WATER RESEARCH COMMISSION

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The WRC operates in terms of the Water Research Act (Act 34 of 1971) and its mandate is to support water research and development as well as the building of a sustainable water research capacity in South Africa.

TECHNICAL BRIEF

Mine-water management

The feasibility of using irrigation using acid mine-water

The WRC has successfully tested the feasibility of using irrigation as part of a long-term acid mine-water management strategy in the Vaal River basin.

Background

The imminent problem of poor quality mine-water facing the Vaal River basin has potentially major economic, social and environmental repercussions. Essentially, it is a salt problem, because while the water can effectively be neutralised to remove acidity, metals and radioactivity, this leaves a brackish water for the dilution of which there is insufficient clean water to achieve fitness-of-use objectives.

A feasibility study, commissioned by the Government to find short- and long-term solutions, has been completed, recommending neutralisation in a high density sludge plant followed by conventional reverse osmosis (RO). This will potentially solve the salinity problem, but is accompanied by huge economic and energy cost. In addition, extremely saline brine from the process would still require disposal.

Previous work done by the University of Pretoria in Mpumalanga has shown that common field crops can be economically grown using poor quality coal mine-water when the water contains relatively high concentrations of calcium and sulphate. The reason for this is that as the crops transpire and concentrate the soil solution, the calcium and sulphate ions precipitate out as gypsum, and are so effectively removed from the water.

This results in root zone salinity being maintained at levels suitable for crop production and far below what would be expected when irrigating with saline water containing higher levels of more soluble salts, such as sodium, magnesium and chloride. Furthermore, gypsum precipitation was found not to result in any physical or chemical changes that would adversely affect soil productivity over the long term. An opportunity to effectively use this technology as part of a treatment strategy for the more pressing gold mine-water problem was therefore identified. The main aim of this project was to rapidly identify and quantify ways in which irrigation could be used to avoid the high treatment costs associated with RO, utilising laboratory studies, crop modelling, lifecycle and economic assessments and geographic information system queries.

Laboratory study

A short, laboratory-based project was conducted to evaluate a long iron (Fe)-manganese (Mn) wad and aluminium (Al) sulphate as alternative treatments for metalliferous mine-water as well as to experimentally simulate land treatment of the mine-water using Ergo mine tailings and two soils, amended with limestone or slaked lime.

Combinations of Fe-Mn wad from a mine near Ventersdorp, Al sulphate from a factory near Springs and reagent grade calcium carbonate ($CaCo_3$) and calcium hydroxide ($Ca(OH)_2$) were used in a series of laboratory experiments to find conditions that would be suitable for the removal of metals, chiefly Ca, Fe and Mn, and sulphate from mine-water that was collected from a decant point near Randfontein on the western Witwatersrand.

Direct application of the same mine-water to mine tailings from the Ergo tailings storage facility (TSF) near Brakpan and two soils from adjacent agricultural lands, suitably amended with either limestone or lime to neutralise the acidifying effects of the mine-water, was carried out in order to simulate land treatment of the mine-water by irrigation at an average depth of 5 mm/day for ten years, incorporating the amendments and precipitated solids to a depth of between 0.2 mm and 1 m.

On the mine tailings as much as 75% of the added salts could be sequestered by this simulated land treatment. A black clay soil was able to sequester about 90% of added salts even without the addition of an alkaline treatment.

Both Fe-Mn and Al sulphate can be used in an auxiliary role with lime and limestone for removal of metals from mine-water. The wad's effectiveness for Mn removal by oxidation may be reduced when ferrous Fe is present, however, since this will be oxidised preferentially.

Similarly, the cation exchange capacity of Mn oxide in the wad may preferentially be occupied by Ca because of mass action which would further reduce the capacity of the ward to remove Mn and other metals from solution.

Aluminium sulphate and hydrated lime work synergistically as conditioners for mine-water to effect a rapid depletion of contaminants at a near neutral pH. The order in which these reagents are added to the mine-water makes a great difference to the resultant composition. The quality of the water produced is probably quite sensitive to small changes in reaction conditions, and further investigation should make use of more accurately controlled pH, temperature and gas composition.

The results represent clear proof of concept that land treatment, either with mine tailings and/or a clay soil, suitable amended with fine limestone or possibly fly ash from power stations, is technically attractive and could offer solutions to two environmental challenges at once: erodible mine tailings and large volumes of contaminated mine-water.

Cropping system simulations

Long-term simulations of crop growth and salt dynamics using the SWB-Sci model show 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 up to 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 or mine-water neutralised using a limed Al sulphate treatment developed in this project.

Root zone salinity levels were simulated to remain 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.

Average total dissolved solids concentrations in the leachate were estimated to range from 3 716 to 5 486 mg/ℓ. The sodium adsorption ratio (SAR) correlated with the electrical conductivity of the leachate, implying that the sodium hazard per se is of little concern, since when sodicity is high it is salinity that is likely to be the limiting factor.

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

Lifecycle assessment

A reduced scope lifecycle assessment was used to compare conventional RO treatment of mine-water with a treatment strategy which includes irrigation with and without the desalination of the smaller quantities of irrigation return flows. Only the environmental impacts related to electricity consumption to drive the treatment processes were considered.

The functional unit considered was 1 ton of salt removed from the mine-water. Due to conventional RO being a very energy intensive process, this translated into high potential impact for all the categories considered – global warming potential, acidification potential, and non-renewable energy (fossil fuel) and blue water consumption.

For the Western Basin limestone-neutralised mine-water, irrigation was estimated to have an 89% lower impact, while for a treatment strategy that further involved using conventional RO on the irrigation return flows, the impact was estimated to be 70% lower.

The lowest environmental benefits of using irrigation instead of RO were estimated for the Eastern Basin, but impacts were still reduced by 52% for the irrigation plus conventional RO of return flows options.

This work shows that while using conventional RO to treat mine-water will have very clear benefits on water quality, some burden shifting is expected. In addition to water scarcity problems, South Africa faces electricity generation challenges, which also need to be carefully considered.

A major weakness in the lifecycle assessment is no or inadequate consideration of salinity impacts, making it a biased form of environmental impact assessment. Ongoing research aims to address this weakness.

Availability of land and economic analysis

SWB-Sci model outputs indicate that for a wheat-soybean rotation cropping system, 1 363, 3 217 and 5 562 ha will be needed for the Western, Central and Eastern basins, respectively. The spatial analysis showed that, in theory, ample suitable land is available for irrigation with neutralised mine-water. Water may need to be piped 17 to 30 km, depending on individual basin characteristics.

South Africa is a net importer of both wheat and soybean resulting in higher commodity prices when compared to crops which tend to be more export parity related, such as maize. The current crushing capacity of soybeans is under-utilised and additional production of roughly 500 000 t of soybean is required for the price to start trading at export parity levels.

Using industry-related water costs, average production expenditure when all three crops are combined was R19 900 per hectare (Scenario 1 – farmers pay for the water but not transfer from extraction points). If producers were to carry the full burden (CAPEX and OPEX) of getting the water to their production areas, this cost could increase on average to R23 300 per hectare (Scenario 2).

The model accounts for the market volatility in commodity prices and maize prices were assumed to decrease slightly, while wheat and soybean prices are expected to move sideways from their current prices.

Under the worst case scenario (Scenario 2) producers could still realise a farm/small business income of R243 320 per annum (excluding family and tax expenses) on 40 hectares irrigated with neutralised mine-water if they continue to achieve the modelled yields.

From an economic sustainability perspective, more than 300 producers could benefit financially by each cultivating a 40 ha pivot as a separate business unit. If all of these hectares could come under production, approximately 10% of the current soybean crushing demand could be attained. Total gross revenue that can be generated by the 11 992 ha under wheat and soybean rotational cropping would be approx. R73-million based on 2014 prices and costs, while it could increase to R108-million on a higher return per hectare.

Further reading:
To order the report, *Feasibility study on the use of irrigation as part of a long-term acid mine-water management strategy in the Vaal Basin* (**Report No. 2233/1/14**) contact Publications at Tel: (012) 330-0340, Email: orders@wrc.org.za or Visit: www.wrc.org.za to download a free copy.