Help to assess the fitness for use of irrigation water at a specific site using a risk-based approach

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Water quality guidelines have two main applications. Firstly, and more commonly, water quality guidelines are used to assess the fitness for use (FFU) of a given water for a specific purpose. Secondly, water quality guidelines are used to determine the desired composition of water that would pose minimal risk when used for a specific purpose, the so-called Water Quality Requirements (WQR). In this article we will focus on the first of these applications and specifically introduce a newly developed electronic Decision Support System (DSS) that guides the user to assess the fitness for use of a potential irrigation water.

Before embarking on any irrigation development and at regular intervals afterwards, it is prudent to determine the fitness of the water source in order to pro-actively identify and circumvent potential water quality-induced problems. Several classification systems have been developed to assess the suitability of water for irrigation. Arguably the best known of these is the system published by the US Salinity Laboratory Staff in 1954. They identified salinity (which affects crop yield) and sodicity (which affects soil permeability) as the most important components determining the suitability of water for irrigation purposes. Subsequently several guidelines which consider a much larger range of water quality constituents and their effects have been published.

The South African Water Quality Guidelines, published in 1996 by the Department of Water Affairs and Forestry, comprise one of the most widely-used tools in water quality management in the country. However, a panel of experts appointed by the Department of Water Affairs in 2008, identified the need for updated water quality guidelines. This article describes the development and main features of the newly established DSS for irrigation, which address these needs and which emanated from a project initiated by the South African Water Research Commission through a directed call with published terms of reference and co-funded by the Department of Agriculture, Forestry and Fisheries (du Plessis et al, 2017)

Fundamental differences

The "new" water quality guidelines differ in several fundamental ways from the earlier 1996 guidelines. Not only are they risk-based, they also allow for much greater site-specificity and are available primarily as a software-based DSS.

The software-based DSS operates at two tiers:

i. *Tier 1 resembles the current South African generic guidelines, with some modifications. These guidelines are similar to those developed for other countries. Tier 1 relies on the minimum user defined input, and provides a conservative water quality assessment, highlighting potential problems if the conservative assumptions are not met. Should a Tier 1 evaluation indicate potential problems, a more rigorous and site-specific Tier 2 evaluation is indicated.*
ii. *Tier 2 allows for site specificity, the extent of which is predetermined by the site-specific variables that are provided for as part of the DSS. The DSS allows a user to conduct a more in-depth water quality assessment and guideline generation, by making use of a relatively sophisticated crop growth - soil water balance and chemistry model which uses selectable site specific input parameters, to simulate the response of soils, crops and irrigation equipment to irrigation water quality under specific climatic conditions.*

Figure 1 depicts the overall structure of the DSS. At the highest level, a user has to decide whether he or she wants to use the DSS to assist with:

i. *assessing the FFU of a water for irrigation, or*
ii. *setting WQR for irrigation users, or*
iii. *obtaining additional information, as indicated in Figure 1.*

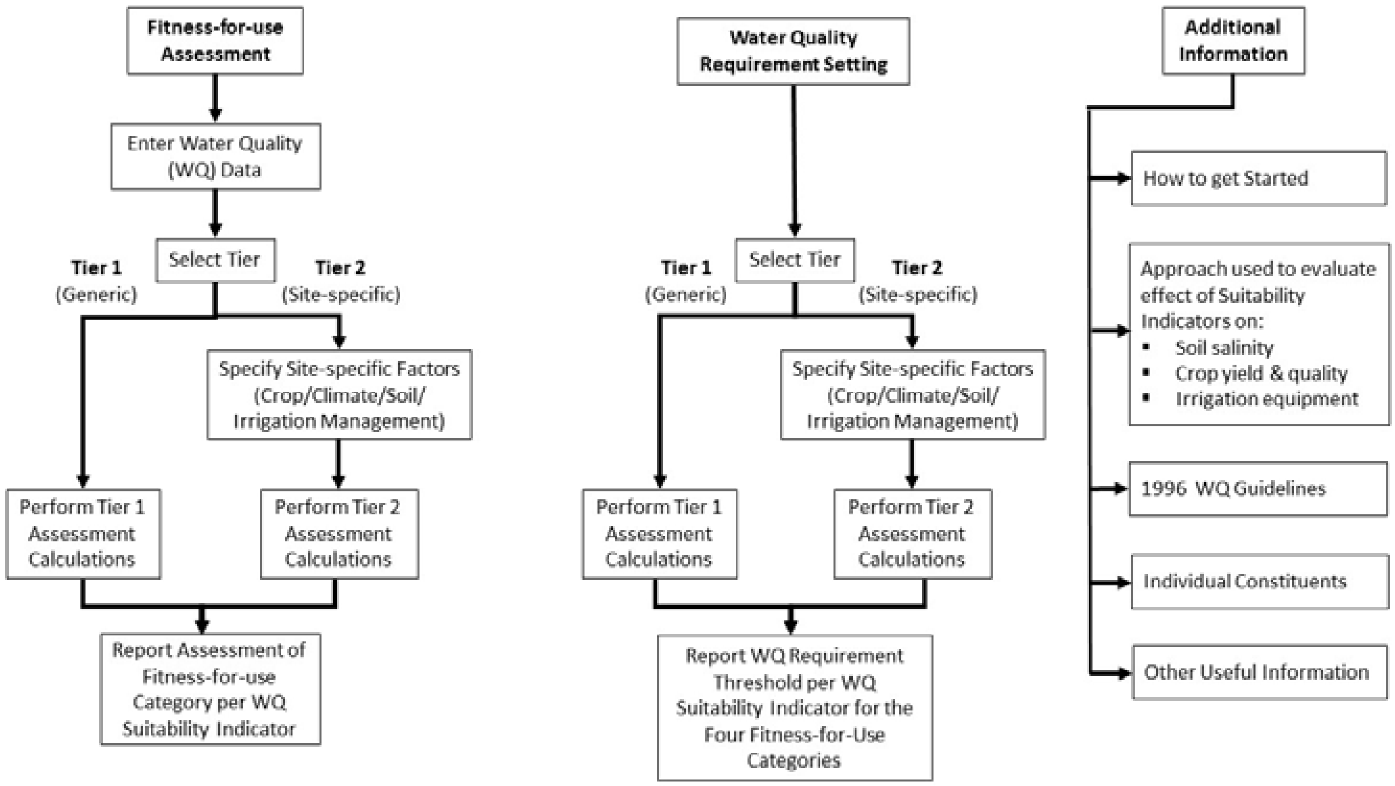

Figure 1. Simplified schematic representation of the DSS structure

After selecting the appropriate DSS functionality to access, the user is guided through a decision tree to choose between different options and select the appropriate route in order to process the user's need and provide output in a user-friendly format.

Water Quality Constituents and Suitability Indicators

The DSS provides for assessing the fitness of a given water for irrigation from the concentrations of eight major constituents, two biological constituents, three nutrients and twenty trace elements. Constituents are evaluated for the effect they have on soil quality, crop yield and quality and irrigation equipment. At least the concentrations of the major constituents are required in order to conduct an FFU assessment. While analyses for other constituents are not mandatory, their effect on FFU will only be assessed if analyses are provided.

Effect of water quality constituents on soil quality

The impacts irrigation water quality constituents have on soil quality are primarily indirect as a result of the interaction between the water quality constituents and soil components. This interaction is modified by the fact that soil also acts as a temporary store of water for plant use, and that crops extract almost pure water, leaving most of the water quality constituents in the soil. The degree to which these constituents accumulate in soil and interact with soil components, determines how water quality constituents affect soil quality. The DSS considers the following suitability indicators to assess the effects irrigation water constituents have on soil quality:

i. *Root zone salinity;*
ii. *Soil permeability;*
iii. *Oxidisable carbon loading; and*
iv. *Trace element accumulation*

Effect of water quality constituents on crop yield and quality

The impact irrigation water quality constituents have on crop yield and quality are both direct and indirect. Direct contact of irrigation water with a crop mostly affects crop quality, while indirect impacts mostly affect crop yield. Indirect impacts are a consequence of the accumulation and redistribution of irrigation water constituents within the root zone. The DSS considers the following suitability indicators to assess the effects irrigation water constituents have on crop yield and quality:

i. *Root zone effects of salinity, B, Cl and Na on yield;*
ii. *Leaf scorching when wetted;*
iii. *Contribution to NPK uptake by the crop;*
iv. *Microbial contamination, and*
v. *Qualitative crop damage by atrazine.*

Effect of water quality constituents on irrigation equipment

The impact irrigation water quality constituents have on irrigation infrastructure to distribute and apply water, is a direct result of the interaction between water quality constituents and irrigation equipment. This interaction is determined primarily by the material irrigation equipment is made of, or the type of irrigation system used. The DSS considers the following suitability indicators to assess the effects irrigation water constituents have on irrigation equipment:

i. *Corrosion or scaling of irrigation equipment*
ii. *Clogging of drippers*

Presentation of DSS Output

Throughout the DSS, water quality is assigned to one of four colour coded FFU categories, associated with the risk of using the water. The classification system is based on a DWS system which describes four suitability categories, defined in generic terms applicable to any water use (Table 1).

Table 1
A generic description of the DWS fitness-for-use classification of water

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

Calculating Procedures

Both the FFU and WQR are assessed based on the effect water constituents have on soil quality, crop yield and quality, as well as irrigation equipment. For Tier 1 assessments, simplified conservative assumptions requiring no user input, were used to determine WQR, and only the irrigation water composition to establish FFU. In this way, a rapid "conservative" assessment of irrigation water quality is obtained. Should the Tier 1 assessment not indicate potential water quality problems, the water is deemed fit for use on all crops, under all but the most exceptional circumstances. On the other hand, should the Tier 1 assessment identify potential water quality problems, a more detailed, site-specific assessment as provided by a Tier 2 assessment, is indicated.

Tier 2 assessments allow the user to choose between default site specific conditions, in order to provide a significantly enhanced assessment of how the water can be expected to affect a specific crop, under specific climatic conditions, using a specified irrigation system managed in a particular way, when irrigating a soil of a selected texture. Tier 2 assessments, therefore, allow the user to assess how the implementation of alternative site-specific management options (e.g. a different crop, soil, irrigation system etc.), can be expected to modify an FFU or WQR determination. This is highlighted because adoption of different management practices may reduce or overcome the effects of a specific water quality problem.

Tier 1 calculations of soil-crop-water interactions assume an idealised 4-layer soil in which crops withdraw 40% of their water requirement from the top layer, 30% from the second, 20% from the third and 10% from the bottom layer. The steady state (or equilibrium) concentration of soluble constituents in each layer is calculated from the concentration of constituents in the irrigation water and a 10% leaching fraction for the profile as a whole. Tier 2 calculations make use of a simplified version of the dynamic Soil Water Balance (SWB) model that is run for a minimum of 10 years using data from an appropriate weather station to calculate the water requirements and uptake of a user selected crop. It also simulates transient salt transport and simplified soil chemical interactions. This output is used to derive yield and other outputs, from which the likelihood with which specific yield intervals occur over time, can be calculated.

DSS Output

An FFU assessment of water with a given composition, produces separate output pages that indicate how the suitability indicators for soil quality, crop yield and quality and irrigation equipment are affected.

Root zone salinity, one of the suitability indicators used in the DSS to assess how the composition of irrigation water affects soil quality, was selected to illustrate the differences between DSS output for Tiers 1 and 2 FFU assessments. Note that in all cases the criteria defining the FFU category remains the same.

For the Tier 1 FFU evaluation (Table 2), the DSS calculates a single root zone salinity, which places it in the Acceptable FFU category. Since the value of root zone salinity is given (and not only the FFU category), information is conveyed to the user about how close the root zone salinity is to the boundary of the FFU category.

Table 2.
Tier 1 output of how root zone salinity is affected by irrigation water composition

	Fitness for Use	ECe interval (mS/m)	Predicted equilibrium root zone salinity (mS/m)
Root Zone Salinity	Ideal	0 - 200	
	Acceptable	200 - 400	234
	Tolerable	400 - 800	
	Unacceptable	>800	

For Tier 2 assessments, the DSS calculates at least 10 annual mean root zone salinity values (one for each year the SWB model is run with different climatic data). These values are likely to fall into different FFU categories and are reported as the % of time for which the values fall within a specific FFU category (Table 3). In this way, information is conveyed to the user about the longer-term risk of experiencing different levels of root zone salinity and salt build-up or leaching. These differences are brought about by differences in rainfall and crop water demand as a result of climatic differences from year to year.

Table 3.
Tier 2 output of how root zone salinity is affected by irrigation water composition.

	Fitness for Use	ECe interval (mS/m)	% of time root zone salinity is predicted to fall within a particular Fitness for Use category
Root Zone Salinity	Ideal	0 - 200	60
	Acceptable	200 - 400	30
	Tolerable	400 - 800	10
	Unacceptable	>800	

CONCLUSIONS

The DSS described in this paper provides the user with an assessment of how a water with a given composition will affect soil quality, crop yield and quality, as well as irrigation equipment. A range of suitability indicators were identified for this purpose. Criteria have been established for each suitability indicator, which enables an assessment of the effect that the water composition could have on the suitability indicator. This effect is categorised as being ideal, acceptable, tolerable or unacceptable.

The DSS provides the user with the ability to conduct either a rapid conservative (Tier 1) or extensive site-specific (Tier 2) evaluation of the suitability of a specific water for irrigation. Should the Tier 1 FFU assessment (that makes use of a number of conservative assumptions) not indicate potential problems with any of the suitability indicators, the water is deemed fit for use on all crops, under all but the most exceptional circumstances.

On the other hand, should the Tier 1 assessment identify potential problems with one or more of the suitability indicators, a more detailed, site specific assessment as provided by a Tier 2 assessment, is indicated. The Tier 2 assessment allows the user to select more appropriate site-specific variables (such as crop, irrigation system and management, soil texture and climatic data) to simulate effects with the use of a soil water balance model, and produce a much more rigorous assessment of soil-crop-water interactions. Running the Soil Water Balance model over a number of years, enables the calculation of the likelihood of yield and other parameters falling in different suitability categories.

Reference

DU PLESSIS M, ANNANDALE J, BENADE N, VAN DER LAAN M, JOOSTE S, DUPREEZ C, BARNARD J, RODDA N, DABROWSKI J, GENTHE B and NEL P 2017 Risk based, site-specific, irrigation water quality guidelines: Volume 1 Description of Decision Support System. WRC Report No.TT 728/17 Water Research Commission, Pretoria

Electronic copies of the DSS can be downloaded from: https://www.nbsystems.co.za/downloads.html
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