Facilitating Sustainable Mine Water Irrigation

John George Annandale[1], Phillip Dale Tanner[1], Sarah Nicole Heuer[1], Gideon van der Walt[1], Karabo Deane[1], Heinrich Meiring du Plessis[1]

[1]*Department of Plant and Soil Sciences, University of Pretoria, South Africa*

Abstract

Responsible mine water irrigation can reduce water treatment costs and create sustainable livelihoods upon closure. However, guidance is required to assess mine water fitness-for-irrigation, and the steps to take to set up a successful mine water irrigation scheme need to be clearly set out. As proof of concept and to facilitate informed decision making around establishment and regulation of mine water irrigation schemes, a carefully monitored commercial scale Demonstration Site has been successfully irrigated for five cropping seasons with untreated circum-neutral mine water. Technical Guidelines for Mine Water Irrigation were developed to assist potential irrigators and regulators.

Keywords: Mine water irrigation, irrigation water quality guidelines, irrigation site selection, monitoring, adaptive management

Introduction

Modelling and past experience has shown that irrigation with especially gypsiferous mine waters, can be successfully and sustainably undertaken (Annandale *et al.* 2002). However, regulators and practitioners are understandably concerned about the productivity and environmental impacts of a large-scale roll out of mine water irrigation. To overcome their concerns, and to facilitate informed decision making around the establishment and regulation of mine water irrigation schemes, support is needed. To this end, a commercial scale Mine Water Irrigation Site was established to demonstrate the feasibility of mine water irrigation, and Technical Guidelines for Mine Water Irrigation were developed to assist potential irrigators and regulators.

Commercial Scale Mine Water Irrigation Demonstration

Location and Water Quality

A 19 ha irrigation centre pivot was established on previously un-mined land in Middelburg, Mpumalanga Province, South Africa. This field has been irrigated with untreated circum-neutral mine water since September 2017, and has been carefully monitored to ascertain if crops are economically produced, if produce is safe to consume, and if any environmental impact is within acceptable limits. A Google Earth image of the Demonstration Site is presented in Figure 1, with the location of ground and surface water monitoring points indicated.

The irrigation water quality is gypsiferous, with pH ranging over the last five cropping seasons from 7.5 to 8.1, electrical conductivity (EC) was between 140 and 240 mS/m, with sulfate levels as low as 640 and as high as 1070 mg/L. Cumulative irrigation of this site is in excess of 1400 mm, with 23.6 t/ha sulfate, 4.7 t/ha Ca, 2.3 t/ha Mg, 1.8 t/ha Na, 0.65 t/ha K and 0.5 t/ha Cl applied to this field.

Cropping System and Food Safety

The field is farmed commercially by a local farmer who specialises in maize (*Zea mays*) production. Except for a three-month period in which stooling rye, a small grain planted for grazing, was produced on request of the research team, this field has been under mono-culture maize production. It is important to know whether crops produced are safe for human and animal consumption, as it is pointless to produce high yields of a food or fodder crop that cannot be utilised. In such cases, non-edible industrial crops could be considered.

Figure 1 *Location of the Demonstration Pivot and surface and ground water monitoring points*

It is therefore important to analyse grain and whole plant samples and compare their elemental concentrations to current guidelines for food and fodder safety. Since maize is produced for local and international markets, it is important to ensure that it falls within both local and international guidelines for food and fodder safety.

The guidelines provide accepted thresholds for elements of concern such as arsenic, lead and other trace elements. Table 1 presents concentrations of the five elements of potential concern found in the local and international food and fodder guidelines for maize grain. It can be seen that grain elemental concentrations were an order or two of magnitude below the accepted local and international thresholds, thus indicating that they are extremely safe for human and animal consumption.

Table 1 *Comparison of grain element concentrations with accepted food and fodder safety thresholds for the 2021-2022 season*

Element	Average concentrations in white maize grain	China	EU/USA	Ireland	SA Feed safety
			ppm or mg/kg		
As	-	0.5	-	-	2
Cd	0.01	0.1	0.1	0.1	1
Zn	0.2	-	-	-	150
Pb	0.01	0.2	0.2	0.1	10
Hg	<0.001	0.02	-	-	0.1

Table 2 *Yields and profitability of dryland and irrigated maize (current exchange rate ~ R18/USD)*

Season	Yield (t/ha)		Cost per ha		Maize price per ton	Earnings per ha		Profit/Loss per ha	
	Irrigated	Dryland	Irrigated	Dryland		Irrigated	Dryland	Irrigated	Dryland
2017/18	13.5	4.5	R18000	R16000	R2103	R28390	R9460	R10390	R6540
2018/19	11.6	5.5	R18770	R16800	R2910	R33760	R16010	R14990	R790
2019/20	14.3	4.9	R19700	R17700	R2450	R35040	R12010	R15340	R5690
2020/21	12.2	8.4	R20600	R18580	R3508	R42800	R29470	R22200	R10890
2021/22	14.2	8.7	R2200	R19509	R4079	R57920	R35490	R35920	R15980

Environmental Impact

No discernible changes in soil quality have been observed since the commencement of irrigation. Surface water quality is monitored at the downstream Beestepan Dam (Figure 1). This water body's quality is closely monitored, and it was initially decided that if a 20% increase in sulfate concentration was observed from the average pre-irrigation SO4 concentrations between 2014 and 2017, then irrigation would need to stop immediately. This trigger value, however, was later deemed flawed, as the monitoring point is also downstream of a discard dump (Figure 1). As a result, any increases in sulfate or any other elements could not automatically be deemed to be as a direct consequence of irrigation alone, and accordingly the "stop" instruction has been modified so that irrigation will only cease if any increase in pollution of the Beestepan Dam can be directly attributed to flows from the Unmined Pivot. Despite this concern, the threshold for sulphate concentration (642 mg/L) is yet to be reached (see Table 3).

Groundwater is monitored at a shallow (10 m) and deeper (30 m) depth, in boreholes sited both up and downstream of the irrigated field. Figure 2 presents SO4 concentrations since the commencement of irrigation in 2017. It is clear that the discard dump downstream of the irrigated field influenced groundwater quality before mine water irrigation started. The sharp increase in SO4 concentration in the wet summer months of 2020 is suspected to reflect the effect of runoff water from the stockpile, and it seems that no deterioration in groundwater quality can be ascribed to irrigation at this stage.

Technical Guidelines for Mine Water Irrigation

A Technical Guideline has been developed to support water users considering irrigation with mine waters, and those who will be required to regulate such irrigation schemes (Heuer *et al.* 2021). A separate set of guidelines, aimed at providing guidance for obtaining regulatory approval of irrigation with mine waters has also been published (Pocock and Coetzee, 2021).

The *Technical Guideline for Irrigation with Mine-Affected Waters*, follow a logical decision tree structure, with a source-pathway-receptor approach to determining monitoring requirements and thresholds for action. They provide a standardised framework for the establishment and stewardship of irrigation with specific mine-affected waters in South Africa. They advise on the use of the Irrigation Water Quality Decision Support System (DSS) published by du Plessis *et al.* (2017), to provide site-specific, risk-based assessments of the fitness for use of mine

Table 3 *Average water quality for Beestepan Dam*

Parameters	Oct '14 to May '17	Sept '17 to May '18	Sept '18 to May '19	Sept '18 to May '20	Sept '20 to Aug '21	Sept '21 to Aug '22
pH	7.1	8.1	7.93	7.7	7.72	7.52
EC(mS/m)	115	70	102	105	122	111
SO_4 mg/L	535	282	406	402	485	401
Na	52	30	45	45	48	48

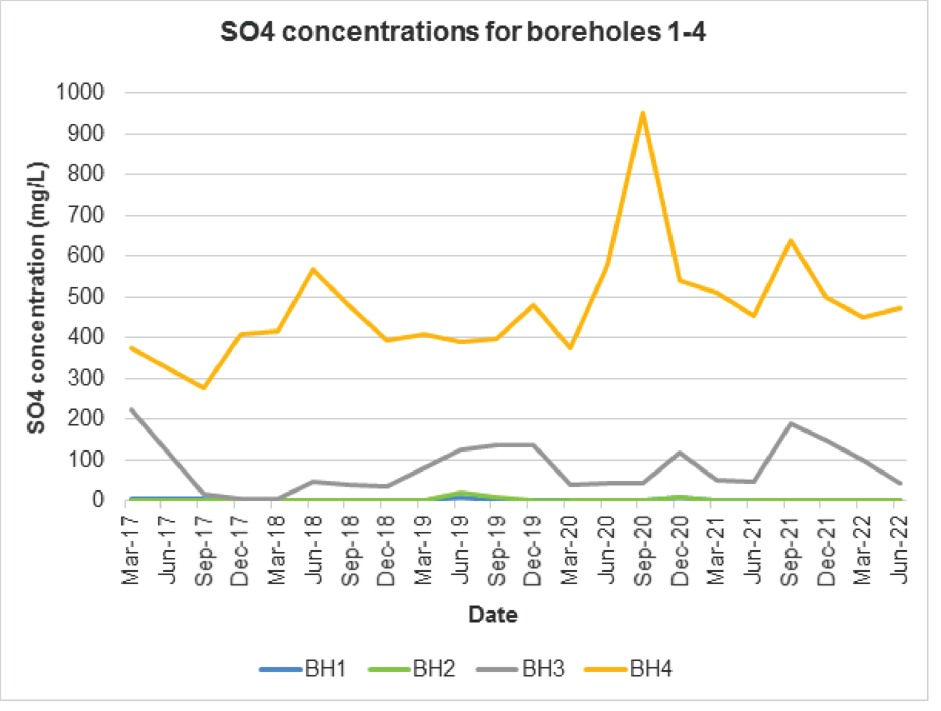

Figure 2 *Borehole sulfate concentrations since the commencement of irrigation. BH1 – deep upstream, BH2 – shallow upstream, BH3 – deep downstream, BH4 – shallow downstream*

waters for irrigation. In addition, appropriate site irrigability characterisation procedures are provided in order to identify an irrigation landscape capable of sustainably supporting a mine water irrigated cropping system. A risk assessment framework to identify potential key unwanted events that may occur as a result of irrigation with mine water is proposed, with guidance on a methodology to identify constituents of potential concern and to determine thresholds for action. An integrated monitoring regime is proposed to ensure that qualities of soils, waters and crops fall within acceptable environmental thresholds, and in the event that monitoring identifies constituents of concern exceeding acceptable levels, adaptive management strategies to remedy the situation are recommended.

The recommendations of the guideline should be of value regardless of geographical region, the resource mined, and the nature of the mine water considered for irrigation. The consideration of site-specific factors is emphasized as key to project success. Key aspects of the guideline are briefly highlighted:

Water Resource

It is essential that estimates are made as reliably as possible, of mine water volumes and quantities expected over time, as these are the key drivers of any mine water irrigation scheme. In addition, it is important to estimate the seasonality of water supply and to ascertain if water storage is available for times when irrigation is not possible, like in wet weather or during crop maturation drying off or fallow periods. If the site does not have a long-term positive water balance, then irrigation should not be considered.

Fitness-for-Use (FFU) Assessment

Having determined that surplus water of an estimated or known quality will need to be managed, the next step is to ascertain if there are conditions under which it can be used for irrigation. Such assessments are site specific, as climate, cropping system, and irrigation method and management, all affect the usability of a specific water source. The

Irrigation Water Quality DSS of du Plessis *et al*. (2017) can be used to make site-specific and risk-based FFU assessments. The DSS considers the effect of irrigation with a specific water quality on soil resources, crop yield and quality, and possible effects like corrosion and scaling of irrigation infrastructure. These simulations also estimate crop water use of different cropping systems, thereby enabling estimates of irrigated area required to utilise the available water. Crop water use predictions also assist with estimates of storage capacity, if required. If the mine water can be responsibly used for irrigation, and a cropping system and irrigation management strategy has been selected, then Water Quality Requirements (WQR) can be assessed with the DSS to provide benchmark water qualities required for this specific use. These are useful, because if water quality deteriorates, decisions need to be taken around partial water treatment, or perhaps an alternative cropping system with more tolerant crops needs to be considered. Obviously if the mine water source is not suitable for irrigation, other water management options need to be investigated.

Siting the Irrigation Scheme

It will clearly be most economical, from an irrigation infrastructure point of view, to site irrigated fields as close to the water source as possible. However, it is essential that free draining fields of gentle slope be selected, as excessive levels of soluble salts building up in the soil profile will result in the scheme failing over time. Ecologically sensitive and wetland areas are to be avoided.

Gypsiferous mine waters are particularly suitable for mine water irrigation (Annandale *et al*. 2006), as root water uptake concentrates the soil solution and gypsum precipitation results. This lowers root zone salinity, which is beneficial for crop production, and reduces salt mobilisation to ground and surface water bodies, thereby reducing environmental impact. The position of irrigated fields in the hydrological landscape is also important, as it is essential to ensure that the increase in recharge rate brought about by irrigation, will not result in water logging and salinization of the irrigated fields.

Environmental Monitoring and Adaptive Management

It is important to identify potentially negative impacts of irrigation with mine waters. Effects on soil, water and crop resources should be considered. The DSS highlights potential constituents of concern, and a monitoring programme needs to be put in place, with clearly defined thresholds for action. Adaptive management is suggested should thresholds be exceeded, but if environmental impact appears to be unacceptable, then irrigation should cease and alternative water management plans need to be implemented.

Competent, independent experts' recommendations and oversight are essential to the success and sustainable use of mine water for irrigation.

Conclusions

A successful commercial scale mine water irrigation demonstration site has been established, that has proved useful as a proof of concept for regulators and mining houses considering irrigation as a water management option. Technical Guidelines set out propose processes to follow to establish mine water irrigation schemes, that include assessing volumes, seasonality and quality of water available, as well as storage requirements, the selection of appropriate cropping systems, site selection to ensure that soils are irrigable and well positioned in the hydrological landscape, and the development of monitoring programmes, thresholds for action, and adaptive management strategies.

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