable AMD to a quality acceptable for discharge to the aquatic environment.

The design capacity of the BWPCW is 10 ML/d. The plant is designed to receive two waste streams, one from the north with a 'high' total dissolved salts (TDS) load (> 3 000 mg/L), and another from the south with a 'low' TDS load (< 3 000 mg/L). An indication of the mean and worst AMD quality associated with the northern stream reported by Bell *et al.*, (2001) is provided in Figure 5. Soda ash is added to the final effluent stream to provide the water with additional buffer capacity (Janse van Rensburg, 2003).

In November 2007, the BWPCW had been inactive for a year due to various factors (Tshikukununu, personal communication, 2007).[2] These included, but were not limited to, a shortage of staff, theft of electrical cables providing power to the facility, and lack of maintenance. The plant infrastructure and machinery itself was in fair to good condition, and it would require relatively little effort and cost to return the plant to operation.

Controlled Discharge Scheme

Following a rise in the sulphate concentration of water in the Witbank Dam to ~ 300 mg/L circa 1996 (WCI, 2002), Anglo Coal and other coal producers, together with DWAF, investigated options to deal with this trend. The successful controlled releases in the

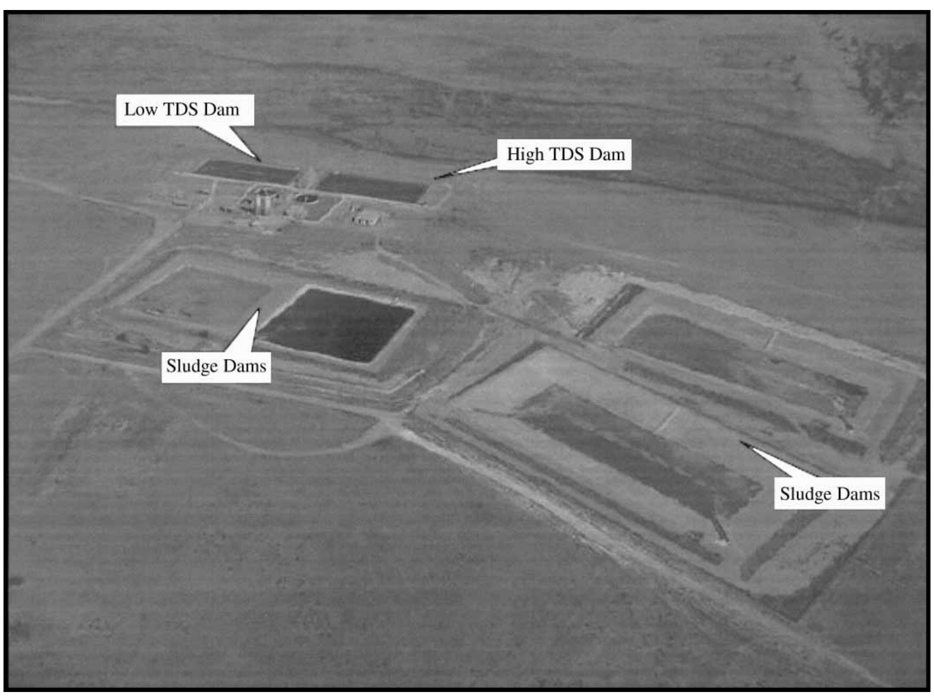

Figure 4. Aerial photograph of the Brugspruit Water Pollution Control Works (from Janse van Rensburg, 2003).

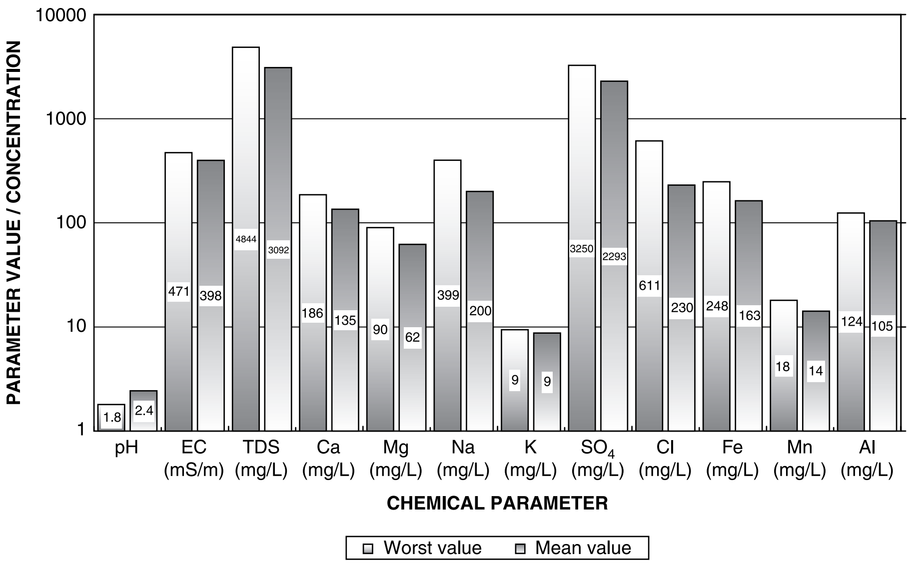

Figure 5. Comparison of BWPCW worst and mean AMD water quality (after Bell *et al.*, 2001).

Hunter Valley, New South Wales, Australia, based on the use of the available assimilative capacity of rivers during periods of high rainfall, was assessed (WCI, 2002). During periods of high rainfall, high runoff and water levels increase the dilution capacity in rivers. When such conditions occur, local industries are permitted to discharge polluted water to the rivers, but in a controlled manner. These discharges reduce the volumes of polluted water that need to be stored in mined-out areas. During low flow conditions, discharges to the rivers are prohibited.

The controlled discharge scheme (CDS), based on the Hunter Valley example, was introduced in the upper Olifants River catchment in 1997 with the support of industrial stakeholders. Industries in the region (including mines and power stations) made significant capital and operational investments towards this project. Anglo Coal alone invested in excess of R100 million (€9.88 million in December 2007) in drainage, storage and treatment systems to improve the quality and quantity of its discharges (WCI, 2002). Cooperation and coordination between the stakeholders also improved significantly.

The CDS realized the subdivision of the upper Olifants River catchment into management units, each with a distinct waste load allocation based on the available assimilative capacity determined for the unit. During the high flow release period, the waste load allocation and assimilative capacity for each unit is calculated on a daily basis. Participating industries are then allowed to discharge poor quality water to the host management unit in proportion to the assimilative capacity of the unit and each industrial partner's share in the scheme (Limpitlaw *et al.*, 2005). This follows a rule-based approach developed from an integrated hydrodynamic salinity simulation model that determines the timing and quantity of releases. The scheme participants must apply to the DWAF annually for controlled release licences (WCI, 2002).

The CDS has generally succeeded in meeting its original aim of reducing sulphate concentrations in the Witbank Dam to < 155 mg/L (WCI, 2002). Failure in this regard occurs mainly during extended dry periods. It has successfully controlled the short- to medium-term water quality problems in the catchment, and provided a number of benefits to the community and scheme participants. The flood risk in mine workings, the risk of uncontrolled discharge to the river and the retention time of water in the workings have been reduced. There is also an increased awareness of water management amongst mine operators in the catchment, and water quality in a short reach of the upper Olifants River has improved markedly (WCI, 2002).

Emalahleni Water Reclamation Plant

The Emalahleni Water Reclamation Plant (EWRP) southwest of Witbank (Figures 2 and 6) represents a state-of-the-art treatment plant able to treat 25 ML/d of acid mine water to a potable water standard (Günther *et al.*, 2006). Its realization, at a cost of almost R300 million (€29.69 million in December 2007), marks the culmination of a decade of planning, design, implementation and negotiation primarily driven by Anglo Coal in pursuit of sustainable mine water management. The negotiation aspects associated with the project navigated the often treacherous waters represented by a potentially obtrusive and explosive mix of innovative private enterprise, staid local government and authoritarian state intervention.

The mine water feed is a blend sourced from four mines in the surrounding area. Three of these, viz. Kleinkopje, Greenside and Landau collieries, are owned by Anglo Coal, while the fourth, the defunct South Witbank Colliery is owned by Ingwe Collieries Ltd. (Günther *et al.*,

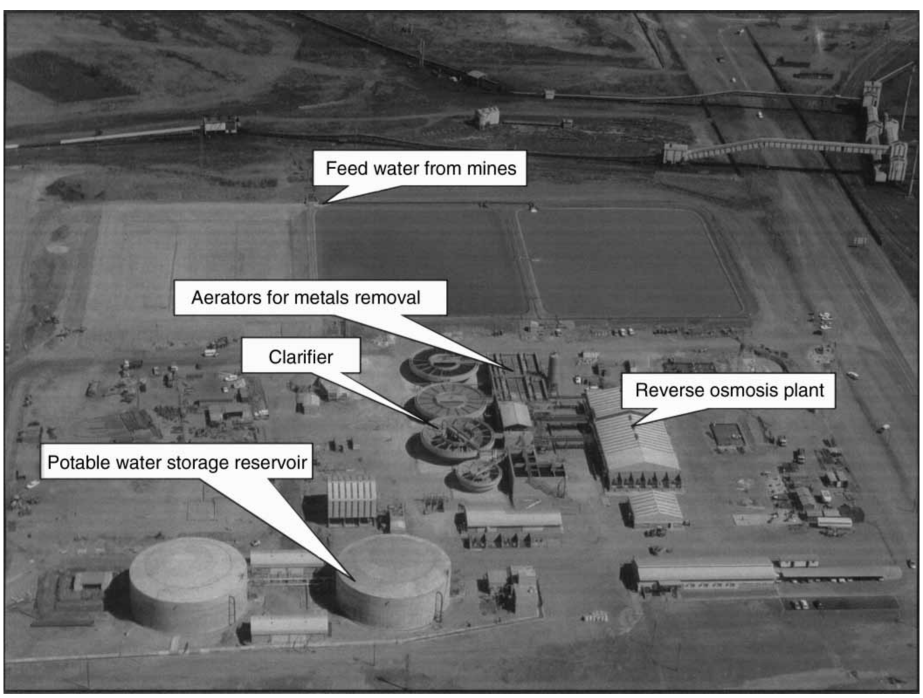

Figure 6. Aerial photograph of the Emalahleni Water Reclamation Plant (photo courtesy of Anglo Coal).

2006). While the Emalahleni Local Municipality (ELM) benefits directly from the treated mine water, the aquatic environment also benefits from being spared the impact of AMD.

The feed water quality sourced from the contributing mines is based on the 95 percentile concentration of the Landau Colliery mine water (Günther *et al.*, 2006). This is compared to the final treated water quality in Figure 7. The final cost to the ELM of the treated mine water delivered into the distribution reservoir is R3.90/kL (€0.39/kL in December 2007) (Naidu, personal communication, 2007).[3] This tariff is linked to the consumer price index. The EWRP is a more viable source of water to the ELM than the Vaal River Eastern Subsystem Augmentation Project (VRESAP) (Holtzhausen, 2006).

The success of the EWRP initiative has been achieved within a framework that needed to reconcile four pieces of legislation administered by three different government departments, and secure the participation of four different mines managed by two different mining houses as well as the crucial support of a local municipality (Günther *et al.*, 2006; Tshwete *et al.*, 2006). A public participation process was also factored into this equation, which aimed to create acceptance by the final consumers of the water, i.e. negating potentially negative perceptions and opinion regarding the origin of the EWRP water.

The EWRP example has precipitated a similar initiative in the West Rand Basin near Krugersdorp (Motaung *et al.*, 2008, this issue). Here, the Western Utilities Corporation (WUC) has been established to deal with AMD derived from defunct gold mines in a similar manner as that addressed for coal mine AMD in the upper Olifants River catchment.

Future Challenges to the State and Industry

Arguably, the most important change in DWAF policy towards mine water management, including mine closure, is the shift in emphasis from a holistic ‘one strategy for all’ approach, to a more diverse approach (Postma & Schwab, 2002). This is embodied in

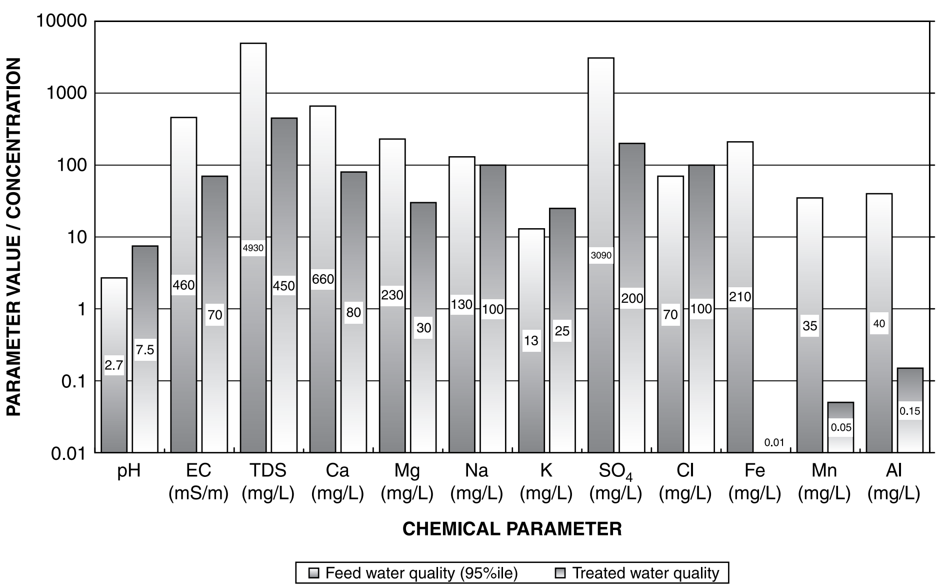

Figure 7. Comparison of EWRP feed water and final treated water quality (after Günther *et al.*, 2006).

DWAF's *Best Practice Guideline on Mine Closure*, a document intended for use as an adaptable, non-prescriptive planning tool for this industry, and facilitating a logical, step-wise and flexible approach to closure (Eksteen & Schwab, 2005). Instead of attempting to prescribe one set of guidelines applicable to all mining operations, the tendency has shifted to one set of objectives to be reached, with a varying level of guidance for different mining activities. The objective is to use guidelines as minimum requirement for a small mining activity, but also allowing the larger mining companies to use the same guidelines in applying self-regulation through the use of internal expertise to comply with the set objectives (Postma & Schwab, 2002). This change in management strategy allows mine closure planning between small and large mines to vary substantially, subject to compliance with the set objectives.

Another change in emphasis is embedded in the application of a risk-based approach towards long-term water management. This requires mines to quantify the potential current and long-term risks associated with mining activities, and then apply appropriate management actions to minimize or mitigate the potentially significant risks (Postma & Schwab, 2002; Eksteen & Schwab, 2005). This approach also informs the third change in mine closure water management strategy, the recognition of the end land use objectives (Postma & Schwab, 2002; Bosman & Kotze, 2005).

The consideration of inter-mine groundwater flow and pollution loads, and its influence on mine closure applications within the context of shared responsibility, represents the one remaining challenge (Postma & Schwab, 2002; Pulles *et al.*, 2005). Mine closure can only be considered positively if groundwater impacts due to a specific mining activity can be isolated and managed to acceptable standards (Vermeulen *et al.*, 2005). Where inter-mine flow exists, the responsibility for impact management with regard to such flow needs to be defined before closure can be considered favourably. In practice, however, adjacent mines do not reach or apply for closure simultaneously, do not allow groundwater to recover simultaneously and do not necessarily implement the same level of environmental management (Postma & Schwab, 2002). Numerous mines seeking closure receive groundwater flow from adjacent abandoned or liquidated mines, and are forced to carry the cost in determining responsibilities in terms of groundwater impact management. As a consequence, either closure applications do not sufficiently address the groundwater issues on a larger scale, or the industry becomes convinced that application for closure is a futile exercise.

Conclusion

Despite the progress made in shifting policy frameworks to address mine closure and mine water management in South Africa, and despite the efforts of the mining industry to change practices to conform to new regulations, areas for improvement remain. A holistic view should be taken of the life cycle of a mine insofar as integrated water management should address all phases from the feasibility or scoping phase through to closure and the post-closure long-term residual water resource impacts. The current perception that mine closure is unachievable needs to be addressed through technical as well as policy guidance. The implications of Section 19 of the NWA that a mine be held responsible for its impacts on water resources even after achieving certificated formal mine closure from DME, remains the basis for long-term water management employing a risk-based approach (Postma & Schwab, 2002).

The lack of action to successfully address AMD issues timeously, has the potential to de-legitimize government as well as endeavours to achieve sustainable development (Turton, 2006; Adler & Rascher, 2007). In this regard, the Brugspruit Water Pollution Control Works example reflects the scale of liabilities associated with defunct, ownerless and derelict mines inherited by the state, compounded by a 'go-it-alone' approach that limits capacity to effectively address the challenge. Conversely, the Emalahleni Water Reclamation Plant example illustrates the successful intervention by a well-resourced and dynamic mining industry in a model public-private partnership that fosters sustainable AMD management. Complementary to these interventions, the Controlled Discharge Scheme demonstrates a cost-effective and informed opportunistic measure based on an acceptable and calculated environmental risk managed and regulated by the state.

Acknowledgements

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Notes

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2. Tshikukununu, N. (2007) Personal communication. Assistant Plant Operator, site visit, Witbank, 1 November.
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