Should Irrigation With Mine-Affected Water Be Considered Part Of The Long-Term Strategy To Manage Acid Mine Drainage In The Witwatersrand Goldfields?

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Abstract

Due to South Africa's mining legacy, large volumes of acid mine drainage (AMD) threaten the quality of water resources. Treatment technologies exist, but are expensive and energy intensive. In the Witwatersrand Goldfields, three High Density Sludge water treatment facilities were established as emergency measure to neutralise large volumes of AMD in the Eastern, Central and Western Basins. These have been effective short-term measures, but sustainable long-term solutions are sought. Productive, cost-effective use can be made of these mine-affected waters if used for irrigation, and livelihoods will be created. It is worthwhile to attempt to address any potential concerns with this option.

Keywords: irrigation, AMD, DSS, Goldfields, Mine-closure

Introduction

Many deep underground mines in the Witwatersrand Goldfields closed in the late 1990s and early 2000s and began to flood. Pyrite exposed to air and water generates acid mine drainage (AMD). When mines close, active pumping and water treatment ceases, and this water starts to decant with potentially serious downstream consequences.

Specifically, the salt load to Vaal River System was highlighted by the Department of Water and Sanitation (DWS). Target salinities of 600 mg/L have proved difficult to meet, necessitating the unsustainable release of 5-11 units of expensive Lesotho Highlands water for dilution, for each unit of AMD entering the system. This could lead to a surplus of water in the lower catchment where it is not needed. The decant risk was identified for the whole of the Witwatersrand Goldfields which is divided into the Eastern Basin, Central Basin and the Western Basin.

Short-term solution

When mine water decanted from the Western Basin and spilled into a nearby nature reserve, a sense of urgency was created. This, together with the risk of flooding infrastructure, motivated the introduction of the "short-term" solution. Decisions had to be made on pumping water from the basins and keeping levels below "Environmental Critical Levels" to protect the environment and infrastructure. High Density Sludge (HDS) plants were built in the Eastern Basin (80 Ml/d), Central Basin (72 Ml/d) and Western Basin (33 Ml/d).

HDS is a relatively cheap water treatment option that addresses the acidity of water and reduces trace element levels. However, the salt load to the Vaal River System is still unacceptable, and longer-term solutions are sought. Reverse Osmosis (RO) was mooted as the preferred technology for the long-term solution, as it is a proven technology that has been successfully demonstrated. However, it has high capital and running costs and is energy intensive.

Long-term solutions

The volume of AMD is relatively small compared to that required by local water utility, Rand Water. Treating this mine-affected water to potable standards with RO, therefore, will not make a big contribution to the fresh water supply of Gauteng. It will also be expensive and energy intensive to treat, and there may be resistance to domestic consumption of purified mine water. Due to the prevalence of abandoned and ownerless mines, this is a taxpayer liability.

The key water management requirement is to keep as much salt as possible out of the Vaal River. This makes irrigation, a consumptive use of water with the opportunity to precipitate gypsum in the soil, worth considering (Annandale *et al*, 1999). Apart from creating livelihoods, irrigation should be a cost-effective option. In addition, commercial irrigation with water from the Vaal System was curtailed several years ago, as it was not considered a priority water use. Hence, there is clear motivation for other water sources (grey water, sewage, industry and mine water) to be used for irrigation.

Irrigation with mine-affected waters

A number of concerns arose when irrigation with mine water was suggested as a potential long-term option. These were:

- Are the waters suitable for sustained irrigation?
- What is the environmental impact?
- Is land available in the built up Witwatersrand region?
- Will farmers be willing to irrigate with these waters?
- What are costs/benefits of this option?

This paper attempts to respond to these concerns, with some covered in more detail than others.

Are waters suitable for irrigation?

Data for untreated and treated mine impacted waters from the Goldfields' was supplied by DWS. This data was collated to determine the 95th percentile of constituents, and the 5th percentile for pH, in order to provide a "worse case" assessment of the suitability of these waters for irrigation. These water qualities are given in Table 1.

Although these treated and untreated waters contain fair amounts of Na and Cl and a high total salt concentration (EC), they are primarily gypsiferous waters from which gypsum precipitation can be expected, when irrigating to achieve a low leaching fraction. Consequently, the negative effect of the high EC can expected to be less pronounced than when irrigating with a water of similar salinity, but that is non-gypsiferous.

A site-specific, risk-based irrigation water quality Decision Support System (DSS), developed by du Plessis *et al* (2017), was used to ascertain under what conditions these waters may be suitable for irrigation. In a nutshell, the DSS is able to assess the implications of irrigating with a range of waters, including mining-impacted waters, on soil and crop resources, as well as on irrigation equipment. This is done through the assessment of Suitability Indicators, with each divided into one of four Fitness-For-Use (FFU) classes, which are colour coded to make output intuitive, and are presented as being 'ideal', 'acceptable', 'tolerable' or 'unacceptable.

Table 1 *Water qualities used to assess suitability for irrigation. EB (Eastern Basin), CB (Central Basin) and WB (Western Basin). AMD denotes untreated water, and HDS is treated water.*

Constituent	EB AMD	EB HDS	CB AMD	CB HDS	WB AMD	WB HDS
pH	6.2	7.2	5.8	8.4	5.8	8.6
EC mS/m	300	260	490	403	350	385
Ca mg/l	370	340	517	668	520	650
Mg mg/l	120	95	251	178	130	90
Na mg/l	200	206	207	192	110	170
SO4 mg/l	1600	1660	3760	2710	2200	2400
Cl mg/l	120	120	96	97	80	85
HCO_3 mg/l		166				50
SAR	2.3	2.6	1.9	1.7	1.1	1.6
Fe mg/l	100	0.2	610	0.13	120	1.3
Mn mg/l	0.4	0.1	25	1.5	30	3.1
Al mg/l			144	0.05		
Ni mg/l				0.02	3	0.05
B mg/l					1.3	1.6
F mg/l					1.3	1.4
U µg/l				5	86	29

Table 2 Salinity response of selected crops after Maas and Hoffmann (1977).

Crop	Threshold ECe (mS/m)	Slope (% per dS/m)
Maize	170	12
Soybean	500	20
Wheat	600	7.1

The DSS was used for several site-specific, 45 year simulations, using the water quality of the specific basins, before and after treatment. A representative weather station close to each basin was selected, with sprinkler irrigation so foliage is wetted to assess scorching, and for irrigation to field capacity after 30 mm soil water depletion with 10 mm room for rain. Therefore, any leaching would occur through rainfall. Maize mono-cropping in summer, or a crop rotation of soybean in summer and a small grain in winter (wheat or stooling rye), were selected as the cropping systems. Crops vary greatly in their tolerance to salinity, and the thresholds above which yields decline, and the rate at which they decline for these crops, are presented in Table 2 (Maas and Hoffman, 1977).

The results of the DSS simulations are presented briefly below:

Root Zone Salinity

Except for untreated Central Basin water, root zone salinity is predicted to fall mostly in the ideal or acceptable suitability categories. Of more importance is that the effect of salinity on yield of the selected crops (maize, soybean and wheat). This is discussed below.

Soil Permeability

Having lower SAR values, the Western Basin waters are assessed to present less soil permeability problems than the Eastern Basin waters. They fall predominantly within the ideal/acceptable categories. Soil infiltration was identified as a tolerable problem for irrigation with treated Eastern Basin water. However, by adopting appropriate management practices, it should be possible to overcome any soil physical problems.

Trace Element Accumulation

Several trace element concentrations were reported as below detection limits (BDL). In such cases, the detection limit was taken to conservatively assess the waters for irrigation. Where such trace elements come up as potentially problematic, more careful analyses with lower detection limits are indicated. Specifically for these simulations, Se and Hg are highlighted. Table 3 presents DSS output for trace elements of potential concern, before and after water treatment.

On face value, the concentrations of several trace elements in untreated waters will accumulate to unacceptable levels within an unacceptably short period of time. Treatment clearly addresses any concerns around Fe, Al and Ni, as well as for Mn in the Eastern

Table 3 Years to reach international soil threshold values of selected trace elements of potential concern. Colours indicate fitness-for–use classes. EB (Eastern Basin), CB (Central Basin) and WB (Western Basin). AMD denotes untreated water, and HDS is treated water.

Mine Water	EB AMD	EB HDS	CB AMD	CB HDS	WB AMD	WB HDS
Fe	7	>1000	1	>1000	5	463
Mn	65	260	1	17	1	8
Al	-	-	5	>1000	-	-
F	-	-	-	-	185	172
Ni	-	-	-	>1000	8	482
U	-	-	-	260	14	42

Basin. Mn is still assessed to be potentially Unacceptable after treatment in the Central and Western Basins.

In view of the fact that Fe, Al and Mn are present in high concentrations in natural soils, it is debateable to what extent their concentrations pose a real problem as far as trace element accumulation is concerned. If necessary, their concentrations in the soil solution can probably also be managed by liming the soil and maintaining a suitable redox potential, conditions essential for successful irrigated crop production. The high Fe and Mn concentrations can, however, also present problems with deposits forming on produce irrigated with overhead application systems (an aspect that is not assessed by the DSS).

Uranium is obviously an element of concern to the general public, and the Western Basin waters should be more carefully analysed to ascertain if levels are indeed problematic, and if so, potential solutions should be sought.

Root Zone Effects on Crop Yield

There appear to be no concerns about salinity effects on yields of maize, soybean and wheat using waters from the Eastern and Western Basin, whether treated or not. The poorest water quality is for the Central Basin. In summer, moderate yield depression is expected for maize, and only a slight yield depression for more salt tolerant soybeans, if we irrigate with untreated mine water. Although wheat is quite salt tolerant, moderate yield loss is also expected in winter, as there is little to no rainfall to dilute salinity in the root-zone. Once the water is treated, none of our crops should show any meaningful yield depression due to salinity.

Problems with Irrigation Equipment

All of the untreated waters are predicted to present corrosion problems, while the treated Eastern Basin waters are predicted to be ideal, treated Central Basin water presents a tolerable level of corrosiveness, and the treated Western Basin water is predicted to be scaling to a tolerable degree. The Western Basin waters are predicted to present various degrees of problems if used with drip irrigation, while it is only the Fe content of the untreated Eastern Basin waters that is expected to present clogging problems. Untreated Central Basin water has high levels of Fe and Mn that would cause problems with micro irrigation systems, and after treatment, it is the pH and to a lesser extent Mn that would need to be considered. These effects are not important if overhead sprinkler irrigation is used.

Environmental impact – the fate of solutes

Irrigation is a consumptive use of water, and with calcium and sulphate dominated mine waters, there is an opportunity to precipitate a large amount of gypsum in the soil profile, thereby removing these salts from the water system. Such gypsum precipitation is not harmful to the soil, and the capacity for such precipitation is not limited. A large fraction of the salt applied to fields with these waters is predicted to precipitate in the soil profile as gypsum. For the Eastern Basin waters, just under 40% of the salt is expected to precipitate after HDS treatment, and just over 40% for untreated water. For the Western Basin, in excess of 60% of the salt should precipitate post treatment, and just over 50% pre-treatment. Predictions for the Central Basin are that around 35% of salts will be immobilised with irrigation using untreated water, rising dramatically to around 55% immobilisation irrigating with treated water.

Salts not precipitating must be leached from the root-zone for irrigation to be sustainable. It is likely that salt plume concentrations leaching from irrigated fields will be greatly attenuated by rainfall, and the ultimate fate of these salts will depend heavily on the irrigated field's position in the hydrologic landscape, but lags between irrigation application and salts surfacing in water bodies are likely to be decades or even much longer (Annandale *et al*, 2006). Should irrigation be considered, a geohydrological modelling exercise will be useful to best site irrigated fields. It may also be possible to site fields in order to be able to intercept percolation for possible re-use or treatment, but the salt load in this water will be considerably lower than the salt load applied to fields through irrigation. This will obviously have cost implications for the irrigation water use option of managing mine water.

Availability of land and willingness of farmers to irrigate with mine water

Dryland farming is a risky business, and margins are currently under pressure. It is expected that commercial farmers would welcome the availability of mine water for irrigation, as long as there is surety of supply at low cost, if reasonable crop yields are attainable, and if their soils and ground water resources will not be polluted. Irrigation should reduce their production risk substantially. The capital costs for irrigated farming are high, as are the input costs for seasonal production, but these can be carried by the growers in exchange for a commitment to productively utilise the mine water supplied to them. Irrigation is not only likely to be a cost effective way of dealing with the mine water problem, but increased production will create employment.

Table 4 indicates the area needed to utilise the mine water. Area required depends on cropping system and the availability of storage for times when little or no water can be used for irrigation.

There has been concern expressed over the availability of irrigable land near the mine water sources. A report by van der Laan *et al* (2014) indicates that land is available, especially if piped out of heavily built up areas. If water is conveyed to regions of lower elevation, it can be supplied to farmers under pressure, which will save greatly on electricity costs to pump water, making the irrigation option even more financially feasible and sustainable for growers. If water is allowed to decant, this may result in several smaller streams that may be easier to utilise through irrigation, but detailed studies will be required to determine the opportunities and risks of this option.

Economic aspects of mine water irrigation

The Goldfields waters are not very acidic, and it appears feasible to utilise untreated mine waters (except for the Central Basin), especially if growers commit to the application of limestone to their fields. The HDS treated waters are more suitable for irrigation than the untreated waters, but it is unlikely that growers will be able to bear these pre-treatment costs, should this be required.

The cost to the taxpayer of the irrigation option will depend on whether water is pumped or allowed to decant, as well as the cost of any necessary conveyance infrastructure. In addition, the cost of current pre-treatment with the HDS process will remain if irrigation with untreated water is deemed undesirable. There will also be the cost of interception and treatment of water percolating beyond the root-zone, if this is required.

Because there are so many potential irrigation options available, and their economic analyses are scale and cropping system dependent, it is essential to undertake detailed economic analyses of any specific proposed irrigation schemes. However, if the irrigated crop production system is set up to deliver yields close to those obtained with good quality water, an income should be generated from mine water, instead of a treatment cost. The economic activity and job creation associated with the irrigation option will also be of great benefit to the country.

Conclusions

It seems clear that with careful planning, irrigation with mine-impacted waters are an option worthy of serious consideration in the Goldfields of South Africa. The potential financial and energy savings compared to

***Table 4** Irrigated areas required for two cropping systems in the three basins.*

Mine Water	Eastern Basin 80 Ml/d		Central Basin 72 Ml/d		Western Basin 33 Ml/d	
Cropping system	Maize 221 mm	Soy-wheat 767 mm	Maize 222 mm	Soy-wheat 771 mm	Maize 244 mm	Soy-wheat 831 mm
Area	13200 ha	3800 ha	11800 ha	3400 ha	4900 ha	1500 ha

other treatment options, combined with the job creation and productive use of these waters, certainly make this a potentially attractive option. It would be prudent to control or regulate the process if considered. Assessments made here rely on the accuracy of the water quality data supplied. It is imperative that decisions are made based on reliable data.

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