Using a risk based, site-specific DSS to determine the suitability of mine water for irrigation

by

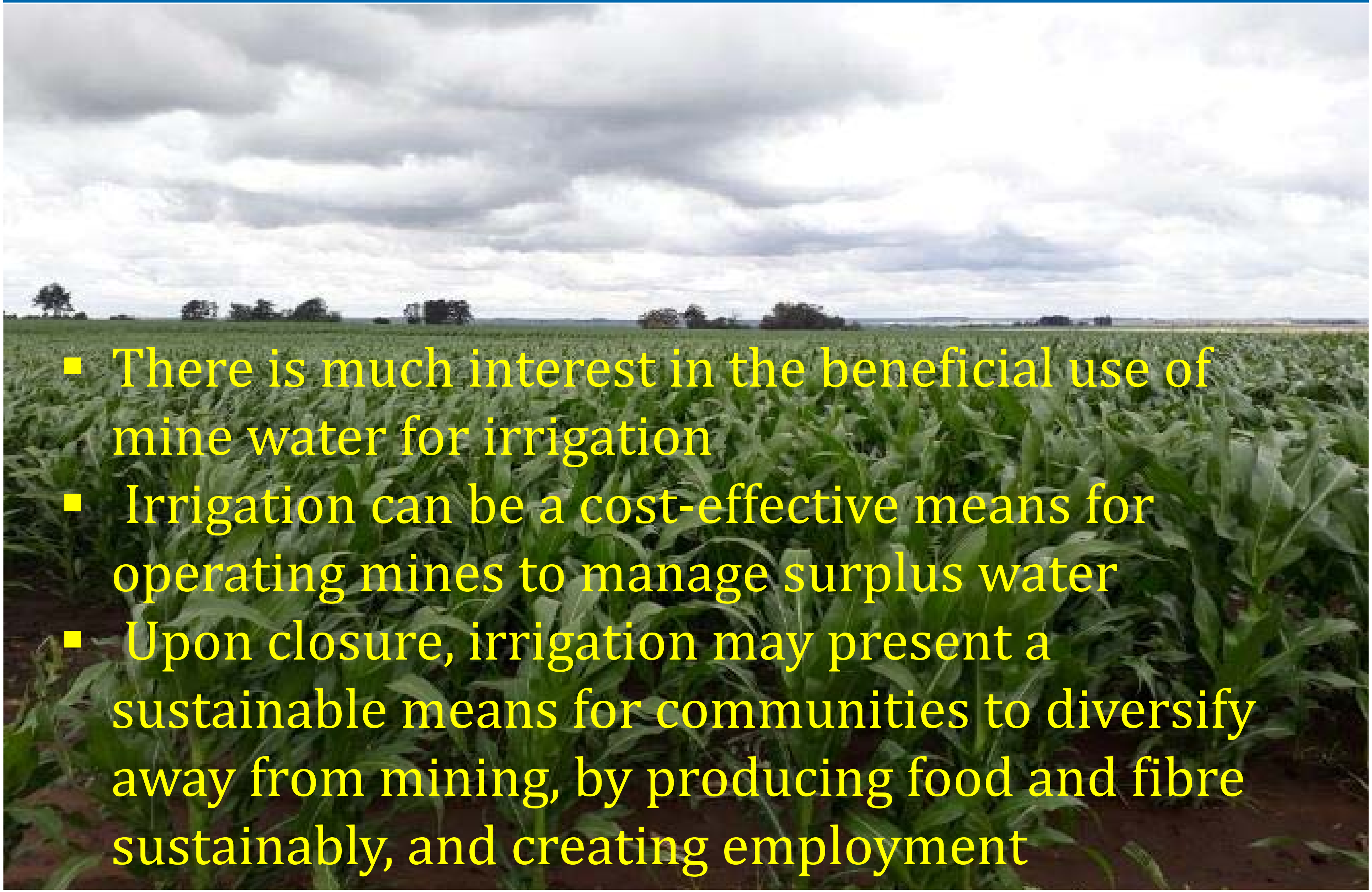
John Annandale, Meiring du Plessis,

Phil Tanner and Jo Burgess

UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA

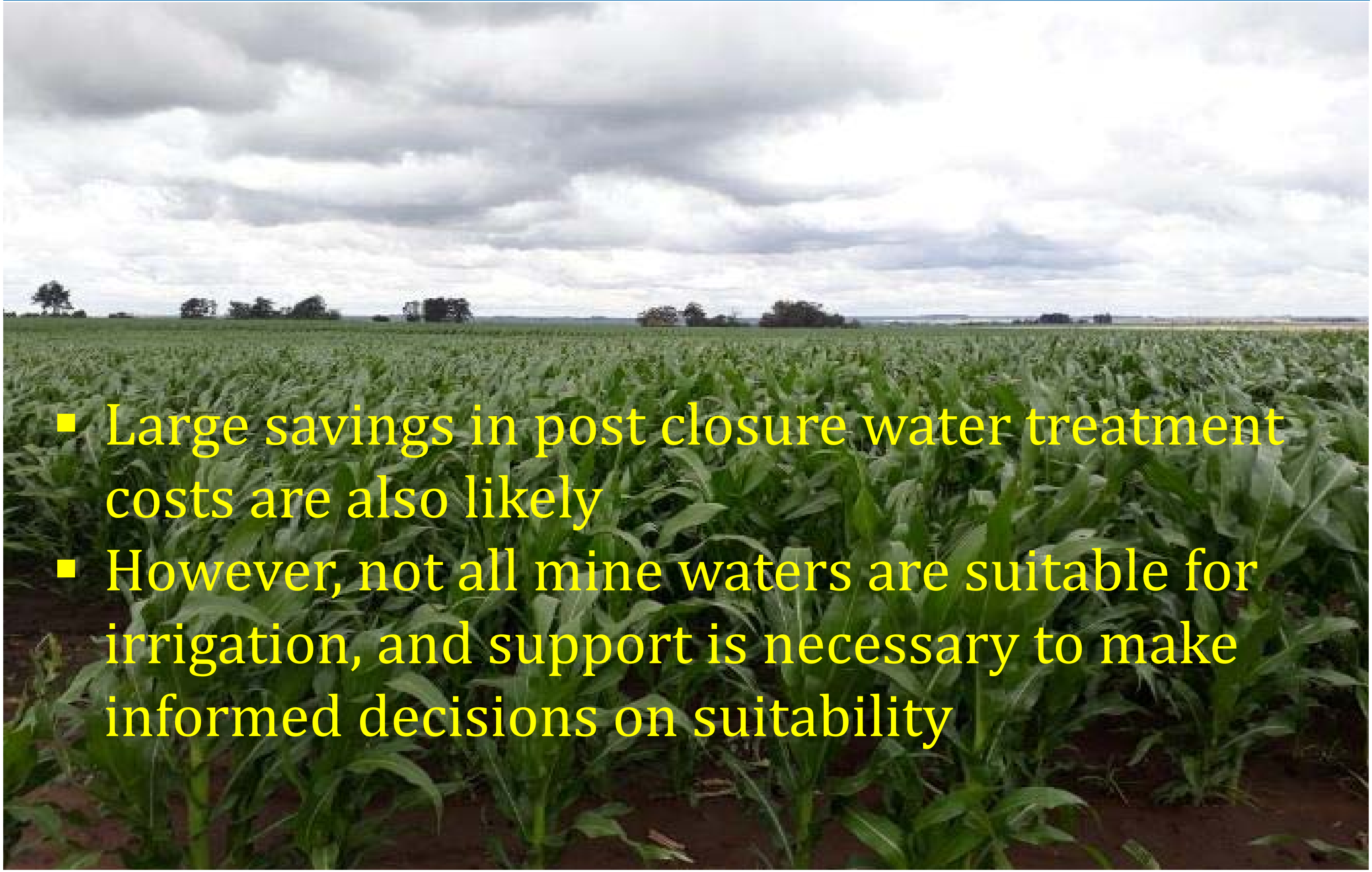
agriculture, forestry & fisheries
Department:
Agriculture, Forestry and Fisheries
REPUBLIC OF SOUTH AFRICA

Mine water irrigation



- There is much interest in the beneficial use of mine water for irrigation
- Irrigation can be a cost-effective means for operating mines to manage surplus water
- Upon closure, irrigation may present a sustainable means for communities to diversify away from mining, by producing food and fibre sustainably, and creating employment

Mine water irrigation



- Large savings in post closure water treatment costs are also likely
- However, not all mine waters are suitable for irrigation, and support is necessary to make informed decisions on suitability

Risk-based irrigation water quality DSS

South African Water Quality Guidelines (version 11 Aug 2017)

Tools Help

IWQG Exit

Irrigation Water Quality Descision Support System (Beta Version 1.1)

DISCLAIMER

This descision support system was developed to provide guidance on the effect of irrigation water quality on soil quality, crop yield and quality, and irrigation equipment.

Extreme attention to detail has been given to ensure that calculation procedures in this model are sound.

Nevertheless, the authors, the University of Pretoria and the Water Research Commission will not accept liability for any damage or loss suffered as a result of the use of this model.

Accept & Proceed   Decline & Exit

WATER RESEARCH COMMISSION

UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA

Selected Suitability Indicators

Soil Quality	**Crop Yield & Quality**	**Irrigation Equipment**
Root zone salinity	Crop yield	Scaling
Soil permeability	Leaf scorching	Corrosion
Excessive C loading	Microbial contamination	Clogging of drippers
Trace element accumulation / release to crops	Nutrient effects on crop yield and quality	
	Effect of pesticides on crop yield	

Fitness-for-Use Classes

Ideal	NO IMPAIRMENT to the Fitness-for-Use of the water for its intended use
Acceptable	SOME IMPAIRMENT to the Fitness-for-Use of the water for its intended use
Tolerable	INCREASINGLY UNACCEPTABLE IMPAIRMENT to the Fitness-for-Use of water for its intended use
Unacceptable	UNACCEPTABLE IMPAIRMENT to the Fitness-for-Use of the water for its intended use

Suitability Indicator Criteria

Fitness-for-Use Category	**Root zone salinity (mS/m)**	**Potential soil HC / IB problems**	**No of years for trace element build-up**	**Relative crop yield (%)**	***E. Coli* - Excess infections per 1000 p.a.**
Ideal	0 - 200	None	>200	90 - 100	<1
Acceptable	200 - 400	Slight	150 - 200	80 - 90	1 - 3
Tolerable	400 - 800	Moderate	100 - 150	70 - 80	3 - 10
Unacceptable	> 800	Severe	< 100	< 70	>10

Fitness-for-Use at three Tiers

- Tier 1
  - Generic, conservative assumptions
  - If WQ ideal with these assumptions, then probably no need for mine to treat water (unlikely)
- Tier 2
  - Default model parameters selected to make assessment more site specific
  - Select weather station, soil texture, crop, irrigation system and management
- Tier 3
  - Default parameters not available – need to determine them yourself
  - May need more detailed investigation or another model

Mine water qualities considered

- Mine waters we have irrigated with:
  - lime treated AMD
  - sodium bicarbonate rich water (CBM)
  - sodium sulphate rich water
- A chloride rich water was "generated"
  - keep properties of our actual lime treated AMD, but swop sulphate and chloride concentrations on a mol charge basis
- AMD water of pH 3
  - Looking at irrigating heavily limed soil with AMD to negate the need for a liming plant

Mine water composition major constituents

	Lime treated AMD	Chloride rich water	Sodium bicarb rich water	Sodium sulphate rich water	AMD
Major constituent					
Calcium (mg/l)	615	615	25	32	227
Magnesium (mg/l)	208	208	0	88	132
Sodium (mg/l)	10	10	2000	796	13
Bicarbonate (mg/l)	41	41	5000	450	0
Chloride (mg/l)	5	1500	375	18	3.5
Sulphate (mg/l)	2082	7	7	1647	2919
pH	5.7	5.7	7.5	8.9	3
EC (mS/m)	377	377	750	372	360
TDS (mg/l)	2961	2961	7407	3031	3295
SAR $(mol/l)^{0.5}$	0.1	0.1	111	16.5	0.2

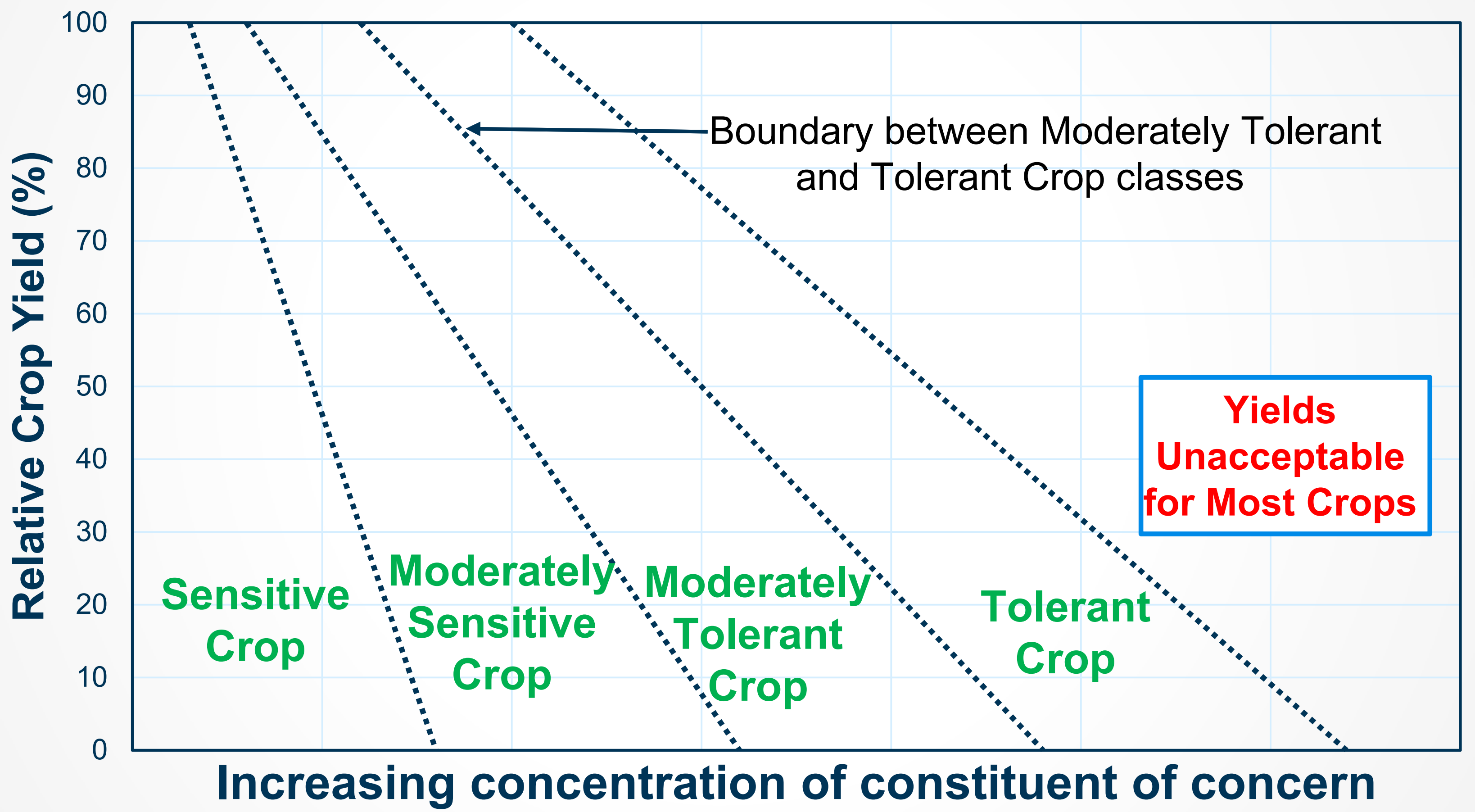
Mine water composition
Trace elements and nutrients

	Lime treated AMD	Chloride rich water	Sodium bicarb rich water	Sodium sulphate rich water	AMD
Trace elements					
Aluminium (mg/l)	2				158
Iron (mg/l)	31				233
Manganese (mg/l)	28				72
Nutrients					
Nitrogen (mg/l)	16				19.5
Phosphorus (mg/l)	0.4				0.5
Potassium (mg/l)	6				7

Relative yields - 5 mine waters

- Weather data from Loskop Dam
- Simulated 45 years of irrigation
  - long period to estimate risk of irrigation with these waters
  - relative yields presented as fraction of time they fall in a particular fitness for use category
- Maize, soybean and wheat
- Irrigation management practice
  - 20 mm every time the soil profile had a deficit to field capacity of 25 mm
  - leaving room for at least 5 mm of rain

Tier 2: Calculation of Crop Response to EC, B, Cl & Na



Crop Salinity Tolerance

Crop	Threshold ECe (mS/m)	Slope (% per 100 mS/m)
Maize	170	12
Soybean	500	20
Wheat	600	7.1

Relative maize yield (% of time)

Fitness-for-Use	Relative crop yield (%)	Lime treated AMD	Chloride rich water	Sodium bicarb rich water	Sodium sulphate rich water	AMD
Ideal	90 - 100	91				
Acceptable	80 - 90	9			9	
Tolerable	70 - 80				36	
Unacceptable	< 70		100	100	55	100

Relative wheat yield (% of time)

Fitness-for-Use	Relative crop yield (%)	Lime treated AMD	Chloride rich water	Sodium bicarb rich water	Sodium sulphate rich water	AMD
Ideal	90 - 100	100	82	39	100	27
Acceptable	80 - 90		12	24		30
Tolerable	70 - 80		6	21		24
Unacceptable	< 70			15		18

Effect of location (climate)

- Warmer, drier climates will be less suited to irrigation with saline waters than cooler wetter climates, where
  - atmospheric evaporative demand is lower
  - higher rainfall induced leaching environment
- Loskop compared to Vaalharts, the biggest irrigation scheme in South Africa
  - Loskop – wetter summer
  - Vaalharts – drier summer
- Expect summer maize will perform better in Loskop's more humid environment

Effect of location (climate)

Fitness-for-Use Sodium sulphate rich water	Relative maize yield (%)	Loskop Dam (more humid summer)	Vaalharts (Drier)
Ideal	90 - 100		
Acceptable	80 - 90	9	
Tolerable	70 - 80	45	36
Unacceptable	< 70	45	64

Effect of Irrigation Management

- Two irrigation strategies compared:
  - "Deficit" irrigation is designed to minimise leaching and use rainfall more efficiently
    - a wise strategy when using good quality water,
  - Leaching Requirement irrigation strategy
    - irrigation is a salt concentrating practice
    - crop roots extract water and exclude salts
    - the higher the salinity, the greater the leaching requirement for sustainable irrigation
- Better yields predicted when effective leaching is increased

Effect of Irrigation Management Vaalharts

Fitness-for-Use Sodium sulphate rich water	Relative maize yield (%)	Deficit Irrigation (room for rain)	Leaching requirement
Ideal	90 - 100		9
Acceptable	80 - 90	27	27
Tolerable	70 - 80	55	64
Unacceptable	< 70	18	
Irrigation	mm	710	699
Effective Leaching	%	7.5	9.5

Crop nutrient supply through mine water

- Some mine waters quite high in essential plant macro-nutrients
  - N, P, K (Ca, Mg, S)
- May be beneficial for crop production
  - saving in buying and applying fertiliser
- However, some crops may be negatively affected by high concentrations of nutrients
  - excessive vegetative growth and lodging, delayed maturity and reduced crop quality
  - may complicate fertiliser management and limit control over nitrate leaching and P wash off

Crop nutrient supply

- Rationale adopted in the DSS:
  - the higher the nutrient content and the greater the supply of nutrients to the crop
  - harder it becomes to manage crop nutrient requirements
  - so high nutrient levels displayed as less desirable
- However, crops vary greatly in their nutrient requirements
  - e.g. pasture crops will not easily be adversely affected by high nutrient loads which can be used beneficially
  - so crop selection once again important when irrigating with mine impacted waters

N supply – lime treated AMD (16 mg N/l)

Fitness-for-Use	Contribution to crop N removal	Soybean		Wheat	
		Time (%)	Applied (kg/ha)	Time (%)	Applied (kg/ha)
Ideal	0 – 10%				
Acceptable	10 – 30%	53	102		
Tolerable	30 – 50%	47	130	100	88
Unacceptable	> 50%				

Trace element accumulation

- A concern often raised with mine water irrigation
  - the fate of trace elements in the water
- circum-neutral waters usually no great concern
- with lower pH waters this should certainly not be ignored
- DSS calculates how many years it will take to reach protective threshold soil values in the top 150 mm of the soil profile

Trace elements

- Soil accumulation thresholds
  - Al 2500 mg/kg
  - Fe 2500 mg/kg
  - Mn 100 mg/kg

	Lime treated AMD	AMD
Al	2 mg/l	158 mg/l
Fe	31 mg/l	233 mg/l
Mn	28 mg/l	72 mg/l

Trace elements

Fitness-for-Use	Soil accum thresh (years)	Al		Fe		Mn	
		Lime treated AMD	AMD	Lime treated AMD	AMD	Lime treated AMD	AMD
Ideal	>200	250					
Acceptable	150-200						
Tolerable	100-150						
Unacceptable	<100		3	16	2	1	0

Trace element accumulation

- Al, Fe and Mn are trace elements in mine impacted waters most likely to be flagged by regulators
- However, the fact that they are found in abundance in natural soils raises the question whether or not guidelines should be relaxed somewhat
- To ascertain the real risk of detrimental food or forage safety due to trace element accumulation, more research needs to be done

Effect on Soil Physical Properties

- DSS predicts effect of water quality on:
  - infiltration
  - hydraulic conductivity
- Na is particularly problematic
  - negative effect somewhat counteracted by high salinity levels

Corrosion and Scaling

- DSS uses the Langelier Index to estimate corrosion or scaling of irrigation equipment
  - may not be best index for sulphate rich waters
  - was developed for carbonate rich waters
- Scaling waters
  - $NaHCO_3$ and Na_2SO_4 rich waters
- Corrosive waters
  - Lime treated AMD, Cl rich, especially the AMD

LI – Corrosion (-) Scaling (+)

Fitness-for-Use	Lime treated AMD	Chloride rich water	Sodium bicarbonate rich water	Sodium sulphate rich water	AMD
Ideal					
Acceptable			0.84		
Tolerable	-1.62	-1.61		1.34	
Unacceptable					-6

Conclusions

- Not all mine waters are suitable for irrigation
- However, the DSS is able to assess:
  - site-specific factors (Tier 2) that influence suitability of mine waters for irrigation
  - present risk taken in using such waters as far as:
    - crop yield and quality
    - soil factors, and
    - irrigation equipment is concerned

Conclusions cont.

- In some cases, a more detailed Tier 3 assessment is required, to ascertain if negative Tier 2 assessment issues can be mitigated
  - This may require expert input by crop or soil scientists
- The DSS will assist in making decisions on:
  - whether or not mine water irrigation is advisable
  - in consideration of mine closure options

Future Research

- Assessment of food and forage safety
- Improvement of algorithms for scaling and corrosion for gypsiferous waters
- Look into whether it is necessary to discriminate against waters rich in trace elements that are abundant in natural soils
- Expand and improve model parameters e.g. include leaf scorching for acidic waters

Thank you

UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA

WATER RESEARCH COMMISSION

South African
WATER RESEARCH COMMISSION
Supporting sustainable development through research funding, knowledge creation and dissemination

agriculture, forestry & fisheries
Department: Agriculture, Forestry and Fisheries
REPUBLIC OF SOUTH AFRICA

AngloAmerican

Mafube COAL

Strategic Water Partners Network
SOUTH AFRICA

MWCB
Mine Water Coordinating Body


23 August 2018