Guidelines for Rehabilitating Mined Land to Irrigable Standard

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Abstract

Irrigation with suitable quality untreated or partially treated mine waters may be a beneficial, cost effective option for mine water management. Suitable rehabilitated mined land near such waters could be ideal for irrigation, as off-site environmental impacts are expected to be reduced relative to irrigation of unmined land falling outside of the mining footprint. Sustainable, productive irrigation requires soils to be irrigable, not just arable. Guidelines for mine land rehabilitation to irrigable standard are provided, as well as pointers for assessing the irrigability of rehabilitated land. In addition, remediation approaches for sub-optimal field areas are proposed.

Keywords: Irrigability assessment, mine influenced water, rehabilitated mined land, remediation

Introduction

Managing or treating large volumes of mine water is expensive, and irrigation may be a beneficial, cost effective option to consider (Annandale *et al*. 2002). This enhances food security, and can improve livelihoods of nearby communities, especially post-closure, thereby supporting the Just Energy Transition. Suitable rehabilitated mined land near such waters could be ideal for irrigation, as off-site environmental impacts are expected to be minimal and manageable if return flows accumulate in old pit voids and are contained. However, due to physical limitations, rehabilitated land is generally less favourable than unmined land for crop production.

The technical guidelines for irrigation with mine water (Heuer *et al*. 2021) include the Irrigation Water Quality Decision Support System (IrrigWQ-DSS) (du Plessis *et al*. 2023), which assists with assessing mine water suitability for irrigation, appropriate crop selection, and estimating the irrigable land area required to utilise the available mine water. Guidelines for obtaining regulatory approval for this practice in South Africa (Pocock and Coetzee 2021) have also been developed. The current Land Rehabilitation Guidelines for Surface Coal Mines (LaRSSA 2019) provide guidance on rehabilitation to arable standards and thus need to be supplemented with guidance on rehabilitating mined land to irrigable standard. Such guidelines should also contain procedures for assessing irrigability of rehabilitated land, and offer recommendations for remediation of sub-optimal rehabilitated areas.

The ***Guidelines for Rehabilitating Mined Land to Irrigable Standard*** presented here, exclusively consider physical land and soil characteristics, as it is assumed that chemical limitations to crop production, such as soil fertility, are easier to address than physical limitations.

Mine water is often of poor quality, requiring uniform irrigation application to minimize salinisation risk in irrigated fields. Due to the high risk of emitter blockage, mine water is unsuitable for micro-irrigation systems. Therefore, these guidelines assume that overhead centre-pivot irrigation, will be the preferred method for using mine water.

These proposed guidelines expand on the (LaRSSA 2019) guidelines, and are presented in three sections; SECTION A (summarises best soil handling practices, from stripping to replacement, as outlined in the LaRSSA

2019 guidelines), SECTION B (presents the assessment of irrigation potential of rehabilitated mined land), and SECTION C (recommends remediation approaches for areas of sub-optimal irrigability in rehabilitated mined land).

Although the development of all three sections have been guided by established and recognized practices or standards, the Rehab Irrigation Suitability (RIS) assessment model presented in section B is novel and is the main focus of this paper.

Approach

These guidelines stress the need to carefully follow the LaRSSA (2019) mine land rehabilitation guidelines to improve the chances of rehabilitating land to irrigable standard. This requires correct placement of suitable soil materials to sufficient depth, and the minimisation of compaction. Factors rendering rehabilitated mined land unsuitable for irrigation are poor surface drainage due to subsidence and low infiltrability, causing ponding, and poor internal profile drainage, causing water logging and salinisation.

Developing the Rehab Irrigation Suitability (RIS) model

The ***Rehab Irrigation Suitability (RIS)*** assessment procedure was developed by integrating the evaluation criteria of physical land and soil factors from commonly used quantitative land suitability models which evaluate the suitability of natural land for irrigation, including the Storie Index (SI) (Storie 1978) and the Parametric Model (Sys *et al*. 1991).

The ***RIS*** model evaluates six physical land and soil factors that often render rehabilitated mined land unfit for irrigation. These include: position in the landscape (PL); slope (S); depressions (Dep); infiltrability (IB); permeability or drainage rate (Perm) and water holding capacity (WHC).

Due to the expected high spatial variability of rehabilitated mined land, a 50 x 50 m sampling grid is advised at which to evaluate each of the six parameters in the desired sampling area. In-field measurements are compared to parameter-specific criteria and rated from "Ideal" to "Unacceptable". The overall irrigability class (Table 1) of an area is determined by the factor expected to most limit sustainable production. This classification system was adapted from the *Irrigation Water Quality Decision Support System* (IrrigWQ-DSS) (du Plessis *et al*. 2023), as it was considered simple, intuitive, and suitable for these guidelines.

The importance of each of the six assessment factors as well as their respective assessment criteria are presented.

Position in the landscape (PL)

Areas intended for irrigation should not be situated in low-lying areas such as floodplains, which may become water-logged and unproductive due to surface flooding after heavy rainfall. Furthermore, infiltration, erosion and sedimentation vary based on slope position (Ontl and Schulte 2012). Consequently, irrigated areas on slopes, especially those situated on backslope and toeslope regions (Fig. 1) may require up-slope drainage channels to prevent surface flow, erosion and sediment deposition, which may compromise the irrigated area (Ali 2011).

Ideally, the summit is the preferred area for irrigation, as it is expected to have more suitable infiltration, minimal sedimentation and erosion risks, subsequently requiring minimal, if any controls to reduce off-site environmental impacts.

Table 1 *Irrigability classes of the Rehab Irrigation Suitability (RIS) model.*

Irrigability class	Description
Ideal	High irrigation potential
Acceptable	Irrigable, with occasional yield penalty expected
Tolerable	Irrigable, but continuous yield penalty expected
Unacceptable	Serious yield limitations, irrigation not recommended

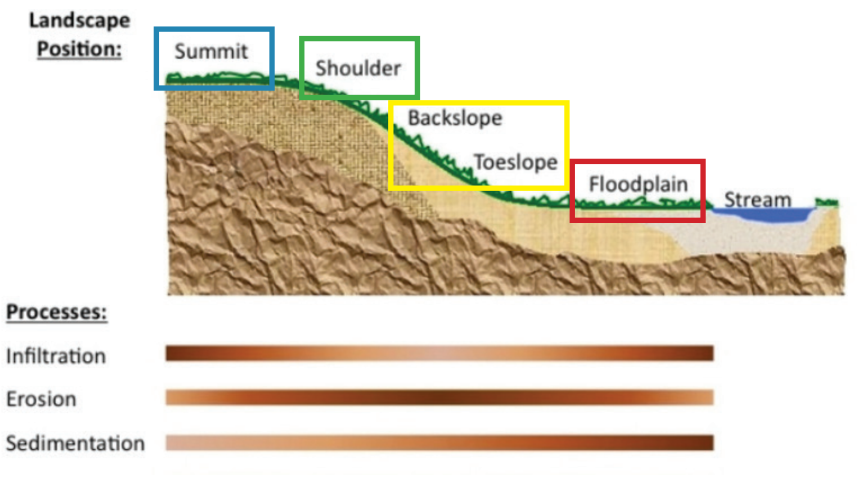

Figure 1 *Illustration of different slope positions (Ontl and Schulte 2012).*

Slope gradient (S)

When irrigating field crops with mine waters which are often saline, fields should be relatively flat (< 2%) to promote uniform distribution of irrigation water (Van Rensburg *et al.* 2012). However, the LaRSSA (2019) guidelines recommend a minimum slope of 1% to ensure effective surface drainage, preventing waterlogging and maintaining productivity in areas where subsidence or depressions may form.

Table 2, presents the RIS assessment criteria of slope gradient (%), which was adapted from the Storie Index (SI) (Storie 1978) and the Parametric Model (Sys *et al.* 1991). Moderate slopes (8–12%) were considered "Tolerable", and steep slopes (> 12%) "Unacceptable". These steeper slopes pose a higher risk of erosion and surface runoff.

Micro-relief or depressions (Dep)

Micro-relief is typically not of concern after land levelling, however, incorrectly constructed rehabilitated land is susceptible to secondary subsidence. The resettling of replaced material results in the formation of depressions which are often poorly drained, prone to waterlogging and salt build-up, making them unproductive under irrigation (LaRSSA 2019; Van Rensburg *et al.* 2012)

The risk of a depression becoming unproductive will depend on the likelihood of ponding, which is influenced by run-on, surface drainage or runoff, infiltrability and permeability. Determining both the presence of depressions, as well as the severity of ponding (Table 3), aids in better evaluating the potential risk of a depressed area becoming unproductive.

Infiltrability (IB) and permeability (Perm)

Surface soil texture, surface compaction and soil crusting will influence infiltrability, the potential rate at which water can enter the soil profile (Indoria *et al.* 2020). It is important that only the top 5 cm of the profile is assessed for infiltrability.

Permeability or internal drainage, on the other hand, is the rate water can pass through the profile and beyond the rooting zone. Poor permeability may be due to restrictive layers within the rehabilitated profile such as compacted material and stratified layers with textural contrasts (Rethman 2006). For profile

Table 2 *Assessment criteria of slope gradient (%).*

Slope gradient (%)			
Ideal	Acceptable	Tolerable	Unacceptable
<2%	2–8%	8–12%	>12%

Table 3 Assessment criteria of the occurrence and severity of depressions within a rehabilitated landscape.

Occurrence and severity of depression			
Ideal	Acceptable	Tolerable	Unacceptable
No depression	Slight depression	Medium depression	Large depression

Slight depression – Low risk of ponding and limited expected loss of productivity.
Medium depression – Moderate risk of ponding which may result in loss of productivity.
Large depression – High risk of ponding, where irrigation will most likely be unsuccessful.

permeability, textural changes down the profile are assessed, with the lowest permeability class considered the limiting layer.

The measured hydraulic conductivity ranges for Infiltrability assessment criteria (Table 4), were based on the South African Irrigation Institute's (SABI 2021) ideal surface infiltration rates of greater than 150 mm/h, specifically for centre pivot irrigation.

For Permeability (Table 5), the minimum natural soil drainage rates of greater than 2.5 mm/h recommended by soil irrigability guidelines of the USBR (2005), were adjusted to rates exceeding 5 mm/h, to ensure that rehabilitated land irrigated with poor quality mine waters will be free draining, and not prone to waterlogging and salinisation.

Using permeameters to measure hydraulic conductivity is time-consuming. A more convenient, albeit less accurate approach, involves estimating hydraulic conductivity from soil texture (Table 5). The LaRSSA (2019) guidelines assess bulk densities of various soil textures to identify levels that restrict root penetration, using this as a proxy for compaction induced impermeability.

Water Holding Capacity (WHC)

Water Holding Capacity depends on effective soil depth and the soil's ability to retain water. An approximation of WHC is often only related to effective soil depth. However, the WHC of a specific soil will be largely influenced by its soil texture. Sandy soils can

Table 4 Assessment criteria for infiltrability of the surface.

	Infiltrability (mm/h)			
	Ideal	Acceptable	Tolerable	Unacceptable
Hydraulic conductivity (mm/h)	> 150 mm/h	60–150 mm/h	5–60 mm/h	< 5 mm/h
Soil texture (% clay)	Coarse sand (< 5%)	Loamy sand, sandy loam (5–20%)	Loam*, silt loam*, silt*, sandy clay loam, clay loam, silty clay loam, sandy clay* (20–40%)	Silty clay, clay (> 40%)

Note: * indicates soil textures which do not strictly correlate with the clay % range specified per class.
Description: "Ideal" – Very rapid, "Acceptable" – rapid, "Tolerable" – moderate, "Unacceptable" – slow

Table 5 Assessment criteria of permeability of the most limiting layer.

	Permeability in mm/h of limiting layer			
	Ideal	Acceptable	Tolerable	Unacceptable
Hydraulic conductivity (mm/h)	> 50 mm/h	20–50 mm/h	5–20 mm/h	< 5 mm/h
Soil texture (% clay)	Sand, loamy sand, sandy loam* (< 10%)	Loam*, silt loam*, Sandy clay* (10–20%)	Silt*, clay loam, silty clay loam, sandy clay loam, (20–40%)	Silty clay, clay (> 40%)

Note: * indicates soil textures which do not strictly correlate with the clay % range specified.

Table 6 Soil depths (m) of different texture materials (% clay) to meet specific irrigability class requirements for provision of Readily Available Water.

Soil depth (m) relative to % clay						
	< 5%	5–10%	10–20%	20–40%	Available Water (mm)	
Ideal	> 2.5 m	> 1.25 m	> 0.80 m	> 0.66 m	> 100	> 50
Acceptable	1.5–2.5 m	0.75–1.25 m	0.5–0.80 m	0.4–0.66 m	60–100	30–50
Tolerable	0.75–1.5 m	0.37–0.75 m	0.25–0.5 m	0.2–0.4 m	30–60	15–30
Unacceptable	< 0.75 m	< 0.37 m	< 0.25 m	< 0.2 m	< 30	< 15

Assuming the profile is irrigated to field capacity, under hot dry conditions with a full canopy cover:
Ideal: Profile can provide readily available water to the crop for a week without irrigation
Acceptable: Crop should remain productive for at least 5 – 7 days before irrigation is needed
Tolerable: Full cover crop will need irrigation every 3 to 5 days in hot dry weather
Unacceptable: Profile will need to be irrigated at intervals of less than 3 days in hot dry weather

often hold only 40 mm available water per m soil, while clayey soils easily hold 150 mm/m. Therefore, sandy soils need to be deeper than clayey soils to hold the equivalent amount of water (Sys *et al.* 1991).

Despite irrigated agriculture relying less on rainfall than dryland production, the profile still requires sufficient soil or similar root-accessible material that will store sufficient water to reduce crop water stress between irrigation cycles or even during breakdowns.

Plant Available Water (PAW) is the water held between field capacity (FC) and wilting point (WP). FC is the upper limit where drainage is negligible, while WP is the lower limit, below which plants cannot extract water. As a rule of thumb, for optimal production under irrigation, no more than half of PAW should be depleted. This is known as Readily Available Water (RAW) (FAO 1985).

Approximate PAW and RAW requirements for various irrigability classes assume that a full cover crop under hot, dry conditions, should be able to sustain optimal growth with a weekly irrigation interval. From these PAW and RAW thresholds, together with available water contents of specific soil textures (% clay) published by (Sys *et al.* 1991), one can predict the irrigation potential class from effective soil depth and texture, as seen in Table 6.

Although not included here, rehabilitated areas, may have underlying spoil material that is permeable, uncompacted and chemically suitable for root growth. This can contribute significantly to PAW, and is especially important for profiles with limited soil cover.

Remediation strategies to improve the irrigability of sub-optimal rehabilitated mined land

The guideline's final section recommends remediation actions to improve rehabilitated land with low or unsuitable irrigation potential, as identified by the RIS model. Common remediation strategies are highlighted in Table 7.

Discussion

Rehabilitating mined land to an irrigable standard from the outset is ideal, allowing for strategic site selection and suitable soil placement. However, many mines that need to manage water surplus have already rehabilitated land to different standards and must assess its suitability for irrigation using mine water. These guidelines present the six-factor ***Rehab Irrigation Suitability (RIS)*** model.

This, together with digital maps for each of the six factors assessed can create an overall Irrigation Potential/RIS map for a rehabilitated area. This map will identify suboptimal areas requiring remediation or, if the extent of area not suitable for irrigation or cost of remediation is too great, for locating areas more suitable for irrigation.

Conclusions

These draft guidelines aim to support the rehabilitation of open-cast mined land to irrigable standards, assess irrigation potential, assist with site selection, and offer guidance on improving sub-optimal sites for sustainable irrigation. Future fieldwork will assess the guidelines' validity and practicality, allowing for necessary refinements.

Table 7 Remedial recommendations to improve sub-optimal rehabilitated mined land.

Type of physical limitation	Remedial action recommendations
Position in landscape and slope	Levelling slopes greater than 12% is impractical, while slopes of 8–12% need proper irrigation systems, management, and dense perennial ground cover. Gentler slopes (2–8%), especially those with poor infiltration and erosion risks (areas on backslope to toeslope regions), may require contour ridging and upslope drainage to manage run-on and runoff and prevent sediment accumulation.
Depressions	Determine whether ponding is due to surface run-on, poor infiltration or poor drainage. If ponded due to poor infiltration and drainage, refer to respective sections. If filling and reshaping are not feasible, consider creating an outflow for excess water to drain, ensuring erosion is avoided.
Infiltrability	Soil infiltration issues caused by crusting, compaction, or clayey surfaces can be improved by adding organic matter to low-carbon soils, gypsum to sodic soils, and shallow cultivation or ripping to enhance structure and water retention (FAO 1985). Ensure irrigation rates meet the soil's infiltration capacity, while impermeable clay material should be removed and replaced with permeable material.
Drainage -Permeability (impermeable layer)	Poor drainage from impermeable layers can be addressed by deep ripping into the soil-spoil interface or installing artificial drainage systems (FAO 1985; LaRSSA 2019). If these are infeasible, alternative options include planting on ridges or using waterlogging-tolerant species like tall fescue (Mollard *et al*. 2008).
Water holding capacity	For areas with restrictive subsurface layers or shallow soil, deep ripping beyond the restrictive layer or 300 mm past the soil-spoil interface enhances root and water movement. If ineffective, suitable soil material will need to be trucked in and levelled to achieve the appropriate soil depth.

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