Where there's muck there's brass: irrigated agriculture with mine impacted waters

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Abstract Investigations completed in 2009 and 2014 concluded that irrigation with coal and gold mine water was both feasible and desirable. Irrigated agriculture provides an opportunity to sequester up to 70% of salts contained in these waters by precipitation of gypsum within the soil profile, without adversely affecting soil condition or plant growth, while generating a revenue stream and providing sustainable employment. While the concept is feasible, large-scale implementation has lagged. The current project exposes the "irrigation with coal mine water" practice to a much larger reference group, and the principal factors delaying the adoption of this technology have been identified.

Keywords Mine water irrigation, risk and opportunity assessment, mine closure

Introduction

Coal and gold are the two largest mining sectors in South Africa – which is one of the world's major resource locations. Both coal and gold have been mined for more than 150 years, with major intensification over the last 50. Both resources are associated with pyrite mineralization, and this results in operations generating substantial volumes of saline mine water. Disposal of this water has become a major issue over the last 20 years, particularly because many of the older operations are now closing. Current philosophy is to desalinate the water, largely by reverse osmosis (RO), but closure funds and the national exchequer cannot afford this requirement. Further, the energy demand of RO is prohibitive and the wastes generated (gypsum and brine) are problematic. Beneficial use through irrigated agriculture is an opportunity to sequester a significant proportion of the salts contained in many of these waters, to generate a revenue stream, to facilitate rural development and land tenure, and to provide sustainable employment opportunities in post-mining communities (van der Laan et al. 2014).

The National Planning Commission (NPC) identified the creation of a million jobs in agriculture and the development of integrated rural economies as key goals for achieving vision 2030 of the National Development Plan (NDP) (NPC 2011). Taking into consideration the goals of the NDP, the proposed incorporation of irrigation with neutralised gypsiferous mine water as part of the growth path for expanding agriculture, both commercially and from an emerging famer perspective, is attractive. South Africa is a water-scarce country, and irrigated agriculture has reached its threshold from a water allocation perspective (DWAF 2013). The opportunity exists for mine waters, which otherwise constitute a major "waste disposal problem" and which have not currently been allocated as a resource, to be used to support the NDP irrigation goals.

South Africa traditionally irrigates crops using low salinity waters and the guidelines in existence do not permit the use of saline waters (DWAF, 1996). The majority of circum-neutral coal and gold mine waters are dominated by calcium sulphate, and the opportunity exists, by dint of good irrigation scheduling, to precipitate out limitless quantities of gypsum within the soil profile, thus providing a valuable soil amendment, saving on water treatment costs, and generating cash returns with the creation of sustainable jobs thorough beneficial water use to produce agricultural products.

Previous waste water irrigation projects have focused on maximizing disposal, rather than gainful use, thus often negating benefits due to over-irrigation.

Despite the presence of a substantial body of scientific study over an extended period that indicates that beneficial use is possible (e.g. Barnard et al. 1998; Annandale et al. 2002; 2007; van der Laan et al. 2014), use of mine water for commercial irrigation has not been widely implemented and indeed current regulatory structures hinder roll out of this technology. Accordingly, as a follow up to the intensive scientific and demonstration work already done, an additional set of centre pivot demonstrations, using coal mine water, have been set up in the coalfields of Mpumalanga, South Africa, to further explore unresolved issues that may be restricting large-scale uptake of this technology for areas with suitable waters and suitable soils.

Methods

This research programme, since 1993, has focused on agricultural productivity, groundwater protection and soil conservation, and included life cycle assessment. The work has been done in several phases.

During the period between 1993 and 1996 a wide range of crop and pasture species were screened for tolerance to irrigation with lime-treated AMD at Landau Colliery (Emalahleni, Mpumalanga Province) (Jovanovic et al. 1998).

This was followed by three years of field trials on a commercial scale on two sites in Mpumalanga, and prediction of long term effects (30 years) were made using the Soil Water Balance (SWB) model (Annandale et al. 2002).

Several more sites were set up under centre pivot irrigation (Optimum, New Vaal and Syferfontein Collieries), and these were commercially cropped for a number of years (Annandale et al. 2007).

In 2014, the potential for beneficial use of gold mine waters for irrigation purposes was also evaluated (van der Laan et al. 2014). This feasibility study developed long-term simulations of crop growth and salt dynamics using the SWB-Sci model, which is a mechanistic, generic-crop, daily time-step soil water and salt balance model (Annandale et al. 2002). Summer maize (*Zea mays* L.) or soybean (*Glycine max* L.) – winter wheat (*Triticum aestivum* L.) production was simulated for 50 years, using climatic data from 1950 to 2000. Virtual planting dates were 25 November (summer) and 29 May (winter). Irrigation to field capacity was simulated when crop available soil water was depleted by 30mm.

Finally, in 2016, a further two 19 ha centre pivots were commissioned at a colliery in Mpumalanga Province, one on land unaffected by mining, the other on land previously strip mined and subsequently rehabilitated. While active cropping has yet to commence, the technical assessment methods for soil, crop and water effects will remain similar to those used for the earlier centre pivot experiments.

However, these current trials are differentiated from the earlier work in two important respects:

Firstly, a greatly enlarged project review team has been assembled, to include all key interest groups who may be involved in the change from technology based research to practical on-the-ground implementation.

Secondly, Risk Assessment has been used to identify key issues that may restrict the conversion of the concept into implementation. For this purpose, the WRAC (Workplace Risk and Control) methodology was used (Joy & Griffiths, 2007), with participation of all key interest groups in the risk assessment process.

Results and discussion

The use of circum-neutral saline mine water for irrigation of agricultural crops has been tested for more than 20 years in South Africa, in several phases.

The commercial production of crops irrigated with mine-water through centre pivot systems has been tested in field trials at Kleinkopjé Colliery (Witbank) since 1997, and at Syferfontein (Secunda), and New Vaal Colliery (Vereeniging) since 2001.

Higher crop yields were obtained under sprinkler irrigation with treated mine-water compared to dryland production, without any foliar injury to the crops.

Sugar-beans, wheat, maize and potatoes were successfully produced under irrigation with $CaSO_4$ and $MgSO_4$ rich mine-waters. Site selection, land preparation and fertilization management are, however, critical for successful crop production, especially on mined land that has been rehabilitated.

A seasonal fluctuation in soil salinity was observed due to rainfall in the summer season with dry winters. In summer, low soil salinities were maintained because the salt load is lower (less irrigation) and the opportunity for flushing salts that do not precipitate in the root zone is higher than in winter. Measurements taken between 1997 and 2007 showed that soil salinity increased from a low base and varied around 250 mS m^{-1}.

Barnard et al. (1998) used SWB to predict the soil water and salt balance of lime treated acid mine water irrigated crops. Predictions of crop growth, soil water content and saturated soil solution extract electrical conductivities (ECe) for single season simulations gave good agreement with observed data.

Gypsum precipitation was also shown to be taking place in the soil. The presence of gypsum did not create any physical or chemical property changes that could adversely affect crop production and soil management.

Annandale et al. (2002, 2007) also used SWB to estimate the long-term impact of several coal-mine water qualities on a number of soils and crops, under different climatic conditions for various irrigation management scenarios. Soil salinity levels increased from pre irrigation levels, but stabilised due to gypsum precipitation at levels still conducive to production of many important agronomic crops.

Once the research results had shown that the impact of irrigating crops and soils with gypsiferous mine water was both minimal and manageable, the focus of the research shifted to evaluate the possible impact of irrigation on groundwater quality. Boreholes drilled inside or in close proximity to irrigated fields showed very little salt moving through the soil profile in the short term (2-8 years). According to Vermeulen et al. (2008), the leaching salts are attenuated by different mechanisms between the soil surface and the shallow aquifers, often by clay layers. This monitoring was on a localised scale and could therefore not be extrapolated to unequivocally determine larger-scale irrigation impacts. Thus, Annandale et al. (2006) investigated the impact of large-scale irrigation with gypsiferous mine water on groundwater resources in South Africa. Results of their study suggested that irrigating large areas with gypsum-rich coal-mine water could be feasible and sustainable if careful attention is paid to the specificity of each situation. They concluded that irrigation with gypsiferous mine water, if properly managed, could seriously be considered as part of the solution towards the challenge of managing the considerable volumes of coal-mine water available during mining and post closure.

In 2014, long-term simulations of crop growth and salt dynamics using the SWB-Sci model for gold mine water (specifically for waters currently accumulating in the Witwatersrand Western, Central and Eastern Basins) showed that a large fraction of the salt can potentially be removed from the neutralised mine water as a result of irrigating with it. While uncertainties exist regarding the quality of the mine water that will be pumped from the mine voids and its quality following neutralisation, simulations estimated that 34-69% of the salts could be precipitated as gypsum. Highest gypsum precipitation was estimated for the Western Basin mine water neutralised using limestone and lime (fig. 1).

In the simulation studies, root zone salinity levels remained below the threshold which would have an impact on wheat and soybean growth, while yields of maize were simulated to be impacted, consistent with its greater sensitivity to salt.

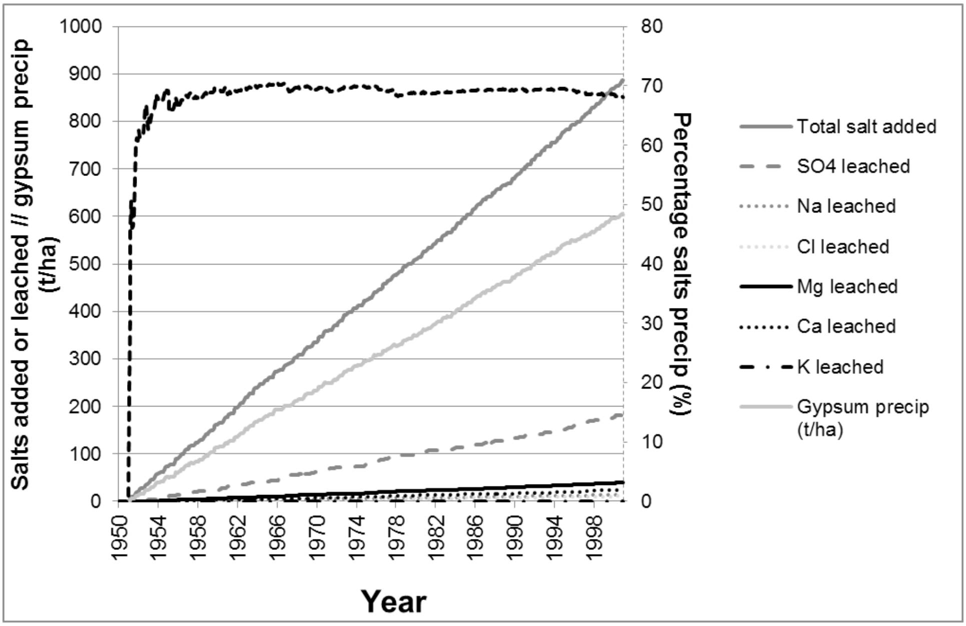

Figure 1 *Total salt added, gypsum precipitation and ion leaching load for the Western Basin limestone plus lime treated water simulation over the 50 year simulation period.*

For a simulation in which irrigation with the neutralised mine water was discontinued after 25 years and the system switched to rain-fed maize, it was estimated to take over 250 years for all of the precipitated gypsum to be re-mobilised through drainage.

The SWB-Sci model outputs indicate that for a sustainable wheat-soybean rotation cropping system, 1363, 3217 and 5562 ha could be irrigated by the water generated within the Western, Central and Eastern Basins, respectively. Spatial analysis showed that, in theory, ample suitable land is available for irrigation with neutralised mine water within a maximum distance of 30 km, depending on individual basin characteristics.

Crop modelling outputs indicate that although wheat and soybean production utilising neutralised mine water is comparable to production with good quality irrigation water, maize yields were estimated to decrease on average by 46% when irrigating with treated water due to this crop being more salt sensitive. From an economic sustainability perspective, more than 300 producers could benefit financially by each cultivating a 40 ha pivot as a separate business unit. The overall advantage of using these cash crops are not merely production based, but also demand driven, as South Africa is a net importer of both wheat and soybean oilcake.

In brief, the 2014 project concluded that “The favourable implementation of this technology can have far reaching consequences, not only in the Witwatersrand Goldfields, but also the Mpumalanga Coalfields, and many other regions around the world with a legacy of intensive mining.”

It is clear that the technology holds great promise for management of one of mining's greatest challenges; however, despite the lengthy research programme, no practical implementation has occurred to date. Consequently, the current (2016 – 2020) project is establishing two pivots on an Mpumalanga coal mine, to be evaluated in the same manner as the previous pivots, but with a greatly enlarged reference and control group, in order to ensure that concerns of key stakeholders are identified and addressed.

Risk assessment has identified the key "risks" that may prevent the conversion of the concept into large-scale reality. The risk assessment team included key participants from government departments, NGOs, academia and mining companies.

The top risks that may hamper the practical implementation of the technology were identified as follows:

- A legal framework that does not cater for the productive use of mine wastewater. Mine water should not cost the user more than freshwater.
- Use of mine water for irrigation attracts a waste discharge charge. (Irrigation not seen as a reuse option).
- Difficulty in aligning legislation requirements for different government departments involved in permitting irrigation with mine water results in delay in introduction of mine water use for agriculture.
- Lack of trained and motivated personnel to effectively manage schemes (this is particularly relevant for community farming, and would be a lesser issue with organised agriculture).
- Failure to develop systems that make this an effective community-based activity; failure to provide appropriate incentives so that the community want to farm.

Addressing these risks and opportunities has become part of the current project.

Representatives of four key government departments (Environment, Water and Sanitation, Mineral Resources, and Agriculture) have participated in steering the project, together with relevant NGO representation; the project is currently recognized by the Department of Water and Sanitation as one of its flagship projects. It is expected that the strengthened regulators' representation will greatly assist in defining the way to overcome current legislative hurdles.

It is intended that these centre pivot systems, over the four years of commercial irrigation, will play a key role as training centres for development of the necessary skills in appropriate communities. In addition, Best Practice Guidelines will be generated that address the key requirements of adequate technical controls to ensure correct irrigation methodology is applied, and monitoring to ensure that any environmental impact is acceptable.

Conclusions

Use of mine impacted waters through irrigated agriculture provides an opportunity to sequester a major portion of salts contained in many of these waters, while generating a revenue stream and providing sustainable employment in post-mining communities. Mines can obtain permission to close *only* if they specify and demonstrate sustainable post-closure land use. Our technique enables mines to defray the cost of pumping and actively treating mine-impacted water, and enables agriculture to occur in the post-mining landscape, even where no water is available from conventional sources.

Most of the coal- and gold-mine waters are dominated by calcium sulphate, and the sequestration occurs by precipitation of gypsum within the soil profile. Up to 70% of salts contained in these waters may be sequestered without adversely affecting soil condition or plant growth. Crop model simulations estimate that irrigating with neutralised mine water can result in wheat yields of approximately 9 t/ha and soybean yields of 5 t/ha when grown in rotation. Even under worst case scenarios in which farmers have to pay for the infrastructure to deliver the mine water to their farms, a very respectable emerging farmer income of more than R240 000/year is predicted to be realised for a 40 ha farm. The Rand has been quite volatile, but at the time of writing the exchange rate was around R13-50 to the US$.

Two Water Research Commission projects, completed in 2009 and 2014 respectively, have concluded that irrigation with mine water is both feasible and desirable. Indeed, the concluding comment by van der Laan et al. (2014) was that “The favourable implementation of this technology can have far reaching consequences, not only in the Witwatersrand Goldfields, but also the Mpumalanga Coalfields and many other regions around the world with a legacy of intensive mining.” Despite this glowing endorsement, this technique has not yet been adopted in South Africa.

A further project has now been initiated, which continues with the assessment of the impacts of irrigation using affected mine water in the Mpumalanga Coalfields. It again assesses the viability of irrigation using mine-affected water with two commercially farmed centre pivots at a different coal mining location in Mpumalanga Province.

It is differentiated from earlier work by the inclusion of a greatly expanded reference group that includes both government and NGO representatives, and the inclusion of risk and opportunity assessment as a tool to identify reasons for the failure of “this technology” to be adopted, and to devise appropriate controls to stimulate the implementation of this technology.

There are major opportunities, worldwide, for agriculture to exploit the tremendous potential of suitable quality mining-impacted water to help solve the impending water-energy-food crisis, without compromising soil and groundwater quality.

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