

**Prospects for irrigation using potential mine affected
waters from Volspruit Mine, Limpopo**

Report to

Kara Nawa Environmental Solutions

by

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DISCLAIMER

The IrrigWQ decision support system (DSS) was developed to provide guidance on the effect of irrigation water quality on soil quality, crop yield and quality, and irrigation equipment.

Great attention to detail has been taken to ensure that calculation procedures in this model are sound. Nevertheless, the authors, Annandale Farming and Consulting, the University of Pretoria, the Department of Agriculture and the Water Research Commission, will not accept liability for any damage nor loss suffered as a result of the use of this DSS.

Prospects for irrigation using potential mine affected waters from Volspruit Mine, Limpopo

Introduction

Volspruit Mine is considering irrigation as a mine water management strategy. Detailed water balance studies were undertaken, with several scenarios presented, predicting different possible water volumes and qualities. Credible estimates of crop water use for an intensive three crop system (sugar beans, wheat and maize) were made by Prof Martin Steyn. These were used as input into the groundwater simulations that were performed. In turn, the groundwater predictions were used to estimate potential water qualities, that vary greatly depending on wetness of the season, and the relative amount of evaporation from the open pit at different times of year.

The scenarios generated were the following (Table 1).

Table 1. Water balance scenarios for the Volspruit Mine.

Scenario	Description	Water Volume Megalitres per month
Base Case	Water balance	151
Scenario 1	Water balance plus evaporation	61.2
Scenario 2	Low flow	11.2
Scenario 3	High flow	148.1
Scenario 4	Summer	51.8
Scenario 5	Winter	66.9

To evaluate the site-specific, and risk-based suitability of these predicted waters for irrigation, the IrrigWQ Decision Support System (DSS) was used. These simulations consider water quality, cropping system, location and water management.

Predicted water qualities

Geohydrologists predicted six different water qualities, each linked to water balances provided to them by groundwater modellers. These were entered into the IrrigWQ DSS, and are presented in Figures 1 to 6.

Figure 1. Base-case water qualities for irrigation.

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Water sample
ID Description

Major constituents (* = required data)

* Calcium (Ca ²⁺)	36.0	mg/L	* Bicarbonate (HCO ₃ ⁻)	24.4	mg/L
* Magnesium (Mg ²⁺)	45.0	mg/L	* Chloride (Cl ⁻)	51.0	mg/L
* Sodium (Na ⁺)	10.0	mg/L	* Sulphate (SO ₄ ²⁻)	71.0	mg/L
* pH	8.0		Sodium Adsorption Ratio (SAR)	0.3	(mmol/L) ^{1/2}
* Electrical Conductivity (EC)	81	mS/m	Suspended Solids (SS)		mg/L
Total Dissolved Solids (TDS)	237.4	mg/L			

Biological constituents

Escherichia coli		CFU/100 mL
Chemical Oxygen Demand (COD)		mg/L

Pesticides

Atrazine		µg/L
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Trace elements

Aluminium	1	µg/L	Lead		µg/L
Arsenic		µg/L	Lithium		µg/L
Beryllium		µg/L	Manganese	0	µg/L
Boron		µg/L	Mercury		µg/L
Cadmium		µg/L	Molybdenum		µg/L
Chromium		µg/L	Nickel	1	µg/L
Cobalt		µg/L	Selenium		µg/L
Copper		µg/L	Uranium		µg/L
Fluoride	418	µg/L	Vanadium		µg/L
Iron	26	µg/L	Zinc		µg/L

Nutrients

Total inorganic nitrogen (N)	39.0	mg/L
Total inorganic phosphorus (P)		mg/L
Total inorganic potassium (K)	4.000	mg/L

Apparent reliability of analysis

Sum cations (mmol/L)	6.0
Sum anions (mmol/L)	3.4
Charge balance error (%)	57.1
TDS / EC	2.93

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Figure 2. Scenario 1: Water balance plus evaporation - water qualities for irrigation.

Water sample	
ID 48	Description Volspruit Scenario 1 (Water balance and evaporation)
Major constituents (* = required data)	
* Calcium (Ca2+) 94.0 mg/L	* Bicarbonate (HCO3-) 18.3 mg/L
* Magnesium (Mg2+) 101.0 mg/L	* Chloride (Cl-) 127.0 mg/L
* Sodium (Na+) 25.0 mg/L	* Sulphate (SO42-) 175.0 mg/L
* pH 8.0	Sodium Adsorption Ratio (SAR) 0.4 (mmol/L) ^{1/2}
* Electrical Conductivity (EC) 194 mS/m	
Total Dissolved Solids (TDS) 540.3 mg/L	Suspended Solids (SS) mg/L
Trace elements	
Aluminium 1 µg/L	Lead µg/L
Arsenic µg/L	Lithium µg/L
Beryllium µg/L	Manganese 0 µg/L
Boron µg/L	Mercury µg/L
Cadmium µg/L	Molybdenum µg/L
Chromium µg/L	Nickel 2 µg/L
Cobalt µg/L	Selenium µg/L
Copper µg/L	Uranium µg/L
Fluoride 1037 µg/L	Vanadium µg/L
Iron 26 µg/L	Zinc µg/L
Biological constituents	
Escherichia coli CFU/100 mL	
Chemical Oxygen Demand (COD) mg/L	
Pesticides	
Atrazine µg/L	
Nutrients	
Total inorganic nitrogen (N) 97.0 mg/L	
Total inorganic phosphorus (P) mg/L	
Total inorganic potassium (K) 10.000 mg/L	
Apparent reliability of analysis	
Sum cations (mmolc/L) 14.4	
Sum anions (mmolc/L) 7.6	
Charge balance error (%) 61.2	
TDS / EC 2.79	
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Figure 3. Scenario 2: Low flow water qualities for irrigation.

Water sample	
ID 46	Description Volspruit Scenario 2 Low Inflow
Major constituents (* = required data)	
* Calcium (Ca2+) 322.0 mg/L	* Bicarbonate (HCO3-) 12.2 mg/L
* Magnesium (Mg2+) 329.0 mg/L	* Chloride (Cl-) 416.0 mg/L
* Sodium (Na+) 82.0 mg/L	* Sulphate (SO42-) 569.0 mg/L
* pH 7.0	Sodium Adsorption Ratio (SAR) 0.8 (mmol/L) ^{1/2}
* Electrical Conductivity (EC) 631 mS/m	
Total Dissolved Solids (TDS) 1730.2 mg/L	Suspended Solids (SS) mg/L
Trace elements	
Aluminium 1 µg/L	Lead µg/L
Arsenic µg/L	Lithium µg/L
Beryllium µg/L	Manganese 0 µg/L
Boron µg/L	Mercury µg/L
Cadmium µg/L	Molybdenum µg/L
Chromium µg/L	Nickel 7 µg/L
Cobalt µg/L	Selenium µg/L
Copper µg/L	Uranium µg/L
Fluoride 3400 µg/L	Vanadium µg/L
Iron 27 µg/L	Zinc µg/L
Biological constituents	
Escherichia coli CFU/100 mL	
Chemical Oxygen Demand (COD) mg/L	
Pesticides	
Atrazine µg/L	
Nutrients	
Total inorganic nitrogen (N) 316.0 mg/L	
Total inorganic phosphorus (P) mg/L	
Total inorganic potassium (K) 34.000 mg/L	
Apparent reliability of analysis	
Sum cations (mmolc/L) 47.6	
Sum anions (mmolc/L) 24.1	
Charge balance error (%) 65.6	
TDS / EC 2.74	
Refresh	

Figure 4. Scenario 3: High flow water qualities for irrigation.

Water sample			
ID	49		
Description	Volspruit Scenario 3 (High inflow)		
Major constituents (* = required data)			
* Calcium (Ca ²⁺)	63.0	mg/L	
* Magnesium (Mg ²⁺)	71.0	mg/L	
* Sodium (Na ⁺)	17.0	mg/L	
* pH	8.0		
* Electrical Conductivity (EC)	134	mS/m	
Total Dissolved Solids (TDS)	378.7	mg/L	
* Bicarbonate (HCO ₃ ⁻)	20.7	mg/L	
* Chloride (Cl ⁻)	87.0	mg/L	
* Sulphate (SO ₄ ²⁻)	120.0	mg/L	
Sodium Adsorption Ratio (SAR)	0.4	(mmol/L) ^{1/2}	
Suspended Solids (SS)		mg/L	
Biological constituents			
Escherichia coli		CFU/100 mL	
Chemical Oxygen Demand (COD)		mg/L	
Pesticides			
Atrazine		µg/L	
Trace elements			
Aluminium	1	µg/L	
Arsenic		µg/L	
Beryllium		µg/L	
Boron		µg/L	
Cadmium		µg/L	
Chromium		µg/L	
Cobalt		µg/L	
Copper		µg/L	
Fluoride	712	µg/L	
Iron	26	µg/L	
Lead		µg/L	
Lithium		µg/L	
Manganese	0	µg/L	
Mercury		µg/L	
Molybdenum		µg/L	
Nickel	2	µg/L	
Selenium		µg/L	
Uranium		µg/L	
Vanadium		µg/L	
Zinc		µg/L	
Nutrients			
Total inorganic nitrogen (N)	67.0	mg/L	
Total inorganic phosphorus (P)		mg/L	
Total inorganic potassium (K)	7.000	mg/L	
Apparent reliability of analysis			
Sum cations (mmolc/L)	9.9		
Sum anions (mmolc/L)	5.4		
Charge balance error (%)	59.6		
TDS / EC	2.83		
Refresh			

Figure 5. Scenario 4: Summer - water qualities for irrigation.

Water sample			
ID	50		
Description	Volspruit Scenario 4 (Summer)		
Major constituents (* = required data)			
* Calcium (Ca ²⁺)	112.0	mg/L	
* Magnesium (Mg ²⁺)	119.0	mg/L	
* Sodium (Na ⁺)	30.0	mg/L	
* pH	8.0		
* Electrical Conductivity (EC)	229	mS/m	
Total Dissolved Solids (TDS)	634.1	mg/L	
* Bicarbonate (HCO ₃ ⁻)	17.1	mg/L	
* Chloride (Cl ⁻)	150.0	mg/L	
* Sulphate (SO ₄ ²⁻)	206.0	mg/L	
Sodium Adsorption Ratio (SAR)	0.5	(mmol/L) ^{1/2}	
Suspended Solids (SS)		mg/L	
Biological constituents			
Escherichia coli		CFU/100 mL	
Chemical Oxygen Demand (COD)		mg/L	
Pesticides			
Atrazine		µg/L	
Trace elements			
Aluminium	1	µg/L	
Arsenic		µg/L	
Beryllium		µg/L	
Boron		µg/L	
Cadmium		µg/L	
Chromium		µg/L	
Cobalt		µg/L	
Copper		µg/L	
Fluoride	1224	µg/L	
Iron	26	µg/L	
Lead		µg/L	
Lithium		µg/L	
Manganese	0	µg/L	
Mercury		µg/L	
Molybdenum		µg/L	
Nickel	3	µg/L	
Selenium		µg/L	
Uranium		µg/L	
Vanadium		µg/L	
Zinc		µg/L	
Nutrients			
Total inorganic nitrogen (N)	114.0	mg/L	
Total inorganic phosphorus (P)		mg/L	
Total inorganic potassium (K)	12.000	mg/L	
Apparent reliability of analysis			
Sum cations (mmolc/L)	17.0		
Sum anions (mmolc/L)	8.9		
Charge balance error (%)	62.4		
TDS / EC	2.77		
Refresh			

Figure 6. Scenario 5: Winter - water qualities for irrigation.

Water sample			
ID	51		
Description	Volspruit Scenario 5 (Winter)		
Major constituents (* = required data)			
* Calcium (Ca ²⁺)	84.0	mg/L	
* Magnesium (Mg ²⁺)	91.0	mg/L	
* Sodium (Na ⁺)	22.0	mg/L	
* pH	8.0		
* Electrical Conductivity (EC)	174	mS/m	
Total Dissolved Solids (TDS)	487.5	mg/L	
* Bicarbonate (HCO ₃ ⁻)	19.5	mg/L	
* Chloride (Cl ⁻)	114.0	mg/L	
* Sulphate (SO ₄ ²⁻)	157.0	mg/L	
Sodium Adsorption Ratio (SAR)	0.4	(mmol/L) ^{1/2}	
Trace elements			
Aluminium	1	µg/L	
Arsenic		µg/L	
Beryllium		µg/L	
Boron		µg/L	
Cadmium		µg/L	
Chromium		µg/L	
Cobalt		µg/L	
Copper		µg/L	
Fluoride	931	µg/L	
Iron	26	µg/L	
Lead		µg/L	
Lithium		µg/L	
Manganese	0	µg/L	
Mercury		µg/L	
Molybdenum		µg/L	
Nickel	2	µg/L	
Selenium		µg/L	
Uranium		µg/L	
Vanadium		µg/L	
Zinc		µg/L	
Biological constituents			
Escherichia coli		CFU/100 mL	
Chemical Oxygen Demand (COD)		mg/L	
Pesticides			
Atrazine		µg/L	
Nutrients			
Total inorganic nitrogen (N)	87.0	mg/L	
Total inorganic phosphorus (P)		mg/L	
Total inorganic potassium (K)	9,000	mg/L	
Apparent reliability of analysis			
Sum cations (mmol/L)	12.9		
Sum anions (mmol/L)	6.9		
Charge balance error (%)	80.5		
TDS / EC	2.80		
			

Water quality assessment for irrigation

A Decision Support System, IrrigWQ, has recently been developed for the site-specific assessment of water qualities for irrigation (du Plessis et al, 2017). Site-specificity is important, as crop choice, irrigation management, weather and climate all have a bearing on the suitability of specific waters for irrigation. For this reason, long-term weather data from a station in close proximity to Volspruit Mine was used for the simulations. In addition, two different cropping systems were considered, and the assumption was made that centre pivot irrigation would be the method of choice for utilising these waters.

Driving variables for evaporation

Volspruit Mine is located in the Limpopo Province, near the town of Mokopane, previously known as Potgietersrus. The Potgietersrus Tobacco Cooperative (24.18° S, 29.02° E, 1160 m.a.s.l.) is the nearest representative weather station to the mine on the DSS database, with a long-term rainfall and temperature record. The 50-year daily record of rainfall (average of 522 mm per annum) and maximum and minimum temperatures (annual minimum 13 °C and maximum 26.3 °C) is used in this analysis to estimate evaporative demand and water input to the soil water balance through rainfall. Evaporative demand (ET_o – short grass evaporation) is estimated from temperatures, latitude and

time of year which determine solar irradiance, with assumptions made for wind speed. The FAO (Food and Agricultural Organisation of the United Nations) developed ETo as a reference for evapotranspiration estimates (Allen et al., 1998). This is by far the most widely used method to estimate atmospheric evaporative demand.

The weather data quality was inspected graphically, and appears to be very good. Precipitation is presented in Figure 7, and in Figure 8, maximum and minimum temperatures are presented.

Figure 7. Daily precipitation over a 50-year period (1950-2000) for Mokopane (Potgietersrus)

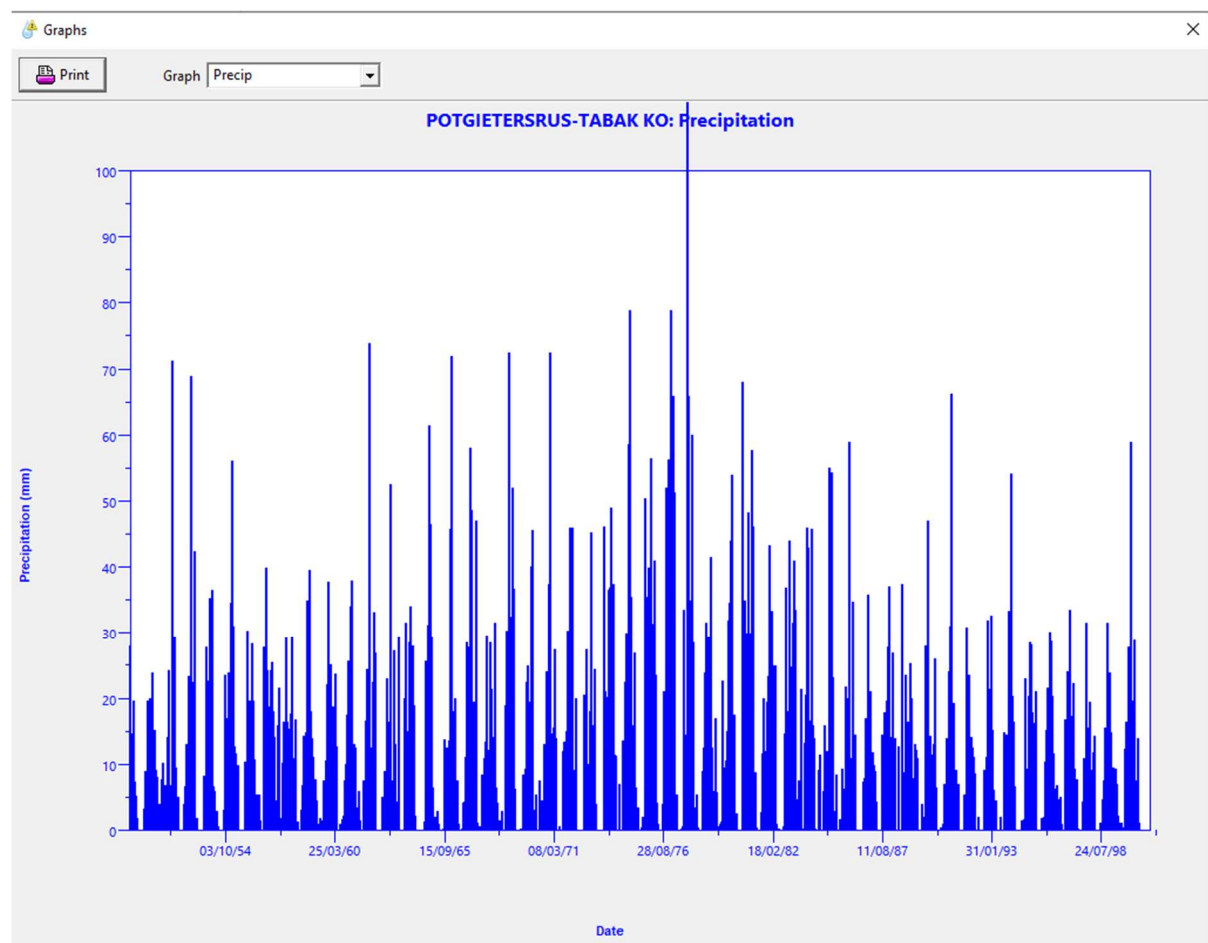
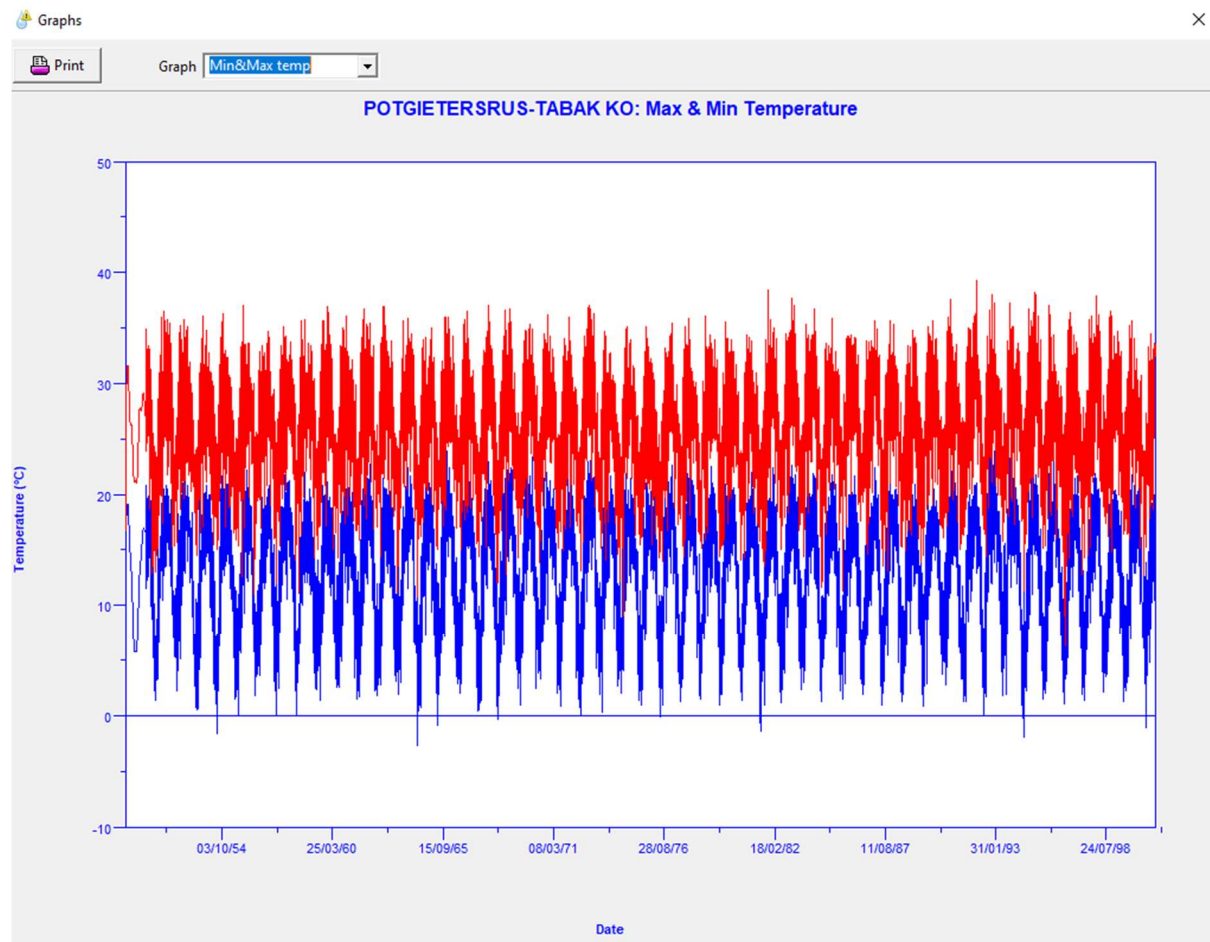


Figure 8. Daily maximum (red) and minimum (blue) temperatures over a 50-year period (1950-2000) for Mokopane (Potgietersrus)



Site specific irrigation water quality assessments

Two cropping systems, appropriate for the region, were selected. It has become common in this part of Limpopo, to plant maize and beans in rotation (two crops per year), but both of these crops are quite sensitive to salinity. For this reason, a sorghum-wheat rotation was also simulated, as both of these crops are quite tolerant to salinity. Planting dates selected were 1st September for maize, and middle February for beans, and for sorghum a planting date of 1st October was selected, with wheat planted on 1st March.

Overhead irrigation of a 1 m deep sandy loam soil was selected, with irrigation to field capacity when 15 mm was predicted to have been lost from the profile. This is a reasonable assumption for centre pivot irrigated crops, and leaching of excess salts was therefore through rainfall, and not purposeful over irrigation. Surface runoff from rainfall was assumed to be negligible.

Site specific parameters for the maize – bean simulations are given in Figure 9, and for sorghum – wheat in Figure 10.

Figure 9. Site-specific assumptions for the maize – bean cropping system.

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Site

Id 46
Description Volspruit Mokopane
Cropping system Crop rotation
1st Crop Maize (Corn)
1st Crop plant date (DD/MM) 1 / 9
2nd Crop Bean
2nd Crop plant date (DD/MM) 15 / 2

Weather

Weather station POTGIETERSRUS-TABAK KO
Latitude (S) -24.18
Longitude (E) 29.02
Elevation (m) 1160.0
Simulation (yrs) 45

Soil

Soil depth (m) 1.00
Soil texture Sandy loam
Initial water content Wet (FC)
Initial salt content Low
Profile available water (mm) 120
Plant available water (mm/m) 120
Field capacity (m/m) 0.22
Wilting point (m/m) 0.10
Bulk density (Mg/m3) 1.4

Irrigation management

Irrigation timing Amount (mm) 15
Refill option Field capacity
Irrigation system Overhead (foliage wetted)

Initial soil chemical properties

Trace element concentrations Defaults

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Figure 10. Site-specific assumptions for the sorghum – wheat cropping system.

Site

Id 47
Description Volspruit Mokopane - Sorghum and Wheat
Cropping system Crop rotation
1st Crop Wheat
1st Crop plant date (DD/MM) 1 / 3
2nd Crop Sorghum
2nd Crop plant date (DD/MM) 1 / 10

Weather

Weather station POTGIETERSRUS-TABAK KO
Latitude (S) -24.18
Longitude (E) 29.02
Elevation (m) 1160.0
Simulation (yrs) 45

Soil

Soil depth (m) 1.00
Soil texture Sandy loam
Initial water content Wet (FC)
Initial salt content Low
Profile available water (mm) 120
Plant available water (mm/m) 120
Field capacity (m/m) 0.22
Wilting point (m/m) 0.10
Bulk density (Mg/m3) 1.4

Irrigation management

Irrigation timing Amount (mm) 15
Refill option Field capacity
Irrigation system Overhead (foliage wetted)

Initial soil chemical properties

Trace element concentrations Defaults

Update
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Maize – bean rotation

Maize planted in this area at the beginning of September, is predicted on average, to require 280 mm of irrigation. Beans planted in mid-February will require 390 mm of irrigation. These figures can be used to estimate the irrigated area required to utilise the mine waters, and to calculate storage requirements and/or treatment capacity if this is required by regulators. The leaching fraction for this rotation, managed as described, is just under 15%.

Maize is classified as having medium sensitivity to salinity, with a threshold for yield decline of 170 mS/m (EC_e – electrical conductivity of a saturation paste extract) and a decline in yield (slope) above this threshold of 12% per 100 mS/m (Maas and Hoffman, 1977). Very little to no yield penalty is expected for maize with the different waters, except for Scenario 4 (Summer), where yield losses in excess of 10% can be expected one year in ten, and for the low flow Scenario 2, where extreme yield losses will be experienced most of the time.

Beans are classified as being sensitive to salinity, with an EC_e threshold of only 100 mS/m and a slope for yield decline above this threshold of 19%. This crop also receives a greater proportion of its water through irrigation than is the case for maize, because of when it is planted. For these reasons, beans are not as tolerant to the predicted waters as maize is. Beans can be successfully irrigated with the Base-case and Scenario 3 (High inflow) waters, but quite large to very severe yield penalties are predicted with the other waters.

Sorghum – wheat rotation

Sorghum planted in this area at the beginning of October, is predicted on average, to require just over 200 mm of irrigation. Wheat planted in the beginning of March will require 620 mm of irrigation. The leaching fraction for this rotation, managed as described, is 13%.

Sorghum is classified as having medium tolerance to salinity, with a threshold for yield decline of 680 mS/m and a decline in yield above this threshold of 16% per 100 mS/m. Very little to no yield penalty is expected for sorghum with the different waters, except for the low flow Scenario 2, where yield losses in excess of 10% can be expected one year in ten.

Wheat is also classified as having a medium tolerance to salinity, with an EC_e threshold of 600 mS/m and a slope for yield decline above this threshold of 7.1%. Wheat can be successfully irrigated with all of the waters from a salinity perspective, but excessive nitrogen will be applied at these irrigation rates with all of the waters except with the Base-case water quality.

Nutrients and trace elements

The waters used in these simulations contain nitrogen and potassium. Nutrients applied to the field through irrigation depend on their concentration and the irrigation amount. In general, potassium is not of great concern, but the same cannot be said for nitrogen, and some form of treatment will be required if the predicted concentrations for the different Scenarios are realised. One approach could be to use the water as supplementary irrigation (basically as fertigation), if other sources of water are available to see the crop through its growth cycle.

The only trace element flagged by the DSS is fluoride for Scenario 2 water. This element is predicted to accumulate to unacceptable levels after 7 to 9 decades, but irrigation with such poor quality water is unlikely to continue for this length of time at Volspruit.

Soil physical properties

Irrigation waters can influence the infiltrability and permeability of soil. In general, higher salinity favours these properties through increased flocculation of soil particles, and high sodium is detrimental, as it causes de-flocculation. The recommendation is to apply gypsum as part of the fertilisation programme, as the calcium from the gypsum will displace sodium and improve permeability.

Effects of irrigation waters on irrigation infrastructure

The DSS calculates the Langelier Index in order to give an indication of whether waters are expected to be corrosive or scaling. The model also considers the effects of water quality on the clogging of micro-irrigation infrastructure. However, it is not a good idea to attempt micro-irrigation with high pH, poor quality mine waters, so this aspect is not discussed here.

No scaling is predicted, and most waters can be expected to be slightly corrosive. This should be brought to the attention of the irrigation system designer, as it may have some bearing on material selection.

Conclusions

The consideration of irrigation to utilise excess mine waters and reduce treatment costs at Volspruit Mine, is certainly worth pursuing. Some of the predicted water qualities are not very suitable for irrigation, so regular monitoring of water quality is essential, in order to adjust the irrigation management strategy, or to initiate partial treatment to irrigable standards. The waters are predicted to be quite saline, so it will be prudent to focus on the production of crops that are quite salt tolerant. Nitrogen levels are generally very high, and although much of the N can be used to

replace expensive fertilisers, excessive levels will be seen as problematic from an environmental impact perspective.

Any irrigation scheme initiated will require regular monitoring, and adaptive management as conditions change. This is advocated in the Technical Guidelines for irrigation with mine impacted waters (Heuer et al, 2021).

A Water Quality Requirement simulation can be undertaken to indicate to what levels waters can deteriorate before treatment may be necessary. This will depend heavily on the cropping system selected and the salinity tolerance of the crops produced.

It is clear that mine water irrigation is a technical undertaking, and it would be wise to keep revisiting the best approach to follow to productively utilise the waters the mine has to deal with. This will be especially valuable as more certainty develops around actual volumes and qualities that need to be managed. Should irrigation with mine water be seriously considered, it may be prudent to also consult the guidelines on attaining regulatory approval for this practice (Pocock and Coetzee, 2021).

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