TECHNICAL GUIDELINES FOR IRRIGATION WITH MINE-AFFECTED WATERS

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WATER RESEARCH COMMISSION

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Technical Guidelines for Irrigation with Mine-Affected Waters

Report to the
WATER RESEARCH COMMISSION

by

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GUIDELINE INTENT

This Guideline has been developed to provide a technical platform for guidance for water users looking to irrigate with mine-affected waters (MAW). The sustainable agricultural use of certain mine-affected waters for irrigation has been well demonstrated, and may provide a cost-effective water management option for South African agricultural and mining industries.

The design of an irrigation strategy by competent water and agricultural professionals, in consultation with relevant authorities, should assist the user in gaining regulatory approval for irrigation with mine-affected waters. The Water Research Commission (WRC) has published a separate set of guidelines, aimed at providing guidance for obtaining regulatory approval of irrigation with MAW (TT Report 837/21).

The intent of this *Technical Guideline for Irrigation with Mine-Affected Waters* follows:

- To provide a standardised framework for the establishment and stewardship of irrigation with certain mine-affected waters in South Africa;
- To advise on the use of the Irrigation Water Quality Decision Support System (DSS) to provide site-specific, risk-based assessments of the fitness for use of mine waters for irrigation;
- To provide appropriate site irrigability characterisation procedures in order to identify an irrigation landscape capable of sustainably supporting a mine water irrigated cropping system;
- To provide a risk assessment framework that will identify potential key unwanted events that may occur as a result of irrigation with mine water;
- To provide a methodology for identifying constituents of potential concern and determining thresholds for action;
- To provide an integrated monitoring regime 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, to recommend adaptive management strategies to remedy the situation.

This Guideline was compiled using relevant existing information. There may be gaps and omissions, and this document should be reviewed and revised on a regular basis. Authors, the University of Pretoria, and the WRC cannot be held liable for decisions taken based on these guidelines. It is the Guideline user’s responsibility to ensure sound procedures are followed when considering irrigation with MAW, and that the relevant stakeholders and authorities are engaged.

The recommendations in this guideline should be of value regardless of the resource mined and the nature of the MAW. The consideration of site-specific factors is emphasized as key to project success.

ABBREVIATIONS

BPG	Best Practice Guidelines
CoC	Constituents of Concern
DAFF	Department of Agriculture, Forestry and Fisheries
DALRRD	Department of Agriculture, Land Reform and Rural Development
DEA	Department of Environmental Affairs
DEM	Digital Elevation Model
DSS	Decision Support System
DWAF	Department of Water Affairs and Forestry
DWS	Departments of Water and Sanitation
EC	Electrical Conductivity
FFU	Fitness For Use
ISO	International Organization for Standardization
IUA	Integrated Units of Analysis
IWWMP	Integrated Water and Wastewater Management Plan
MAT	Maximum Available Threshold
MAW	Mine-Affected Water(s)
NFEPA	National Freshwater Ecosystem Priority Areas
RQO	Resource Quality Objectives
SABI	South African Irrigation Institute (SA Besproeiings Instituut)
SAPWAT	South African Procedure for determining crop WATer requirements
SAWQI	South African Water Quality guidelines for Irrigation
SPR	Source-Pathway-Receptor
TG	Technical Guidelines
TIL	Total Investigative Level
TMC	Total Metal Content
TMT	Total Maximum Threshold
WMA	Water Management Areas
WQR	Water Quality Requirement
WRC	Water Research Commission
WRRP	Water Reuse and Reclamation Plan

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BACKGROUND

South Africa has been classified as a water scarce country[1,2]. Water is thus at the forefront of decisions made by major government bodies and private sector industries of the South African economy. One of the objectives set out in the Irrigation Strategy for South Africa, is to increase the contribution of irrigated agriculture to food production[3]. The Irrigation Strategy sets out to support initiatives that revitalise irrigation schemes as well as develop new irrigation schemes, but this is constrained by the availability of scarce water resources.

The total land area of South Africa is 122.5 million hectares. Of this, the area used for commercial agriculture is 46.4 million hectares, approximately 38% of the total[4], with around 7.6 million hectares of arable land. The estimated actively irrigated area is 1.4 million hectares, comprising 18% of the arable land, with 6.2 million hectares being rainfed[5] (Figure 1). It is estimated that two thirds of South Africa does not have sufficient rainfall to support dryland agricultural practices[6]. South Africa thus has major scope for irrigated land expansion. Yet, with increasing pressure on South Africa's fresh water availability, alternative water supplies are sought.

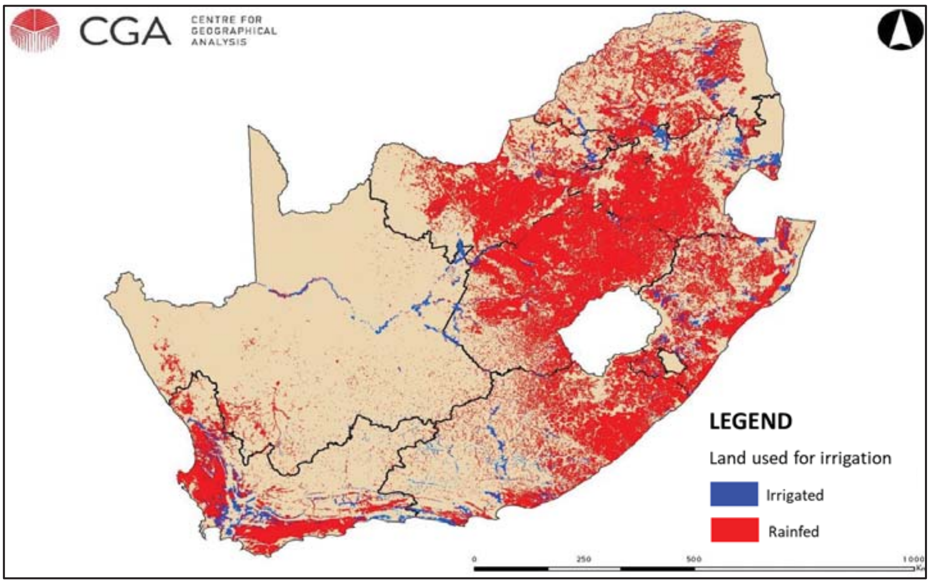


Figure 1: Irrigated and rainfed areas in South Africa[7].

The mining and agricultural industries can be amongst the most lucrative in South Africa, but both are resource input intensive. As both industries use a large amount of water, sustainable use and good governance of this scare resource is crucial. The mining industry negatively affects the quality of large volumes of water, and these need to be treated or productively used. With agriculture requiring large water inputs to improve and optimise yields of crops, a noteworthy opportunity arises. Using mine-affected water of appropriate quality for irrigation should reduce water treatment costs incurred by mines and taxpayers, and an additional and supplemented water supply should contribute to increased agricultural production. However, not all mine-affected waters are suitable for irrigation purposes, thus risk-based approaches and long-term monitoring are imperative for ensuring sustainable irrigation with acceptable environmental impact.

The primary aim with the development of this Technical Guideline is to provide a framework for beneficially using suitable mine-affected waters and soil resources within the agricultural environment, to produce crops sustainably, while limiting environmental impact. All potential risk factors associated with soils, waters and crops irrigated with mine waters should be assessed, to indicate monitoring requirements and to identify means of setting thresholds for action, in order to respond when monitoring indicates constituents of concern are outside acceptable limits. These Technical Guidelines are intended to be a practical reference for all stakeholders, including prospective irrigation water users, and policy and decision makers.

Site-specificity is fundamental when planning, structuring and developing an irrigation scheme of this nature. Mine-affected waters' suitability for irrigation first needs to be determined, as the long-term viability of irrigation hinges on this fitness-for-use determination. Using a locally developed Irrigation Water Quality Decision Support System (DSS)[8], it is possible to model the effect of irrigation management practices with a specific mine-affected water on a specific crop's performance, soil properties and irrigation equipment, thereby indicating whether there are conditions under which the proposed irrigation project is likely to be sustainable in the long-term, or not. The DSS will also facilitate the identification of potential constituents of concern (CoC) in the irrigation water.

Once the water is deemed fit for use for irrigation, an assessment of the proposed irrigated site should be completed. Site selection is essential for ensuring the long-term productivity and environmental sustainability of the irrigation project.

An integrated environmental monitoring programme tailored to the specific site is required to maintain the integrity of the irrigated environment. Monitoring procedures should be chosen according to the identified constituents of concern and their potential impact on environmental receptors (crop, soil and water resources).

Setting constituent thresholds for action ensures that identified constituents of concern in the three receptors of the irrigation site can be controlled before unacceptable environmental harm is caused.

The success of irrigation with mine-affected waters (MAW), will depend on effective communication between MAW users and relevant authorities; continuous, assured mine-water supply (quality and quantity); and regular strategic monitoring of water, soils, and crops.

It is highly recommended to refer to the mining sector resource protection and waste management strategy and operational Best Practice Guidelines (BPG)[9-13] to ensure the mine-affected water irrigation activities are carried out according to the principles set out in these documents. This Guideline assumes that stakeholders looking to irrigate with mine-affected waters will engage with specialists who are competent, and who have the relevant and applicable knowledge to provide technical support for a project of this nature.

The purpose of this Technical Guideline (TG) is:

- To recommend the use of the electronic Decision Support System (DSS) as the assessment tool for risk-based, site specific, irrigation water quality assessments;
- To inform mine-affected water users on site selection considerations before irrigation scheme development commences;
- To identify and determine which constituents of concern (CoC) to consider within the soil, water and crop proximal environments;
- To develop a monitoring plan for the irrigated area for identified CoC;
- To give guidance on the establishment of thresholds for action for identified CoC; and
- In the event that monitoring identifies CoC exceeding acceptable levels, to suggest adaptive management strategies in an attempt to remedy the situation.

These footnotes have bearing on the aforegoing text under the heading **Background**, appearing on pages 1-3:

[1]DWAF. 2004. National Water Resource Strategy. Pretoria, South Africa: Department of Water Affairs and Forestry.

[2]Reinders F. 2010. Contribution of irrigation to stable agricultural production. Agri SA Water Conference, Birchwood Conference Centre, Kempton Park, South Africa.

[3]DAFF. 2015. Irrigation Strategy of South Africa

[4]Census of Commercial Agriculture. 2008. *Agricultural Statistics South Africa.* Statistics South Africa. Available online at http://www.statssa.gov.za

[5] Van der Stoep I, Tylcoat C. 2014. South African irrigation statistics: an analysis of the 2014 WARMS data.

[6]World Wide Fund for Nature. 2018. Agriculture: Facts and Trends, South Africa [online]. World Wide Fund. Available from (http://awsassets.wwf.org.za/downloads/facts_brochure_mockup_04_b.pdf [Accessed 7 August 2020].

[7]Van Niekerk A, Jarmain C, Goudriaan R, Muller SJ, Ferreira F, Munch Z, Pauw T, Stephenson G, Gibson L. 2018. An Earth Observation Approach towards Mapping Irrigated Areas and Quantifying Water Use by Irrigated Crops in South Africa. WRC Report no. TT 745/17. Pretoria: Water Research Commission.

[8]Du Plessis HM, Annandale JG, Benade N, Van der Laan M, Jooste S, Du Preez CC, Barnard J, Rodda N, Dabrowski J, Nell P. 2017. Risk based, site-specific, irrigation water quality guidelines: Volume 1: Description of Decision Support System. WRC Technical Report. No TT 727/17. Water Research Commission. Pretoria.

[9]DWAF. 2006. Best Practice Guideline – H1: Integrated mine water management. Pretoria, South Africa: Department of Water Affairs and Forestry.

[10]DWAF. 2006. Best Practice Guideline – H2: Pollution prevention and minimisation of impacts. Pretoria, South Africa: Department of Water Affairs and Forestry.

[11]DWAF. 2006. Best Practice Guideline – H3: Water Reuse and Reclamation. Pretoria, South Africa: Department of Water Affairs and Forestry.

[12]DWAF. 2006. Best Practice Guideline – H4: Water treatment. Pretoria, South Africa: Department of Water Affairs and Forestry.

[13]DWAF. 2006. Best Practice Guideline – G2: Water and Salt Balances. Pretoria, South Africa: Department of Water Affairs and Forestry.

INTRODUCTION

This Technical Guideline assumes that stakeholders looking to irrigate with mine-affected waters (MAW) will engage with specialists who are familiar with South African mining and environmental legislation applicable to this practice. A separate set of guidelines that focus on attaining regulatory approval for mine water irrigation have been developed by the WRC (TT report 837/20)[14], and this framework should be consulted for policies and regulations surrounding the permitting of irrigation with MAW. Competent, independent professionals should be engaged throughout the feasibility study and decision-making processes of a mine water irrigation project. Identifying and understanding risks and predicting long, -medium and short-term impacts, as well as any suitable mitigation practices, should provide the necessary assurance for project lifespan success.

The goal is sustainable use of irrigation with MAW. Effective collaboration, planning, adaption, and management of resources, is necessary in order to attain sustainability (Figure 2). Identified competent, independent professionals have the necessary academic qualifications, vocational experience and professional registration within the related field, to advise on the technical aspects of an irrigation environment[15]. Engaging with relevant authorities (DWS, DEA, DALRRD) ensures compliance with South Africa's environmental laws and are followed throughout the irrigation project's lifecycle. Site specific environmental risk assessments identify possible hazards and their associated impacts within the irrigation environment. Using the Decision Support System (DSS), in conjunction with site selection procedures, an irrigation environment's suitability can be characterized. Adaptive management and flexibility are required to ensure the irrigation strategy changes according to the needs of the specific irrigation environment. If followed, these listed factors will assist in the development of a sustainable irrigation with MAW project.

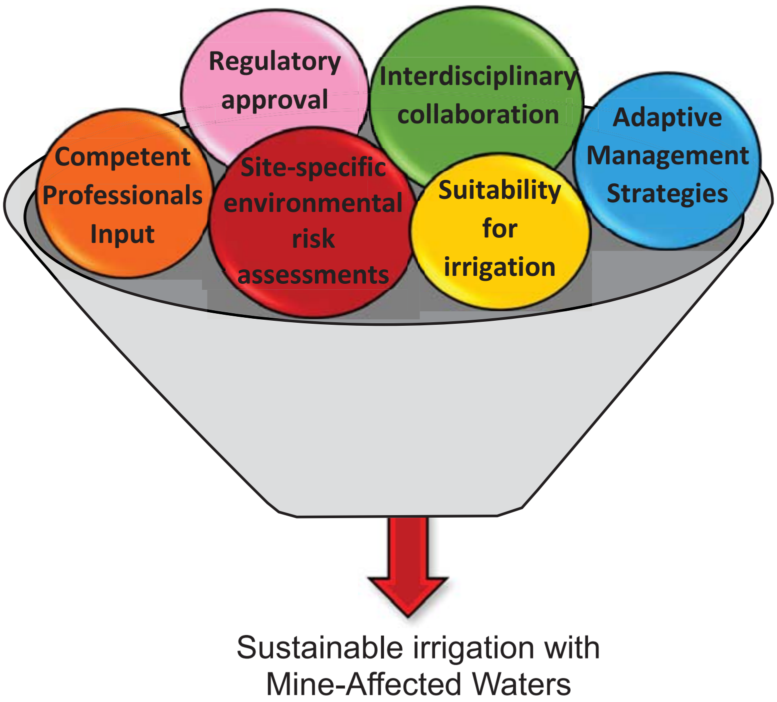


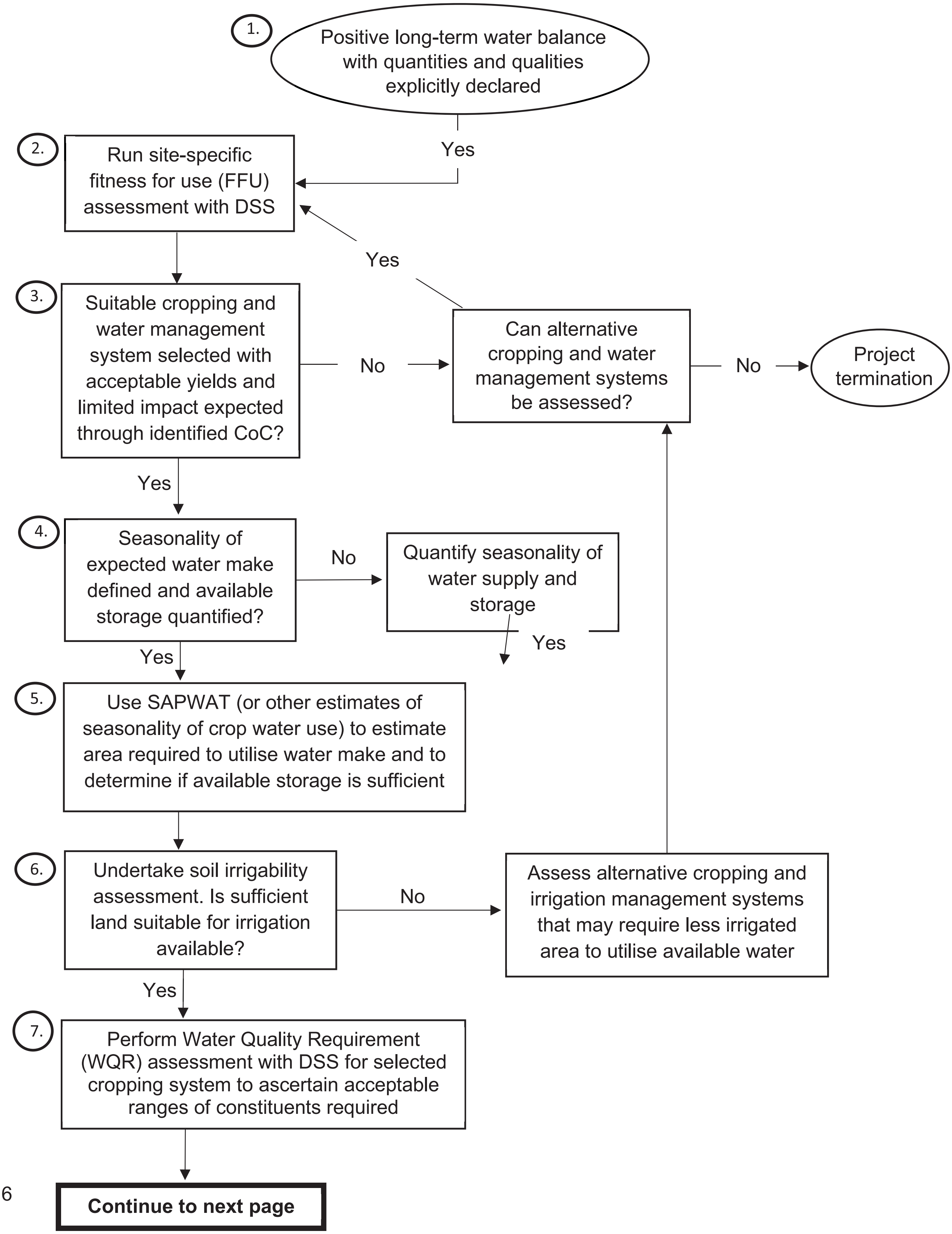
Figure 2: Factors pivotal to project success and sustainable irrigation practices with mine-affected waters.

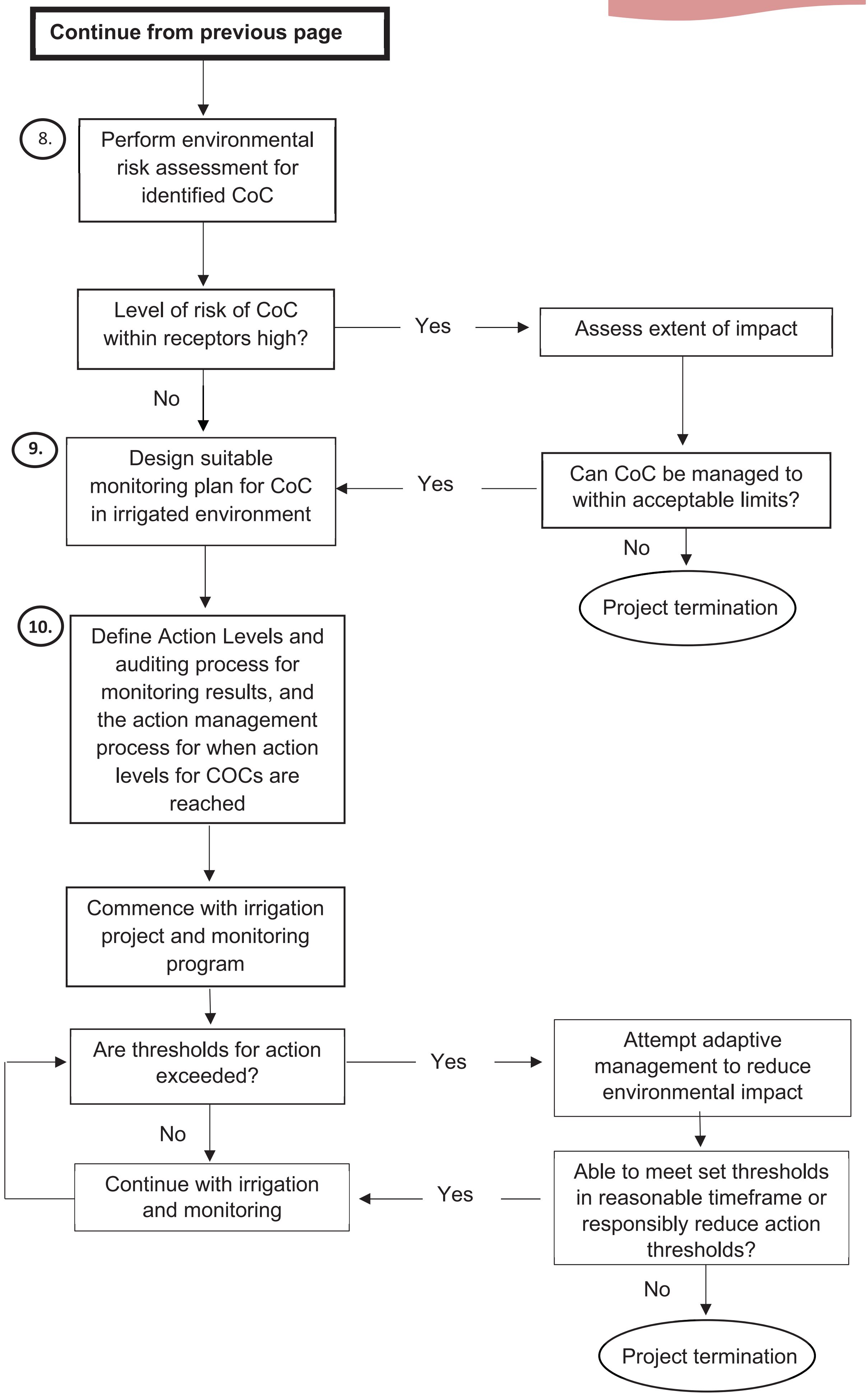
Regardless of geographical region, the resource mined, the mine-affected irrigation water quality and quantity, an integrated framework for evaluating an irrigation with mine-affected water project is required. Using a risk-based management approach should ensure appropriate scientific methods and oversight are employed throughout the irrigation project. A decision tree, which relies on the key points listed below, is suggested as a guide for using mine-affected water for irrigation:

1. Mine has positive long-term water balance with expected quantities and qualities explicitly declared
2. Run Fitness-for-Use (FFU) assessment with Decision Support System (DSS)
3. Establishment of suitable cropping and water management system with acceptable yields and limited environmental impact expected through identified CoC
4. Seasonality of expected water make defined and available storage quantified
5. Use of SAPWAT or other estimates of seasonality of crop water use to estimate area required to utilise water make and to determine if available storage is sufficient
6. Undertake soil irrigability assessment to ascertain if sufficient irrigable land is available
7. A Water Quality Requirement (WQR) assessment with the DSS is completed to indicate acceptable ranges of irrigation water constituents for the proposed irrigation project
8. Environmental risk assessment is performed for identified constituents of concern
9. A subsequent monitoring plan is developed according to the mobility of the identified constituents of concern within receptors (soil, crop and water resources)
10. Action levels are determined for the identified constituents of concern, where applicable, with expert recommendations on adaptive management approaches to ensure project sustainability

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

The following decision tree can be used as a guide on the sequence of steps to take in assessing if mine-water irrigation in a specific setting is feasible:

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8.
Perform environmental risk assessment for identified CoC
Level of risk of CoC within receptors high?
Yes
Assess extent of impact
No
9.
Design suitable monitoring plan for CoC in irrigated environment
Yes
Can CoC be managed to within acceptable limits?
No
Project termination
10.
Define Action Levels and auditing process for monitoring results, and the action management process for when action levels for COCs are reached
Commence with irrigation project and monitoring program
Are thresholds for action exceeded?
Yes
Attempt adaptive management to reduce environmental impact
No
Continue with irrigation and monitoring
Yes
Able to meet set thresholds in reasonable timeframe or responsibly reduce action thresholds?
No
Project termination

These footnotes have bearing on the aforegoing text under the heading **Introduction**, appearing on pages 4-7:

[14]Pocock G, Coetzee L. 2021. Guidance for Attaining Regulator Approval of Irrigation as a Large Scale, Sustainable Use of Mine Water. Water Research Commission Technical Report No TT 837/20, Water Research Commission, Pretoria, South Africa.

[15]Dippenaar MA, van Rooy JL, Breedt N, Huisamen A, Muravha SE, Mahlangu S, Mulders JA. 2014. Vadose zone hydrology: Concept and Techniques. Water Research Commission Technical Report No TT 584-13, Water Research Commission, Pretoria, South Africa.

SECTION A: MINE-AFFECTED WATER

1. WATER BALANCE, QUALITY AND QUANTITY

Mine water characterisation requires the determination of the water chemistry and production volumes a mine is likely to generate over its lifetime and post-closure (Figure 3). Quantifying the characteristics of mine water intended for irrigation use, enables scientifically sound decisions to be made. Geochemical modelling can attempt to predict the long-term water chemistry, and a hydrological model can simulate long-term affected water production volumes. These studies can therefore attempt to predict the magnitude and temporal nature of a mine's potential impact on its proximal receiving environment.

A mine's water balance quantitatively defines hydrological inflow and outflow of a geological unit. Mines with a water surplus or positive water balance are ideal to investigate the potential for irrigation with mine-affected water, as irrigation is a consumptive use of water. Quantifying the volume of water produced, its seasonality and available storage capacity, ensures that a cropping system is selected to best suit the mine's water balance. Knowing the rate of mine water supply, constant or intermittent, in conjunction with an area's rainfall regime, appropriate irrigation scheduling can be recommended to ensure water delivery is tailored to a specific crop's water use. Constant re-evaluation of a mine's water balance is required to ensure water production is correctly predicted, updated and managed, and sufficient water is available for crop production. Many mines do not have accurate or reliable predictions of the volume of water "make" that will emanate from the mine post-closure, and expert assistance is essential to determine this key factor. The selection of crops for tolerance to water quality constituents must be harmonised with crop water requirement and water availability. Provisions must be made for years with above or below average rainfall (additional area for cropping or water storage).

Characterising mine water quality for irrigation entails ascertaining the major and minor anions and cations present in the water. Continuously assessing the quality of mine water ensures predictions can be made of the response of the crops, soil and irrigation equipment to irrigation. It is imperative that mines have characterised their water quantities and qualities as accurately as possible, as all proposed cropping and irrigation management actions are determined using this data in the Decision Support System (DSS) simulations[8]. The DSS should also be used to ascertain appropriate Water Quality Requirements (WQR) of the selected site-specific cropping system, as these represent the ranges of constituents within which the water quality must remain for the selected irrigation project to remain viable.

Appropriate irrigation system design procedures should be followed, that suit the irrigated area and cropping requirements. Consultation with competent irrigation professionals will ensure the irrigation equipment is designed and implemented according to industry standards[16]. Specific attention needs to be paid to the effect of the water quality on irrigation equipment, as mine waters could be scaling or corrosive.

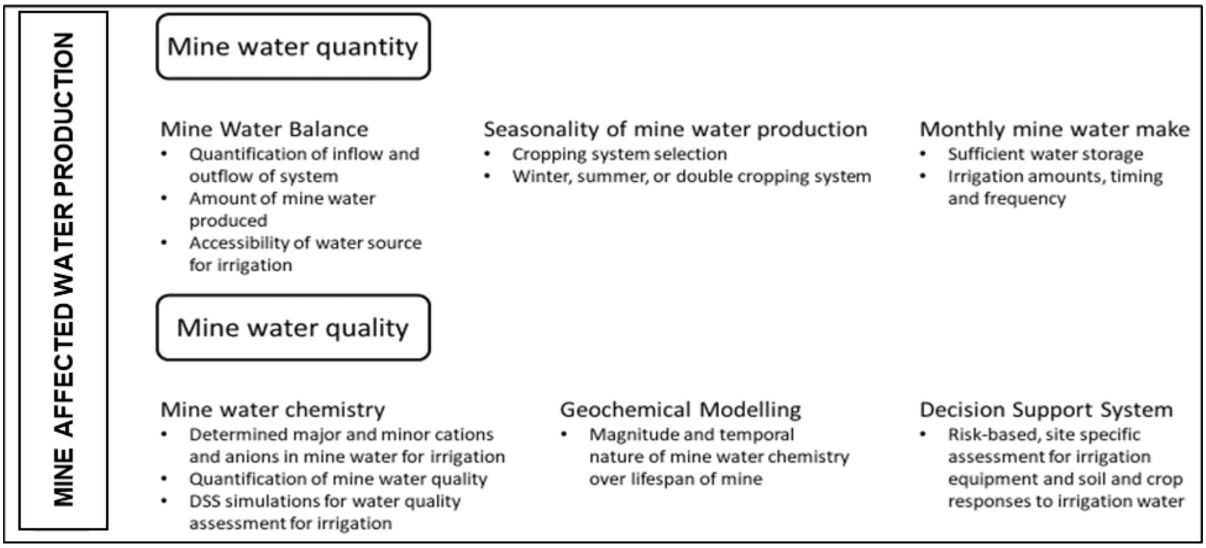


Figure 3: Summary of water and solute balances to consider for mine water irrigation planning.

2. DECISION SUPPORT SYSTEM

A locally developed, software-based, Irrigation Water Quality Decision Support System (DSS), provides site-specific, risk-based guidance on the fitness for use for irrigation of water sources, as well as determining water quality requirements for a specific cropping system and water management approach[8]. The DSS provides irrigation water users with information about the associated risks of using a specific water quality for irrigation, under specific site conditions (climate, soil, crop, water management options), including associated risks for irrigation equipment and soil and crop resources.

The DSS is structured into three tiers. Tier 1 encompasses the generic and conservative 1996 South African Water Quality Guidelines[17] that are likely to be of limited use for poorer quality mine-affected waters. The fitness-for-use (FFU) assessment categorises water constituents into different levels of acceptability and implied risk.

Tier 2 allows site-specificity to be taken into account, with user defined climatic conditions, irrigation management, and selectable soil and crop variables. This is a useful approach to take for the majority of mine-affected waters, as it can assist the user in determining if there are conditions under which a particular mine water is usable for irrigation. Tier 2 permits a more in-depth water suitability assessment than that outlined in the 1996 Irrigation Water Quality Guidelines[17]. Within a given irrigation scenario, specific risks are thus quantified according to the description, consequences, and likelihood that the specific risk would occur.

Where required, in exceptional and ad-hoc circumstances where Tier 2 assessments are inadequate, Tier 3 assessments are indicated. This requires specialised resources and expertise that may not explicitly form part of the DSS.

The decision tree below will guide the water user through the options available in the DSS. Firstly, the user would assess the fitness for use of a particular water. For this, water quality data are required, and to take site specifics into account, a Tier 2 simulation is required. Once a suitable cropping system and irrigation management strategy has been decided upon based on the FFU simulation, the user can run a Water Quality Requirements simulation for these specific conditions, to generate output on the range of water qualities that should be acceptable for this intended use. Tier 2 FFU evaluation and outcome reports indicate the fitness-for-use, and the expected impact of a specific water quality, on crop yield and quality, soil quality, and irrigation equipment, for a specific location. The DSS can also supply additional information if required.

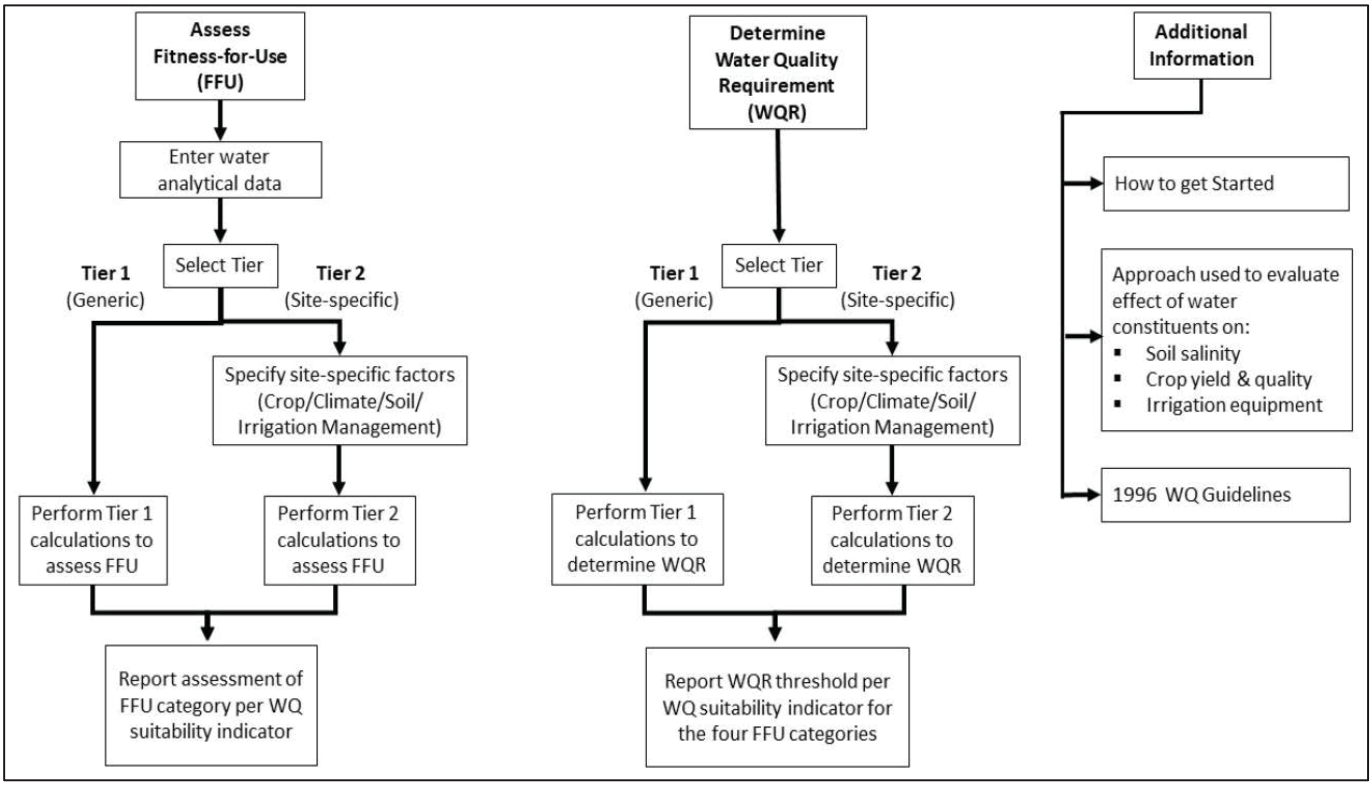


Figure 4: The structure of the Decision Support System (DSS) when assessing the suitability of water for irrigation.

Figure 5 presents the water quality input screen, where the minimum user defined inputs are indicated as the major cations and anions, as well as pH and electrical conductivity (EC). However, for mine water, it will also be essential to enter key trace elements present in the water, and possibly nutrients. This will assist in the identification of potential constituents of concern. The input screen shown in Figure 6 is used to define site-specific conditions.

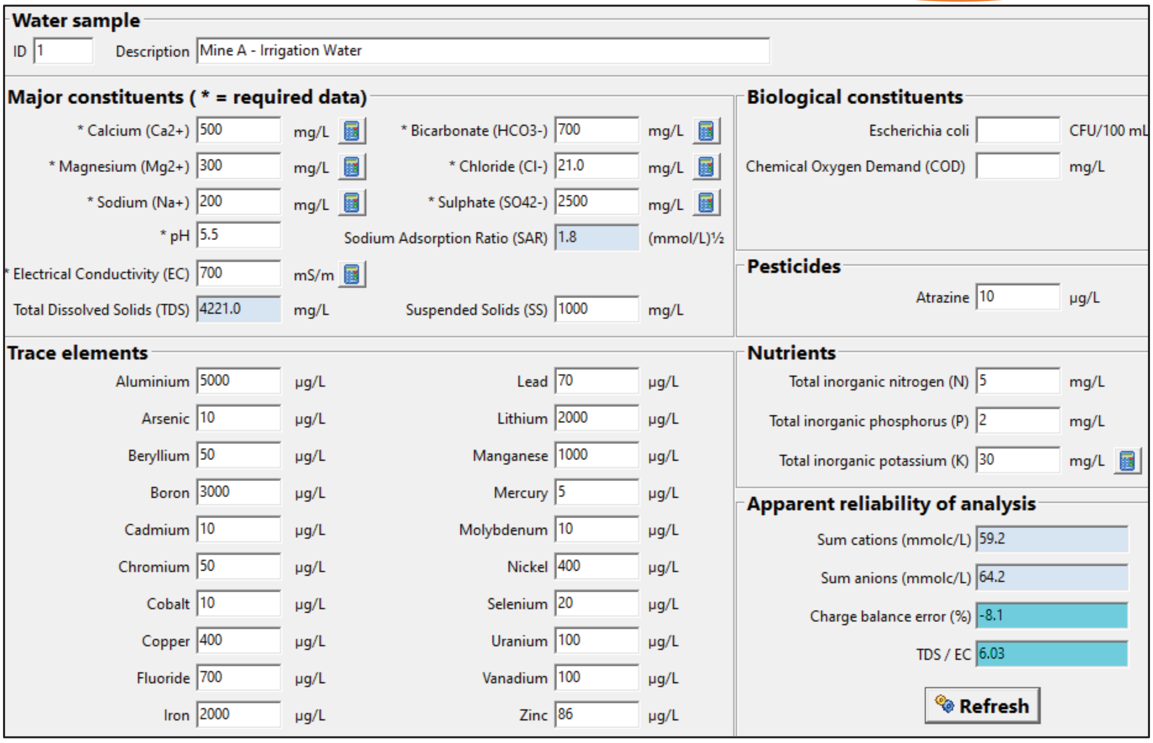


Figure 5: The water quality input screen as seen in the DSS.

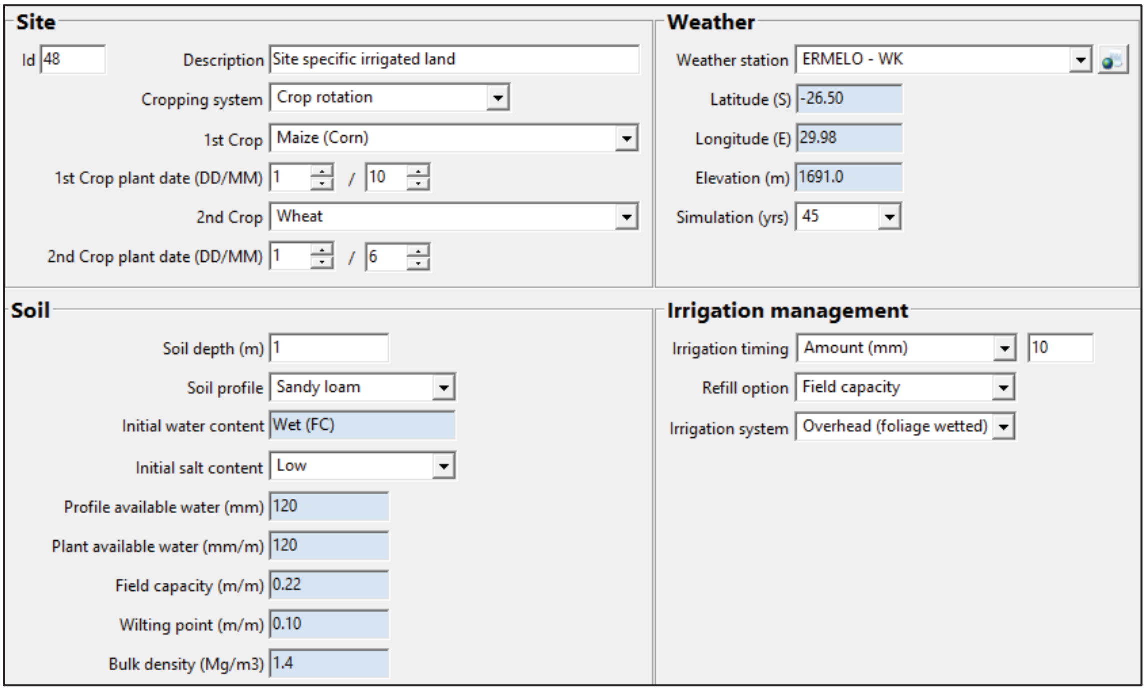


Figure 6: The input screen where site specific details are selected.

Colour coded classification of the water quality categorises the fitness-for-use into four classes, corresponding to the increased level of risk (Table 1). These four FFU suitability categories and their accompanying colour schemes, are consistently used throughout the DSS.

Table 1: A general description of the DSS fitness-for-use categories for water quality.

Fitness for use category	Description
Ideal	A water quality that would not normally impair the fitness of the water for its intended use
Acceptable	A water quality that would exhibit some impairment to the fitness of the water for its intended use
Tolerable	A water quality that would exhibit increasingly unacceptable impairment to the fitness of the water for its intended use
Unacceptable	A water quality that would exhibit unacceptable impairment to the fitness of the water for its intended use

The DSS reports the following suitability indicators to assess the impact a water quality may have on the soil quality, crop yield and quality, and irrigation equipment:

- Soil quality – Soil Profile Salinity, Soil Permeability, Oxidizable Carbon Loading, and Trace Element Accumulation
- Crop Yield and Quality – Root Zone Effects on Yield, Leaf Scorching when wetted, Contribution to NPK Removal, Microbial Contamination and Qualitative Atrazine Damage
- Irrigation Equipment – Corrosion or Scaling, and Clogging of Drippers

All further information regarding the DSS, description and setup (Volume 1)[8] as well as the technical support document (Volume 2)[18] can be found on the WRC's website, http://www.wrc.org.za/wp-content/uploads/mdocs/TT%20727-17.pdf. The DSS is known as SAWQI (South African Water Quality for Irrigation), and can be downloaded from the NB Systems' website, www.nbsystems.co.za.

The DSS is a unique and appropriate tool for the assessment of mine-affected waters for irrigation. As not all mine-affected waters are suited for irrigation under all conditions, the DSS enables one to ascertain how site-specific factors influence the suitability of a specific water for irrigation. Assessing under what conditions a mine-affected water may be suitable for irrigation using the DSS, is a crucial first step in order to design a sustainable irrigation project. The Water Quality Requirement (WQR) functionality of the DSS can then be used for this site-specific situation to determine the ranges within which water constituents need to fall for the sustainability of the proposed cropping system. This information will be very useful for a water user to gain regulatory approval and for ensuring sustainable irrigation practices.

These footnotes have bearing on the aforegoing text under the heading **Section A: Mine Affected Water**, appearing on pages 9-13:

[16]SABI South African Irrigation Institute. 2017. SABI Norms for the design of irrigation systems.

[17]South African Water Quality Guidelines. 1996. Volume 4: Agricultural Use: Irrigation, Second Edition. Department of Water Affairs and Forestry, Pretoria, South Africa.

[18]Du Plessis M, Annandale J, Benade N, Van Der Laan M, Jooste S, Du Preez C, Barnard J, Rodda N, Dabrowski J, Nell P. 2017. Risk based, site-specific, irrigation water quality guidelines: Volume 2: Technical Support. WRC Technical Report. No TT 728/17. Water Research Commission, Pretoria.

SECTION B: SITE SELECTION

1. INTRODUCTION

South Africa's irrigation footprint is limited by water scarcity, making alternative water sources such as mine-affected water, an invaluable and viable irrigation water source. Dryland fields and appropriately rehabilitated fields in close proximity to mine water sources could use this additional water in the rain-fed growing season, as well as to produce crops in the dry season. The yield potential of such areas is expected to increase dramatically, with subsequent growth in the local economy, and benefit to water users and the surrounding community.

When identifying areas for irrigation with mine water, an integrated and multi-disciplinary approach to site selection is required. Not only does the soil profile need to be irrigable, but the position in the landscape and proximal environment is important when selecting a suitable site. Although many mine waters suitable for irrigation are gypsiferous in nature, not all of the salt in the irrigation water will precipitate as gypsum in the soil profile. For irrigation to be sustainable, salts not precipitating need to be leached from the root zone. The fate of solutes passing through the soil profile, should be predicted, and the impact determined to be acceptable for the project to continue. For irrigation with mine-affected waters, the water logging and salinization risk also determines the suitability of an area of land for this type of water use. Areas that are susceptible to salinisation, and have a high potential to affect the surrounding natural environment, should be identified and excluded from consideration. Alternatively, mitigation measures must be put in place for improved drainage, and if necessary, interception and management of solutes leaving the field.

Identifying risks and conducting a comprehensive site risk assessment should ensure the selection of an environmentally sustainable irrigation site, if sufficient detail and insight is acquired during the execution of the site selection processes listed below.

Determining the agricultural potential of land and ensuring on-site conditions and positioning within the surrounding environment are appropriate for irrigation, provides a scientifically sound basis for site selection. A source - pathway - receptor (SPR) analysis should be employed to assess the risks, susceptibility and capacity of an environment to receive mine-affected water through irrigation[19].

2. SOIL IRRIGABILITY

Not all soils are suitable for irrigation, and characterising the soil is essential for determining irrigability. It is highly recommended that a qualified professional soil scientist be consulted when determining the suitability of land for irrigation.

The following factors can be used to determine land suitability for irrigation[20,21]:

- Effective soil depth
- Internal soil profile drainage
- Surface drainage

Effective Soil Depth

Determining the potential rooting depth of the soil profile throughout the irrigated area ensures sufficient soil is available for root development, nutrient uptake, water storage capacity and adequate drainage.

Soil Profile Internal Drainage

Many mine waters are gypsiferous, and this presents the opportunity to precipitate gypsum in the soil profile, thereby reducing soluble salt load on the water environment. However, irrigation is not sustainable if excess soluble salts cannot be leached from the profile. A number of considerations are involved in assessing the internal drainage ability of a soil profile:

- Identifying if there are any limiting layers present in the soil profile throughout the irrigated area.
- Identifying whether such limiting layer(s) would inhibit root growth and development and restrict crop production.
- Identifying the extent to which limiting layer(s) restrict drainage and whether the soil profile is at risk of water logging or salinisation.
- Determining the soil's infiltrability and permeability to indicate if drainage problems are likely to arise, and if any mitigation measures should be implemented.

Surface Drainage

Determining the uniformity of the slope of the land allows for inferences to be made on potentially problematic ponding areas, run-off, recharge, and erosion rates, as well as assisting with irrigation system design. This is important for planning for mitigation measures, if applicable, to be implemented to lower the risk of soil material losses, water logging, and salinisation of the irrigated land.

An irrigable soil classification (Table 2) broadly groups soils into three irrigation categories, **irrigable, conditionally irrigable and non-irrigable[20,21].** Irrigable soils can generally be irrigated under most conditions. Conditionally irrigable soils may have some limitations, require a higher degree of management, and introduction of supplemental surface or subsurface drainage may be necessary. Irrigation of non-irrigable soils may cause further soil degradation and soil productivity loss, and mitigation measures would have little to no effect.

Table 2: Irrigable soil classification[20,21].

	Irrigable	Conditionally irrigable	Non-irrigable
Soil depth	> 750 mm	500 – 750 mm	< 500 mm
Soil profile drainage			
Limiting layer occurrence	Little to none	Slight	Dominant
Restriction to root growth	Low to none	Slight restriction	Severe
Risk of water logging	Low to none	Possible	Severe
Risk of salinization	Low to none	Possible	Severe
Surface drainage			
Slope	Little to none	Gentle	Steep and/or undulating
Risk of surface ponding	Low to none	Slight	Severe

Site considerations where irrigation with mine-affected waters may not be permissible:

- Environmentally sensitive areas which are susceptible to water pollution (below 1:100-year flood line, wetlands, vleis, pans and flood plains)
- Areas where groundwater recharge is great and shallow water tables exist
- Areas of steep slopes where slope stability, run-off and soil erosion are problematic
- Areas of consistent or intermittent ponding or water logging
- Protected areas or proclaimed national parks (natural habitats of endangered plant or animal species)
- Areas of instability (dolomitic or karst areas where subsidence or sinkholes are prevalent, seismic or fault zones)

Irrigation with mine-affected waters in such areas may be reconsidered if the water user can prove there are adequate mitigation measures in place to alleviate any unacceptable, potentially negative effects.

The following spatial analysis tools can be used to assist in assessing site suitability for irrigation:

- Land capability assessment [22]
- Digital elevation models (DEM)
- National hydrogeological overview map series[23]
- National web-based environmental screening tool[24]
- National Freshwater Ecosystem Priority Areas (NFEPA)[25]

It is recommended that if specialised studies are to be performed, professional hydrogeologists, soil scientists, agriculturists and environmental practitioners should be consulted. As part of the responsibility of the water user, should there be any environmental concerns raised during site selection, in accordance with national legislation, appropriate authorities need to be consulted and measures put in place to ensure sustainability, before implementation of the irrigation project.

These footnotes have bearing on the aforegoing text under the heading **Section B: Site Selection**, appearing on pages 14-16:

[19] Sayers PB, Gouldby BP, Simm JD, Meadowcroft I, Hall J. 2002. Risk, performance and uncertainty in flood and coastal defence - A review, Defra/Environment Agency report no. FD2302/TR1 SR587, HR Wallingford Ltd, UK.

[20] US Bureau of Reclamation. 2005. Technical Guidelines for Irrigation Suitability Land Classification. Technical service centre, Land Suitability and Water Quality Group, Denver, Colorado.

[21] Scherer, T. 2018. Compatibility of North Dakota Soils for Irrigation. North Dakota State University Extension, Fargo, North Dakota

[22] DAFF. 2016. Draft Framework Policy and Bill on the Preservation and Development of Agricultural Land.

[23] DWAF. 2003. 1:500 000 Hydrogeological map series: Groundwater quality, expected borehole yield and aquifer type. Groundwater Resource Assessment. Department of Water Affairs, Pretoria.

[24] DEA. 2017. National Environmental Screening Tool. Department of Environmental Affairs, Pretoria.

[25] SANBI. 2011. National Freshwater Ecosystem Priority Areas Project (NFEPA). Department of Environmental Affairs, Pretoria.

SECTION C: ENVIRONMENTAL RISK ASSESSMENT

1. INTRODUCTION

The risk assessment process should follow the International Standard (ISO 31000:2018) Risk Management Principles[26]. Risk assessments should be regularly revised and updated as the project progresses to ensure stated risks are continuously reviewed as more data is received to validate the models used to predict impacts. The international standard recognises five steps to be undertaken in the risk management process. These are:

Setting the context;
Risk identification;
Risk analysis;
Risk evaluation; and
Risk treatment.

These five steps are then linked by monitoring back to the context setting, so that this is a continuously repeating cycle of determining risk levels and identifying appropriate risk mitigation strategies. Undertaking a risk assessment requires the assembly of an appropriately skilled technical team, with representatives of the irrigation project management team and the use of a trained facilitator, in order to ensure that the outcome accurately reflects the true “unwanted events” (risks) that face the project, and identifies appropriate control measures that are simple, measurable and implementable.

In addition to the evaluation of internal risks associated with soil, water and crop variables, the risk assessment must also focus on risks posed by management and external issues. Competency of irrigation project staff, availability of long-term expert supervision, risks associated with climatic damage, crop harvesting, marketing, crime and the socio-economic status of surrounding communities, will all be factors which should be fully evaluated in the risk assessment process for any irrigation project. Although the formal risk assessment process for a proposed irrigation project should encompass all the above issues, this should be effectively managed by carefully following ISO 31000 (2018) principles, and accordingly, the detail of this will not be covered further in this guideline.

The remainder of this section on risk assessment will focus on the requirements to identify unwanted events related to the impacts of particular constituents of concern in the irrigation water, and how they can be expected to interact with the site environment. Effective environmental risk assessment for mine water irrigation is essential when looking to determine an acceptable impact level a constituent may have on the receiving environment (soil, crop and water resources). Categorising and prioritising on-site irrigation constituent risks, ensures that applicable mitigation strategies can be developed and employed.

The following steps can be used when determining potential constituents of concern, their impact, and whether a monitoring plan and threshold levels for action are necessary:

- From DSS output reports, identify which constituent(s) have been highlighted as potentially problematic, tolerable or of an unacceptable level
- Distinguish which constituents identified are mobile, and which receptor(s) (soil, crop and water resources) would be impacted (environmental risk matrix)
- Characterise the constituents which would have greater impacts on the receptors, and devise monitoring requirements and a plan to observe and detect changes in the receptors
- Define logical threshold levels and monitoring locations based on identified CoC environmental mobility

2. CONSTITUENTS OF CONCERN

2.1 Identification of CoC

Constituents of concern (CoC) can be identified in the soil quality, and crop yield and quality outcome reports obtained from the DSS simulations. Constituents of concern can be identified as higher risk if highlighted as tolerable or unacceptable fitness for use in the DSS reports. At the discretion of a competent agriculturist, soil scientist or environmentalist, with relevant expertise, some constituents that are deemed tolerable or unacceptable in the DSS reports, may be deemed of low risk on site, with sufficient justification (Tier 3 assessment). Once a list of constituents of concern has been made, the risk to the receptors can then be determined.

2.2 Receptors of CoC

The source-pathway-receptor (SPR) system describes the movement of constituents from the irrigation water (source) through pathways to the receiving environments (soil, crops, water resources)[27]. Identifying in which realm specific CoC may have their greatest impact and effect, assists in determining the risk a constituent may pose to receiving environments.

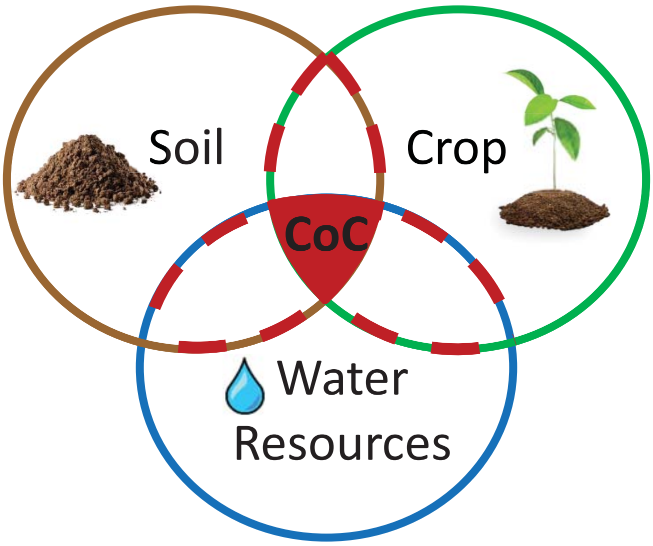


Figure 7: Three potential receptors of a constituent of concern CoC, in an irrigated environment.

2.3 Characterisation of CoC

Characterising the risk a constituent may pose to each receptor will guide the water user, consultants and relevant authorities, with regard to necessary monitoring plans or thresholds for action that should be put in place. Appropriate techniques for impact prediction on water resources can be found in DWAF's Best Practice Guideline (G4)[28]. Tables 3 to 5 can be used to determine the mobility, the expected extent of the impact the constituent(s) of concern may have on receiving environments (soil, crops, water resources), and the level of risk associated with each constituent.

Table 3: Levels of mobility of constituents in the receiving environment.

Mobility	
Mobile	Constituent is **present** in the receptor
Considerably mobile	Constituent is **likely** to be present in the receptor
Marginally mobile	Constituent is **unlikely** to be present in the receptor
Immobile	Constituent is **not present** in the receptor

Table 4: Levels of impact constituents may have on the receiving environment.

Impact	
Severe	Presence of constituent causes **permanent** damage to receptor
High	Presence of constituent causes **impairment** to receptor
Medium	Presence of constituent causes **slight changes** to receptor
Low	Presence of constituent causes **little** damage to receptor

Table 5: Example of how to characterise a constituent's risk to receiving environments.

Example: Iron	Soil	Crop	Water resources
Mobility	Immobile	Marginally mobile	Marginally mobile
Impact	Low	Low to medium	Low
Risk level	Low	Medium	Low

Constituents deemed as low risk to the receptors (soil, crop and water resources) can be seen as being of an acceptable impact, and should not require additional monitoring. Constituents deemed as medium to high risk may require further investigation as to the extent of impact, and appropriate monitoring regimes and thresholds for action must be determined on a site-specific basis.

These footnotes have bearing on the aforegoing text under the heading **Section C: Environmental Risk Assessment**, appearing on pages 18-20:

[26]ISO. 2018. International Standardization Organization (ISO) 31000: 2018, Risk management – Principles and Guidelines (English).
[27]DWS (Department of Water and Sanitation). 2017. Water Quality Management Policies and Strategies for South Africa. Report No. 2.2 Integrated Water Quality Management (IWQM) Policy. 2nd ed. Water resource planning systems series, DWS Report No.: 000/00/21715/13. Pretoria.
[28]DWAF. 2008. Best Practice Guideline – G4: Impact Prediction. Pretoria, South Africa: Department of Water Affairs and Forestry.

3. MONITORING PLAN

A plan should be set up to monitor any constituents of concern, and other potential "unwanted events" that have been identified in the risk assessment. Constituents of concern may affect one, two or all of the receptors (soil, crop and water resources) in an irrigated environment. The level of risk a constituent of concern may have on a receptor will determine the intensity and frequency of monitoring required. The following is a recommended approach to designing and implementing an environmental monitoring plan for constituents of concern when irrigating with mine-affected waters:

1. **Design** - State constituents of concern to be monitored.
   Define correct chemical state of constituent to be monitored (e.g. Fe^{2+}, Fe^{3+}, Total Fe)
   <u>Questions to be asked in order to establish a representative monitoring plan are*:</u>
   What receptors (soil, crop, water resources) need to be monitored on-site?
   How often and for how long do these receptors need to be monitored?
   What monitoring or sampling method will be employed for this specific receptor?
   *(dependent on constituents' mobility, impact and risk level it imposes on receptors).

   This stage entails identification of the locations and density of the monitoring stations, as well as the frequency and timing of sampling of on-site soil, crop and water resource receptors.

2. **Appraisal** – Relevant interested and affected parties should have an opportunity to review the final monitoring plan design.

3. **Implementation –** Persons responsible for each aspect of the monitoring plan should be identified and have the necessary qualification to perform the monitoring task. Necessary equipment should be acquired and made freely available to the persons tasked with monitoring. Easy access to the irrigation site for data collection by monitoring personnel must be ensured.

4. **Data collection** - Correct sampling strategies should be followed in order for the data to be accurate and representative. The frequency and timing of sampling should be strictly adhered to, to ensure compliance with set monitoring requirements. Monitoring quality control measures should be applied continuously to ensure the integrity of the dataset.

5. **Data analyses** – Samples collected from the irrigated fields and the environment in close proximity to the site need to be analysed, correctly evaluated and interpreted. Data should be presented in a form that allows decision makers to easily understand and interpret the monitoring results.

6. **Continual review of monitoring system** - The monitoring plan and the quality of the results obtained should be audited regularly to ensure that the irrigation plan has been implemented and is achieving the set objectives. The audit should identify any limitations to current monitoring protocols or opportunities for improvement to the monitoring system or to the irrigation.

7. **Auditing** - The audit report should be sent to the person directly responsible for the implementation of the irrigation project, and to the responsible government departments, so that informed decisions can be made regarding the continuation of the project. The information and trends documented on the state of the irrigated area and surrounding environment, as obtained from the monitoring data, can be used to refine site-specific thresholds for action. Communication of the information to relevant water resource managers and decision makers should ensure a sound and continuous strategy is employed on a general and site-specific level, for on-going, sustainable irrigation.

The environment is dynamic and in a constant state of flux, therefore the applicability of an irrigation project plan and its monitoring protocol, needs to be constantly reviewed. Developing a monitoring plan is highly dependent on site-specificities. As South Africa's geology, soils, hydrology, and climate vary greatly, there is no one size fits all approach to implementing a monitoring plan. More information regarding water management monitoring plans can be found in DWAF's Best Practice Guideline (G3)[29]. Competent persons should be employed to carefully develop and evaluate the design and applicability of any monitoring plan to be implemented on an irrigation site.

[29]DWAF. 2007. Best Practice Guideline – G3: Water Monitoring Systems. Pretoria, South Africa: Department of Water Affairs and Forestry.

4. ACTION LEVELS

Thresholds for action are upper limits or tolerance levels set for an environment to ensure the water use activity does not unacceptably degrade the physical, chemical or biological status of the irrigated area and its surrounding environment.

4.1 Water and Soil Trace Element Thresholds

The 1996 South African Irrigation Water Quality Guidelines[17] set out maximum concentrations and threshold levels for irrigation water qualities and irrigated soils, with these being conservative and protective levels to ensure limited environmental degradation would occur (Table 6). These can be used to develop initial guidelines for action levels; however, they are likely to result in an excessively conservative approach. Ongoing research should permit a better understanding of soil, crop and drainage waters' ability to tolerate higher loadings of certain key elements (Fe, Mn, Al in particular) than is currently postulated in the 1996 guidelines.

As trace element loading is of concern in a large majority of mine-affected waters in South Africa, it is currently deemed appropriate to have thresholds for action for trace elements when looking to irrigate with waters rich in them. The 1996 South African Irrigation Water Quality Guidelines used a very similar approach, with minor modifications made to guidelines developed by the US EPA (US Environmental Protection Agency, 1973), for deriving irrigation water quality and soil accumulation thresholds for trace elements. The maximum acceptable soil trace element accumulation concentrations set in the 1996 South African Irrigation Water Quality Guidelines, were calculated assuming soils are irrigated for 100 years at an irrigation application rate of 1000 mm p.a., at an effective soil depth of accumulation of 150 mm and a soil bulk density of 1333 kg/m^3. A more lenient short-term standard was derived by assuming irrigation of up to 20 years on "forgiving soils", fine-textured calcareous or neutral to alkaline soils. Tier 1 DSS simulations consider exceedance of the maximum acceptable soil trace element accumulation concentrations set in the 1996 South African Irrigation Water Quality Guidelines over a period of irrigation for 100 years or less, as unacceptable, and accumulation over a period of 200 years or more as the ideal. It does not provide for the more lenient short-term standard for periods up to 20 years (Table 6). Tier 2 DSS simulations use the same criteria as Tier 1, but provide for considering a soil's background trace element concentration, and calculating the trace element accumulation from the actual irrigation application and a soil bulk density derived from the chosen soil texture. Site-specific threshold for action limits should be investigated and determined by competent professionals using specialised Tier 3 investigations, if Tier 2 output appears to be overly protective of the environment. This is especially likely in the case of mine waters rich in the trace elements Al, Fe and Mn, as these trace elements are abundant in natural soils, and unlikely to be of concern in limed and well-aerated soils that will be encountered with productive irrigated systems, as such environments will typically render these elements insoluble. For these reasons, excluded Al and Mn from their list of recommended maximum concentrations of trace elements in irrigation waters.

With the wide range of geologies, soils and hydrological regimes present throughout South Africa, and the corresponding wide differences in natural background levels of inorganic constituents in soils and waters, the environments receiving irrigation will vary greatly, and applying a rigid blanket approach to trace element thresholds for action seems inappropriate. Quantifying the load a specific irrigation environment can receive, will assist in setting site-specific threshold levels for on-site soil and water resources.

Site-specific thresholds should be determined for each site, because each site has different abilities to sequester COC. For instance, the quaternary sands of the Sandveld, West Coast region of South Africa and the high potential clay-loam soils of the Mpumalanga region would have a radically different reaction to certain metals of concern. Setting the same threshold limits for both these regions would be inappropriate, as the irrigated environments would manage the load from irrigation waters in completely different ways due to their unique soil properties. It is recommended that a revised irrigation water quality guideline be developed which accounts for the natural background soil and water concentration levels found in South African.

Table 6: The maximum acceptable trace element content of irrigation water for short (20 years) and long (100 years) term use, and corresponding concentrations and loads of trace elements in soil[17].

Trace element	1996 SA Irrigation Water Quality Guidelines		Concentration in irrigated soil		Load applied to irrigated soil	
	100 years	20 years	100 years	20 years	100 years	20 years
	mg/L		mg/kg		kg/ha	
Aluminium	5.0	20.0	2500	2000	5000	4000
Arsenic	0.1	2.0	50	200	100	400
Beryllium	0.1	0.5	50	50	100	100
Boron	0.5	Vary	250	-	500	-
Cadmium	0.01	0.05	5	5	10	10
Chromium (VI)	0.1	1.0	50	100	100	200
Cobalt	0.05	5.0	25	500	50	1000
Copper	0.2	5.0	100	500	200	1000
Fluoride	2.0	15.0	1000	1500	2000	3000
Iron	5.0	20.0	2500	2000	5000	4000
Lead	0.2	2.0	100	200	200	400
Lithium	2.5	-	1250	-	2500	-
Manganese	0.2	10	100	1000	200	2000
Mercury	0.002	-	1	-	2	0.4
Molybdenum	0.01	0.05	5	5	10	10
Nickel	0.2	2.0	100	200	200	400
Selenium	0.02	0.05	10	5	20	10
Uranium	0.01	0.1	5	10	10	20
Vanadium	0.1	1.0	50	100	100	200
Zinc	1.0	5.0	500	500	1000	1000

Thresholds for action and values for trace elements in soil irrigated with mine-affected waters have been adapted from the 1996 Irrigation Water Quality Guidelines[17] and the Guidelines for the Utilisation and Disposal of Wastewater Sludge, Volume 2: Requirements for the agricultural use of wastewater sludge[30]. The method presented in the Wastewater Sludge Guidelines, is to define a Total Investigative Level (TIL), which is a 30% reduction in the concentration of the Total Maximum Threshold (TMT) of trace elements in the soil. A conservative estimate of 2.5% of the Total Maximum Threshold (TMT) determine the Maximum Available Threshold (MAT) (in mg/kg) of trace elements in the soil[30]. This approach has been extended here to include elements in the published irrigation water quality guidelines (Table 7).

Soil properties influence the solubility of trace elements, and are important indicators of their plant-availability. Total trace element concentration is not the best indicator of trace element plant-availability due to numerous factors. These factors include, but are not limited to, pH, adsorption-desorption reactions, chemical complexation, redox reactions, organic and inorganic ligands, humic and fulvic acids, root exudates, and microbial metabolites[31]. Due to the large number of factors influencing availability, and their considerable spatial and temporal variability in field conditions throughout South Africa, the set threshold limits are tentative and should be assessed on a site-specific basis, by competent agricultural professionals.

The following procedure can be followed when evaluating trace element concentrations in soils irrigated with mine-affected waters:

1. The Total Metal Content (TMC) of the soil should first be determined using the aqua regia extraction method (Appendix 1). Compare these results with Table 7.
2. If the TMC is less than the Total Investigative Level (TIL) then irrigation can continue with soil analyses required after 5 years.
3. If the TMC is above the Total Maximum Threshold (TMT) then irrigation should be terminated[30].
4. If the TMC is above the TIL but below TMT, the mobility and plant available portion of the trace element(s) in the soil needs to be assessed. The available metal content of the soil is determined using the NH_4NO_3 extraction method (Appendix 2).
5. If the available trace metal content of the soil is less than the Maximum Available Threshold (MAT), then irrigation can continue with soil analyses required after 2 years. This 2-year soil monitoring period ensures the available trace metal content remains below the MAT[30].
6. If the available trace metal concentration in the soil exceeds the TMT or the MAT, then irrigation with mine-affected waters should cease.

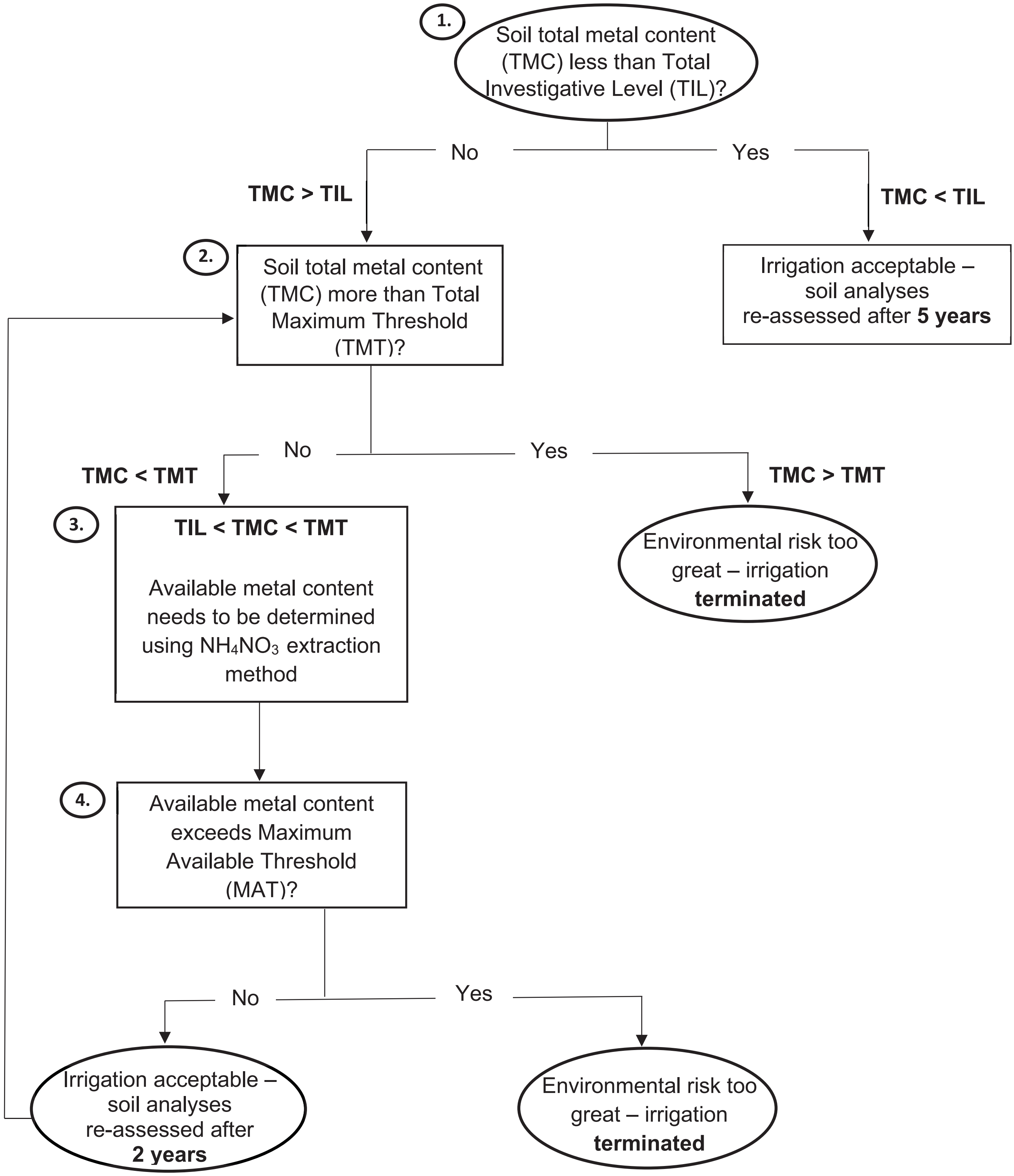
Table 7: Trace element limits for soils irrigated with mine-affected waters[30].

Element	Total Investigative Level (TIL) (Aqua Regia)	Total Maximum Threshold (TMT) (Aqua Regia)	Maximum Available Threshold (MAT) (NH_4NO_3)
	mg/kg		
Aluminium	1610	2300	57.5
Arsenic	85	120	3
Beryllium	35	50	1.25
Boron	175	250	6.25
Cadmium	3,5	5	0.125
Chromium (VI)	53	75	1.9
Cobalt	193	275	6.9
Copper	200	300	7.5
Fluoride	875	1250	31.25
Iron	1750	2500	62.5
Lead	105	150	3.75
Lithium	455	650	16.25
Manganese	700	1000	25
Mercury	0.7	1	0.025
Molybdenum	3.5	5	0.125
Nickel	105	150	3.75
Selenium	5.6	8	0.2
Uranium	5.6	8	0.2
Vanadium	53	75	1.9
Zinc	350	500	12.5

These soil thresholds and suggested monitoring programmes can be used as a reference when determining maximum permissible concentrations in soils irrigated with mine-affected waters. With the application and adjustment of these thresholds and monitoring regime on a site-specific basis, a database of the applicability of these stipulated thresholds for action can be established in South Africa, and a local knowledge base developed. Again, it is noted that due to the wide range of geologies, soils and hydrological regimes present throughout South Africa, these thresholds should therefore be adapted on a site-specific basis.

With the generation of new information regarding the capacity of South African soils to receive constituent loading, thresholds for action and monitoring regimes for soils should be updated

The decision tree below can be used as a guide for determining the thresholds for action, and soil monitoring regime for trace elements in a soil irrigated with mine-affected waters. The limits are for the irrigated soils[30]:



4.2 Water Resource Thresholds

The Decision Support System (DSS) models the fitness for use and effect of a specific water quality on irrigation equipment and soil and crop resources. The DSS does not model the impact an irrigation water has on the water quality of proximal ground and surface water resources.

The Department of Water and Sanitation (DWS) has developed a catchment and resource directed approach to water quality, with the sole goal being the sustainable use and responsible management of surface and ground water resources[32,33]. DWS has generated classes and resource quality objectives (RQO) of significant water resources (rivers, dams, estuaries, and groundwater) within several catchments throughout South Africa. Integrated Units of Analysis (IUA) have been delineated within various Water Management Areas (WMA), that classify the extent of permissible utilization and protection of water resources. RQOs have been defined for each IUA in terms of water quantity, quality, habitat and biota[34]. Various indicators and RQO numerics are set out for the respective water resources within each quaternary catchment and IUA, these values have been deemed critical to ensure the protection and maintenance of aquatic ecosystems.

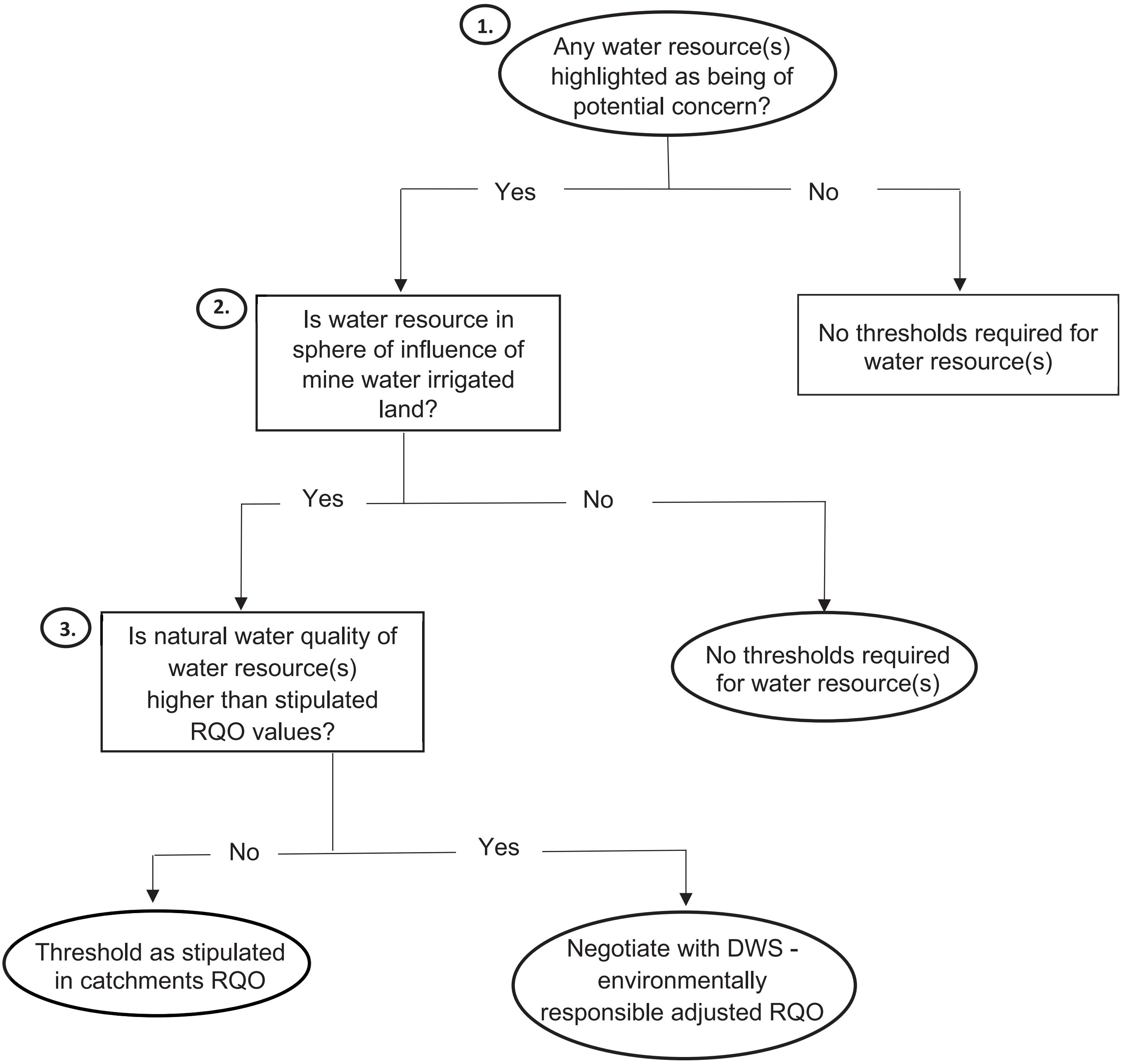
Water use licence water quality threshold levels are set in accordance to the specific IUA Resource Quality Objectives. On a site-specific basis, the potential impact of mine water irrigation on ground and surface waters differs, dependent on the location of the irrigation site within South Africa, the resource proximity to the irrigated area and the position of the resource within the landscape[33]. The natural physical and chemical characteristics and environmental roles of ground and surface waters provide a baseline for which site-specific thresholds can be set within the IUA's RQO.

According to the Resource Quality Objectives (RQO) for groundwater, long-term trends should not show negative quality deviation from natural levels. However, it may be unreasonable to expect there will be no impact on water quality from large-scale mine water irrigation. Therefore, the amount and quality of leachate from irrigated field needs to be quantified in order to determine the solute input from irrigation to groundwater resources. Acceptable threshold levels for the site-specific groundwater body can then be determined, compared and verified. If surface water runoff is of potential concern for the irrigated site, the amount and quality of runoff water should be determined. Acceptable threshold levels for the site-specific surface water can then be determined, compared and verified.

The following methodology can be employed when investigating thresholds for water resources in the vicinity of lands irrigated with mine-affected waters:

1. Identify and prioritise potential water resource(s) of concern;
2. Delineate sphere of influence of irrigated land;
3. Quantify natural water resource(s) quality;
4. Define IUA and RQO water quality limits for irrigated site location, and
5. Negotiate a level of impact from mine water irrigation below the established, reasonable RQO threshold levels.

The following decision tree can be used as a guide for determining the thresholds for potential water resource(s) of concern:



Of the 19 Water Management Areas in South Africa, Resource Quality Objectives have been established for only some catchments (Olifants-Doorn, Berg, Olifants, Mokolo, Matlabas, Crocodile (West) and Marico, Upper, Middle and Lower Vaal, Mzimvubu). Although there is a staggered roll out, with various risks associated with this RQO approach to water quality in South Africa[34] and with some RQOs still under development, this is a first practical step, towards quantifying water resource quality management in South Africa. This can be used as a basis from which thresholds for action can be set for water resources in the proximity of land irrigated with mine-affected waters.

4.3 Food and feed safety

Determining the elemental composition of the edible portions of a crop and comparing this to the South African food and fodder safety guidelines[35], ensures crops are safe to consume. It is noted that the South African guidelines are based on the European food safety guidelines. The South African food safety guidelines include the following potential elements of concern from a food safety perspective; arsenic (As), cadmium (Cd), chromium (Cr), zinc (Zn), lead (Pb) and mercury (Hg). An acid digestion of milled plant parts should be undertaken, at the end of each growing season, and comparisons to current food and fodder safety thresholds should be made. Table 8 provides the threshold values of selected elements for grain food and feed safety. It is noted that such food and feed safety monitoring should only be required if these elements are identified as CoC within the crop.

Table 8: South African food and feed safety thresholds for selected elements in grain.

Element	SA food safety thresholds	SA feed safety thresholds
	ppm or mg/kg	
Arsenic (As)	-	2
Cadmium (Cd)	0,1	1
Zinc (Zn)	-	150
Lead (Pb)	0,2	10
Mercury (Hg)	-	0,1

If crops irrigated with mine-affected waters produce grain with potentially toxic elements above the stated safety thresholds, then the irrigation practice, crop or site selection should be reviewed. Food and fodder safety analyses should be undertaken by competent food and feed quality professionals, to ensure grain quality meets local and international safety standards.

The DSS technical support, Volume 2 guidelines, discuss the risks posed for food safety for microbial contamination. If microbial populations are highlighted as constituents of potential concern in the DSS simulations, the risk assessment and health-based approach set out should be followed to ensure there are no human or animal health associated risks with the crop produced.

These footnotes have bearing on the aforegoing text under the heading **Action Levels**, appearing on pages 23-30:

[30]Pratt PF, Suarez DL. 1990. Irrigation Water Quality Assessments. In: Agricultural Salinity Assessment and Management, TANJI, KK (Ed.). ASCE Manuals and Reports on Engineering Practice No. 71. ASCE New York 1990.

[31]Snyman HG, Herselman JE. 2006. Guidelines for the Utilisation and Disposal of Wastewater Sludge, Volume 2: Requirements for the agricultural use of wastewater sludge. WRC Report No. TT 262/06, Water Research Commission, Pretoria, South Africa.

[32]Violante A., Cozzolino V, Perelomov L, Caporale AG, Pigna M. 2010. Mobility and bioavailability of heavy metals and metalloids in soil environments. *Journal of Soil Science and Plant Nutrition*, 10:3, 268 -292.

[33]Department of Water and Sanitation (DWS). 2016. Government Gazette No 39943, Regulations for the establishment of a Water Resource Classification System, Vol 610. 22 April 2016.

[34]Department of Water and Sanitation (DWS). 2016. Government Notice R810 in Gazette No 33541, Classes and resource quality objectives (RQO) of water resources, 17 September 2010.

[35]Forster SS. 1991. Receiving Water Quality Objectives: The Economic Concept, The Standards, The Implications, Economic Project Evaluation.

[36]Department of Agriculture, Fisheries and Forestry (DAFF). Undesirable substances in animal feeds Reg. 11.3, in the Fertilisers, Farm Feeds, Agricultural Remedies and Stock Remedies Act 1947 (ACT NO. 36 OF 1947).

CONCLUSION

This Technical Guideline for Irrigation with Mine-Affected Waters provides a standardised framework by which a water user can assess whether or not they can successfully irrigate specific crops with a specific mine water, on a specific site. It also identifies potential unwanted events that may pose risk to environmental receptors. Assessing the use of mine-affected waters for irrigation requires a unified and cross-disciplinary approach to ensure sustainable resource management. The strategy set out in this guideline is derived from field-tested and laboratory research studies of irrigation with mine-affected waters over a 30-year period.

Use of this guideline by competent irrigation and agricultural professionals should significantly assist the relevant authorities to grant regulatory approval for irrigation with mine-affected waters.

ANALYTICAL METHODS APPENDIX

1. Method for aqua regia extraction method of soluble trace elements[31,37]

Place 3 g of soil sample and 28 mL of aqua regia for the extraction, followed by filtration of the extract through ashless paper filters and dilution with deionised water.

2. Method for extraction of available trace elements in soil samples using an Ammonium Nitrate (NH_4NO_3) solution[31]

Place 20 g air dry soil in a shaking bottle (100-150 ml), add exactly 50 ml ammonium nitrate solution (1 mol/l) and shake for 2 hours at 20 rpm at room temperature. Then allow the solid particles to settle for 15 min. Decant the supernatant solution and filter (0,45 µm). Dispose the first 5 ml of the filtrate. Collect the remaining solution in a 50 ml bottle for analysis.

Minimum concentrations which have to be quantified accurately with the Ammonium Nitrate extraction method (DIN 19730) for good results in the field of soil protection[38].

Element		1 mol/L Ammonium Nitrate Solution	Ammonium Nitrate extractable in air dry soil
		µg/L	µg/kg
Ag	Silver	< 0,4	< 1
As	Arsenic	10	25
Be	Beryllium	1	2,5
Bi	Bismuth	< 0,4	< 1
Cd	Cadmium	2	5
Co	Cobalt	20	50
Cr	Chromium	4	10
Cu	Copper	100	250
Hg	Mercury	< 0,4	< 1
Mn	Manganese	2000	5000
Mo	Molybdenum	10	25
Ni	Nickel	100	250
Pb	Lead	< 8	< 20
Sb	Antimony	10	25
Tl	Thallium	4	10
U	Uranium	1	2,5
V	Vanadium	10	25
Zn	Zinc	100	250

[37] International Standard ISO 11466 Method Reference number: ISO11466:1995 (E) - Soil quality - Extraction of trace elements soluble in aqua regia, Geneva, Switzerland.
[38] DIN [Deutsches Institut für Normung Hrsg.] 19730 (1997-06): Extraction of trace elements in soils using ammonium nitrate solution - Beuth Verlag, E DIN 19730: Berlin.