Acid Mine Drainage (AMD) in the Witwatersand basins of the Johannesburg area: towards an institutional framework that could enable private companies to treat this water

by

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Abstract (revised)

The city of Johannesburg and the towns to the west and east of it are underlain by a vast network of the tunnels of the gold mines on which their prosperity was built. As mining and dewatering operations have ceased, so these old workings have filled up with water. Over time reactions between the water and the minerals in the rock have led to the creation of a weak sulphuric, which in turn increases the absorption of heavy metals into the water. A number of distinguished scientists have warned of widespread damage and harm to human and environmental health as well as to property and infrastructure should the main body of water be allowed to rise unchecked to the surface. Firstly we provide a brief outline of the current situation and the latest efforts by national government to address the situation. Secondly we consider the failed experiment represented by the Western Utilities Corporation. We do this in an attempt to extract some *rules of the game* for developing an institutional framework that will enable private companies to participate in the treatment of AMD water, and by extension, the treatment of water in general. Finally we report on a search of the international literature for studies on (a) the cost effectiveness of alternative treatment technologies for AMD water, (b) estimates of the economic value of the environmental impacts of AMD and, finally studies that provide (c) details of actual or suggested polices for addressing AMD associated with mining districts in which there are many ownerless and abandoned mines. With sustained effort and ingenuity we "Joburgers" can convert our current legacy of toxic acidic water laced with heavy metals, into an enduring resource of quality water, which will ensure the survival of our city long into the future.

List of Acronyms

ABC	Alkali Barium Chloride technology
AIM	Alternative Investment Market of the London Stock Exchange
AMD	Acid Mine Drainage
DWA	Department of Water Affairs (was formerly the DWAF)
DWAF	Department of Water Affairs and Forestry (former name of the DWA)
ECL	Environmental Critical Level
IMC	Inter Ministerial Committee
CBEC	Central Basin Environmental Company
CSIR	Council for Scientific and Industrial Research
EBEC	Eastern Basin Environmental Corporation
ERPM	East Rand Proprietary Mines
FiT	Feed-in tariff
IPP	Independent Power Producer
MTEF	Medium Term Economic Forecast
PPC	Parliamentary Portfolio Committee on Water and Environmental Affairs
PPP	Public Private Partnership
TCTA	Trans Caledon Tunnel Authority
USSR	Union of the Soviet Socialist Republics
USTDA	United States Trade and Development Agency
WBEC	Eastern Basin Environmental Corporation
WBWC	Witwatersrand Basin Water Collective

1. Introduction

This paper addresses three areas relating to the topical issue of Acid Mine Drainage (AMD) in the Wits Basins near the city of Johannesburg.

(a) Firstly the paper provides a brief account of AMD in the Wits Basins, especially the latest efforts by national government to address the situation.

(b) Then the paper looks at the rather unhappy experience of the first large Public Private Partnership (PPP), the Western Utilities Corporate. It tries to extract some *rules of the game* for developing an institutional framework that will enable private companies to participate in the treatment of AMD water, and by extension, the treatment of water in general.

(c) Finally the paper reports on a search of the international literature for studies on (a) the cost effectiveness of alternative AMD treatment technologies (2) estimates of the economic value of the environmental impacts of AMD and, and finally studies that provide (c) details actual or suggested polices for addressing AMD associated with mining districts in which there are many ownerless and abandoned mines.

Our original intention was to set up a cost effectiveness study of the various technologies that are being developed to treat AMD, particularly those technologies that promise to extract most of the heavy metals. The report to the Inter-Ministerial Committee (IMC) on Acid Mine Drainage (Dec 2010, p76) lists 11 different active chemical and biological treatment systems and technologies that are under development in South Africa alone. One of these technologies has now incorporated into a full scale water treatment plant in eMalahleni (Witbank).

Estimates of the running costs and the potential income that could be generated from the sale of the purified water and the metals extracted are listed in a table on page 76 of the IMC report. The cost data appears to be largely sourced from unpublished research by Prof. J. P. Maree of the Tswane University of Technology. Prof Maree has been involved with the development of two of these technologies and was one of the academic advisers to the IMC. Thus far we have not been able to find documentation of the methodology that Prof. Maree used to estimate costs. Furthermore, and this appears to be a common feature of all the research in this area of AMD treatment, there seem to be no estimates of the likely capital costs of these plants. Thus for the moment we have had to put aside research on the cost effectiveness of the different treatment technologies.

The issue of Acid Mine Drainage is an ongoing issue in most countries with any history of mining. However a combination of the size of the mining void, both in terms of depth and lateral extent, the degree of interconnection between adjacent mining properties and the fact that the AMD water is rising up under the most populous and most economically significant city in the country, makes the AMD issues associated with the Wits Basins near Johannesburg unusual, and some say, unique. To put it in perspective, if New York city had been build in the Appalachian mountains, and if the numerous coal mines in the these mountains had been mined to much greater depths, only then the current day AMD legacy in the coal mining districts of the Appalachian Mountains would be of a comparable magnitude to the AMD legacy of the Wits Basins.

1. What is Acid Mine Drainage? Why has it now become such an issue?

The concepts of Acid Mine Drainage is succinctly explained with reference to South African examples on page 85 of the Report to the Inter-Ministerial Committee on Acid Mine Drainage (Dec 2010).

> Acid mine drainage is formed by a series of chemical reactions that occur between water, sulphide minerals, such as pyrite, and oxygen, which combine to form an iron rich sulphuric acid solution. This will occur in any area where sulphide minerals are exposed to air and water in the environment, but is most prevalent in areas where mining has exposed fresh sulphide minerals to the elements. AMD is known to occur in a number of areas in South Africa, most notably the Witwatersrand Gold Fields, in the country's various Coal Fields and the O'Kiep Copper District. -

The gold reef in most of the major, now mainly historical mining districts in the Johannesburg area is overlain by an extensive dolomitic aquifer. Thus right from the early days of the industry, mining companies had to develop elaborate and extensive dewatering infrastructure to cope with the large inflows of water from the aquifer above their workings. As long as a single mine continues to operate its dewatering pumps, the general level of water in large parts of the mining basin is kept at bay. However, when this mine switches off its dewatering pumps, the water in the aquifer above the mine workings pours down into the mine workings below. The water begins to fill up the mining voids of the various interconnected mines of that particular mining basin and over time large quantities of AMD are created.

In Western Wits Basin situated in the Mogale City (Krugersdorp) area, west of Johannesburg, the last dewatering pumps were switched off in 1998. Four years later in 2002 AMD began decanting (discharging) at surface. In the Central Basin, to the South and South East of Johannesburg, the last dewatering pumps at the ERPM Mine were switched off in 2008, and the first decant of AMD is now expected around the middle of 2012. In the Eastern Wits Basin after many months of high drama, the dewatering pumps in the Grootvlei mine were switched off in 2011.

Contrast the manner in which Acid Mine Drainage is created with the pollution that is created by a classical factory in environmental economics. As a factory operates, so it emits and discharges various pollutants into the atmosphere and the local river system. Once the factory is shut down, it ceases to generate pollution. For simplicity sake we ignore the situation where a factory might stockpile hazardous wastes for storage or later disposal. However, in the case of Acid Mine Drainage created in a mine, the opposite is true. While mining operations continue and the mine runs its dewatering pumps and only a relatively small amount of AMD is created. However, once the mine ceases operations and switches off its dewatering pumps, then nature takes over, and the mine begins to flood and as the years go by more and more AMD is created. An operating factory where the smoke plume from its chimney is visible, presents an easier target for regulatory action that the long abandoned workings of an underground mine from which AMD is discharging.

As the saga of AMD in the Wits Basins unfolds it has revealed a peculiar *free rider story* where the "*last man standing*", the last mine in operating, in a mining district will face strong pressure from the public and environmental authorities to continue it dewatering operations for as long as possible. Furthermore, once the owner stops mining, he is likely to face pressure to provide a disproportionate share of the costs associated with treating the AMD. The *last man standing* is usually old and rather frail, financially speaking, and at best, is capable of only a modest contribution toward the remediation costs. The iniquity of the situation is that society now demands from this *last man* what it should have had the wisdom to extract from all the other mines while they were still in operation.

2. The risk and threats of Acid Mine Drainage in the Wits Basins

The Inter-Ministerial Committee (IMC) lists the threats posed by AMD at two distinct stages. Firstly once AMD rises above a certain threshold level below the surface, referred to as the Environmental Critical Level (ECL) and then secondly when the AMD decants or discharges at the surface.

2.1 Threat associated with AMD rising above the Environmental Critical Level

In the Western, Central and Eastern basins the ECL has been defined at around 160 metres below surface. Some mention of maintaining the water level at greater depths below surface are mentioned where a local mine intends to continue its operations into the future.

- **a.** Rising AMD is likely to contaminate shallow groundwater resources. Thus domestic and particularly agricultural users who access groundwater via boreholes will face the threat that their water supplies becoming contaminated and unusable.
- **b.** Once AMD crosses the ECL threshold, it poses the threat of land instability, specifically the creation of sinkholes. Imagine for a moment, the economic impact on Gauteng should a section of the M1 motorway, or some key railway lines, disappear down a large sinkhole! In contrast to the notorious sinkholes of the Carltonville mining district, which were created when the mines pumped water out of the dolomitic aquifers, modern post-mining sinkholes would be created by the mines doing the exact opposite, namely stopping their pumps. The rise in the water table would bring with it AMD which would then eat away at the dolomitic aquifers.
- **c.** As it continues to rise AMD could in a similar manner weaken the foundations and integrity of building and other infrastructure. Public concern and anger about predictions of AMD rising up into the basins of the office buildings in the Johannesburg central business district seems to be one of the catalysts that helped to break the logjam at national government level.
- **d.** As the rising AMD water gains access to geological faults it acts somewhat like a lubricant and allows easier movement in rock strata on opposite side of these faults. The IMC report provides evidence that since pumping was stopped at the ERPM mine, the incidence of significant local seismic events has doubled from around 5 to 11 events per month.

2.2.The threats posed by decant of AMD at the surface

- **a.** A general threat to water security. This is similar to the first point mentioned under the heading of a rise above the ECL. However in this case the contaminated water flows directly into the surface river system. The contamination of the water in the Tweelopies Spruit in the Western Wits Basin is a graphic example of this.
- **b.** Contamination of water based eco systems. In the Western Basin a number of areas in the local river basin ecosystem have been virtually obliterated.
- **c.** Compromising of natural resources and heritage sites. The AMD discharging on the Western Basin has a major impact on the nearby Krugersdorp Game Reserve and the international heritage site at the Cradle of Humankind. There have been reports that the owner of at least one large and prosperous local trout farm shut his farm, and relocated it to Mpumalanga. Regular mention has been made of the need to protect the underground mine at gold reef City which is a major tourist attraction.

3. The evolution of policy response to AMD

3.1 The polluter pays principle … or find the polluters and make them pay!

The then Department of Water Affairs and Forestry (DWAF) spent many fruitless years trying to track down and hold accountable, companies that had operated or were still operating mines in the area of the Western Basin.

One of the most intractable obstacles was the march of time itself. Gold mining has taken place in this basin for the better part of 100 years. Thus many of the mines in the area had been closed for many years and the companies that had operated them had long ceased to exist. In other words most of the mining void was constituted by long abandoned and ownerless mines. Therefore in most cases no owners could be found and held accountable.

Next there was the rather slippery issue of assigning water volumes and water flows to specific mining properties. The dolomitic aquifers of the Western Basin are fractured and complex and most of the mines are connected to each other. Furthermore the necessary infrastructure to accurately monitor the flow of groundwater was, and still is, largely absent (Cobbing 2008, 456). The absence of a detailed and reliable understanding of the flow of water into and between mines rendered the DWAF's task of assigning responsibility and apportioning the costs of cleaning up AMD, utterly impossible

Finally most of the mining companies that were still in operation were small independent companies which specialized in operating end-of-life mines. Had the DWAF been able to impose a significant portion of the remediation costs upon these companies they would have been driven into bankruptcy. Furthermore these companies were focused on treating surface dumps, and at least one company had never operated underground mines in the Western Basin.

The DWAF remained under considerable pressure, specifically from national government, which was extremely reluctant to take responsibility for financing and managing a solution to the AMD problem. So despite the collectively insuperable obstacles mentioned above, the DWAF soldiered on and did its best to enforce the polluter pays principle. It issued a number of directives instructing various companies to clean up the AMD. In due course these directives either expired or were challenged by the mining companies in the Water Tribunal or in higher courts.

Despite the shaky grounds on which the directives issued by the DWAF rested, Rand Uranium, the unfortunate company on whose property is located the site of the major decant, continued to do the *honourable thing*. Over a number of years it spent a considerable amount of effort and money to treat the AMD water decanting from its property. The chief executive officer of the company went on to become one of the architects of a joint response by the companies still in operation in the three Wits Basins. We continue the story in the next section.

3.2. The short and turbulent life of the first potential Public Private Partnership to treat AMD

Under continued pressure from the DWAF the mining companies of the three Wits Basins jointly set up three section 21 companies, The Western Basin Environmental Corporation (WBEC), the Central Basin Environmental Corporation (CBEC) and the Eastern Basin Environmental Corporation (EBEC) to address the AMD issue in each basin. These three environmental corporations operated jointly through the rather quaintly named Witwatersrand Basin Water Collective (WBWC) which then "mandated" the Western Utilities Corporation to develop a long term solution to their AMD problems. The Western Utilities Corporation was constituted as a Water Utilities Company in terms of a letter of recognition issued by the then Department of Water Affairs and Forestry (Western Utilities Corporation, 2011).

A. Regarding the establishment of a WUC [Water Utilities Company], The Department of Water Affairs and Forestry (DWAF), having also identified the need to address mine water management, has established a task team to made (sic) certain recommendations to facilitate the management of mine water, especially after mine closure. The recommendations are as follows:

1. A mine or group of mines or companies with mining related liabilities can establish a ring-fenced section 21 company to manage water on its or their behalf, which management could include collection, removal, pumping and discharge and/or provision to -

    I. an existing Water Services Provider (WSP) as defined in the Water Services Act, 1997 …, which must have the right of first refusal, and in accordance with a contract with the WSP, for treatment and/or discharge and/or provision to municipal users at the same standard of supply; or

    II. A Water Services Authority …

The Western Utilities Corporation was itself a wholly owned subsidiary of Watermark Global a company listed on the AIM in London. Initially shareholders were the various mining companies that were members of the three Environmental Companies above. Jaco Schoeman, the CEO of the Western Utilities Corporation, mentioned that there were plans to sell are large proportion of the corporation's equity to Black Economic Empowerment (BEE) companies.

The Western Utilities company had managed to line up some influential backers, securing R10 million from Development Back of Southern Africa and a further R5 million from the Industrial Development Corporation. It raised sufficient finance to invest about R75 million in the purchase and development of the ABS (Alkali, Barium Calcium) process which was invented by the CSIR.

The Western Utilities Corporation put forward an ambitious proposal to pump AMD water from all three basins to a single treatment plant located in the Central Basin near Boksburg. It would treat this AMD water up to drinking water quality and then sell it to Rand Water. Since the ABC technology had one of the lowest operating costs of the numerous competing technologies developed in South Africa to treat AMD, and, providing that it was able to sell a large proportion of the water it treated as potable drinking quality water, then its proposal would provide "a zero cost to taxpayer solution". Its proposal would solve the AMD issue for the mines and their surround communities, at no cost to the treasury and taxpayer. Furthermore its solution would provide clean water to the water grid of a conurbation that would soon face water supply constraints.

From a reading of the presentations made to the Parliamentary Portfolio Committee in June 2011 by Jaco Schoeman for the Western Utilities Corporation (Western Utilities Corporation, 2011) and by Munro for the three Environmental Corporations (CBEC etc, 2011) , it seems that the Western Utilities Corporation had made repeated visits and presentations to senior officials in the DWA. Furthermore various authorization and permitting processes had proceeded a considerable way towards final approval. However, it appears that during the deliberations of the Inter-Ministerial Committee the weight of opinion shifted decisively against the Western Utilities Corporation's proposal and that it was informed in a rather offhand way that its proposal would not be approved. The necessary approvals and licensing, as well as the offtake agreement for selling the treated water, were therefore not consummated.

A reading of the press and media articles reveals a laundry list of issues and objections, any combination of which could have been decisive in the DWA's decision to refuse approval. We now list the issues that we have found mentioned in the press. The list is not presented in any particular order of significance.

1. The plant would take two and a half years to come on stream, by which time AMD would have been decanting at surface in the Central Basin for over a year.
2. The proposal would create a powerful private monopoly,
3. The proposal would mean entrusting the entire solution to the AMD problem in all three basins to one company which would use a single technology.
4. In order to make the project economics work, the Western Utilities Corporation's proposal would generate and have to store, a large volume of sludge containing sulphates and various heavy metals. The proposal envisages constructing a second plant to treat the sludge, but this plant would only start treatment 8 years later.
5. A general public distaste regarding the prospect of a private company making a profit from treating water, or more generally the prospect of such companies profiting from "sin"!
6. A concern about the longevity of the mining companies that were currently the core shareholders of the Western Utilities Corporation.
7. There were changes in senior staff at the DWA shortly before the veto decision was made.
8. The presence of the foreign finance in a local water project, and
9. A general feeling of discomfort and suspicion about the possibility of lots of wheeling and dealing going on behind the scenes.

Despite offering a "zero cost to taxpayer" solution, something that the national government had long insisted upon, the proposal put forward by the Western Utilities Corporation fell into disfavor and was vetoed. In this paper we do not attempt to assess the merits of the issues and objections listed above, nor for that matter, their relevant counter arguments. Instead we will, in section 4 on page 12, try to extract and suggest some key criteria, some "rules of the game" that could guide the creation of future public private partnerships, under which private companies would be able to construct and operate plants to treat and clean AMD.

3.3 After interminable dithering by national government … the Department of Water Affairs finally rides to the rescue!

In September 2010 an Inter-Ministerial Committee (IMC) advised by a team of experts from various key government departments and technical bodies was rapidly assembled. In December 2010 the IMC issued a report entitled "Mine Water in the Witwatersrand Gold Fields with special emphasis on acid mine drainage". Since then this report has rapidly become the primary departure point for debate of the AMD issue.

3.3.1 National government has backed the IMCs short term (emergency) proposals and the recommended projects will be managed by the TCTA

One of the main tasks facing the IMC was to come up with practical proposals to address the crisis situation. Of necessity the proposals had to rely on current proven technologies. More innovative technologies and approaches could only be considered as part of a longer term solution. There are three key elements to the IMCs short-term proposals.

1. Prevent AMD decanting (discharge) at surface by pumping this water out of the mining void.
2. Treat the water and then release it into the river systems
   - In the short term neutralize the acidity and remove some metal salts.
   - In the medium to longer term consider various options to further remove salt loads
3. Reduce the "ingress" (inflow) of water from surface down into the mining voids by sealing off various known points of entry. This will reduce the rate of flooding and therefore the future rate of discharge, which will in turn reduce future pumping volumes and costs.

Following the recommendations made by the IMC, the Department of Water Affairs appointed the Trans Caledon Tunnel Authority (TCTA) to manage the pumping and treatment projects. The TCTA is an "inhouse" project management company which the DWA uses to manage various bulk water schemes. The TCTA has in turn subcontracted to consulting engineering companies in the private sector. The TCTA will work through various government channels to get rapid authorizations and in some cases exemptions to allow the project to be completed in half the time that such a project would usually take. By all accounts the project milestones are demanding and the deadlines tight. The key project elements are detailed below.

<u>In the Western Basin</u>

1. The preferred option is to increase the pumping and water treatment capacity on the Rand Uranium's property by 12 megalitres/day, from 16 megalitres/day to 28 megalitres/day.
2. The alternative is to increase capacity at the Mogale Gold property by 12 megalitres/day, from 8 megalitres/day to 24 megalitres/day.
3. Consideration was also given to increasing capacity at both plants by 12 megalitres/day.

<u>In the Central Basin</u>

1. Central Rand Gold had commissioned and purchased two large submersible pumps. The TCTA appears to be considering sharing the cost of operating these pumps and perhaps even taking over operational management of the pumps, in the event that Central Rand Gold ceases mining.
2. Most of the funding will be spent on the construction of a new plant. We assume that the pumping and treatment facility will be constructed at or close to the water treatment plant at ERPM's South West Vertical shaft.

3.3.2 The National Treasury's current and recommended funding of AMD related projects

3.3.2.1 Funding currently committed by the National Treasury

In a presentation given by M. P. Matji, the director of public finance at the National Treasury (National Treasury 2011), to the PPC, it is mentioned that R225 million has been allocated to the Dept. of Water Affairs over fiscal years 2011/12 to 2012/13 to address the AMD issue. Table 2 shows that most of the funding associated with the remediation of AMD, will still be channeled through the Department of Minerals Affairs. Note however that the R128 million allocated over 3 years for the rehabilitation of mines is not specifically for AMD issues, but is provided to address all manner of rehabilitation activities.

Table 1: National Treasury Allocations to AMD related projects in 2011 MTEF

			Fiscal Years			2011
#	**Item**	**Company**	**2010/11**	**2011/12**	**2012/13**	**MTEF**
1	**Dept Mineral Resources**					
a	Rehabilitation of Mines	DMR main budget	31.8	35.7	60.8	**128.3**
b	Rehabilitation of Mines	Mintek	0.0	30.0	30.0	**60.0**
c	Acid mine water (AMD) treatment technology	Mintek	0.0	10.0	20.0	**30.0**
d	Assistance to Private mines - pumping subsidies	Mines / private companies	18.0	18.0	18.0	**54.0**
e	Witwatersrand ingress project	Council for Geo Science	17.0	18.0	21.0	**56.0**
	Total Dept Mineral Resources		**66.8**	**111.7**	**149.8**	**328.3**
2	**Dept of Water Affairs**					
a	Total allocation		?	**75.0**	**150.0**	**225.0**
	Total Allocation Associated with AMD		66.8	186.7	299.8	**553.3**

Source: Presentation by M. P. Matji, director Public Finance, Nat Treasury 21-22June 2011

MTEF = Medium Term Economic Forecast

3.3.2.2 An AMD Levy, to ensure that current operating mines contribute towards costs.

From comments in the press, it seems that the backers of the AMD levy are thinking of it in terms of a classic emissions tax. That the owner of a mine would be taxed on the volume of AMD that the particular mine is responsible for discharging. However as mentioned on page 6 the DWAF was unable to enforce the polluter pays rule, precisely because it could not estimate the volume of AMD generated by particular mines. One of the chief reasons being that since the tunnel networks of different mines are interconnected, water readily flows from one mine into the next mine. Thus the AMD levy could turn out to be something of a cosmetic tax to assuage public anger.

3.3.2.3 A general environmental and water pollution fund

The national treasury has recommended that the Compliance Monitoring and Enforcement unit of the DWAF should be beefed up. With better enforcement the DWA would be able to generate more revenue from penalties and fines already currently in place.

3.3.2.4 A South African Version of the USA's "Superfund".

The USA introduced its "superfund" to remediate "ownerless" toxic waste sites. We have not yet been able to find reference to how many Superfund sites are located in the Appalachian coal fields, nor the amount of money spent on these sites. However since there has been coal mining activity in Appalachian Mountains, for a long time the, it is quite probable that there are many Superfund sites located there. The South African National Treasury has entered into discussions with the US Trade and Development Agency (USTDA) to finance a study tour on acid mine drainage. It is also facilitating discussion between the S.A. Dept of Water Affairs and the UCTDA. As we understand it the Chamber of Mines is also involved in a similar and perhaps related enterprise.

3.3.2.5 Public Private Partnerships (PPPs) to process and sell treated water

Despite the sorrow fate of the Western Utilities Corporation, the option of PPPs, where private companies could construct and operate plants to purify AMD water, still appears to be very much on the agenda. Given the tight deadline of the short term projects being overseen by the TCTA, such PPPs would be part of the longer term solutions. However we suggest that that considerable thought needs to go into thinking about the institutional arrangements and "rules of the game" regarding the participation of private companies in the water treatment industry.

4. **In search of some *rules of the game* to allow private companies to Treat Water**.

First the proposal put forward by the Western Utilities Corporation's would create a private monopoly for the treatment of AMD. The rules of the game would have to provide credible protection against a monopoly abusing its dominant position or place an outright exclusion on the creation of a monopoly.

Secondly there is the closely related point that the proposal would entail entrusting the entire solution to the AMD problem in all three basins to one company that would use a single technology. Doing so would entail taking on both unacceptably high economic and technical risks. Implicit in this line of objection, is the argument that any viable solution must ensure some degree of diversification of both technology and suppliers. On various occasions water scientists have stressed that because of considerable variation in the quality of AMD geographically across the basins but also over time into the future, no single technology should be relied on to treat all the AMD water. In other words a deliberate policy of ensuring a diversity of technology and suppliers must be a part of the solution.

The third point that we wish to deal with is the issue as the proposal by Western Utilities Corporation envisages, that most of the AMD's water would immediately be treated to drinking quality standard. This was essential to generate sufficient revenue to make the project economically viable.
In his submission to the PPC Jaco Schoeman, CEO of the Corporation stated that its project could account for as much as 22% of Rand Water's distribution (PPC, 28 June 2011). Treating AMD water up to drinking quality and then selling it to a water authority probably remains the *Holy Grail* for many of the competing proposals and technologies. However, Turton has on numerous occasions stated his trenchant opposition to this option, suggesting instead that such water should be used for industrial purposes. Other water scientists seem to be willing to consider a gradual or phased evolution, during which time the various competing technologies would have the opportunity to prove themselves.

We suspect that the luxury of being able to turn up one's nose at the prospect of consuming previously contaminated water will not be available much longer in Gauteng. There seems to be a consensus among water engineers that the Greater Johannesburg will within the next few years run up against some significant water supply constraints. For example the year 2014 is mentioned as a deadline for when Rand Water will be unable spare the high quality water which it sources from the Vaal Barrage and uses to dilute AMD water. There is also serious consideration being given to fast tracking the construction of the water pipeline from Clarens in the Free State to Johannesburg.

Despite the unhappy experience of the Western Utilities Corporation there still appears to be a widespread interest in the possibility of public private partnerships, which as mentioned before, we interpret to mean allowing for the possibility of private companies to construct and operate water treatment facilities.

If indeed we urgently need find new and innovative ways to treat AMD water, and if we accept that in the main private companies tend to be considerably better than public organizations at developing and scaling up new technologies, then we arrive at the unpopular position of needing help from private companies. Private companies inevitably mean profits, and the public expresses strong feelings against profits in the water industry. The public belief that it would immoral for private companies to make profits from the treatment and/or supply of water seems to be closely linked to the fear of *opportunistic holdup,* the fear of being held to ransom by a private monopoly. Therefore *the rules of game* should provide credible protection against the eventuality.

So let us now without further ado get the ball rolling and suggest some rules of the game for consideration in situations were private companies own and operate treatment plants that then sell the water they treat to local water authorities.

a. Tight regulation, monitoring and control of the quality of water that is supplied by these plants.
b. The ownership and management of the water grid – dams, pipelines and reservoirs - and thus control of the distribution of water, should remain in the hands of the public sector.
c. A policy that can actively encourage a number of different technologies and companies to enter into the new industry that will treat AMD and other low quality sources of water. This would also serve the related requirement to guard against the water treatment industry becoming dominated by a private company.
d. A limit or ceiling to the amount of profit that a private company can make from the sale of treated water, especially when this water is sold as drinking water.
e. Clauses that might limit or shorten the time horizon of the patents associated with the water treatment technologies, or in some what introduce a quid pro quo as recognition that the public sector is backing the particular technology.

As regards criteria (a) and (b) we do not have anything new or specific to suggest. However we believe say that our key recommendation would not weaken the provision of these requirements. As regards criterion (d) we believe that there are at least two policies that can meet this criterion: These are (1) a tax on "super profits" and (2) using the "business model" of a regulated utility where annual price increases have to be publicly motivated to and approved by an industry regulator.

4.1 Could a Feed–in tariff be transplanted to the water treatment industry?

Feed-in tariffs (FITs), have become the dominant policy used to encourage Independent Power Producers (IPPs) to supply renewal energy to the national electricity grid in many countries. Could a version of feed-in tariff be used to encourage "Independent Water Treaters" to treat contaminated water and supply it the water grid of the Johannesburg area? Consider the basic features of the feed-in tariffs used the electricity supply industry across the world.

a. The fundamental aim of feed-in tariffs is to provide a price high enough to encourage investment in specific renewal energy technologies. In a nutshell, if you want the services of a particular technology then you should pay the developers or more specifically the commercializers of the technology "their price".

b. The tariffs are technology specific and cost-based. Thus for example the tariff offered to companies that generate electricity from Concentrated Solar Power (CSP) are considerably higher than the tariff offered to companies that generate electricity from wind turbines. A significant, but often unstated requirement is that there is sufficient information available to the national energy regulator so that it can produce a reasonably accurate estimate of an international benchmark for the costs of particular technologies.

c. Feed-in tariffs are usually considerably higher than the tariff paid for electricity generated from conventional fossil fuel sources. However the supporters of feed-in-tariffs point out that the large external cost associated with the pollution created by burning fossil fuels, are not included in the cost or price of energy from fossil fuel sources. In other words the price of electricity from fossil fuel is actually artificially low.

d. Local and national grid utilities enter into long-term (10 to 25 year) contracts with Independent Power Producers to purchase the electricity generated by these companies. These long-term contracts provide "certainty", or more realistically, a sufficient degree of comfort or reassurance about the future prices that they, the Independent Power Producers, will receive. With the reassurance that they will be able to cover the capital costs of their investments, Independent Power Producers can approach the banking system and take on significant amounts of debt.

Here is a brief parallel with the water treatment industry. The operating costs of treatment technologies based on Ion Exchange and Reverse Osmosis are considerably more expensive than the technologies based on the use of chemical reagents. If we believe that we need some treatment plants based on ion exchange and/or reverse osmosis, then we have to set the feed-in tariff for these technologies at a sufficiently high level and offer long-term contracts of a sufficient maturity to provide the necessary degree of reassurance to the companies that could provide these technologies.

One apparent difference between Independent Water Treaters and Independent Power Producers is that in addition to purified water, they would sell commercially significant by-product commodities such as sulphuric acid and various heavy metals. The revenues from these commodities would therefore fluctuate depending on conditions in the markets for these commodities.

A feed-in Tariff approach would not be synonymous with a policy of zero cost to the national tax payer, at least not in the short to medium term. It definitely implies a cost to the regional tax payer or rate payer, but in the long it could actually let the national treasury and tax payer off the hook.

5. A search of the international literature on various environmental economics issues related to AMD has thus far yielded little.

A search of the literature on AMD reveals that all the major English speaking mining countries, the USA, Australia and Canada are grappling with their own legacies of Acid Mine Drainage. There are numerous studies in the natural sciences and engineering disciplines on the phenomenon of Acid Mine Drainage, in these countries as well as a wide variety of possible technical solutions. The literature also reveals that even countries which we would not consider to be "mining countries", countries such as Portugal (Martens *et al*, 2010), Cyprus (Gokcekus *et al*, 2003) and Slovakia (Lintnerova, Sottnik and Soltes, 2008) are also confronting AMD issues.

In our search we looked for (a) studies which could provide details of methods and estimates of economic and environmental impacts of AMD, (b) cost effectiveness studies of alternative AMD treatment technologies and approaches (c) studies that provide details of current and suggested polices for addressing AMD associated with ownerless and abandoned mines. Thus far our search has yielded disappointing results. For example much of the policy literature is concerned with the provision of future rehabilitation in the case of single "stand-alone' open pit mines, which are currently in operation or are in the planning phase. For an excellent and up-to-date account of these issues see Kempton, Bloomfield, *et al* (2010). Also good is McCullough (2008).

We have yet to uncover a useful study on policy regarding old abandoned and ownerless mines in mining districts with interconnected underground mines. By default one tends to gain the impression, or should we say prejudice, that the AMD issue in the Wits Basins is larger by an order of magnitude and complexity than are most of the cases mentioned in the literature from these English speaking mining countries.

As regards our search for studies of costs effectiveness analyses, our point (b), we gained the impression that some of the literature on general water treatment might be prospective. For example the dry desert countries of North Africa are considering all manner of ingenious proposals to manage their groundwater resources (Maliva *et al.* 2011 and Abdel-Dayem, 2011).

One of our hunches was that the AMD legacy in the coal mining districts in the Appalachian Mountains on the Eastern Seaboard of the USA must surely be comparable in geographical extent, to that in the Wits Basins, and therefore there might be some useful studies of this mining district. Indeed the Appalachian coal mining district is thus far the only mining district for which we found studies of the economic estimates of the impacts of AMD on the environment. Two studies by Williamson, Thurston, and Heberling (2007, 2008) are thus far our only real "finds". The first study uses a benefit transfer method and the second a hedonic house price approach to estimate some of the economic impacts of AMD in the Cheat River Basin in Western Virginia.

We are surprised by the apparent absence of environmental economic studies of AMD in the large Sudbury basin in Canada, where one might expect there to be copious flows of AMD. We intend to follow up with enquiries regarding the Sudbury Basin with various contacts in the mining and engineering industries. Similarly, there must surely be veritable lakes, if not inland seas of AMD, flowing around the large mining districts of Russia and the ex USSR.

Australia has gone through a rapid and significant evolution of laws, regulations and institutions pertaining to water. In a relatively short period Australia has developed water markets that now rival and perhaps even surpass those of the older established water markets of Colorado in the United States. Barrett, Moran and Cote (2010) suggest that markets for worked water could be developed, where relatively wet mines sell water to relatively dry mines! What are we to make of this suggestion? Well, firstly the annual water volumes are comparatively small compared to the water volumes in the Wits Basins. Furthermore the Western Utilities Corporation looked at the possibility of pumping untreated or partially treated AMD water up to the platinum mining district in Rustenburg. This suggestion has been made at least once before by an earlier water utility company based on the West Rand, which was if I correctly recall, was called Amanzi.

6. Summary and Conclusions

In 1998 the last dewatering pumps in the Western Wits Basin, situated near Mogale City (Krugersdorp), were switched off. As a consequence Acid Mine Drainage (AMD) began decanting at surface in late 2002. At the insistence of national government the then Dept. of Water Affairs and Forestry spend many years in a futile attempt to apply the polluter pays principle. In practice this often meant trying to hold to account companies which had long ceased to exit. The policy also involved a dubious attempt to extract as much as possible of the costs of remediation from the companies still in operation in the Western Basin.

A similar chain of events began in 2008 when the last dewatering pumps were switched off in the Central Basin. According to various forecasts, if left uncheck, the rising groundwater in the Central Wits Basin would result in AMD decanting in volumes 3 to 4 times those that had occurred on the Western Basin. This time the AMD would decant in a populous and highly valuable economically area, right at the very centre of South Africa's industrial heartland.

Spurred on by public debate and agitation, national government made a rapid series of decisions. It set up the Inter-Ministerial Committee on Acid Mine Drainage and then agreed without reservation to the short term action plans suggested by the Committee. Thus the current situation is that something is at last been done and being done at the fastest achievable pace.

The construction and operation of desalination plants to remove most of the heavy metal from AMD appears to be an absolutely critical element of any long term solution. There are many different technologies being currently developed by private companies in South Africa. Our paper attempts to *get the ball rolling* on the issue of the institutional framework that would be capable of encouraging private companies to develop in essence a "national portfolio" of AMD treatment technologies. A national portfolio of technologies that is sufficiently diverse to allow us to treat AMD water no matter how variable in quality this water may prove to be.

Our search of the international literature on various issues of the environment economics of AMD has to date been rather disappointing. Perhaps it is true that the AMD problem in the Wits Basins is uniquely large and complex. However we will go back and search of the international literature again.

We conclude with a restatement of the belief that through sustained effort and ingenuity we "Joburgers" can convert our apparent curse of poisonous acidic water into an enduring blessing of quality water, which will ensure the survival of our city long into the future.

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