ENHANCEMENTS TO THE SITE-SPECIFIC, RISK-BASED DSS FOR ASSESSING IRRIGATION WATER QUALITY

Meiring du Plessis, John Annandale and Nico Benade

WATER RESEARCH COMMISSION

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Enhancements to the Site-Specific, Risk-Based DSS for Assessing Irrigation Water Quality

Report to the
WATER RESEARCH COMMISSION

by

Meiring du Plessis[1], John Annandale[1] and Nico Benade[2]
[1]Department of Plant and Soil Sciences, University of Pretoria
[2]NB Systems

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GEZINA, 0031
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Electronic copies of the DSS can be downloaded from: https://www.wateradmin.co.za/sawqi.html

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Dr GR Backeberg	:	Water Research Commission (Chairman, 2018 to 2019)
Ms L Masilela	:	Water Research Commission
Dr N Taole	:	University of Pretoria
Mr N Rossouw	:	Specialist water quality consultant (Formerly from Aurecon)
Ms MJ Gabriel	:	Department of Agriculture, Land Reform and Rural Development
Mr E Mametja	:	Department of Agriculture, Land Reform and Rural Development
Ms NN Masemola	:	Department of Agriculture, Land Reform and Rural Development
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Mr W Mosefowa	:	Department of Water and Sanitation
Dr T Volschenk	:	Deciduous Fruit, Vines and Wine, Agricultural Research Council (ARC)
Ms B Genthe	:	Specialist water quality consultant (Formerly from CSIR)

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Mr Willie Mosefowa	:	Resource Protection and Waste, DWS
Mr Nico Rossouw	:	Water Quality Specialist, Formerly from Aurecon
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Background and Introduction

The South African Water Quality Guidelines, published in 1996. comprise one of the most widely used tools in water quality management. However, since they were increasingly viewed as outdated, the then Department of Water Affairs (now Department of Water and Sanitation, DWS) commissioned a panel of experts to evaluate their suitability (DWAF, 2008). The panel performed a needs assessment, developed a general philosophy and described the general specifications of a decision support system (DSS) for a revised set of water quality guidelines for South Africa.

The new guidelines were envisaged to be different in several fundamental ways from the 1996 guidelines. Firstly, they would be risk-based – a fundamental change in philosophy from earlier guidelines. Secondly, they would allow for much greater site-specificity – a widely recognised limitation of the generic 1996 guidelines. Thirdly, they would be made available primarily as a software-based DSS.

It was foreseen that new guidelines would be developed for each significant water user. The WRC took the initiative and up to now initiated and funded the development of new generation guidelines for five water user groups, namely for irrigation, domestic use, recreational use, stock watering and aquaculture.

The water quality guidelines for irrigation were the first of the new generation guidelines to be started and completed. These guidelines are reported on in two volumes. The first being a high-level description of the DSS (du Plessis et al., 2017(a)) and the second a technical report with a detailed description of the DSS and the approaches and criteria used in its development (du Plessis et al., 2017(b)).

For a project of the magnitude and complexity of the software-based Decision Support System (DSS) with which to determine Water Quality Guidelines for Irrigation (SAWQI), it was only to be expected that further refinement and the need for additional features to improve utility and user-friendliness would be identified as more people start using it.

The site-specific algorithms of the DSS are quite involved, and incorporate the use of the Soil Water Balance (SWB) model, that relies on several input parameters. The model simulates soil-plant-atmosphere interactions with irrigation water constituents for periods of up to forty-five consecutive years. Although the DSS has been tested under a range of conditions, it was foreseen that further 'debugging' would be required to ensure model validity. This would, however, only become apparent once SAWQI was adopted by a larger group of users. The ability of the DSS to assess fitness-for-use of irrigation water under site-specific conditions is one of its most powerful attributes. It enables more realistic assessments of irrigation water quality than the generic approach of the 1996 and similar guidelines. To ensure that these and other potential benefits of using SAWQI are realised in practice, it is necessary to ensure that it is as “fault free” and user-friendly as possible, that it satisfies user needs, and that a critical mass of practitioners use it for its intended purposes.

It is against this background that the WRC approved a follow-on project with the following aims:

i. Raise awareness of the new site-specific, risk-based, irrigation water quality guidelines.
ii. Identify potential enhancements to the DSS to improve utility and user-friendliness.
iii. Prioritise identified needs for enhancement and improvement of the DSS.
iv. Introduce the most important enhancements to SAWQI.

The methodology for this project as outlined in the project proposal was designed to firstly raise awareness of the new site-specific, risk-based irrigation water quality guidelines, followed by the identification, prioritisation and implementation of those enhancements that will most contribute to the improvement of the utility, acceptability, and ease of operation of the DSS. These actions identified for project execution were not envisaged as once off, but as continuous activities building on one another that continued for the duration of the project.

Overview of the Decision Support System

The structure and functionality of the DSS has been established during the precursor of this project and all key characteristics were left unchanged during this follow-on project. The establishment of the DSS and technical detail about its functionality are contained in the reports on the first project (du Plessis et al., 2017(a and b)). This report focuses on reporting the results of the follow-on project. However, to ensure that the reader has a basic understanding of the functionality of the DSS, a brief overview of the DSS is given.

Throughout the DSS, use is made of a colour-coded generic classification of water quality which categorise fitness-for-use into four categories, coinciding with an increased risk of using the water. These fitness-for-use categories are described in qualitative generic terms, which are generally applicable to all water uses. All water user communities for which DSSs have been developed up to now or are under development adopted this classification system as a common denominator in the description and classification of water quality. The classification system (presented below) is based on a DWS system, which describes four suitability categories to which water quality can be assigned. This four-colour, four-category system that defines water quality in generic terms is used throughout the DSS.

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 has been designed to cater for two diverging applications, namely:

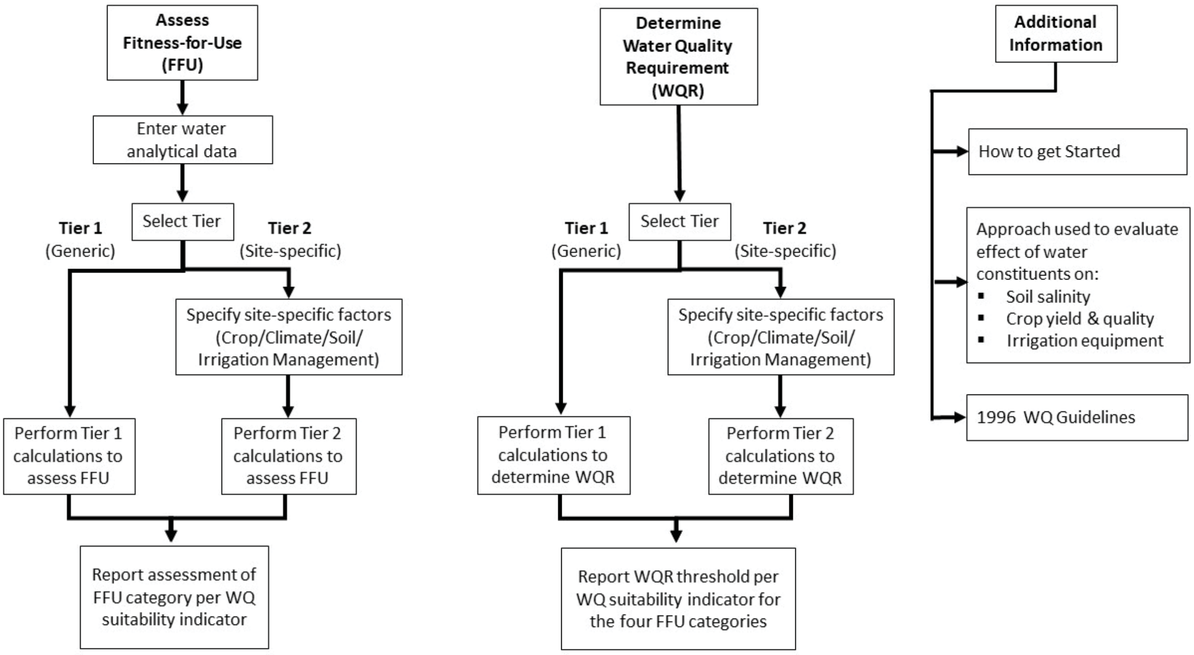
i. To assess the **fitness-for-use** of a water of known composition (water analysis) by determining its fitness-for-use category. This is the more conventional application, and
ii. To determine the threshold water composition for a specific fitness-for-use category. This application is used by water resource managers and users when deliberating on the **setting of water quality requirements** for a given user of a water resource (river stretch or surface or groundwater body)

The input needs, processing procedures and output displays for these two applications are quite different. However, the science and calculations that underlie them are the same. These differences and commonalities are reflected in the structure of the DSS as depicted below.

At the highest level, a user must decide whether he or she wants to use the DSS to assist with:

i. assessing the fitness of a water of known composition for irrigation use, or
ii. determining the water quality requirements for irrigation users, or
iii. obtaining additional information.

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



By selecting the DSS either to assess the fitness-for-use of water of a given composition or to determine water quality requirements, at Tier 1 or 2 levels of site-specificity, the DSS will produce output in one of the following four modes:

i. Tier 1 calculations to assess conservative fitness-for-use of irrigation water of a given composition,
ii. Tier 1 calculations to determine conservative water quality requirements for irrigation use,
iii. Tier 2 calculations to assess site-specific fitness-for-use of irrigation water of a given composition, or
iv. Tier 2 calculations to determine site-specific water quality requirements for irrigation use.

The output in each case is to display four to five separate PDF printable output screens, each reporting on a separate aspect of the fitness-for-use evaluation or water quality requirements evaluation regarding the impact of water constituents on soil quality, crop yield and quality and irrigation equipment.

Raising awareness of the DSS

As undertaken in the project proposal, the Project Team arranged three training sessions for users who wish to become acquainted with the DSS. Training sessions were held in Bloemfontein (17 July 2018), Stellenbosch (19 July 2018), and Pretoria (24 July 2018). In total 42 people attended the training sessions (14 in Bloemfontein, 8 in Stellenbosch and 20 in Pretoria). Attendees were representatives of Government Departments (Department of Agriculture, Forestry and Fisheries (DAFF, now Department of Agriculture, Land Reform and Rural Development, DALRRD) and DWS), agricultural advisory services and research organisations (GWK and ARC), consultants, universities, and analytical laboratories. The attendees were thus representative of a cross section of potential users of the DSS. Most of the attendees were primarily interested in using the fitness-for-use functionality of the DSS, but several were also interested in determining water quality requirements.

All three training sessions followed a similar agenda and consisted of several interactive presentations.

i. Outline of the background to, the need for and the approach followed to compile the updated irrigation water quality guidelines.
ii. Introduction of the DSS and demonstration of its functionality.

iii. Interactive session on how to initialise the DSS and run fitness-for-use assessments.
iv. Discussion of the criteria used to assess the effect of water constituents on soil quality, on crop yield and quality, and on irrigation equipment.
v. Interactive, hands-on demonstration and use of the DSS.
vi. Identification of enhancements for incorporation into the DSS.

The training sessions were for the most part interactive, allowing participants to interject and propose enhancements to the DSS, point out potential errors in the output, and identify where output displays can be improved upon. These were recorded and considered as potential enhancements for incorporation into the DSS.

Special training and awareness raising events, where the availability and functionality of the DSS was explained and/or demonstrated, were presented to DAFF's Directorate: Water Use and Irrigation Development's quarterly meeting of a Working Group on which provinces and other stakeholders are represented (3 May 2018). In addition, the quarterly meeting of DWS's Water Quality Management Forum (7 June 2018), and Head Office staff members of their Directorate: Resource Protection and Waste (29 May 2019), were also presented.

Five presentations were made to learned societies. These presentations served the dual purpose of raising awareness of the existence of the DSS and exposing the science underpinning it to peer review. Two popular articles were published in the SABI Magazine, which caters for the South African irrigation designer community. Popular articles serve the purpose of raising awareness of the existence and features of the DSS and allowing interested parties to acquaint themselves with the underpinning science in their own time and at a pace that suits them. At the invitation of Dr. Backeberg, the Project Team contributed a paper entitled *Site-specific, risk-based, irrigation water quality guidelines*, to a special WRC publication on research-based innovations in irrigated agriculture. The authors trust that this publication, when published, will inform the broader scientific community of the availability and utility of the DSS.

Enhancements incorporated into the DSS

Enhancements considered for incorporation into the DSS are a combination of proposals identified in the final report of the previous project, enhancements suggested during training sessions, suggestions by the user community and enhancements identified by the Project Team. A guiding principle used when considering proposed enhancements was to maintain, as far as possible, the relative simplicity and user-friendly nature of the DSS and retain its primary purpose of assessing fitness-for-use of irrigation water and determining water quality requirements. Four categories of enhancements were distinguished.

Enhancements to the DSS are developments that would improve the functionality or scientific basis of the DSS. Introducing them would mostly require considerable effort and some fundamental changes to, or expansion of, the DSS. Only those considered as being of highest priority, were implemented. **Proposed improvements to the DSS input and output** were considered as soon as they were identified. Improvements deemed as feasible and desirable, were introduced as soon as possible. **Potential calculation errors** were addressed as soon as they became apparent. **Graphical displays** of DSS output were introduced as an enhancement, primarily for advanced users of the DSS. In all cases, the nature of enhancements or errors and how they were addressed are documented in this report. The corrected or updated version of the DSS was made available on the DSS website on a regular basis.

The following **enhancements to the DSS** were introduced:

i. Standardising the period used for calculating soil-plant-atmosphere interactions with irrigation water.
ii. Review of crop nutrient offtake data.
iii. Change calculation of effective root zone depth to which crops respond, to be limited by either soil depth or potential crop rooting depth.

iv. Change basis of crop yield calculation from root uptake weighted root-zone salinity to root zone salinity.
v. Enhancements to indicators of scaling and corrosion.
vi. Improvement of the download and registration process.
vii. Expansion of *Tools* functions for advanced users.

Improvements to **the input-output display,** refer either to enhancements in the way water analyses or site-specific data are captured, or how DSS results are displayed. Appropriate improvements in this regard are thus particularly important, to improve the user-friendliness and acceptability of the DSS. The following enhancements were introduced.

i. Enhancements to the **home screen** include improved stability of home screen selections and the introduction of user-friendlier terminology for the home screen menu.
ii. It is important for the ease of use of the DSS that the **procedures to capture the water composition and site-specific information** is as easy to use as possible and caters for users from different backgrounds. The screen for capturing water composition has been enhanced to do some basic error checking, prevent the capturing of unacceptable data and test for the apparent reliability of the captured analysis. It also provides for the conversion of analytical concentrations in other units to the mg/L and mS/m units used by the DSS.
iii. Improvements to the **capturing of site-specific input** include the display of weather station locality on a map, enabling the importation of weather data into the DSS, and simplifying the selection of irrigation applications.
iv. It is important for a DSS that its **output** is as clear and unambiguous as possible; to allow as little room as possible for misunderstanding and to ensure that incorrect interpretation of results is reduced as far as possible. Six improvements were introduced in this regard.

Several real and suspected **calculation errors** were investigated. They were, in no particular order:

i. Check correctness of criteria for *E. coli* clogging of drippers.
ii. Check correctness of threshold accumulation concentration for iron in soil.
iii. Concern over discontinuous soil hydraulic conductivity (HC) response.
iv. Concern over reported infiltrability response.
v. Fix crop canopy fractional interception going negative at end of growing season.
vi. Investigate suspect Tier 2 Root Zone Salinity values.
vii. Investigate differences in Tier 2 Oxidisable Carbon Loading values between runs.
viii. Modify boron yield calculation for low leaching events.
ix. Allow an open-ended category to calculate the effect of high SAR values on soil permeability.
x. Correct the calculation of trace element concentrations for Water Quality Requirement determinations.
xi. Correct cation/anion imbalance error if no potassium values are entered.
xii. Correct processing of one season less than the specified number.
xiii. Correct incorrect irrigation amount displayed for first crop.
xiv. Activate depletion as irrigation timing option.
xv. Correct incorrect water quality requirement calculation for root zone salinity.

Graphical displays were introduced as enhancement primarily aimed at advanced users of the DSS. DSS output consist of four to five user-friendly output screens which display the results of a fitness-for-use assessment or water quality requirement determination. These screens represent the primary output for users and contain all the information required to interpret and use fitness-for-use assessments or water quality requirement determinations. However, in the process of running SWB simulations that provide the data on which fitness-for-use assessments or water quality requirement determinations are based, much additional useful information is generated that can provide the advanced user with more insight and understanding of how the interaction between the different processes operating in the soil-plant-atmosphere system influence the final outcome. While it is possible for advanced users to export some of these data and further process them in a spreadsheet, this is not a trivial task and one that not many users will undertake. The Project Team agreed to develop a number of basic graphs to illustrate how water balance components and suitability indicators vary over time. This differs from the DSS output, which focus on the statistical variability of suitability indicators over a specified period.

Graphs have been developed that show the changes over time of water balance components that are the drivers of soil-plant-atmosphere processes and time dependant indicators of soil quality, crop yield and crop quality. Users can mostly select between displaying the graph for the first crop, and if crop rotation is selected, the second crop or both. Graphs are a mixture of line graphs and bar charts or, in some cases, a complex graph consisting of a collection of sub-graphs.

Proposed enhancements not incorporated into the DSS

A number of proposed enhancements were not incorporated into DSS. For each of the proposed enhancements, a description is firstly presented in the main report of the reason for the proposed enhancement, followed by the Project Team's response, providing reasons for not acceding to the request. A summary of the proposed enhancements not incorporated into the DSS is given below.

Enhancements requiring structural changes to the DSS.

i. Enable the use of water composition data that changes over time.
ii. Provide for assessing the impact of poor-quality water over short periods of time.
iii. Provide for a two-year cropping cycle.

Enhancements introducing structural changes to SWB.

i. Introduce a feedback loop for crop growth reduction due to salinity.
ii. Replace Robbins chemical calculation procedure with the Unsatchem procedure.
iii. Allow for the definition of soil layers with different properties.

Proposals that would expand the DSS weather database.

i. Enable importation of user selected climate data into the DSS database.
ii. Investigate whether the WRC report by Pegram et al. (2015) can add value to the DSS climate database.
iii. Investigate the availability and suitability of DWS weather data and its importation into the DSS database.

Requests that would require changes to the DSS.

i. Provide for batch processing of water constituent analyses.
ii. A request was made to make DSS results exportable.
iii. Provide for definition of own crops.
iv. As part of DSS output screens for Tier 2 assessments, print the crop parameters of selected crops.
v. Add the leaf scorching effect of bicarbonate.

Request to consider developing an App version of the DSS.

Conclusions and Recommendations.

The Project Team believes that they have succeeded in raising awareness of the availability and functionality of the site-specific, risk-based irrigation water quality guidelines among its potential users. However, unfortunately this does not necessarily translate into an extended active user community. The Project Team further believes that the enhancements that were introduced add much to the functionality and user-friendliness of the DSS.

Although the DSS has been enhanced to a high level of functionality and user-friendliness, it is only to be expected that it will require maintenance and further refinement in future. There is an urgent need for an institution to accept responsibility as custodian of the DSS and promote its future use, or for the WRC to support further development and technology transfer until such an institution can be identified. There is also a need to update the DSS at regular intervals, in order to review its scientific content, and where necessary, to introduce new findings or data, or to expand its functionality.

The Project Team believes that the current version of the DSS, largely complies with the original expectations to establish a software-based DSS with which to determine Water Quality Guidelines for Irrigation and assess the Fitness-for-Use of irrigation water. However, further improvement in some respects would be beneficial and desirable. These include some of the proposed enhancements that were not implemented during this project. The DSS has found application and is often used to assess the fitness-for-use of acid mine waters for irrigation. Emanating from these applications, are a number of issues in need of further research, such as:

i. During irrigation with gypsiferous waters typical of acid main drainage, a significant portion of the salts contained in the water can precipitate as gypsum within the soil profile, resulting in a lower than anticipated salt load in the drainage. It would be very useful to users of this application of the DSS if it could provide them with a salt balance quantifying the fraction of salts applied through irrigation that precipitate in the soil and those that drain to below the root-zone.

ii. Acid mine drainage often contains high concentrations of dissolved iron, aluminium and manganese, which exceed the DSS trace element accumulation thresholds. The question is whether the accumulation thresholds are realistic for these elements in view of the fact that they are abundantly present within soils, and are likely to oxidise and become unavailable for plant uptake.

iii. On the other hand, early experiments at the University of Pretoria identified the risk of foliar absorption of trace elements and the risk ingestion of crops produced with such waters pose to human or animal health. This is also a topic worth investigating, as it has important implications for all international irrigation water quality guidelines.

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LIST OF ABBREVIATIONS

ARC	Agricultural Research Council
DAFF	Department of Agriculture, Forestry and Fisheries
DALRRD	Department of Agriculture, Land Reform and Rural Development
DSS	Decision Support System
DWA	Department of Water Affairs
DWAF	Department of Water Affairs and Forestry
DWS	Department of Water and Sanitation
EC	Electrical conductivity
GWK	Griqualand West Cooperative
SAPWAT	South African Procedure for determining crop Water requirements
SAWQGI	South African Water quality Guidelines for Irrigation
SWB	Soil Water Balance (model)
TDS	Total dissolved solids
UFS	University of the Free State

1 INTRODUCTION

The South African Water Quality Guidelines published in 1996 comprise one of the most widely used tools in water quality management. However, since they were increasingly viewed as out of date, the then Department of Water Affairs (now Department of Water and Sanitation, DWS) commissioned a panel of experts to evaluate their suitability (DWAF, 2008). The panel performed a needs assessment, developed a general philosophy and described the general specifications of a decision support system (DSS) for a revised set of water quality guidelines for South Africa.

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ii. Identify potential enhancements to the DSS to improve utility and user-friendliness.
iii. Prioritise identified needs for enhancement and improvement of the DSS.
iv. Introduce the most important enhancements to SAWQI.

The methodology for this project as outlined in the project proposal was designed to firstly raise awareness of the new site-specific, risk-based irrigation water quality guidelines, followed by the identification, prioritisation and implementation of those enhancements that will most contribute to the improvement of the utility, acceptability, and ease of operation of the DSS. These actions identified for project execution were not envisaged as once off, but as continuous activities building on one another that continued for the duration of the project.

The final report provides a structured overview of the activities during the execution of the project, documents the identification and prioritisation of enhancements that were identified for possible introduction and describes the enhancements that were introduced.

- Chapter 2 provides an overview of the Decision Support System.
- Chapter 3 reports on the activities to raise awareness of the DSS.
- Chapter 4 documents the identification, prioritisation and description of enhancements incorporated into the DSS.
- Chapter 5 describes proposed enhancements that were not incorporated into the DSS.
- Chapter 6 contains a discussion of how successful the project was in meeting its aims, shortcomings that were identified during the course of the project and recommendations for future enhancements to the DSS.

2 OVERVIEW OF THE DECISION SUPPORT SYSTEM

The structure and functionality of the DSS has been established during the precursor of this project and all key characteristics were left unchanged during this follow-on project. As stated above, the aim with this follow-on project is to ensure that the DSS is as “fault free” and user-friendly as possible, that it satisfies user needs, and that a critical mass of practitioners use it for its intended purposes. The establishment of the DSS and technical detail about its functionality are contained in the reports on the first project, namely a high-level description of the DSS (du Plessis et al., 2017(a)) and a technical report with a detailed description of the DSS and the approaches and criteria used in its development (du Plessis et al., 2017(b)). This report will focus on reporting the results of the follow-on project. However, in order to appreciate and follow the reporting, it is desirable to have a basic understanding of the functionality of the DSS. For this reason, a brief overview of the DSS is presented in the following paragraphs.

A primary reason for DWS’ drive to develop risk-based water quality guidelines was that, in this way, they would establish a common language that can be used by the different water user communities (e.g. recreation, natural environment, livestock watering and aquaculture) when they discuss the setting of resource water quality requirements. Initially it was envisaged that it would be possible to quantify risk with a single number. During the establishment of resource quality requirements, the use of a single “risk value” by all users to calculate their corresponding water quality requirements, would ensure that resource quality requirements calculated by different users would represent a similar level of risk (ill effects) to all of them. This ideal was not attained. It was agreed that rather than striving for a single value to express risk, risk would for purposes of the irrigation water quality guidelines, be quantified within a scenario describing the risk being assessed, the consequences should the risk materialise and the likelihood that the risk would materialise. This definition applies to both fitness for use evaluations of water with a given composition and to the setting of water resource quality requirements. While the science and calculations underlying the assessments are the same for both Fitness-for-Use evaluations and for setting Water Quality Requirements, the way in which results are interpreted on the one hand, and conveyed and presented to the user groups, on the other, do differ.

Throughout the DSS, use is made of a colour coded generic classification of water quality, which categorises fitness-for-use into four categories, coinciding with an increased risk of using the water. These fitness-for-use categories are described in qualitative generic terms, which are generally applicable to all water uses. This classification system was adopted as a common denominator in the description and classification of water quality by all water user communities for which DSSs have been developed up to now, or that are under development. The classification system (see Table 2-1) is based on a DWS system, which describes four suitability categories to which water quality can be assigned. This four-colour, four-category system that defines water quality in generic terms is used throughout the DSS.

Table 2-1. A generic description of the DWS fitness-for-use classification of 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
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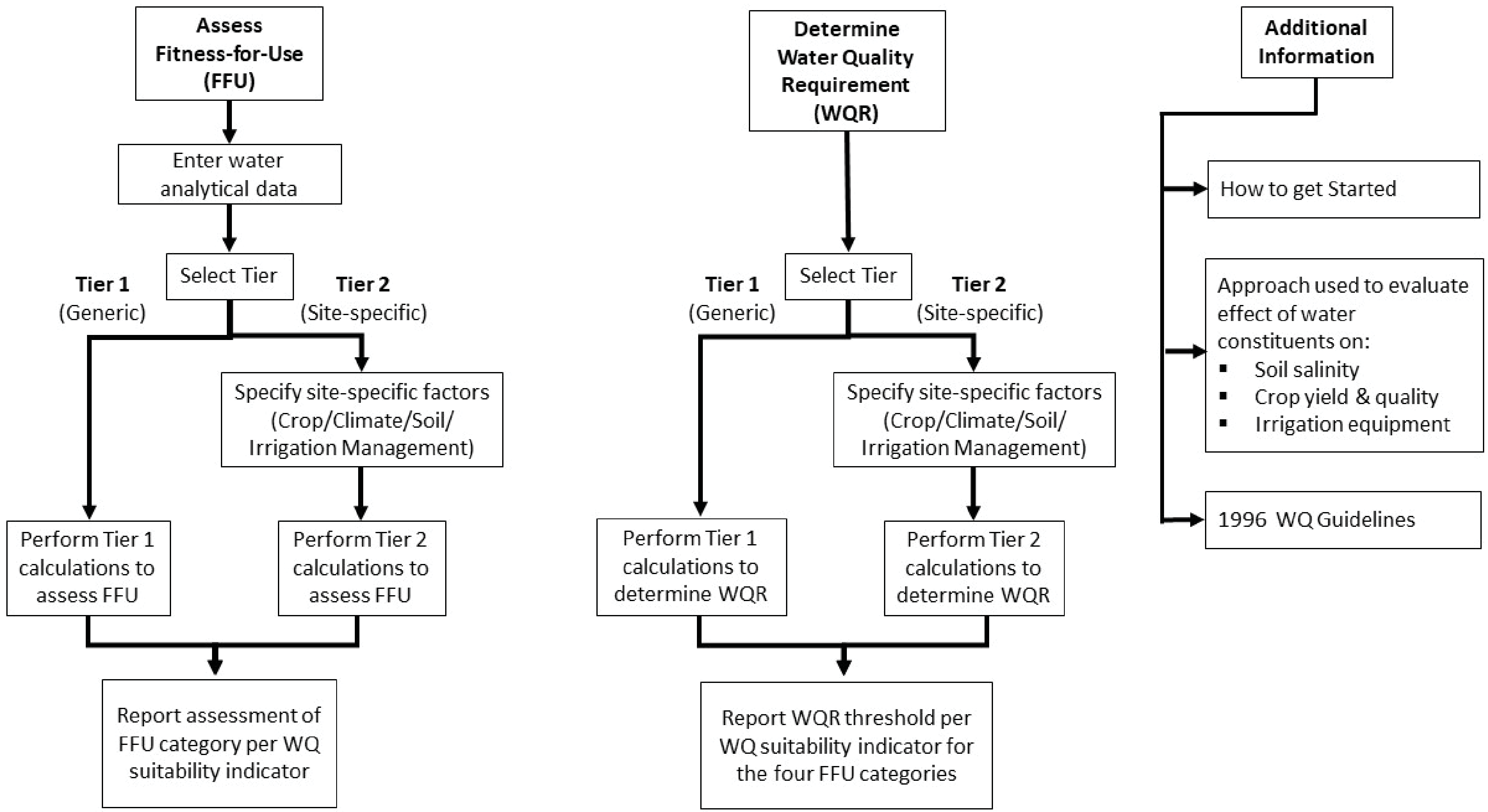


Figure 2-1. Simplified schematic representation of the DSS structure

The DSS has been designed to cater for two diverging applications, namely:

i. To assess the **fitness-for-use** of a water of known composition (water analysis) by determining its fitness-for-use category. This is the more conventional application, and

ii. To determine the threshold water composition for a specific fitness-for-use category. This application is used by water resource managers and users when deliberating on the **setting of water quality requirements** for a given user of a water resource (river stretch or surface or groundwater body)

The input needs, processing procedures and output displays for these two applications are quite different. However, the science and calculations that underlie them are the same. These differences and commonalities are reflected in the structure of the DSS as depicted in Figure 2-1 and Figure 2-2.

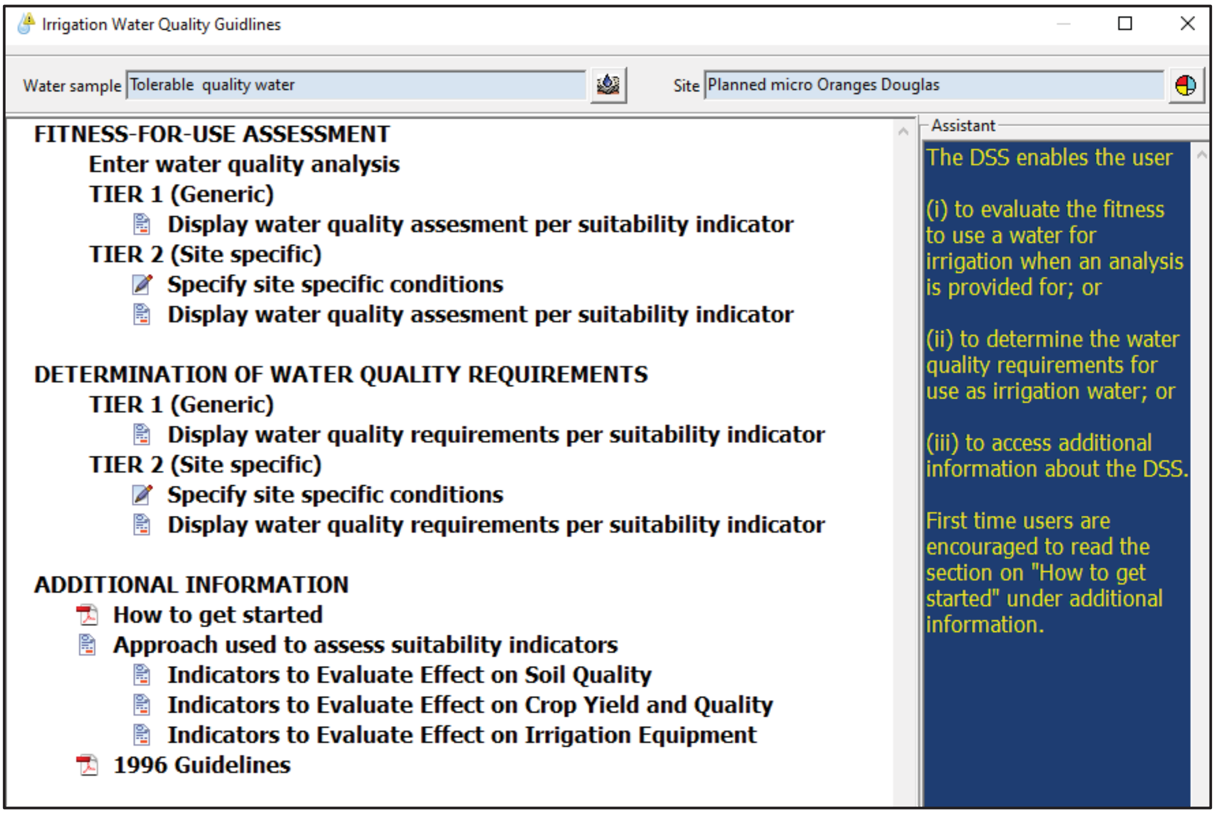


Figure 2-2. The main DSS screen that guides users through the options to perform a fitness-for-use assessment, to determine water quality requirements, or to obtain additional information.

At the highest level, a user must decide whether he or she wants to use the DSS to assist with:

i. assessing the fitness of a water of known composition for irrigation use, or

ii. determining the water quality requirements for irrigation users, or

iii. obtaining additional information.

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

The high-level description of the DSS (du Plessis et al., 2017(a)) and a technical report (du Plessis et al., 2017(b)) provide the interested reader with more information and background about:

i. The general approach and calculating procedures employed by the DSS and how they differ for Tier 1 and 2 calculations,

ii. The input requirements of the DSS and how they differ for Tier 1 and 2 calculations,
iii. The specific approaches and calculating procedures adopted for generic (Tier 1) and site-specific (Tier 2) evaluations of the fitness-for-use and determination of water quality requirements related to soil quality, crop yield and quality and irrigation equipment, and
iv. The criteria to assess and graphically display the impact of water constituents on soil quality, crop yield and quality and irrigation equipment.

Table 2-2. Summary of the output screens / pages content that are generated during fitness-for-use assessments and determination of water quality requirements

Number of Output Screen / Page	**Fitness-for-use Assessment**		**Determination of water quality requirement**	
	Tier 1	**Tier 2**	**Tier 1**	**Tier 2**
Number 1	• Summary of simplifying assumptions • Water composition	• Record of site-specific conditions • Water balance summary • Water composition	• Summary of simplifying assumptions	• Record of site-specific conditions • Water balance summary
Number 2	• Assessment of water composition effect on soil quality	• Assessment of water composition effect on soil quality	• Threshold water quality requirements for soil quality categories	• Threshold water quality requirements for soil quality categories
Number 3	• Assessment of water composition effect on crop yield and quality	• Assessment of water composition effect on crop yield and quality (1st crop)	• Threshold water quality requirements for crop yield and quality categories	• Threshold water quality requirements for crop yield and quality categories (1st crop)
Number 4		• Assessment of water composition effect on crop yield and quality (2nd crop)		• Threshold water quality requirements for crop yield and quality categories (2nd crop)
Number 5	• Assessment of water composition effect on irrigation equipment	Assessment of water composition effect on irrigation equipment	Assessment of water composition effect on irrigation equipment	Assessment of water composition effect on irrigation equipment

By selecting the DSS either to assess the fitness-for-use of water of a given composition or to determine water quality requirements, at Tier 1 or 2 levels of site specificity, the DSS will produce output in one of the following four modes:

i. Tier 1 calculations to assess conservative fitness-for-use of irrigation water of a given composition,
ii. Tier 1 calculations to determine conservative water quality requirements for irrigation use,
iii. Tier 2 calculations to assess site-specific fitness-for-use of irrigation water of a given composition, or
iv. Tier 2 calculations to determine site-specific water quality requirements for irrigation use.

The output in each case is to display four to five separate PDF printable output screens, each reporting on a separate aspect of the fitness-for-use evaluation or water quality requirements evaluation (see Table 2-2).

3 ACTIVITIES TO RAISE AWARENESS OF THE DSS-BASED WATER QUALITY GUIDELINES

In the project proposal, it was anticipated that one-day introductory training sessions would be hosted in three centres to increase the awareness of the user community of the availability of the SAWQI-DSS, on the one hand, and to familiarise them with its operation and functionality, on the other hand. It was envisaged that in this way a core user community would be established which would introduce the use of the DSS to a still wider user community. It was expected that the user community would provide feedback to the project team about desired enhancements to the DSS and identify sets of conditions that may lead to unreliable output requiring some 'debugging'. For practical reasons, it was deemed desirable to present separate training sessions to users that are primarily interested in operating the DSS functionality to assess fitness-for-use, and to users interested in the determination of water quality requirements. It was further envisaged to hold separate training sessions for government officials and private advisors. Government officials would be drawn mostly from the DWS Directorates Water Resource Planning Systems and Resource Quality Services, and the Department of Agriculture, Forestry and Fisheries (DAFF, currently Department of Agriculture, Land Reform and Rural Development, DALRRD) Directorate, Water Use and Irrigation Development. Private advisors would include consultants advising government on determining water quality requirements and organisations interested in fitness-for-use evaluations, such as analytical laboratories specialising in irrigation water and agricultural advisory service organisations.

The WRC initiated the following activities to make its potential user community attentive of the availability and functionality of the DSS:

i. The release of a Ministerial Brief (entitled “Risk-based, site-specific irrigation water quality guidelines”) to DWS and DAFF, in which a description is given of the functionality and availability of the DSS.
ii. An article by Dr Backeberg entitled “Risk-based approach to irrigation water quality management” that was published in Agri-Water.
iii. The official launch at the WRC offices on 8 March 2018 of the DSS for Risk-based, Site-specific, Irrigation Water Quality Guidelines to prospective users and other interested parties. This occasion was also used to announce the start of the follow-on project with its emphasis on promoting the use and enhancing DSS functionality. Attendees were encouraged to participate.

3.1 AWARENESS RAISING TRAINING WORKSHOPS

The Project Team arranged three training sessions for users who wish to become acquainted with the DSS. Training sessions, aimed primarily at persons interested in fitness-for-use evaluations, were held in Bloemfontein (17 July 2018), Stellenbosch (19 July 2018), and Pretoria (24 July 2018).

In arranging the fitness-for-use training sessions, an invitation was distributed to potential attendees with the request to distribute the invitation further to colleagues who may be interested in attending. Attendance was free of charge, but attendees were expected to pre-register and to make their own subsistence and travel arrangements. Attendees were further expected to use their own PCs during training and to download the DSS onto their PCs prior to the training course.

In total 42 people attended the training sessions (14 in Bloemfontein, 8 in Stellenbosch and 20 in Pretoria). Attendees were representative of Government Departments (DAFF and DWS), agricultural advisory service and research organisations (GWK and ARC), consultants, universities and analytical laboratories. The attendees were thus representative of a cross section of potential users of the DSS. Most of the attendees were primarily interested in using the fitness-for-use functionality of the DSS, but several were also interested in determining water quality requirements.

All three training sessions followed a similar agenda and consisted of several interactive presentations, as described in greater detail in the following paragraphs.

3.1.1 Outline of the background to, the need for and the approach followed to compile the updated irrigation water quality guidelines.

This presentation provided a brief overview of water quality guideline development in South Africa, the recommendations of the 2008 Panel of Experts and the needs that gave rise to the decision to revise the 1996 Water Quality Guidelines. The fundamental differences between the 1996 Guidelines currently in use and the new site-specific, DSS and risk-based Guidelines and the fact that irrigation was the first user group to have their guidelines updated, were highlighted. The project team responsible for executing the project were introduced. The presentation concluded with a description of the process followed to update the irrigation water quality guidelines and establish the DSS.

3.1.2 Introduction of the DSS and demonstration of its functionality.

The DSS was introduced by explaining that it was designed for two user groups with diverging needs. Some would be interested in an assessment of the fitness for irrigation use of a water based on the analytical results of a water sample, and others may wish to know what the water composition should be to meet the requirements of users in a specific area. This was followed by highlighting some of the shortcomings of guidelines currently in use and the need for them to be revised. Next, some of the decisions that had to be made during the development of the DSS were discussed, namely, deciding on the water constituents to consider in the DSS, the indicators and sub-indicators to use when the suitability of water is assessed, what should be considered under the different assessment Tiers and how to define different fitness-for-use classes. The structure of the DSS was discussed next, namely that it provides for the assessment of both fitness-for-use and water quality requirements, and also provides additional useful information in electronic format This was followed by a description of the procedure to conduct a fitness-for-use assessment at either a Tier 1 or Tier 2 level. The respective output screens were shown and attention drawn to the similarities and differences in output for the two Tiers. The presentation concluded with simulation results that illustrate the effect of site specificity on predicted outcomes. Crop yield was shown to increase between sites with increasing rainfall when other variables (e.g. using the same quality water) were kept the same.

3.1.3 How to initialise the DSS and run fitness-for-use assessments.

The operation of the DSS was demonstrated by running it live and interactively. The demonstration started with a discussion around the DSS opening screen and an explanation of how the program is downloaded from the internet, the need to register as user and acceptance of the disclaimer. Next, the functionality of the home screen was discussed. The user can choose between conducting a fitness-for-use evaluation, determining a water quality requirement, or accessing additional electronic information. Fitness-for-use assessments were discussed and demonstrated in greater detail. The capturing, editing, printing and other functions available on the screens for capturing water analyses were explained interactively. Next, a Tier 1 assessment was conducted, and the output briefly discussed. This was followed by a live editing of the site-specific input screen and conducting a Tier 2 fitness-for-use assessment. Differences between the output of Tiers1 and 2 and the implications thereof were briefly discussed.

3.1.4 Discussion of the criteria used to assess the effect of water constituents on soil quality.

The background to and rationale for the criteria that are used to determine the fitness-for-use category of suitability indicators, were discussed. The expected effect of irrigation water of a given composition on soil quality and its subcomponents, were briefly elaborated upon. The suitability indicators used to assess the effect of irrigation water composition on soil quality are:

i. Root zone salinity
ii. Hydraulic conductivity
    a. Soil permeability
    b. Infiltrability
iii. Dissolved organic carbon loading
iv. Trace element accumulation

3.1.5 Discussion of the criteria used to assess the effect of water constituents on crop yield and quality.

The background to and rationale for the criteria that are used to determine the fitness-for-use category of suitability indicators used to describe the effect irrigation water of a given composition, is expected to have on crop yield and quality and its subcomponents, were discussed. The suitability indicators used to assess the effect of irrigation water composition on crop yield and quality are:

i. Root zone effects on crop yield as a result of its content of:
    a. Salinity (EC)
    b. Boron
    c. Chloride
    d. Sodium
ii. Leaf scorching
iii. Nutrient effects
iv. Microbial contamination
v. Pesticides

3.1.6 Discussion of the criteria used to assess the effect of water constituents on irrigation equipment.

The background to and rationale for the criteria that are used to determine the fitness-for-use category of suitability indicators used to describe the effect irrigation water of a given composition, is expected to have on irrigation equipment and its subcomponents, were discussed. The suitability indicators used to assess the effect of irrigation water composition on irrigation equipment are:

i. Scaling and corrosion
ii. Clogging of drippers

3.1.7 Interactive, hands-on demonstration and use of the DSS

The activities of the awareness raising training sessions were concluded with an interactive, hands-on demonstration and use of the DSS to assess the fitness-for-use of water samples provided by attendees. Attendees were afforded the opportunity to capture water analytical data hands-on onto their PCs, following the lead of the presenter, who's PC was connected to a video projector. Site-specific conditions selected by attendees were compiled in the same way before using the DSS to assess fitness-for-use using site-specific conditions of their own choice. Assessments were repeated after making changes to site-specific conditions in order to demonstrate the versatility of the DSS and the effect changes in site-specific conditions have on fitness-for-use assessments.

3.1.8 Identification of enhancements for incorporation into the DSS

Participants were in general favourably impressed with the functionality and ease of operation of the DSS and indicated that they would use it on a regular basis. Most of the participants found it relatively easy to download and register as user of the DSS. Others encountered difficulties and had to be assisted prior to the start of training sessions.

The training sessions were for the most part interactive, allowing participants to interject and propose enhancements to the DSS, point out potential errors in the output and identify where output displays can be improved upon. These were recorded and considered as potential enhancements for incorporation into the DSS.

3.2 OTHER KNOWLEDGE DISSEMINATION ACTIVITIES

Several other knowledge dissemination activities in addition to the awareness raising workshops were undertaken during the project term. These included special training and awareness raising events, presentations to learned societies, popular and scientific publications. More information about these activities is presented in Appendix A

4 ENHANCEMENTS INCORPORATED INTO THE DSS.

The identification of desired enhancements to the DSS and conditions that may lead to unreliable output requiring some 'debugging' is a never-ending process. Throughout the project term, the project team on an on-going basis collected suggestions for enhancements from users and identified some of their own. Identifying and finding the root cause to solve an error is seldom a trivial task. It mostly requires significant effort and attention to detail to effect a successful update. This section describes the criteria used to prioritise proposed enhancements and describes the enhancements that were implemented.

4.1 CRITERIA USED TO PRIORITISE PROPOSED ENHANCEMENTS

The project team approached the prioritisation and implementation of proposed enhancements, corrections, and improvements to input and output display, as follows. The guiding principle used when considering especially enhancements and improvements, was to maintain as far as possible, the relative simplicity and user-friendly nature of the DSS and retain its primary purpose of assessing fitness-for-use of irrigation water and determining water quality requirements. This implied careful consideration of any additions or modifications that would complicate its ease of use. Four categories of enhancements were distinguished.

i. **Proposed enhancements to the DSS** are viewed as improvements that will improve the functionality or scientific basis of the DSS. Their introduction would mostly require considerable effort and some fundamental changes to, or expansion of, the DSS. For purposes of this project, their introduction was thus treated as being of a longer-term nature. The project team endeavoured to ascertain the importance that should be attached to the introduction of each proposed enhancement by investigating the need for (or benefit to be derived from) the enhancement and assessing how challenging it would be (and thus how much time would be required) to introduce the enhancement. In this way, a priority was allocated to the introduction of each of the proposed enhancements, and only those considered of highest priority were implemented.

ii. **Potential calculation errors** were addressed as soon as they became apparent. There is no doubt that corrections found to be necessary, had to be attended to immediately to ensure the functionality and integrity of the DSS. These corrections were, therefore, treated as important and urgent, and corrected as soon as possible. The nature of the error and how it was corrected were documented for future reference (as described below), and the corrected version of the DSS posted on the DSS website.

iii. **Proposed improvements to the DSS input and output** were considered as soon as they were received or identified. Improvements deemed as feasible and desirable, were introduced as soon as possible, the nature of the improvement documented for future reference (as described below) and the improved version of the DSS posted on the DSS website.

iv. **Graphical displays** of DSS output were introduced as an enhancement, primarily for advanced users of the DSS. Graphical displays do not form part of the core DSS output that produce either an evaluation of the fitness-for-use of a water sample or a determination of the water quality requirements for irrigation purposes. In all cases, the nature of enhancements or errors and how they were addressed are documented in this report. The corrected or updated version of the DSS was made available on the DSS website on a regular basis.

The enhancements considered for incorporation into the DSS are a combination of proposals identified in the final report of the previous project, enhancements suggested during training sessions, suggestions by the user community and enhancements identified by the Project Team. Three categories of enhancements were distinguished, namely:

i. Enhancements to the DSS;

ii. Correction of potential calculation errors; and
iii. Improvements to input and output display.

In adhering to the guiding principle of maintaining the user-friendly nature of the DSS and not to diminish its primary purpose as a tool to either assess the fitness-for-use of irrigation water, or to determine the water quality requirements of water bodies, the familiar look and feel of the DSS was maintained as far as possible for the intended principal user. Additional features that have been introduced for the benefit of the more advanced user, are therefore not assessable from the DSS main screen.

The proposed enhancements that have been incorporated into the DSS are presented in the following paragraphs. Each of the proposed enhancements is introduced with a description of the problem or issue that gave rise to the proposed enhancement, followed by a description of the remedial action that was implemented.

4.2 ENHANCEMENTS TO THE DSS

An enhancement to the DSS implies an improvement to, or expansion of DSS functionality. By its very nature, enhancements would thus mostly imply fundamental changes or additions to the DSS, that may involve elaborate structural or programmatical changes. Since such changes mostly fall outside of the scope of this project, several proposed enhancements were not accepted for implementation (see section 5.1). However, a few proposed enhancements to the DSS as described below were accepted for incorporation into the DSS.

4.2.1 Standardising the period used for calculating soil-plant-atmosphere interactions with irrigation water.

For Tier 2 fitness-for-use assessments, the SWB model is run for a minimum of 10 years to simulate the soil-plant-atmosphere interactions with irrigation water. This is deemed the minimum number of years necessary to demonstrate the effect that the natural variation in climate is expected to have on soil and plant response to irrigation water composition. The DSS allows for increasing, with increments of five, the number of years the SWB model is run, up to a maximum of 45 years. The DSS makes provision for the planting of a single crop or two crops in rotation during a single year, each with their own selectable planting date. The periods between crops are treated as fallow periods during which model simulations continue in response to rainfall and evaporation, but with no irrigation applications. In the original version of the DSS, Tier 2 simulations were run for exactly 10 calendar year periods, or with five calendar year increments. This had the consequence that unless the second crop completed its growth cycle before the end of a calendar year, the SWB simulation would not complete the intended number of crop growth cycles for the second crop. A further complication with a 10-year simulation arose with the prediction of relatively high crop yields during the first year when irrigating with a saline water on an initially non-saline soil. More realistic yields are predicted after the soil had time to equilibrate somewhat, with saline irrigation water.

To rectify the problems described above, the DSS for Tier 2 simulations was changed to run for two additional years. The simulation now starts on 1 January (rather than the plant date of the first crop) either as a crop being planted, or as a fallow period followed by a crop being planted. The data for the minimum 12-year simulation are processed as follows. The data for the first full year of simulated crop results are treated as belonging to an equilibration period and not considered for processing. The second year's data, up to the planting date of the first crop of the calendar year is also not considered for processing. This is because these data belong to the later growth stages of the first year's second crop. Ten or more, years of data following on the planting date of the first crop of the second calendar year, are used for processing. In this way, provision is made for a brief equilibration period and ensures that exactly 10 years (or more in multiples of five), of completed crop growth cycle data are used during processing of crop response during growth periods.

4.2.2 Review of crop nutrient offtake data

The DSS uses values for crop nutrient offtake, based on attainable crop yields and expected nutrient content, to calculate the percentage of nutrients removed by crops that are potentially replaced by nutrients in irrigation water. This gives an indication of the degree to which fertiliser management is complicated by the nutrient content of irrigation water. The DSS used figures for crop nutrient removal gleaned from various sources. The Project Team made various unsuccessful attempts to obtain the assistance of an authoritative crop nutritionist to evaluate and improve on these values. The Project Team were concerned about the number of crops for which no nutrient offtake data were available in the DSS database, and that the data in the DSS may not be realistic and reflect good farming practice. The Project Team were fortunate to obtain the services of Dr Neil Miles of Soil Health and Plant Nutrition Services (who recently retired from SASRI as their plant nutritionist and soil analytical laboratory specialist) to review and update the data in the DSS crop database. The updated list, which contains references to the data sources used, as well as the original data, appear in Appendix B. The crop database used in the DSS was updated with the data generated by Dr Miles. In the case of crops for which he did not provide new or revised data, the previous values were retained.

4.2.3 Change calculation of effective root zone depth to which crops respond, to be limited by either soil depth or crop rooting depth.

Soil profiles in SWB are defined as consisting of a rootless 50 mm surface layer, from which evaporation takes place, followed by 10 layers of equal depth from which roots can extract water. For the calculation of the root zone salinity to which a crop responds, the salinity of the 10 lower soil layers used to be added together and the total divided by 10 to get the mean salinity to which the crop was exposed. However, it was pointed out that the total rooting depth of a crop (which varies between crops and is one of the crop specific parameters used in SWB simulations) determines the effective root zone depth for a crop. However, it is also possible that the crop rooting depth characteristic, may exceed the specified soil depth. In this case, the specified soil depth determines the effective rooting depth utilised by the crop. The procedure to calculate root zone salinity experienced by the crop differs for these two possibilities.

To rectify the situation, programming code was written to cater for the options of the effective root zone depth being limited by specified profile depth or crop rooting depth. First, it is determined whether the effective root zone depth is determined by the specified profile depth or by the potential crop rooting depth. If it is determined by potential crop rooting depth, root zone salinity is calculated by adding the sum of the salinity of each layer, up to the crop rooting depth, multiplied by layer thickness that is constant in the DSS, divided by the crop rooting depth. If the soil profile depth determines it, the root zone salinity is calculated by adding the sum of the salinity of each layer multiplied by its thickness, divided by the total thickness of the layers.

This change in the calculation of the root zone salinity to which crops respond, does not affect the calculation of the soil quality indicator entitled *Soil profile salinity*, which is calculated as the salinity of each soil profile layer multiplied by the constant layer thickness and divided by the profile depth minus the thickness of the surface layer.

4.2.4 Change basis of crop yield calculation from root uptake weighted root-zone salinity to root-zone salinity.

Since it makes intuitive sense, and there are indications that crop yield is closely related to the time integrated root uptake weighted salinity in soil water (Maas, 1990), and since the SWB model produces the variables required for its calculation, the Project Team initially opted to calculate this measure of soil salinity, chloride, boron and sodium, to estimate their effect on crop yield for Tier 2 calculations. However, these values were found to be considerably lower than the corresponding mean root zone salinity values that are normally used to derive crop yield. The differences found, can be partially explained by the fact that for the calculation of root uptake weighted salinity, roots are exposed to the lower salinity soil layers closer to the soil surface at the start of a growing season and only later during the growing season are they exposed to the higher salinity layers that are located at the bottom of the profile. The mean seasonal profile salinity, on the other hand, considers all soil layers from the beginning of the growing season. It was consequently decided to rather use seasonal (the crop growth period) root zone salinity as measure from which to infer crop yield for Tier 2. This is in line with irrigation quality guidelines of Ayers and Westcott, 1985, who also use mean root zone salinity values to estimate the effect of salinity on crop yield.

4.2.5 Enhancements to indicators of scaling and corrosion.

Scaling and corrosion of irrigation equipment are two of the main problems irrigation water can cause to irrigation infrastructure. The DSS uses a calculation of the Langelier Index value to predict whether a water would display a corrosive or scaling effect on irrigation equipment. Several requests were received to expand its utility.

i. Expand Langelier Index calculations to cover different temperatures.

The Langelier Index serves to predict the risk of corrosion or scaling of irrigation equipment. For purposes of the DSS, the Langelier Index is calculated for a temperature of 20°C. Since the Langelier Index and inferences drawn from it is affected by temperature, it is possible that while the value calculated at 20°C does not indicate scaling, scaling will in fact occur at a higher temperature, in, for example, a dripper line that it is exposed to the sun. Advanced users thus have reason to be interested in Langelier Index values and the implications for corrosion or scaling at different temperatures.

The available space on the DSS output page does not allow for presenting Langelier Index values at different temperatures. The Project Team were, furthermore, of the opinion that this type of information is only required under specific conditions and by advanced users. It was consequently decided to develop a Langelier Index calculator to calculate the Langelier Index at a desired temperature, as one of the DSS tools for advanced users. The Langelier Index calculator can be accessed under the *Tools* icon.

ii. Calculation of Langelier Index for a bicarbonate analysis of zero.

The bicarbonate concentration of a water under investigation is one of the constituents used in the calculation of the Langelier Index. Most natural waters contain some bicarbonate, and do not present problems with this calculation. However, acidic waters, such as acid mine drainage that do not contain bicarbonates, cause a division by zero error during the calculation. This calculation error was overcome by programmatically introducing a bicarbonate concentration of 0.1 mg/L in cases where the bicarbonate concentration was in fact zero. This remedy to overcome the calculation error does not affect the conclusions that can be drawn from the Langelier Index value. The calculated Langelier Index correctly indicates no likelihood of scaling, but an unacceptably high risk of corrosion.

4.2.6 Improvement of the download and registration process.

The Project Team wish to have a record of who downloads and uses the DSS so that users can be informed of improvements and modifications and can be approached to canvas their opinion when required. This requires that users register before they can use the DSS. The registration process requires that the webmaster must send a registration code to the user to confirm his/her authenticity. With unfettered internet access, this process normally proceeds smoothly. However, where the user operates within a corporate environment where firewalls regulate internet access, the registration process can often not be completed. This causes frustration on the part of users and potential users, as well as the webmaster, who must assist telephonically to complete the registration process manually.

The Project Team faced a dilemma trying to resolve this issue and has yet to find a satisfactory solution. On the one hand, they wished to attract only registered users, while, on the other, they did not wish to antagonise potential users with an unnecessarily complicated registration process. An interim compromise was decided on, whereby potential users are advised as early as possible of the potential problems and encouraged to use private internet or other unconstrained internet connections during the registration process. Furthermore, a function was added to the Help facility that provides the user with direct access to the DSS website to check the date and, if required, download the most recent version of the DSS.

4.2.7 Expansion of *Tools* functions for advanced users

Amongst others, the DSS Opening Page provides access to the *Tools* function, which is available to, but seldom accessed by the casual user of the DSS. The *Tools* function provides data and information that are not required or sought after by the casual DSS user. The *Tools* function currently enables the more advanced user to, amongst others, on his or her own copy of the DSS, access and edit the parameters used to determine crop yield, the composition of the model waters used in runs to determine water quality requirements, a Langelier Index calculator, results from the last DSS simulation, etc. It is proposed to expand the scope of functions provided under the *Tools* function to provide value added functions that supplement the DSS output for advanced users. It is specifically planned to:

- Add scaling-corrosion calculations for non-carbonate waters.
- Enable the display graphs that show how variable concentrations, such as root zone salinity, change over time.
- Provide for the definition of own crops.

The benefit of making these value-added functionalities available as part of the *Tools* function and not as an expanded DSS output report is that:

- The relative simplicity and user-friendly nature of DSS output is not compromised.
- The DSS output is not complicated more than necessary.
- It will not be necessary to amend or expand the DSS output screens. This helps to reduce the possibility of introducing unintended output errors.
- Value added functions will be available in one place, rather than distributed over the four to five pages of DSS output, and thus easier to access and use.

4.3 IMPROVEMENTS TO INPUT-OUTPUT DISPLAY

Either improvements to the input-output display refer to enhancements in the way water analysis or site-specific data are captured, or to how DSS results are displayed. Appropriate improvements in this regard are thus particularly important to improve the user-friendliness and acceptability of the DSS. Several improvements were implemented as outlined below.

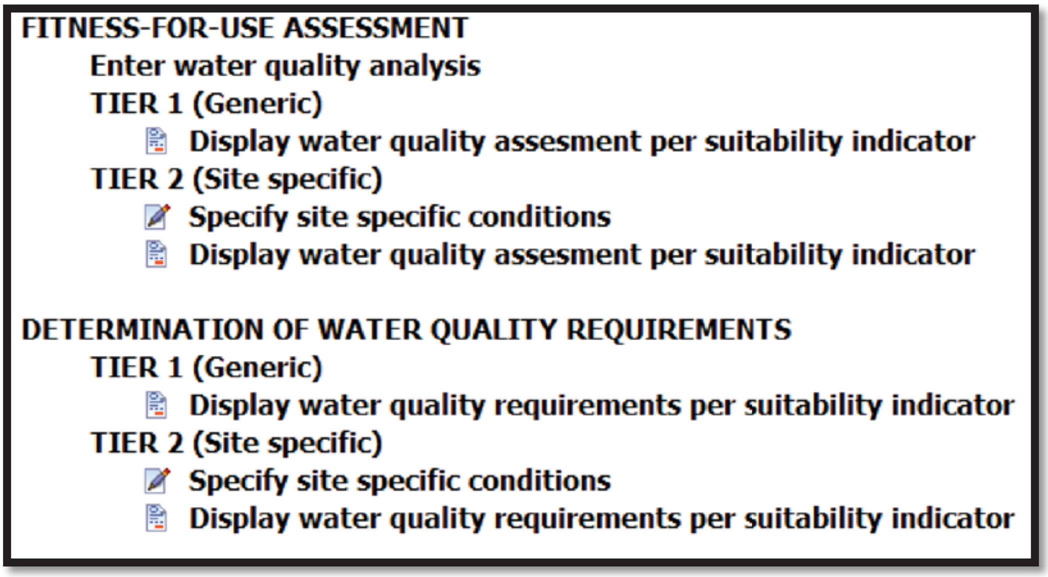
4.3.1 Improvements to home screen

i. Improved stability of home screen choices.

On the main menu screen of the DSS, the Fitness-for-use options used to collapse when the option to *Input water quality analysis* was selected. If not corrected, the unobservant user would inadvertently end up selecting the Water Quality Requirement option without realising it. This caused unnecessary frustration and confusion. A solution was implemented whereby the user selectable choices on the home screen remain stable and the Fitness-for-use options are no longer allowed to collapse.

ii. Introduce user-friendly terminology for the main menu screen.

At the Reference Group meeting held on 26 February 2020, the Project Team were requested to replace terms like “output” and “input” that were used on the main menu screen, with “display” and “enter” that would be more understandable and easier to follow by end users. The Project Team concurred with the suggestion. After introducing the changes, the relevant portion of the main menu screen, was changed to the following.



4.3.2 Improvements to the procedure to capture water quality analysis.

It is important for the ease of use of the DSS that the procedures to capture the water composition and site-specific information is as easy to use as possible and caters for users from different backgrounds. The screen for capturing water composition has been enhanced to do some basic error checking, prevent the capturing of unacceptable data and test for the apparent reliability of the captured analysis.

i. Conversion of analytical concentrations to mg/L and mS/m.

Some laboratories report water analyses in units other than mg/L and mS/m, which are the default units used by the DSS. Users requested that since they are not necessarily familiar with conversion factors, the DSS makes provision for the conversion of different concentration units to mg/L, and different EC units, to mS/m. A conversion calculator was developed and made available on the data-capturing screen next to each macro ion and Electrical Conductivity, as indicated in Figure 4-1. For macro ions, provision has been made to convert from the following units to mg/L. After typing the value of the analysis and selecting the units that need to be converted from, the value of the analysis is displayed in mg/L, where after the corrected value can be saved:

- meq/L
- $mmol_c$/L
- mmol/L
- mg/L as CaCO3

For Electrical Conductivity, provision has been made to convert from the following units to mS/m:

- µmho/cm
- µS/cm
- mmho/cm
- mS/cm
- dS/m

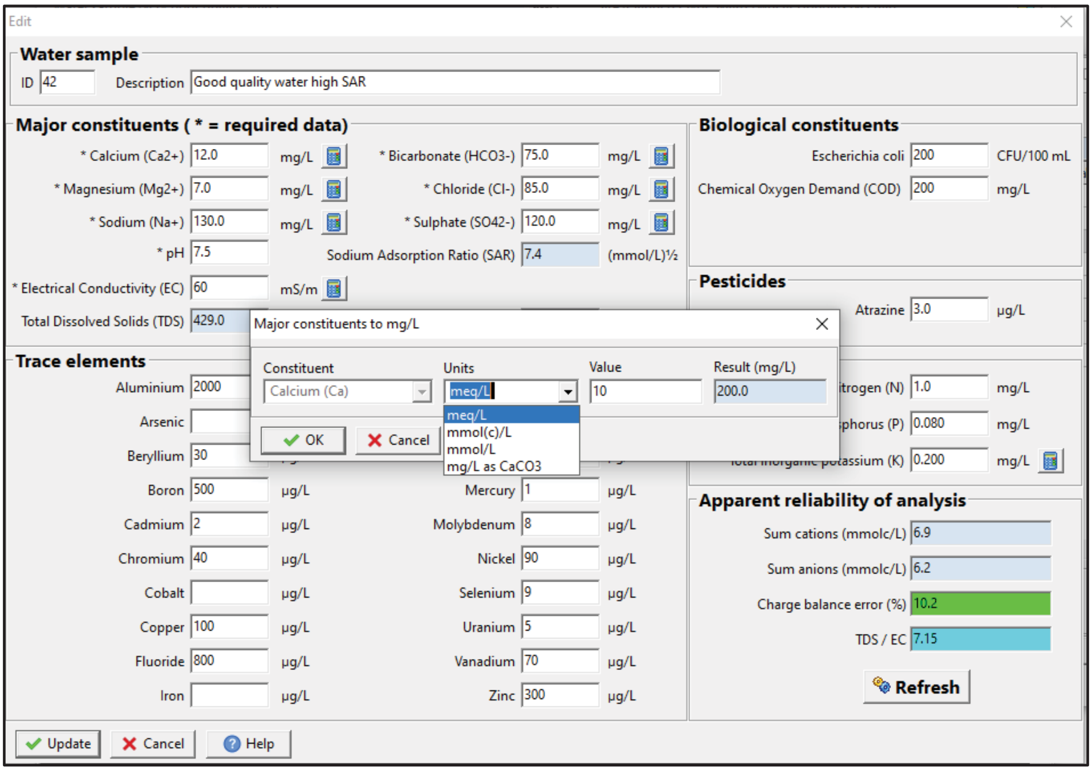


Figure 4-1. Screen to capture composition of water sample, displaying the facility to convert analytical concentrations to mg/L and mS/m.

Testing for apparent reliability of analysis.

Faulty water composition data may result in the generation of misleading output by the DSS and/or cause numerical instability in the program. The Project Team was requested to introduce tests to check on the reliability of the captured analyses. Two tests were introduced to evaluate the apparent reliability of a water analysis, namely the cationic/anionic charge balance of macro ions, and the ratio between the measured EC and TDS as calculated from the macro cation and anion concentrations. The effects of pH and high trace element concentrations on the cationic/anionic charge balance are not taken into account but should be considered by users.

The outcome of these tests is displayed in the right, lower bottom of the screen used for capturing/editing analytical data, as indicated above. After editing the water composition values, the *Apparent reliability of analysis* is recalculated when the *Refresh* button is clicked. The sum of cations and anions and the percentage charge balance error is displayed, as well as the ratio of TDS to EC. The apparent reliability of the charge balance error and TDS/EC ratio are displayed on a coloured background indicating their acceptability as *Ideal* (blue), *Tolerable* (green), *Acceptable* (yellow) or *Unacceptable* (red). The criteria used to determine the acceptability categories, are indicated in Table 4-1.

Table 4-1. Criteria with which to determine the acceptability category of charge balance errors and the ratio between TDS and EC.

Category	Charge Balance Error (%)	TDS/EC (Ratio)
Ideal	>=-10 and <=+10	>=6.0 and <=7.3
Tolerable	>=-20 and <=+20	>=5.3 and <6.0 or >7.3 and <=8.0
Acceptable	>=-30 and <=+30	>=4.67 and <5.3 or >8.0 and <=8.67
Unacceptable	<-30 or >+30	<4.67 or >8.67

For ease of checking the *apparent reliability of analysis* of water samples for which analyses have already been captured, the apparent reliability of the highlighted sample is displayed at the bottom of the screen displaying analyses that have been captured previously.

ii. Prevent input of defective water composition data.

Defective water composition data may result in the generation of faulty output by the DSS and/or cause numerical instability in the program. Although the correctness of input data is the primary responsibility of the person using the program, some measures can be introduced to minimise the capturing of defective data. The following measures were introduced to reduce the likelihood of capturing erroneous water composition data:

- A warning is displayed, and a selectable choice given when it is attempted to capture a double decimal point.
- It is not possible to manually change the programmatically calculated SAR and TDS values.
- Negative values are identified as unacceptable when the captured data is updated.

iii. Editing the ID numbers of water samples and site-specific conditions.

ID numbers are automatically allocated to water samples and site-specific conditions. The DSS automatically allocates an ID number when a new sample is captured, or when a sample is copied. This is to ensure that each sample has a unique numeric identifier, since it is this identifier that is used by the DSS to select the water sample, and site specifications that are used for a specific fitness-for-use assessment or water quality requirement determination. The user-generated description attached to this identification number is not used by the DSS and serves only to provide the user with a fitting description with which to describe the sample or site. The DSS provides for changing ID numbers while using the *Edit* screen, if so required. This enables users to rearrange ID numbers to suit their requirements. However, the new number may not be the same as an existing number. The DSS operating system will not allow the use of duplicate ID numbers and will display an error message if a number already in use is entered.

4.3.3 Improvements to capturing site-specific input.

It is important for the ease of use of the DSS that the procedures to capture the water composition and site-specific information is as easy to use as possible and caters for users from different backgrounds.

i. Display of weather station locality and importation of weather data into the DSS

The DSS initially contained data for 41 weather stations, each comprising 50 years of cleaned up weather data. These weather stations were identified by the Project Team to cover South Africa and provide a reasonable geographical distribution from which to select a suitable weather station for site-specific evaluations. Weather stations are identified by name, which does not always provide enough information about their location. Sometimes this made it difficult to identify the most appropriate weather station for a particular Fitness-for-Use assessment or Water Quality Requirement determination.

It furthermore turned out that users desired a larger selection of weather stations from which to select one appropriate for their use. The Schulze database contains data for 1947 quaternaries and represents the largest long-term weather station database for South Africa known to the Project Team. It is from this database that the initial 41 stations in the DSS were selected. Unfortunately, several of these weather stations contain generated data. Dr Mark Horan of the University of KwaZulu-Natal, (School of Bioresources Engineering and Environmental Hydrology), who is the custodian of the Schulze database, kindly made available the 'real data' they sourced from the South African Weather Service and the Agricultural Research Council to the Project Team. It is the intention of the Project Team to identify and eliminate weather stations with generated data and replace any poorly patched data using the SWB patching routine. In the meantime, advanced users of the DSS can view the location and download data for any of the weather stations in the Schulze database, as described below.

The DSS functionality was enhanced by making it possible to view the location of all weather stations in the Schulze database. By clicking on the icon next to the weather station name in the *Weather* quadrant of the site-specific attribute editing screen, a Google map of South Africa is displayed which indicates the position of all the weather stations in the database.

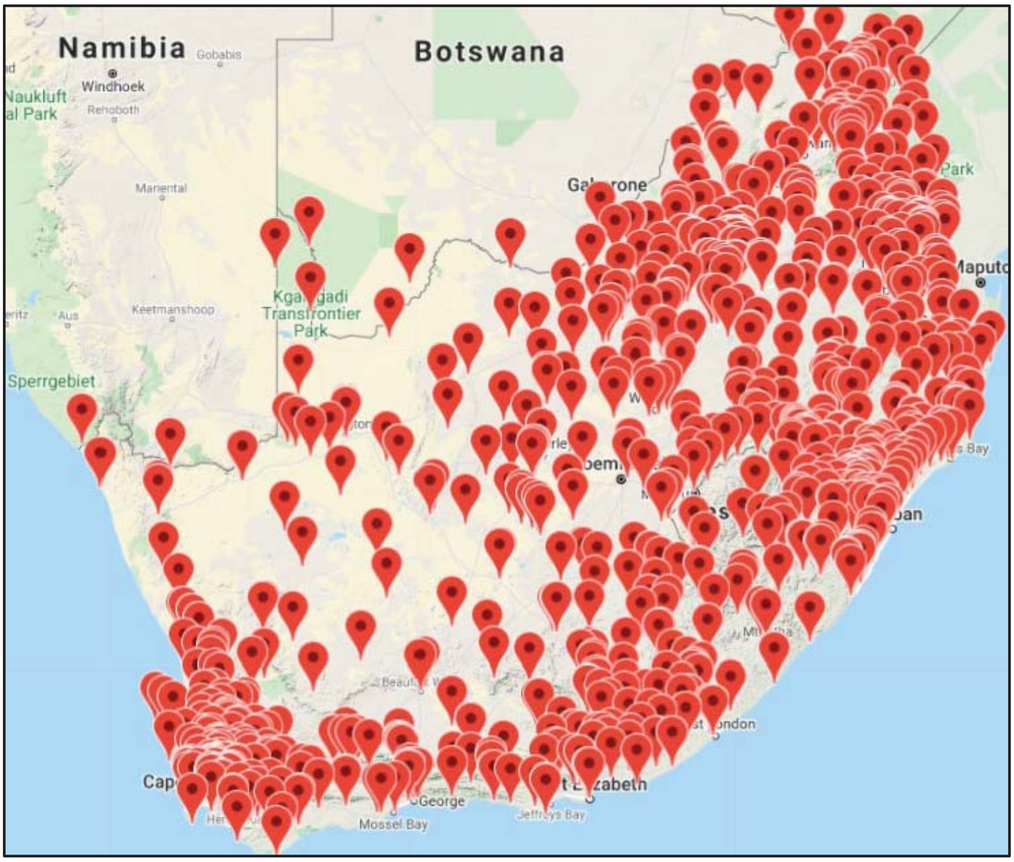


Figure 4-2. Google map indicating the weather stations in the Schulze database, available for downloading into the DSS

The name of a weather station is displayed by clicking on the red pin on the map of South Africa. Since this is a Google map with the position of the weather stations superimposed on it, the map can be manipulated to better decide which weather station would be the most appropriate. For example, the map allows one to zoom in on a particular area to get a better understanding of the weather station's location relative to other geographical features, or the red pin weather station map could be projected onto a satellite image (see Figure 4-2).

Once a suitable weather station has been identified, advanced users can import the data of any of the Schulze weather stations into the DSS database, by using the ***weather stations*** option under the ***Tools*** menu. Before a weather station can be used in a DSS simulation, its data first needs to be downloaded into the DSS database. Should a weather station that does not yet form part of the DSS database, be selected to describe site-specific conditions, an error message providing cryptic instructions for downloading weather station data, will be displayed.

ii. **Irrigation system options reduced to overhead and surface irrigation.**
The DSS uses a scaled down tipping bucket version of the SWB model to calculate the water balance and simulate solute transport. As such, it therefore does not provide for 3D water movement and partial surface wetting conditions as would be required for drip and micro irrigation simulations. The irrigation management component of the site-specific description consists of three attributes, namely irrigation timing (what triggers an irrigation event), refill option (how much water to apply) and irrigation system (through which means the water is applied). The original drop-down list for selecting an irrigation system as part of specifying site-specific conditions, listed sprinkler, pivot, drip, microjet and flood irrigation as common generic irrigation methods to choose from. Identifying drip or microjet as irrigation systems in the DSS, was not intended to imply their spacing and wetting pattern attributes, but rather their foliage wetting attributes. The mention of drip and microjets, nonetheless created mistaken expectations with some users. Furthermore, at a training session, the Project Team was made aware of the fact that microjet is a trademark and not a generic term for micro sprayers. It was suggested that *micro sprayers* be used as the generic term for this type of irrigation system. The "irrigation frequency" and "amount applied" management attributes of the selected irrigation system are set using 'refill options' and 'irrigation timing'.

In practice, the irrigation system that is used determines whether the soil surface is partially or completely wetted, whether foliage is wetted or not and whether irrigation is applied with high-energy droplets (with the potential to cause surface crusting), or not. Since the SWB model used by the DSS, assumes full surface wetting, and in order to remove confusion about the intention for the selection of an irrigation system, the choice has been reduced to only two, namely "overhead (foliage wetted)" or "surface" irrigated. Hereby the possible creation of an impression that the DSS simulates spacing and wetting patterns associated with drip and micro irrigation systems, is removed. Differentiating between overhead irrigation whereby foliage is wetted, and surface irrigation is adequate to assess whether leaf scorching is possible, or not, and to differentiate between irrigation methods that will result in the wetting, or not, of those parts of crops that are destined for human consumption, when microbially contaminated water is used. It also differentiates between water applications that would promote surface crusting triggered by high-energy drops, or not.

4.3.4 Enhancements to output screens.

It is important for a DSS that its output is as clear and unambiguous as possible, to allow as little room possible for misunderstanding, and to ensure that incorrect interpretation of results is reduced as far as possible. Several proposals in this regard were received and implemented.

i. **Improved readability of unacceptable fitness-for-use category output screen.**

It was difficult to read the black lettering in black and white printouts of DSS output screens for unacceptable fitness-for-use categories. The reason for this was the lack of contrast in black and white prints between black lettering and the dark red background used for unacceptable fitness-for-use categories. It was suggested that white, rather than black lettering, be used to improve the contrast and thus readability. However, the Project Team rejected the suggested solution because of concerns that using different font colours for different fitness-for-use categories, may confuse users. Rather than changing the font colour, the background colour was changed to a less intense red, which contrasts well with the black lettering and produced improved black and white prints.

ii. **Correct misleading output display regarding atrazine damage.**

The DSS output for Tier 2 fitness for use assessments displayed “No data” against a blue background when no crop data for assessing atrazine damage was available. While the display of “No data” is correct, the display of a blue background incorrectly implied an ideal fitness for use. The misleading output was corrected by displaying the “No data” output against an uncoloured background.

iii. **Expand on water balance reporting.**

As part of reporting on the seasonal water balance for crops, the DSS already reported on the seasonal water balance components, including rainfall and leaching fraction. This has been expanded to report the mean annual precipitation during the period of simulation, as part of reported weather station information, and the effective annual leaching fraction (i.e. the leaching fraction which includes fallow periods), as part of the reported water balance for the simulation period.

iv. **Change descriptor of soil salinity to *Soil profile salinity.***

The descriptor of soil salinity as a suitability indicator of soil quality was changed from *Root zone salinity* to the more correct *Soil profile salinity, a*nd the heading above the criteria for the *Soil profile salinity* indicator was changed from *Root zone salinity (mS/m)* to *ECe (mS/m).* This is more correct, since soil salinity is measured as EC_e (i.e. the Electrical Conductivity of the soil saturation extract)

v. **Consistency in the display of *No Data* vs *No Parameter* in output display.**

Two conditions result in no fitness-for-use evaluation being returned by the DSS, namely:

- When no analytical data is available with which to assess the fitness-for-use characteristic under consideration, and
- When the crop parameter data that are used to assess the fitness-for-use characteristic under consideration, is not available as part of the DSS crop database.

When either of these data items are unavailable, the DSS assessment for the characteristic under consideration cannot be processed, and the reason for not displaying an assessment (be it *No data* or *No parameter*), is reported. During the development of the DSS it happened that the hierarchy in which the *No data* or *No parameter* was displayed, was not consistent for all fitness-for-use indicators. In order to establish consistent reporting, the following protocol was implemented. When either analytical data or crop parameter data was not available, *No data* or *No parameter* would be displayed, as applicable. When both analytical data and crop parameter data was not available, only *No data* would be displayed.

vi. **Reported significant figures for nutrient applications.**

The FFU output table which displays the degree to which crops remove nutrients which are applied through irrigation, also displays the calculated amount (kg/ha) of nutrient applied through irrigation. These amounts are reported as rounded whole numbers. Calculated amounts between 0.5 and 1.5 kg/ha are thus reported as 1 kg/ha. It was found that amounts lower than 0.5 kg/ha were reported as a blank value. The DSS was programmed to print a nought when the calculated amount of nutrient applied through irrigation is less than 0.5 kg/ha.

The effect of irrigation water composition on crop yield and quality is reported on a separate page for each crop for which fitness-for-use is assessed. The DSS still calculates and reports the amount of nutrients applied to each crop, even when parameters with which to calculate the degree to which crops remove nutrients applied through irrigation, are not available. It was noticed that when two crops are planted in rotation, the amount of nutrients that are applied to the second crop are reported to one decimal whereas no decimals are reported for the first crop. The printout was changed to whole numbers for both.

4.4 Correction of calculation errors

i. Check whether criteria for *E. coli* clogging of drippers is correct.

High *E. coli* concentrations are an indicator of potential clogging of drippers in the DSS. It was questioned whether it is actually feasible for *E. coli* to clog drippers, or whether this is just an indicator of eutrophication that gives rise to slime growth. The Project Team consulted the publication of Nakayama and Bucks (1991), which was used to derive the DSS criteria for clogging of drippers, to confirm the correctness of the criteria used in the DSS. Nakayama and Bucks (1991) refer to a bacterial number of less than 10 000 per mL as posing a minor hazard and above 50 000 as causing a severe hazard of dripper clogging. For purposes of the DSS, *E. coli* was used as a substitute for what they collectively called bacteria and the units for expressing the criteria were converted to one and five million counts per 100 mL, respectively.

ii. Check the threshold accumulation concentration for iron in soil.

Trace element accumulation in soil is evaluated against a set threshold accumulation concentration, above which the accumulation is deemed unacceptable. The threshold concentration of 2500 mg/kg for iron in soil has been questioned as being too high. The threshold concentration of 2500 mg/kg for iron in soil was verified as being correct. It should be noted that in view of their abundance in soil, it is often questioned whether the setting of threshold accumulation concentrations for elements such as iron and aluminium could be justified.

iii. Concern over discontinuous soil hydraulic conductivity (HC) response

There is some concern that the degree of reduced HC does not display a continuous response in Tier 2 assessments. There are cases where ideal and severe implications are displayed with no responses in between. HC values that were recorded for processing on a quarterly basis, was later discovered to be an ill-considered measure to save computer processing time, as it was found to give rise to this erratic result. It was decided to rather calculate HC on a daily basis, and by recording and processing daily HC values, more gradual changes in HC are reported.

iv. Concern over reported infiltrability response

Concern was also expressed about the reported infiltrability response. It should be recalled that infiltrability is a soil surface phenomenon. The formation of infiltrability (IB) limiting crusts is determined by a combination of irrigation water SAR (sodium absorption ratio) and the EC of the infiltrating irrigation water or rain. The more saline the irrigation water, the less the likelihood that it will limit IB, and the higher the irrigation water SAR, the higher the likelihood that IB will be reduced. For a site-specific situation, there is only one IB outcome possible for irrigation water and one for rain. Since the EC of rain is lower than that of irrigation water, it should always give rise to more severe IB problems. The DSS furthermore assumes that when canopy cover exceeds 50%, the energy of rain or sprinkler irrigation droplets is sufficiently reduced to prevent crust formation. It is thus quite possible for the predicted outcome of potential IB problems to be discontinuous.

v. **Fix crop canopy fractional interception going negative at end of growing season.**
The irrigation scheduling routine allows surface evaporation to continue during the fallow period of a single crop, or between crops in rotation, as well as during the leafless period of a deciduous perennial crop. However, the FI (fractional interception of solar radiation by the crop canopy) was found to turn negative when the growing season ended, giving rise to erroneous and unrealistically high surface evaporation levels being calculated. The result was that while irrigation applications by the scheduling routine was expected to cease at the end of the growing season, irrigation continued to be applied to compensate for the high calculated water loss caused by erroneously high calculated surface evaporation.

The problem was resolved by introducing changes to the procedure for calculating the crop water balance. Firstly, calculations using SWB were modified to start on the first day of the available weather data, rather than only on the first day of planting. Next, a "fallow" period was introduced as a land use to depict the period between crops reaching maturity, but before the next crop is planted for single or rotational cropping systems, or for the period between harvesting and the start of the new growing season for deciduous perennial cropping systems. No transpiration occurs during the fallow period and no irrigation takes place, but rainfall and surface evaporation continue to be calculated and accounted for in the calculation of the water balance for the fallow period, without committing any mass balance errors.

vi. **Investigate suspect Tier 2 Root Zone Salinity values.**
The frequency with which Tier 2 Root Zone Salinity values are reported for the different suitability categories appeared to be inconsistent and suspect. Upon investigating the reason behind the under and over reporting of Tier 2 Root Zone Salinity values, it was found the error was linked to a typographical programming error. This caused stored root zone salinity values in the database to accumulate from one run to the next, rather than being cleared in the database between successive runs of the DSS. This error was corrected, and the problem resolved.

vii. **Investigate differences in Tier 2 Oxidisable Carbon Loading values between runs.**
The frequency of reported Tier 2 Oxidisable Carbon Loading values was found to differ between successive runs. Although differences were small, they were deemed indicative of undesirable instability. The cause of the instability was traced to the fact that the results table was not being emptied between runs. This fault was corrected, and it was ensured that all the other result tables are emptied at the start of a new simulation, in order to circumvent potential similar errors with other indicators.

viii. **Modify boron yield calculation for low leaching events.**
The root-zone boron concentration that is used to assess the effect of boron on crop yield, is calculated using the same four-layer steady state calculation procedure as used for Tier 1, also for Tier 2. Whereas a constant 10% leaching fraction is assumed for Tier 1 calculations, the actual seasonal leaching fraction is used for Tier 2 calculations. The seasonal leaching fraction that is part of the SWB output is used for the calculation. For seasons when little or no leaching is calculated to take place, this leads to the calculation of unrealistically high boron concentrations in the root zone and low yields. This problem was resolved by setting a lower limit to the leaching fraction. For seasons during which no leaching is calculated,

evapotranspiration is reduced to 0.98 of the sum of irrigation plus precipitation. This produces a leaching fraction of around 2%, which results in a more acceptable boron induced crop yield.

ix. Allow an open-ended category to calculate the effect of high SAR values on Soil Permeability.

The DSS makes use of criteria listed in Tables 6.5 and 6.6 of the Technical Support Report by du Plessis et al. (2017b) to calculate the effect that sodium in irrigation water has on soil Infiltrability and Hydraulic Conductivity, respectively. The maximum sodium concentrations listed in these Tables are an SAR range of 12 to 20. Since this represents a closed range, it does not explicitly provide for SAR values exceeding 20, with a consequence that SAR values exceeding 20 have an undefined effect on soil permeability. Since an SAR of 20 is high and rarely encountered in irrigated soils, the normal reader of the Tables would extrapolate the effect at SAR 20 to apply also to values exceeding 20. The DSS uses exactly defined programmed formulas, and will therefore not do this, with the result that should an SAR exceeding 20 be encountered, the DSS predicted effect on soil permeability will be undefined. The DSS program was consequently amended so that the criteria to assess the effect SAR will have on soil Infiltrability and Hydraulic Conductivity in the SAR range of 12 to 20, also apply to SAR values exceeding 20.

x. Calculation of trace element concentrations for Water Quality Requirement determinations

To simplify the calculation to obtain the threshold trace element concentrations for the different Water Quality Requirement fitness-for-use categories, trace element concentrations are calculated as fractions of the value for 'Ideal' concentrations. During back testing of the calculated threshold concentration for the 'Acceptable' Water Quality Requirement (which should produce a period of 150 years to reach the Soil Accumulation Threshold), it was found that the DSS calculated a period of 133 years. This erroneous calculation arose because an incorrect fraction was used to calculate trace element concentrations. The faulty procedure assumed that the threshold trace element concentrations for 200 to 150 to 100 years ('Ideal' to 'Acceptable' to 'Tolerable') would decrease in the ratio 1 to 0.75 to 0.5 times the trace element concentration for 200 years ('Ideal'). However, the correct ratios are 1 to 0.6667 to 0.5 times the trace element concentration for 200 years. The values of these ratios are calculated below using the calculation procedure presented by du Plessis et al. (2017b).

The number of years (Years) to reach a known Threshold Accumulation Load (TAL in kg/ha), trace element concentration in irrigation water (Conc in mg/L) and irrigation application (Irrig in mm/year), is calculated as follows:

$$\text{Years} = \text{TAL} / ((\text{Conc} \times \text{Irrig}) / 100\,000)$$

The trace element concentration in irrigation water for the same variables is calculated from:

$$\text{Conc} = (\text{TAL} \times 100\,000) / (\text{Irrig} \times \text{Years})$$

For TAL = 5000 kg/ha (as for Al) and an irrigation application of 1000 mm/year, the following threshold trace element concentrations and ratios are calculated for periods of 100, 150 and 200 years:

Years	Threshold Trace Element Concentration	Concentration Ratio	Water Quality Requirement Category
100	5000	1.0	Tolerable
150	3334	0.667	Acceptable
200	2500	0.5	Ideal

The DSS programming was consequently amended by changing the ratio to calculate the threshold trace element concentration of ’Acceptable’ irrigation water from 0.5 to 0.667

xi. Cation/Anion imbalance error when no potassium values are entered.

Values for pH, electrical conductivity and analytical results for the macro cations and anions are the minimum water quality input required to evaluate the fitness-for-use of a water sample. Potassium does not always form part of analytical results and its importance in the fitness-for-use evaluation, is evaluated as a potential nutrient. However, potassium also contributes to the cation concentration of a water sample and its ionic charge balance. When present, the potassium concentration is thus added to the sum of cations during the ionic charge balance check as part of the quality check on analytical results. The analytical quality indicators are displayed during data capturing, on the screen of captured water samples and on the first display page of the fitness-for-use evaluation. It was found that for a water of acceptable quality, which did not display any indication of analytical errors during data capturing or on the screen displaying captured water samples, an error message indicating unacceptable ionic charge balance was displayed on the first output page of the fitness-for-use evaluation. The cause of the erroneous error message was traced to cases where a null (blank) value was captured for potassium. The error message arose when the ionic charge balance was recalculated for a fitness-for-use evaluation. This recalculation made use of a ‘calculated field’, which has the characteristic of producing an error whenever any of the values it considers is a null. The use of a ‘calculated field’ for the identification of analytical errors were circumvented and the issue resolved.

xii. Processing of one season less than the specified number

Originally, the SWB model was run for the exact number of calendar years of weather data specified during the selection of site-specific characteristics. This had the unintended consequence that when a second crop was selected for simulation, it mostly did not complete its last growth cycle within the last of the specified number of calendar years of simulation. This left the second crop with one too few simulation years of simulation data. This problem was solved by running the SWB model for two extra years in addition to the number specified during the selection of site-specific characteristics. The data for the first year is treated as a “warming-up” period and discarded, while the last year allows the second crop to complete its last growth cycle.

The Results Table records on a daily basis, several processed variables and all the results for variables requiring further processing. It also contains a Seasons Table summarising some processed data for each cropping season (be it a single crop with a fallow period each year or the first and second crops with fallow period(s) each year) together with each cropping season’s start and end dates. These start and end dates are used to specify, extract, and process the data required to process and determine the annual soil profile salinity, and seasonal effects of electrical conductivity, boron, chloride, and sodium on crop yield, thereby solving the problem of the last season’s missing data.

xiii. Incorrect irrigation amount displayed for first crop.

The headings of each of the fitness-for-use and water quality requirement output pages for soil quality and crop yield and quality, displays the mean irrigation application for the relevant soil or crop at the top of the page. It was observed that the correct irrigation application is displayed for both the soil and the second crop. However, for the first crop, the sum of the first and second crop's irrigation applications was displayed. The mistake was corrected, and the correct irrigation application is now displayed for both the first and second crops.

xiv. Depletion as irrigation timing option not activated.

The site-specific specifications for fitness-for-use evaluations and water quality requirement determinations allow several irrigation management options to specify irrigation timing and refill. Irrigation timing can be determined by the *amount* to be irrigated, the *percentage depletion* of available water that is allowed before the next irrigation and the *interval* in days between irrigation events. The refill choices which are available, are replenishing of the soil profile to *field capacity*, irrigation with a fixed *amount* (in mm), to achieve a specified *leaching requirement* or to irrigate leaving a specified amount of *room for rain*. While testing the functioning of available irrigation management options, it was discovered that the option that specifies irrigation after a specific percentage depletion of available water, was not operational.

The irrigation management options provided for in the original SWB model is more extensive than those used in the scaled down model employed for the DSS. During the process of selecting and activating the options for use in the DSS, the depletion option was inadvertently deactivated. This was rectified by reactivating the depletion option. The amount of water that is actually available for depletion is determined by the rooting depth and thus increases throughout the growing season until root development is complete. However, the percentage depletion that is selected to trigger the next irrigation event does not change during the growing season.

xv. Incorrect water quality requirement calculation for root zone salinity

On inspection of calculated water quality requirement values, it was noted that the irrigation water electrical conductivities calculated to give rise to threshold root zone salinities, were too high when compared with fitness-for-use results. Water quality requirement values that will give rise to specified category threshold concentrations, are calculated by interpolation. The process starts with conducting fitness-for-use assessments for a series of model waters with increasing constituent concentrations. Depending on the number of years run, a different number of results (one for each year) are produced. In order to determine the irrigation water salinity that would give rise to a specific root zone salinity value, the 95th percentile highest root zone salinity for each of these model water electrical conductivities are determined. Selecting the 95th percentile highest root zone salinity ensures that the likelihood of the irrigation water causing a higher root zone salinity, is small. Then, the 95th percentile root zone salinity values are plotted against the irrigation water electrical conductivities that gave rise to them. This allows for determining the irrigation water electrical conductivity that will give rise to the root zone salinity value used in the water quality requirement determination. In this case, where the calculated water quality requirement irrigation water electrical conductivity values were too high, the error arose because the irrigation water EC values were linked to the output for crop yield, rather than root zone salinity. This programmatical error was corrected.

4.5 INTRODUCING GRAPHICAL DISPLAYS.

DSS output consists of four to five user-friendly output screens which display the results of a fitness-for-use assessment or water quality requirement determination. These screens represent the primary output for users and contain all the information required to interpret and use fitness-for-use assessments or water quality requirement determinations. However, in the process of running SWB simulations that provide the data on which fitness-for-use assessments or water quality requirement determinations are based, much additional useful information is generated that can provide the advanced user with more insight and understanding of how the interaction between the different processes operating in the soil-plant-atmosphere system influence the final outcome. While it is possible for advanced users to export some of these data and further process them in a spreadsheet, this is not a trivial task and one that not many users will undertake. The Project Team agreed to develop a number of basic graphs to illustrate how water balance components and suitability indicators vary over time. This differs from the DSS output, which focuses on the statistical variability of suitability indicators over a specified period.

Graphs have been developed that show the changes over time of water balance components which are the drivers of soil-plant-atmosphere processes and time dependant indicators of soil quality, crop yield and crop quality. A list of the available graphs is presented in Table 4-2. The list consists of three columns. The first contains the graph title that is a concise description of the graph's contents. The second column contains information about the graph subdivisions that are available. For many graphs, no subdivisions are available. For others, the user can select between displaying the graph for, e.g. the first crop, the second crop or both (rotation). The third column provide information on the graph type. Graphs may be either a line graph or a bar chart or, in some cases, a complex graph consisting of a collection of sub-graphs.

Table 4-2. List of graphs available to advanced users.

Graph Title	**Graph subdivisions**	**Graph type**
	Water Balance Components	
Water Balance Components	None	Collection of bar charts
Cumulative Water Balance	1st Crop / 2nd Crop / Rotation	Cumulative line graph
Cumulative Water Balance summary	1st Crop / 2nd Crop / Rotation	Cumulative line graph
Seasonal Irrigation:	None	Bar chart
Seasonal Precipitation:	None	Bar chart
Seasonal Evaporation:	None	Bar chart
Seasonal Transpiration:	None	Bar chart
Seasonal Evapotranspiration:	None	Bar chart
Seasonal Drainage:	None	Bar chart
Seasonal Eff leaching frac (%):	None	Bar chart

Graph Title	Graph subdivisions	Graph type
	Soil Quality	
Soil profile salinity	1st Crop / 2nd Crop / Rotation	Line graph
Effect of rain and irrigation events on infiltrability	None	Scatterplot
Seasonal distribution of qualitative hydraulic conductivity	None	Scatterplot
Monthly oxidisable carbon loading	None	Bar chart
	Crop yield and quality	
Yield as affected by 4 constituents	1st Crop / 2nd Crop / Rotation	Collection of line charts
Yield as affected by salinity (EC)	1st Crop / 2nd Crop / Rotation	Line graph
Yield as affected by Boron	1st Crop / 2nd Crop / Rotation	Line graph
Yield as affected by Chloride	1st Crop / 2nd Crop / Rotation	Line graph
Yield as affected by Sodium	1st Crop / 2nd Crop / Rotation	Line graph
% NPK supplied by irrigation	1st Crop / 2nd Crop / Rotation	Combined bar charts & statistics
Seasonal % NPK supplied by irrigation	1st Crop / 2nd Crop / Rotation	Line graph
Cum. Irrig added NPK	1st Crop / 2nd Crop / Rotation / Rotation statistics	Combined bar charts, line graph & statistics
Seasonal Irrig. Added N	1st Crop / 2nd Crop / Rotation	Bar chart
Seasonal Irrig. Added P	1st Crop / 2nd Crop / Rotation	Bar chart
Seasonal Irrig. Added K	1st Crop / 2nd Crop / Rotation	Bar chart
% NPK supplied by irrigation	1st Crop / 2nd Crop / Rotation	Combined bar charts & statistics
Seasonal distribution of atrazine load	1st Crop / 2nd Crop	Bar chart

For the graphs presented in the following paragraphs, to illustrate their functionality, a fitness-for-use assessment was run for a period of 10 years using weather data for the Vaalharts Irrigation Scheme, a maize / wheat rotation, irrigated every 15 days up to field capacity with a 200 mS/m, 3.8 SAR water.

4.5.1 Water balance graphs.

The main water balance components are summarised in the water balance components graph as illustrated in Figure 4-3. Note the variability that is apparent in these components, which are driving the water balance and thus influencing the dynamics of the soil-plant-atmosphere system. Note that the width of the bars is proportional to the length of each crop's growing season and that the narrow white strip separating red and green bars represents a brief fallow period after maturation of the maize crop and before planting of wheat.

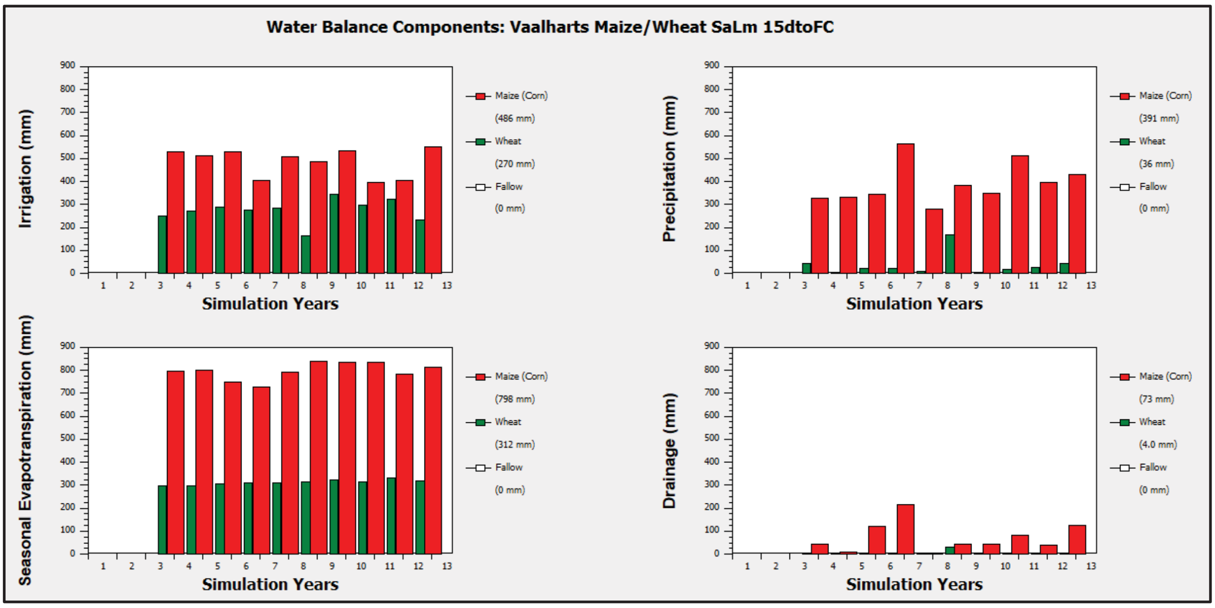


Figure 4-3. Water balance components graph that displays the main water balance components in a single combined graph.

Bar charts of each of the water balance components are also available. Figure 4-4 illustrates the variability that can be found in the leaching fraction between years and between crops (because they are planted in different seasons with differing precipitation).

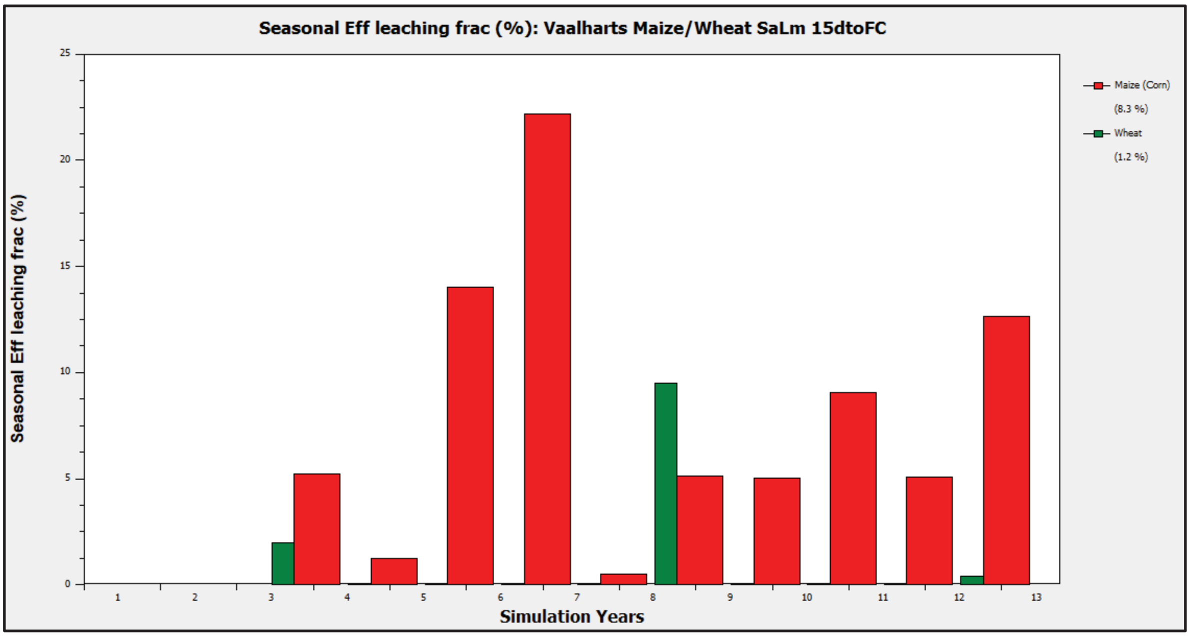


Figure 4-4. Bar chart of seasonal leaching fraction illustrating the annual variability and differences between crops.

4.5.2 Soil quality graphs.

Standardised graphs have been prepared to display how time dependant soil quality indicators change over time. The change in soil profile salinity over time is illustrated in Figure 4-5. Notice the decrease in soil profile salinity between years five and eight, which coincides with the increased leaching fraction for the same years that can be observed in Figure 4-4.

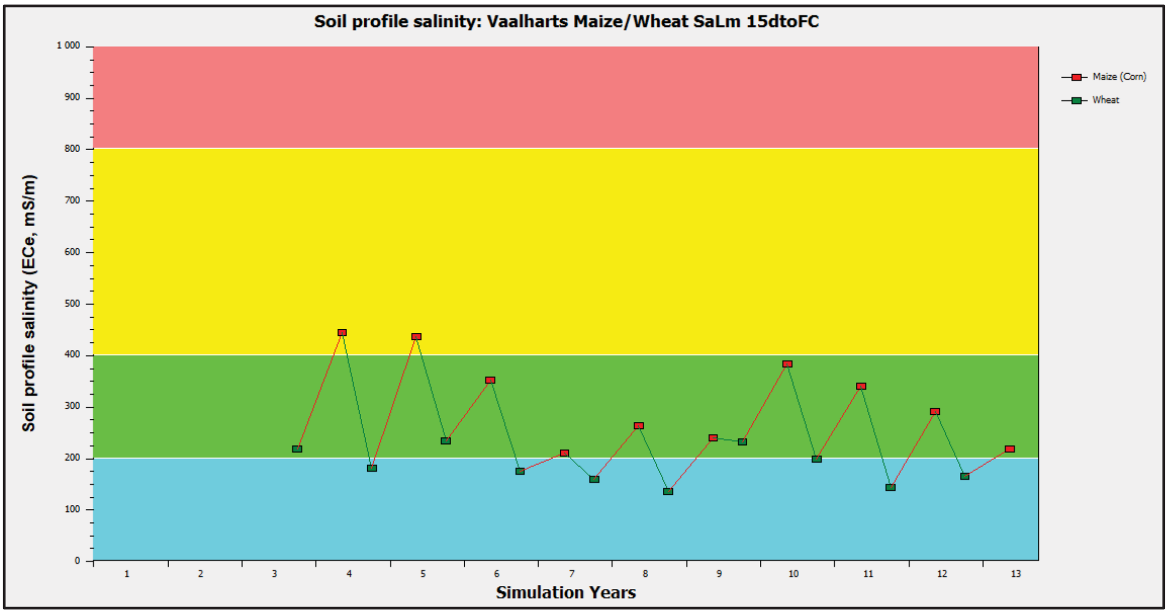


Figure 4-5. Change in soil profile salinity over time for a maize/wheat crop rotation, against a background indicating the fitness-for-use categories.

The monthly variation in irrigated COD load is depicted in Figure 4-6 against a background displaying the fitness-for-use criteria, illustrating how frequently the ideal criteria are exceeded. The variability displayed in this graph can be compared with the numerical percentages used in the fitness-for-use evaluation as displayed below.

	Fitness-for-use	COD Load (kg/ha per month)	% of time Chemical Oxygen Demand (COD) Load is predicted to fall within a particular Fitness-for-use category
Oxidisable Carbon Loading	Ideal	0 - 400	62
	Acceptable	400 - 1000	38
	Tolerable	1000 - 1600	
	Unacceptable	>1600	

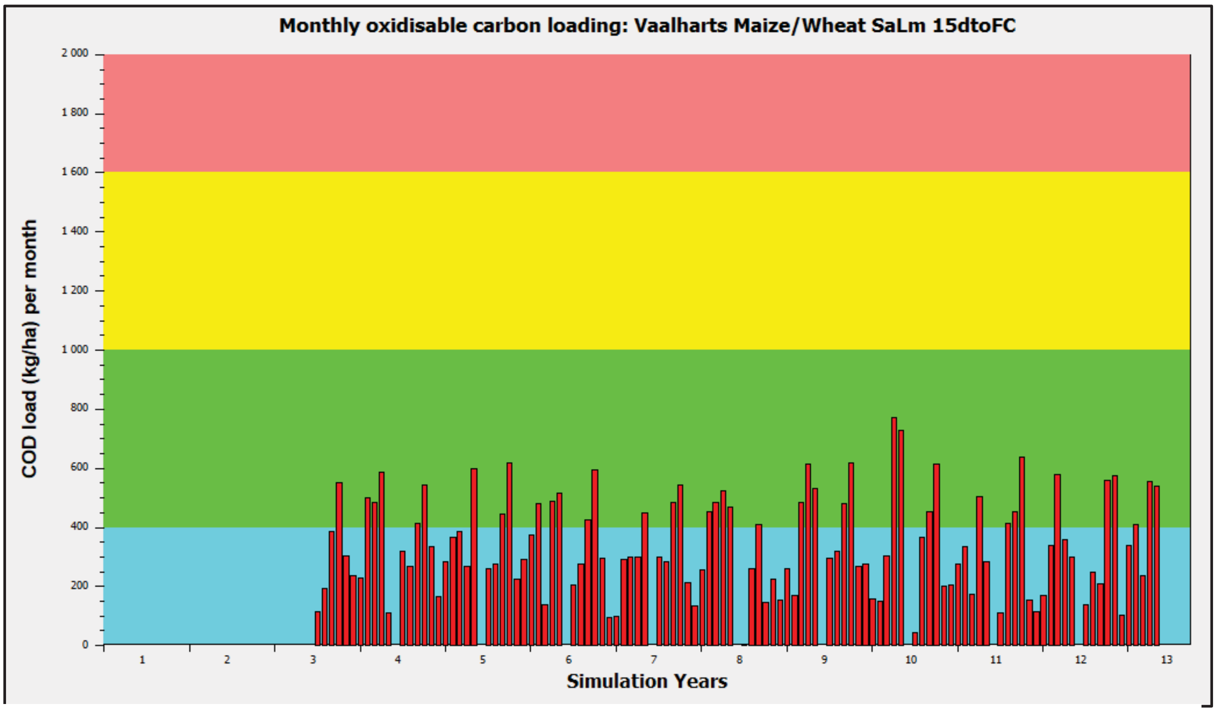


Figure 4-6. Bar chart depicting the monthly COD load against a background displaying the fitness-for-use categories.

4.5.3 Crop yield and quality graphs.

A range of graphs are available to display the effect of EC, chloride, boron and sodium on crop yield. Figure 4-7 presents a graph that combines graphs for the effect of these four constituents on yield into one graph.

It is clear that apart from its response to boron, maize is the more sensitive of the two crops and its yield is more affected. This is in agreement with their relative tolerances to these constituents and the differences in salt distribution during their respective planting seasons, as shown in the profile salinity graph (Figure 4-5).

The amount of nutrients added to crops during their annual growing season through irrigation, is depicted in Figure 4-8. These amounts are determined by the nutrient content of irrigation water and the seasonal irrigation application. Also shown is the cumulative nutrient load applied during the simulation period.

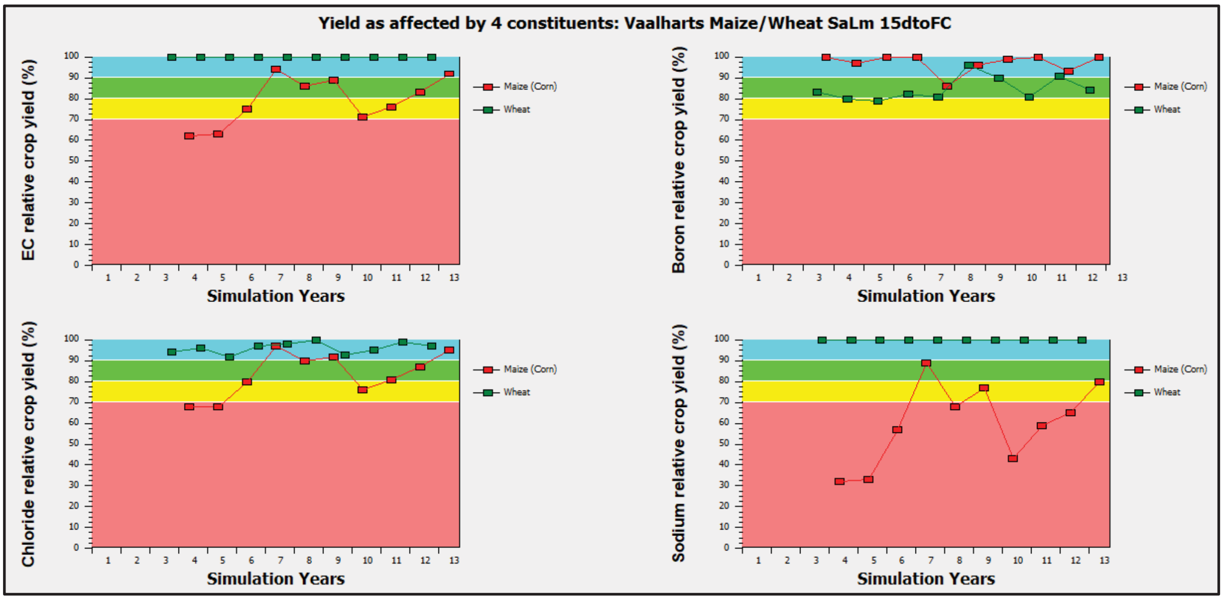


Figure 4-7. Combined graph displaying the effect of four constituents on yield of a maize / wheat rotation.

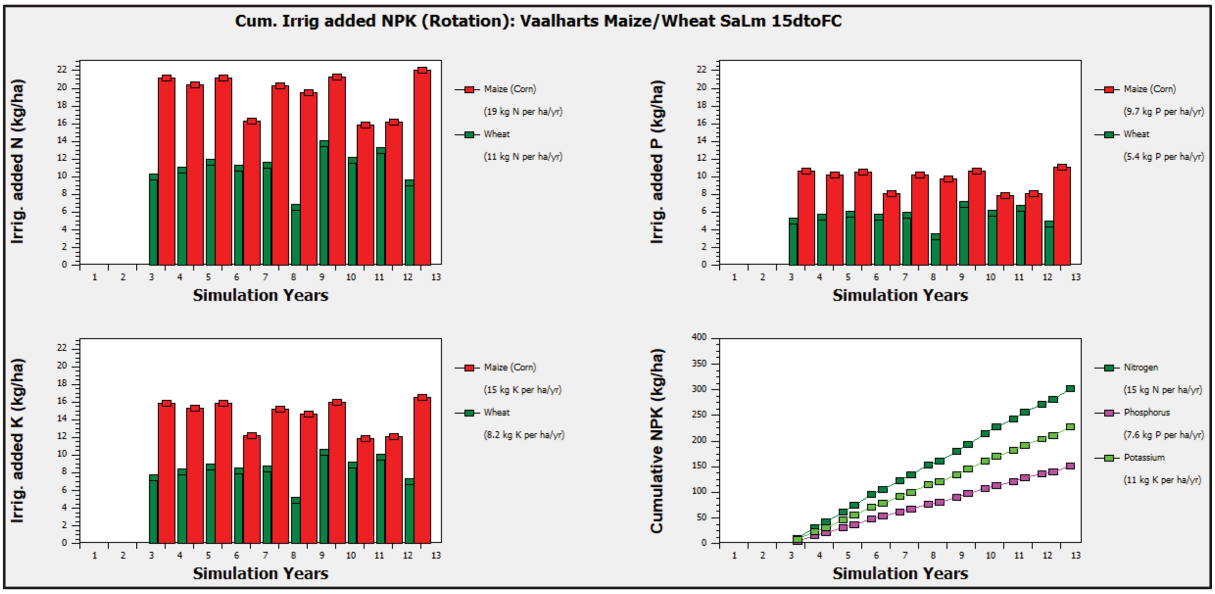


Figure 4-8. Depiction of nutrient load supplied to crops as a result of irrigation applications and cumulative amounts applied during the simulation period.

Figure 4-9 compares nutrients applied through irrigation water to those removed by crops. These fractions are displayed as percentages, against a backdrop of the fitness-for-use criteria, which allows for an immediate interpretation of the results. Additionally, calculations are also presented on how variable these applications are.

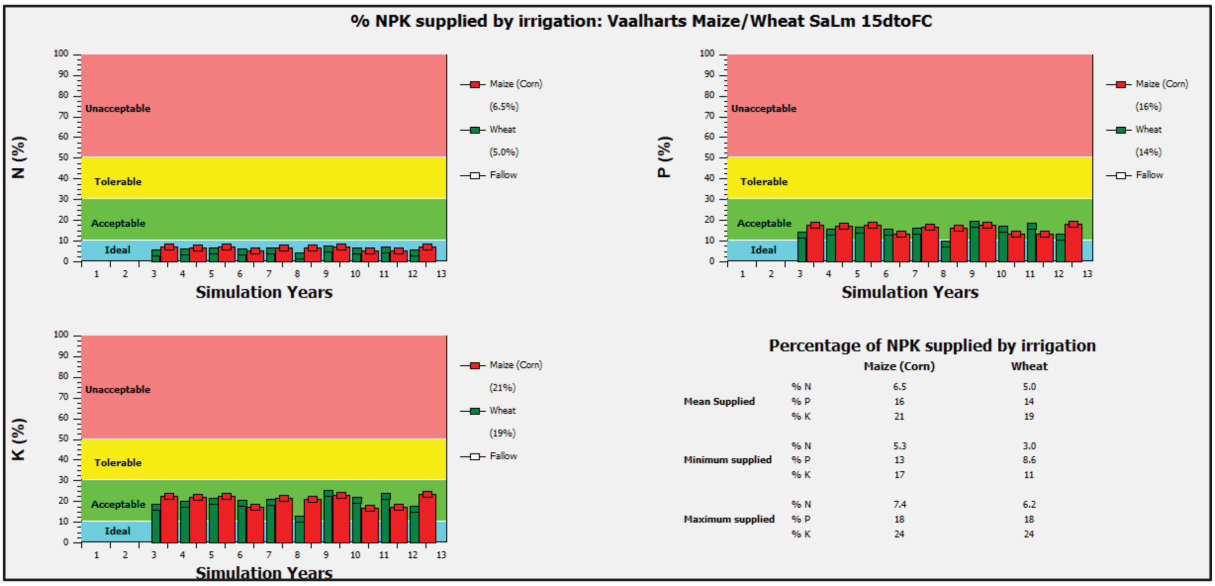


Figure 4-9. Display of contribution of nutrients in irrigation water to amount removed by crops, against backdrop of fitness-for-use criteria, as well as calculated statistics.

5 PROPOSED ENHANCEMENTS NOT INCORPORATED INTO THE DSS

The following is a list of proposed enhancements that were not incorporated into DSS. For each of the proposed enhancements, a description is firstly given of the need giving rise to the proposed enhancement, followed by the Project Team's response, providing the reasons for not acceding to the request. The requested enhancements are not listed in any particular order. No importance should thus be attached to the order in which they are listed.

5.1 ENHANCEMENTS REQUIRING STRUCTURAL CHANGES TO THE DSS.

The structure of the DSS that would be required to assess the fitness-for-use of irrigation water and determine water quality requirements, was decided on early during the development phases of the preceding project. It will thus be difficult to introduce enhancements requiring structural changes at this stage. The Project Team nonetheless tried to be as accommodating as possible.

5.1.1 Enable the use of water composition data that changes over time.

The DSS was developed to use a constant water composition when assessing fitness for use, for both Tiers 1 and 2. However, in practice, water qualities do change over time. A request was made to provide for changes in water composition over time for Tier 2 fitness for use assessments.

Project Team response: The Project Team view this as an important modification that should advance the usefulness of the DSS. This facility should, for example, make it possible to evaluate the effect of seasonal or long-term changes in water composition. However, the introduction of changing water composition is not as simple or trivial as it would appear upon first consideration. Several of the tables reporting fitness for use evaluations, will need to be modified, meaningful representation of long-term changes will probably require that graphical presentation of long-term changes be developed, and care will be required to realistically link changes in water composition with climatic variability. The Project Team view these changes as outside of the scope of the project and more in line with Tier 3 type evaluations. In line with Tier 2 philosophy, the effect of seasonal changes in water composition can be assessed by conducting two assessments using, e.g. typical winter and summer water compositions, to get an idea of the extreme effects of seasonal water compositional changes on fitness-for-use. It was therefore, decided not to try to introduce a facility that would allow water composition to change over time.

5.1.2 Provide for assessing the impact of poor-quality water over short periods of time.

Requests like this originate from the need during periods of deteriorating water quality (often associated with a drought), for an assessment of the effect the deteriorating water quality will have on short- and longer-term crop yield and survival.

Project Team response: The project team view this request as similar to proposed enhancement No. 5.1.1. For similar reasons it is not recommended to introduce this facility to the DSS.

5.1.3 Provide for a two-year cropping cycle.

At the Tier 2 level, the DSS accumulates and reports most of its results for an annual cycle. Currently the DSS provides for selecting between a single crop and a crop rotation (each with its own planting date), during this annual cycle. This request is to provide for a two or three to four-year cropping cycle, which would tie in with cropping practices in different parts of the country. Specific requests made were to consider making provision for three crops in a two-year cycle, with one season fallow, and another request was to provide for planting Lucerne for 3 to 4 years, followed by a season of maize.

Project Team response: The project team appreciates that advisors using the DSS to advise clients may wish to select a cropping pattern that is as close as possible to that used in practice. However, the current structure of DSS calculations and reporting makes complying with this request practically impossible. A separate calculation and reporting procedure will have to be developed to cater for this request. For example, the DSS is run for a minimum of 10 years on an annual basis to generate basic statistics. The DSS will have to be run for much longer (and variable periods) to achieve the same level of statistical relevance. The databases used to store results will also have to be redesigned and reprogrammed. The Project Team believe that the cropping cycle options that are currently provided should satisfy most needs. Where it does not do so exactly, it would mostly still be possible to devise a simulation (or more than one simulation) that would provide an adequate assessment of the fitness-for-use of water of a specific composition for the crop or crops in question. It was thus decided not to comply with this request.

5.2 ENHANCEMENTS REQUIRING STRUCTURAL CHANGES TO SWB.

Although a scaled down version of the SWB model is used to simulate the soil-plant-atmosphere and water interactions, the results of which are used to assess the effect a specific water composition has on soil quality, crop yield and quality and irrigation equipment, it is still a complex model requiring some processing time. It would thus not be advisable to increase its complexity unnecessarily. Introducing changes to such a model also pose the risk of introducing unexpected errors.

5.2.1 Introduce a feedback loop for crop growth reduction due to salinity.

One of the major mechanisms used to explain the reduction in crop yield with increasing soil salinity is that crop water uptake (and consequently yield) is reduced with increasing salinity. Water uptake is reduced because the decreasing osmotic potential (as salinity increases) reduces the availability of soil water for crop uptake. As a salt stressed crop uses less water than is currently assumed by the SWB model under non-stressed conditions, the actual surplus water applied, in turn, would result in additional leaching to achieve a degree of self-compensation of root zone salinity, as the salinity of irrigation water increases. A feedback loop is thus created that has the effect that salt accumulation in soil and the resulting yield loss is less than would be predicted by the current DSS.

Project Team response: The Project Team recognise the importance of this feedback loop to describe the processes operating in the soil-plant-atmosphere continuum, when viewed from a conceptual perspective. However, the introduction of this enhancement is not expected to significantly advance the usefulness of the DSS at a practical use level. It should be recalled that the modified SWB model used in the DSS represents a simplification of the important processes in the soil-plant-atmosphere continuum. It is important that the different processes be described at approximately the same level of sophistication. The Project Team believe this to be the case for the current Tier 2 simulation. In our opinion, the introduction of a salt-yield-reduction-increased-leaching loop belong more at the level of Tier 3 simulations. The introduction of this enhancement is, furthermore, not a trivial task. The Project Team is of the opinion that the available budget should rather be used to introduce enhancements of greater urgency. The introduction of this advancement will be flagged as a possible theme for a future MSc-study.

5.2.2 Replace Robbins chemical calculation procedure with the Unsatchem procedure.

The inclusion of chemical equilibrium calculations as part of Tier 2 simulations is, *inter alia,* important to distinguish between the effect of chloride rich vs. sulphate rich waters on effective soil salinity and crop yield. The “Robbins” chemical equilibrium model was originally built into the SWB model to simulate the precipitation of gypsum and predict its beneficial effect on crop yield, when irrigating with gypsiferous mine water. This model was developed at Utah State University and assumes an unlimited lime source in the soil. The “Robbins” model was retained for Tier 2 level SWB simulations and calculation of chemical equilibria and interactions in the DSS. The United States Salinity Laboratory (USSL) developed the more sophisticated “Unsatchem” model to simulate chemical equilibria upon concentration or dilution, between cations and anions normally occurring in irrigation water. “Unsatchem” provides for the presence or absence of a gypsum and / or a source of lime.

Project Team response: The Project Team agree that “Unsatchem” is probably the more deterministic of the two models and that by replacing the “Robbins” model improved simulations should be obtained. It may also achieve a higher level of credibility within the larger scientific community. However, it is debateable whether the introduction of this enhancement will significantly advance the usefulness of the DSS at a practical use level. During a visit to the USSL for this purpose by Prof Annandale and Dr Jovanovic, they obtained similar output for the two models when using the same input water composition in several simulations. Replacing the “Robbins” model with “Unsatchem” is, furthermore, not a trivial task. The Project Team is therefore of the opinion that the available budget should rather be used to introduce enhancements of greater urgency. The introduction of this advancement will be flagged as a possible theme for a future MSc-study by a suitably qualified candidate.

5.2.3 Allow for the definition of soil layers with different properties.

The modified SWB model used for Tier 2 simulations is a cascading water balance model, which allows for a profile of variable depth, consisting of ten layers of equal thickness and a thin surface layer. The profile texture is selectable and determines the profile’s water holding properties. This requested modification would allow water holding properties and layer thickness to be different for each layer. Such a change would make it possible to define more realistic soil profiles and to simulate the response of duplex soils.

Project Team response: The Project Team appreciate the benefit of the requested modification to define more realistic soil profiles. Unfortunately, the structure of the modified SWB model does not provide for these modifications. To effectively introduce these modifications would require a finite difference model, which is at the level of Tier 3 assessments. In fact, this modification is available in the SWB cascading version. To incorporate it in this downscaled version of SWB would, however not be a trivial task from a programming point of view. It is furthermore unlikely that the feature would be widely used by the target community of the DSS.

5.3 ENHANCEMENTS THAT WOULD EXPAND THE DSS WEATHER DATABASE.

5.3.1 Enable importation of user selected climate data into the DSS database.

Some users or institutions have long-term data of their own, or of a specific area of interest, which they would like to use in the DSS assessment of fitness-for-use or calculation of resource quality requirements.

Project Team response: The Project Team is of the view that since the facility was created whereby the data from the extensive Schulze weather station database could be imported into the DSS weather database (see section 5.3.3 i), the need to import own data would be greatly reduced. It was thus decided not to create the requested functionality at this stage.

5.3.2 Investigate whether the WRC Report of Pegram et al. (2015) can add value to the DSS climate database.

The availability of a WRC Research Report by Pegram et al. (2015), was brought to the attention of the Project Team, with the request to investigate whether its results could improve on the climate database that forms part of the DSS. A major advantage of the Pegram report is that rainfall data has been updated to 2014, while the DSS climate database contains data only up to 1999.

Project team response: It would indeed be advantageous for the DSS climate database to contain data that are more current. However, the availability of more recent data would have little, if any, effect on the functionality of the DSS. The primary purpose of a long-term database is to cover as much as possible of the climatic variation that can be expected at a given site over time, so that a reliable statistical assessment can be obtained of the effect climate variability can be expected to have on crop and other responses over time. A further critical requirement of the DSS climate database is that it should contain climatic parameters required by SWB to calculate components of the water balance and determine crop growth parameters. Unfortunately, the Pegram report contains only daily rainfall data, and is thus deficient regarding the other climate parameters that are required. Replacing only the rainfall component of the current DSS climate database with that of the Pegram report, represents a major task with a major risk of introducing errors. The Project Team thus believes that the potential benefits of incorporating rainfall data of the Pegram report into the DSS climate database, does not warrant the effort.

5.3.3 Investigate the availability and suitability of DWS weather data and its importation into the DSS database.

The Project Team was made aware of climate data collected by DWS at major storage dams and requested to investigate the possibility of adding the data to the DSS climate database.

Project Team response: In view of the availability of the extensive Schulze climate database for incorporation into the DSS weather database (see section 5.3.3 i), the project team deemed it more important to focus on other enhancements to the DSS than to expand the climate database.

5.4 ENHANCEMENTS TO THE DSS.

5.4.1 Provide for batch processing of water constituent analyses.

The DSS currently provides for one-at-a-time fitness-for-use assessments or water quality requirement determinations. A water analysis laboratory requested a facility to enable batch processing of water analyses. This would involve the import and consecutive processing of multiple water constituent analyses and the output of results.

Project Team response: The Project Team can see the advantages to a laboratory of being able to batch process several water analyses at a time when they have a large throughput of samples. Since analytical laboratories are recognised as important potential users of the fitness-for-use assessment function of the DSS, the Project Team would like to make it easy for them to use. However, this is not a trivial task and its implementation will require detailed discussions with laboratories to ensure that their need is fulfilled, before embarking on implementation. It may turn out that different laboratories have different requirements. While it would be relatively straight forward to batch process water samples at Tier 1 level, as no site-specific information is required, it would be much more involved at Tier 2 level, where site-specific information is required for each water sample. The project team decided not to accede to this request, but to allow individual laboratories to develop custom made applications if required.

5.4.2 Make results exportable.

A request was made to make DSS results exportable.

Project Team response: It is unclear what this request encompasses. The DSS currently provides for the printing or storing as PDF files, the output of its fitness-for-use assessments and water quality requirement determinations. The DSS also allows for the exportation and re-importation in 'csv' format of site-specific and composition of water sample data.

5.4.3 Provide for definition of own crops.

The DSS provides ready populated crop growth and tolerance parameters for a large selection of crops as part of its crop database. These parameters represent all the information that could reasonably easily be sourced or inferred by the Project Team. However, the list of crops and associated parameters is not complete, and it is possible that users will have parameters better suited to their conditions or may wish to add crops that are not listed. The request is to allow for the incorporation of these modifications into the DSS.

Project Team response: The Project Team recognises the need by some users for this enhancement. The DSS currently allows these modifications to be made only by the developers. It would be relatively easy to make this provision also available to advanced users. However, a word of caution needs to be sounded regarding the unchecked changing of crop parameters by users. The use of the parameters captured in the DSS and printing the version number as part of output, ensures uniformity in output by different users. Should users be allowed to change parameters, this uniformity in output by different users, will be compromised. It was thus decided not to enable users to introduce changes to the crop database, and only allow the developers to change parameters on request.

5.4.4 As part of DSS output screens for Tier 2 assessments, print the crop parameters of selected crops.

Currently the first DSS output screen for Tier 2 fitness for use assessments, displays the chemical composition of the water being assessed, some site-specific characteristics (plant date of crops, irrigation management parameters, soil characteristics and selected weather station) and components of the water balance. The request is to also print crop parameters for the crops selected for simulation, as part of the site-specific characteristics.

Project Team response: The Project Team realises that crop parameters (crop growth characteristics and sensitivity to EC and specific ions) are useful information to have readily available when interpreting the DSS output. Unfortunately, the first DSS output screen for Tier 2 fitness for use assessments is already fully utilised, leaving no room for adding crop parameters. Since there are already four to five output screens, the project team would not like to add additional screens to the DSS output. Fortunately, crop characteristics can be reasonably easily accessed since they are available as part of the crop table under “Tools”.

5.4.5 Add the leaf scorching effect of bicarbonate.

Consider adding bicarbonate as a constituent causing scorching of leaves, similar to already done for sodium and chloride.

Project Team response: The Project Team could not find criteria for leaf scorching caused by exposure to bicarbonate, in the current water quality guidelines that were consulted. While the formation of white spots caused by calcium carbonate precipitation is mentioned and criteria are given, the issue was not considered of sufficient importance to include in the DSS.

5.5 DEVELOPMENT OF AN APPLICATION VERSION OF THE DSS.

5.5.1 Consider developing an App version of the DSS.

There is a significant trend among users of computer programs to demand an application with similar functionality that can be run on a cell phone. The project team was requested to investigate the feasibility to develop an Application for the DSS.

Project Team response: The Project Team investigated the feasibility of developing a DSS application that can be used on a cell phone. It was found that it would probably not be practical or desirable to develop a complete version of the DSS for use on a cell phone. It would be easier and more practical to run a web-based version of the DSS on a cell phone. In this case, the relevant analytical data and site-specific information would be captured on the cell phone using screens similar to the current data capturing screens used in the PC version. The captured data would then be transmitted to the web-based version of the DSS for processing, and the results returned to the cell phone. The results would then be displayed on the cell phone using screens similar to those currently used for the PC-based DSS.

It thus appears that it would be feasible to develop a cell phone-based App for the DSS. However, it is expected to be a major task that will consume a disproportionate portion of project resources. It should furthermore be borne in mind that discussing the implications and alternatives for using a particular water, is mostly not a process where time is of the essence. The output is also quite extensive, and not suitable to be displayed on a small cell phone screen. In addition, there seems to be some movement away from apps due to the continually changing operating systems that make apps difficult to develop and maintain. Instead, links to websites are expected to become more popular in future, so perhaps the question should rather be whether a web-based utility for the DSS should be developed. The project team decided not to pursue the development of either a cell phone application or a web-based utility for the DSS as part of this project.

6 DISCUSSION, CONCLUSIONS AND RECOMMENDATIONS

This project followed on the project entitled *Revision of the 1996 South African Water Quality Guidelines: Development of a risk-based approach using irrigation water use as a case study*, which culminated in the development of the software-based Decision Support System (DSS) with which to assess the water quality requirements for irrigation farming.

Potential enhancements to the DSS were identified in many ways. Some were identified at the conclusion of the previous project, others were identified during training and information sessions, others were identified by the Core User Group and other individual users and still others by the Project Team itself. Four categories of enhancements were distinguished, namely:

i. Enhancements to the DSS.
ii. Correction of potential calculation errors.
iii. Improvements to input and output display.
iv. Graphical displays.

The project team approached the prioritisation and implementation of proposed enhancements, corrections, and improvements to input and output display, as follows. The guiding principle used when considering especially enhancements and improvements, was to maintain as far as possible, the relative simplicity and user-friendly nature of the DSS and retain its primary purpose of assessing fitness-for-use of irrigation water and determining water quality requirements. This implied careful consideration of any additions or modifications that would complicate its ease of use. For this reason, additional features which have been introduced for the benefit of the more advanced user, are currently not assessable from the DSS main screen, and somewhat hidden as part of the *Tools* menu. This, however, may change in future.

The Project Team submitted a list of potential enhancements with proposed priorities for consideration and approval at each of the project Reference Group meetings. Since proposed enhancements to the DSS aimed at improving its functionality or scientific basis would mostly require considerable effort and some fundamental changes to, or expansion of, the DSS, only those deemed of highest priority were implemented. When potential calculation errors were found to be real, they were immediately corrected. Proposed improvements to the DSS input and output were considered as soon as they were received or identified. Improvements deemed as feasible and desirable, were introduced as soon as possible.

The Project Team believes that they have succeeded in raising awareness of the availability and functionality of the site-specific, risk-based irrigation water quality guidelines among its potential users. However, unfortunately, this does not necessarily translate to an extended active user community. The Project Team further believes that the enhancements that were introduced add much to the functionality and user-friendliness of the DSS.

Although the DSS has been enhanced to a high level of functionality and user-friendliness, it is only to be expected that it will require maintenance and further refinement in future. There is an urgent need for an institution to accept responsibility as custodian of the DSS and promote its future use, or for the WRC to support further development and technology transfer until such an institution can be identified. There is also a need to update the DSS at regular intervals, in order to review its scientific content, and where necessary, to introduce new findings or data, or to expand its functionality.

The Project Team believes that the current version of the DSS largely complies with the original expectations to establish a software-based DSS with which to determine Water Quality Guidelines for Irrigation and assess the Fitness-for-Use of irrigation water. However, further improvement in some respects would be beneficial and desirable. These include some of the proposed enhancements that were not implemented during this project (such as introducing a feedback loop for the effect of salinity induced water use, batch processing of results, rationalising the number of crops and weather stations, replacing the Robbins chemical equilibrium model with UNSATCHEM and graphing changes in soil salinity profiles over time). The DSS has found application and is often used to assess the fitness-for-use of acid mine waters for irrigation. Emanating from these applications are a number of issues in need of further research, such as:

i. During irrigation with gypsiferous waters such as acid main drainage, a significant portion of the salts contained in the water can precipitate as gypsum within the soil profile, resulting in a lower than anticipated salt load in the drainage. It would be very useful to users of this application of the DSS, if the DSS can provide them with a salt balance quantifying the portions of irrigation-applied salt that precipitate in the soil and drain to below the root-zone.
ii. Acid mine drainage often contains high concentrations of dissolved iron, aluminium and manganese, which exceed the DSS trace element accumulation thresholds. The question is whether the accumulation thresholds are realistic for these elements in view of the fact that they are abundantly present within soils.
iii. On the other hand, early experiments at the University of Pretoria identified the risk of foliar absorption of trace elements and the risk ingestion poses to human health. This crop uptake mechanism is not accounted for in the DSS, nor in any of the other international irrigation water quality guidelines.

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APPENDIX A

OTHER KNOWLEDGE DISSEMINATION ACTIVITIES

Several knowledge dissemination activities in addition to the awareness raising workshops, were undertaken during the project term. These included special training and awareness raising events, presentations to learned societies, popular and scientific publications, as described in the following paragraphs.

1. Special training and awareness raising events

DAFF's Directorate: Water Use and Irrigation Development hosts quarterly meetings of a Working Group on which provinces and other stakeholders are represented. At their meeting on 3 May 2018, Dr Backeberg gave a presentation on the availability and functionality of the DSS. It was agreed that participants interested in training with the DSS, would either attend training sessions organised by the Project Team, or make their own arrangements for such training.

At the invitation of DWS, the Project Team gave a presentation on the DSS at the quarterly meeting of DWS's Water Quality Management Forum on 7 June 2018 at the Roodeplaat Training Centre. The presentations covered the background to the development of the DSS, introduced the DSS and demonstrated its functionality. All the officials involved in water quality management from head office and DWS regions participate in activities of this Forum. Presenting at this Forum thus enabled the Project Team to alert DWS officials involved in water quality management from all over the country, to the availability and functionality of the DSS.

A presentation to introduce about 25 Head Office staff members of DWS' Directorate: Resource Protection and Waste to the functionality and utility of the SAWQI-DSS, was made on 29 May 2019 in the Emanzini Boardroom. The following topics were covered, and followed by a discussion of how the DSS could be of benefit to the Directorate:

i. Background to the developing of the electronic Decision Support System (DSS).
ii. Introduction to and demonstration of DSS functionality.
iii. Demonstration of setting up and running fitness-for-use assessments using the DSS.
iv. Background to criteria used to assess water quality.
v. Interactive demonstration of DSS functionality to assess wastewater quality.

DWS' Directorate: Resource Protection and Waste invited the Project Team to advise them about the need for and formulation of potential amendments to the General Authorisations applicable to irrigation with wastewater. In terms of the Water Act, these regulations need to be reviewed in a five-year cycle. (This review process was underway at the time). The Project Team met the group responsible for introducing amendments to the General Authorisation for irrigation, as requested, for a few interactions and assisted with the formulation of some clarifications and additions to the existing General Authorisations for irrigation.

2. Presentations to learned societies

Presentations to learned societies serves the dual purpose of raising awareness of the existence of the DSS and exposing the science underpinning it, to peer review. Several presentations were made to learned societies, namely:

i. An oral presentation, entitled *Suitability of Mine-Water for Irrigation: A Risk-Based, Site-Specific DSS*, by JG Annandale, HM du Plessis, PD Tanner and J Burgess, was presented at the 11th ICARD / IMWA WISA MWD 2018 Conference, which was held from 10 to 14 September 2018, in Pretoria.
ii. An oral presentation, entitled *An Electronic Decision Support System to Determine the Site-Specific Fitness-for-Use of Irrigation Water*, by HM du Plessis, JG Annandale and N Benade, was presented at the SANCID Symposium 2018, which was held from 13 to 15 November 2018, in White River.
iii. An oral presentation, entitled *Site-Specific Determination of the Fitness-for-Use of Irrigation Water using Electronic Decision Support*, by HM du Plessis, JG Annandale and N Benade, was presented at the Combined Congress 2019, which was held from 21 to 25 January 2019, in Bloemfontein.

iv. A poster presentation, entitled *An electronic Decision Support System to determine risk-based, site-specific fitness for use of irrigation water*, was presented at the Ninth International Symposium on Irrigation of Horticultural Crops, which was held from 17 to 20 June 2019, in Matera, Italy.
v. An oral presentation, entitled *An Electronic DSS to Assess Risk-Based, Site-Specific Fitness-for-Use of Irrigation Water*, was presented at the South African Irrigation Institute Congress 2019, which was held from 13 to 19 August 2019, in Durban.

3. Popular articles

Popular articles serve the purpose of raising awareness of the existence and features of the DSS and allowing interested parties to acquaint themselves of with the science underpinning the DSS in their own time and at a pace that suits them. Two popular articles were published in the SABI Magazine, which caters for the South African irrigation designer community. A series of two papers were published:

i. Help to assess the fitness for use of irrigation water at a specific site using a risk-based approach, SABI Magazine Vol. 11 (Issue 5): 20-25 (June/July 2019).
ii. Suitability indicators to assess site-specific, risk-based irrigation water quality, SABI Magazine Vol. 12 (Issue 1):26-29, (October / November 2019).

4. Scientific publications

The Project Team was invited by Dr. Backeberg to contribute to a special WRC publication on research-based innovations in irrigated agriculture. A contribution entitled *Site-specific, risk-based irrigation water quality guidelines*, covers the development of the DSS and was submitted to the WRC. The authors trust that this publication, when published, will inform the broader scientific community of the availability and utility of the DSS.

APPENDIX B

REVISED LOOK UP TABLE FOR NPK REMOVAL BY CROPS AS USED IN THE DSS[1]

Common name	Botanical name	Yield[2]	N offtake	P offtake	K offtake	Reference[3]
		t/ha	kg/ha			
Lucerne (Alfalfa)	*Medicago sativa*	20	667	60	440	Miles, 2021
Almond	*Prunus duclis*	4	247	29	231	Almond Australia, 2009
Apple	*Malus sylvestris*	70	31	7	82	Palmer and Dryden, 2006
Avocado	*Persea american*	15	39	15.8	70.5	Wolstenholme, 2004
Barley	*Hordeum vulgare*	5	100	18	25	Sahota, 2015
Bean	*Phaseolus vulgaris*	27	100	16	76	Reid and Morton, 2019
Bean, mung	*Vigna radiata*	27	100	16	76	Assumed to be same as Bean
Bean, snap	*Phaseolus vulgaris*	27	100	16	76	Assumed to be same as Bean
Beet, red	*Beta vulgaris*	60	146	22	167	Reid and Morton, 2019
Bermuda grass	*Cynodon Dactylon*	14	364	25	280	Miles, 2021
Broccoli	*Brassica oleracea botrytis*	16	67	10	53	Reid and Morton, 2019
Cabbage	*Brassica oleracea capitata*	68	169	19	142	Reid and Morton, 2019
Carrot	*Daucus carota*	100	174	31	288	Reid and Morton, 2019
Cauliflower	*Brassica oleracea botrytis*	33	134	20	98	Reid and Morton, 2019
Clover, ladino	*Trifolium repens*	8	320	240	160	Miles, 2021
Clover, red	*Trifolium pratense*	10	230	26	174	Miles, 2021 and IPNI Portal, 2014
Maize (Corn)(grain)	*Zea mays*	10	120	30	40	Miles, 2021
Maize (Corn) (forage)	*Zea mays*	17.5	222	37	175	Miles, 2021
Corn, sweet (Maize)	*Zea mays*	24	93	14	51	Reid and Morton, 2019
Cotton	*Gossypium hirsutum*	2.8	93	18	29	Rochester, 2007
Cucumber	*Cucumis sativus*	35	49	9		Du Plessis *et al.*, 2017

Common name	Botanical name	Yield[2]	N offtake	P offtake	K offtake	Reference[3]
		t/ha	kg/ha			
Fescue, tall	*Festuca arundinacea*	12	360	36	300	Miles, 2021
Grape	*Vitis vinifera*	12	50	8	36	Howell, 2018
Grapefruit	*Citrus X paradisi*	50	100	35	150	Leeks, 2019
Lemon	*Citrus limon*	40	80	28	120	Leeks, 2019
Lettuce	*Lactuca sativa*	30	73	9	73	Reid and Morton, 2019
Love grass	*Eragrostis sp.*	15	300	27	180	Miles, 2021
Oats (grain)	*Avena sativa*	5.2	104	20	26	Miles, 2021
Onion	*Allium cepa*	8	120	18	112	Reid and Morton, 2019
Orange	*Citrus sinensis*	40	120	28	120	Leeks, 2019
Orchard grass	*Dactylis glomerata*	12	300	30	300	Miles, 2021
Pea	*Pisum sativa*	15	44	5	27	Reid and Morton, 2019
Peanut (nuts)	*Arachis hypogaea*	5	175	12.5	35.5	Miles, 2021 and IPNI Portal, 2014
Pear	*Pyrus communis*	75	18	2		Du Plessis *et al.*, 2017
Pepper	*Capsicum annum*	35	207	27		Du Plessis *et al.*, 2017
Potato	*Solanum tuberosum*	76	208	29	312	Reid and Morton, 2019
Pumpkin	*Cucurbita Pepo*	70	147	39		Du Plessis *et al.*, 2017
Ryegrass, perennial	*Lolium perenne*	14	560	35	420	Miles, 2021
Sorghum (grain)	*Sorghum bicolor*	10	130	34	45	Miles, 2021 and IPNI Portal, 2014
Soybean	*Glycine max*	5	275	26	100	Miles, 2021
Spinach	*Spinacia oleracea*	20	88	9	95	Reid and Morton, 2019
Strawberry	*Fragaria sp.*	26	49	7		Du Plessis *et al.*, 2017
Sugarcane	*Saccharum officinarum*	100	130	20	200	Miles, 2021
Sunflower	*Helianthus annuus*	3	77	6	26	Du Plessis *et al.*, 2017
Sweet potato	*Ipomea batatas*	100	240	53		Du Plessis *et al.*, 2017
Tobacco	*Nicotiana tabacum*	19	350	60	720	Du Plessis *et al.*, 2017
Tomato	*Lycopersicon lycopersicum*	150	200	26	287	Reid and Morton, 2019

Common name	Botanical name	Yield[2]	N offtake	P offtake	K offtake	Reference[3]
		t/ha		kg/ha		
Watermelon	*Citrullus lanatus*		90	15		Du Plessis *et al.*, 2017
Wheat	*Triticum aestivum*	8	200	33	32	Miles, 2021
Generic sensitive	*Not applicable*	20	50	10	10	Du Plessis *et al.*, 2017
Generic moderately sensitive	*Not applicable*	20	100	20	25	Du Plessis *et al.*, 2017
Generic moderately tolerant	*Not applicable*	20	250	40	50	Du Plessis *et al.*, 2017
Generic tolerant	*Not applicable*	20	500	80	100	Du Plessis *et al.*, 2017

[1] The data in this table was compiled by Miles, 2021.
[2] Dry matter yield for forages.
[3] References:

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