RISK-BASED AND SITE-SPECIFIC ANIMAL WATERING WATER QUALITY GUIDELINES
Volume 1: Decision Support System

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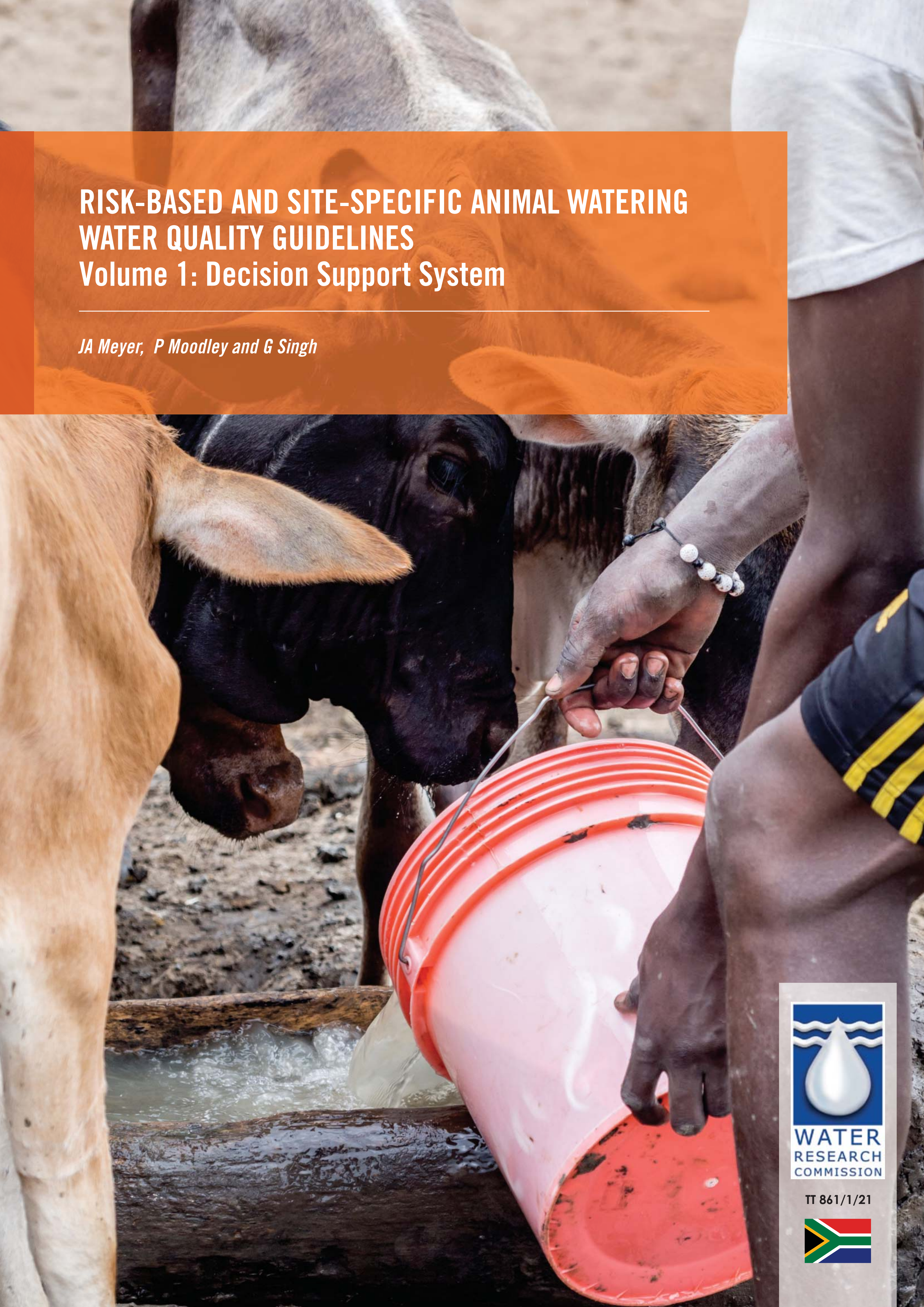

WATER RESEARCH COMMISSION

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RISK-BASED AND SITE-SPECIFIC ANIMAL WATERING WATER QUALITY GUIDELINES

Volume 1: Decision Support System

Report to the
Water Research Commission

by

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The publication of this report emanates from a project entitled *Development of a Risk-based Approach for assessing Animal Watering and Aquaculture Water quality Guidelines* (WRC Project No. K5/2817//4).

This report forms part of a series of four reports. The other reports in the series are:

- *Development of a Risk-based Approach for Assessing Animal Watering Water Quality Guidelines Volume 2: Technical Support Information (***WRC Report No. TT 861/2/21**)
- *Development of a Risk-based Approach for Assessing Aquaculture Water Quality Guidelines Volume 1: Description of a Prototype Decision Support System (***WRC Report No. TT 862/1/21**)
- *Development of a Risk-based Approach for Assessing Aquaculture Water Quality Guidelines Volume 2: Technical Support (***WRC Report No. TT 862/2/21**)

EXECUTIVE SUMMARY

BACKGROUND AND PROJECT APPROACH

The current series of South African Water Quality Guidelines (SAWQGs) (DWAF, 1996) have contributed significantly to water resource management, however, there are new scientific approaches to managing water quality. The need for a risk-based approach and decision support function for water quality guidance has subsequently emerged. It has become increasingly apparent that guidelines are needed that address these applications and issues related to risk, site specificity and guidance for an expanded set of water quality constituents.

In 2008, a national review by the Department of Water and Sanitation (DWS) recognized the need for a quantifiable assessment system to judge fitness for use and suitability of water quality that moves beyond simple numeric values to provide an assessment in terms of the nature of the resource and the water user. This led to following three phased approach being planned for the development of South African Risk-based Water Quality Guidelines:

Phase 1: Development of philosophy
Phase 2: Application of philosophy and development of prototype guidelines
Phase 3: Development of tools for higher-tier site-specific guidelines.

The Phase 1 Needs Assessment and Philosophy document (DWS, 2008) led to the Water Research Commission (WRC) commissioning a series of projects developing risk-based approaches for water quality guidelines per user group, encompassing phase 2 of the process.

This project addresses the 'Development of a Risk-based Approach for assessing Animal Watering and Aquaculture Water quality Guidelines' as part of the series, presenting new approaches to expand the scope of water quality guidelines in terms of how they are presented, applied and the decision support that is provided to the user. Risk-based approaches for irrigation, recreation and domestic use water quality guidelines have recently been developed.

The risk-based water quality guidelines support site specificity and are based on a risk philosophy, whilst providing for a tiered assessment approach to cater for varied target user groups and degree of complexity and are presented as a software-based decision support (DSS) tool. The project aims that were formulated to achieve this included:

- A revision and update of the constituent ingestion rate risk assessment approach for livestock watering.
- Selection of relevant water quality variables and animal watering categories (up to a maximum of 5 livestock types).

- Building upon the approach to guideline formulation related to types (e.g. account for site-specific risk factors; water intake, user specific ingestion).
- A systematic review of relevant literature to identify and critically appraise best available evidence and new information sources.
- Refinement of the quantification methodologies for quantifying the risk based on new information and scientific evidence.
- Refinement and extension of the Constituent Ingestion Rate Risk Assessment decision support system that is piloted as the proposed approach.

The Needs Assessment and Philosophy document envisaged a final product which should comprise a three-tiered system as follows:

- Tier 1 is equivalent to 1996 generic guidelines and is made available in the DSS and hard copy manuals;
- Tier 2 allows for site-specificity in specified contexts and is facilitated by the DSS;
- Tier 3 allows for site-specificity in other ad hoc contexts, using modules of the DSS and possibly requiring significant expertise.

In order to achieve the aims of the project the following components were addressed and compiled:

- An inception phase that focused on the description of the project objectives and context, definition of the project outputs and the process to be followed for the development of the risk-based approach for animal watering guidelines. The status of the progress on the animal watering risk-based water quality guidelines approach was presented as a baseline literature survey.
- Recommendations on the key updates and changes that are required for the Risk-based Animal Watering Guidelines with specific reference to a decision support system (DSS) that was previously developed for the WRC, namely the Constituent Ingestion Rate Risk Assessment Versions (CIRRA), which provides the user with two water quality guideline index systems (WQGIS) to choose from: a Generic-WQGIS and a Specific-WQGIS.
- An update to Constituent Hazard Assessment Approach for Risk-based guidelines. Updates and changes were recommended, with the focus on the central source reference documentation of the DSS for which both user systems were compiled, referred to as the Water Ingestion Rate Reference Documents (WIRRDs).
- Risk calculation methodology development to apply the tiered approaches from the Generic to the Specific Guideline Application Levels, with the focus on the different rules and assessments provided, modifications to the central source reference documentation and compilation methods for the new WIRRDs. This included description of methods by which the results of the data input fields were assessed and compared to the reference documentation and the similarities thereto to a source, pathway and receptor analysis, in order to include the tiered approach.
- Decision Support System update and revision addressed and detailed the user-interface and methods by which the results of the data input fields were assessed and compared to the reference

documentation and the similarities thereto to a source, pathway and receptor analysis in order to include the tiered approach. A draft DSS prototype version was developed as a preliminary demonstration of the most important features and the tiered approach to the tool for the water quality constituents selected.

This final report provides a summary of the risk-based approach adopted and prototype DSS for animal watering. This report highlights the approach adopted, components updated and/or revised, new norms, fundamental changes to both the 1996 guidelines and CIRRA model, risk methodologies and calculation procedures, and finally, the DSS design. This report consists of two volumes, Volume 1: The Decision Support System (this report) and Volume 2: Technical Support Information.

APPROACH ADOPTED

The new DSS is an updated version of the previous Constituent Ingestion Rate Risk Assessment (CIRRA) programme developed for the WRC. Due to advances in the fields of science relating to water quality, animal production, programming and technology platforms available the DSS is fundamentally different from a modelling, software and coding perspective.

The fundamental objective of a risk-based approach is to optimally utilise the available water resources in a water-scarce country. The objective is thus not to remove all risk and provide safe water quality, but to recognise that some risks are acceptable, can be mitigated, and for the specific intended purpose, remain fit for use without appreciable loss to the sustainability (and where applicable profitability) of the water use.

The primary benefit in adopting both (i.e. a more realistic Generic approach and moving towards a site-specific approach for the Specific-WQGIS model) is that the pressure to move water resource management and related activities in a direction of unrealistic and ever lowering water quality constituent concentrations is avoided, this being achieved as the presence of a potentially hazardous water quality constituent in terms of detection at a specific concentration alone is increasingly acknowledged to not imply an adverse effect, but more accurately a hazard that may be manipulated to reduce the risk of such an outcome.

The methodologies adopted are thus risk-based with the concept of “acceptable risk” underpinning the system whilst still retaining a precautionary approach to ensure the applicable norms for the water user are conservatively addressed.

Risk is a statistical concept defined as the expected likelihood or probability of undesirable effects resulting from a specified exposure, with risk being posed when there is a source, a potential exposure pathway and a receptor (receiving environment, for example, animals). Risk is not a concentration, dose, other value-based point, or even non value-based levels, but rather the probability that a particular adverse effect occurs during a stated period of time.

Risk-based can be defined as recognising the risk factors giving effect to risk and the DSS is in effect a risk management system which is fundamentally based on the recognition and input of site-specific factors, following which a risk assessment process identifies the key risk factors applicable which may then become the risk management objective.

The detection and quantitative determination of a potential hazard in water is required for the risk to be inferred as the probability of specific adverse/undesired effects to the animal using the water. The hazard refers to a range of water quality constituents that may be present in the water that renders it less fit for use, and its consequences based more on ingestion specifics and less on concentration.

Risk is thus a function of hazard and exposure. Where ***hazard*** = biological, chemical or radiological agent that has the potential to cause harm, ***hazard effect*** = adverse impact on health that can result from exposure to a substance and ***exposure*** = contact between a substance and a population.

Animal watering is complex due to the vast array of different animal types and breeds and production systems (rural to intensive commercial), with production occurring across significantly differing environments.

A statement on fitness for use is dependent on water composition in relation to its intended use. This therefore implies that site specificity is necessary so that decision making on water fitness for use can be assessed accurately based on its character and context of the intended use and the guidelines address this by allowing the fitness for use assessments to be done for specific animal watering scenarios, thus including different animal types, production systems, with varying input detail for animals, environments and nutrition.

Several other key considerations were made in the risk approach adopted. Management goals are also required for both water resource management aspects and animal production system requirements, with animal watering thus not considered to be in isolation of other water users. Agricultural use of water for irrigation and animal purposes often occur simultaneously, and in rural communal production and subsistence systems water is used for domestic purposes, irrigation of village, community or household crops, and for animal watering. The scarcity of alternative resources in these settings requires a combined approach in the consideration of appropriate constituents and endpoints applicable, noting the precautionary approach required when dealing with community health hazards. The valuable use of animal responses to potential water quality hazards as sentinel information to guide community health-based studies was also recognised.

Provision also has to be made for updates which are also continually required in terms of the new knowledge subsequently gained in terms of water quality and community health, with notable issues that had to be addressed including endocrine disrupting chemicals and contaminants of emerging concern.

In order to allow for sustainable long-term animal production and for compliance monitoring requirements, the inclusion of guidelines addressing water quality constituents and their effects on biodegradable industrial wastewater activities also receives attention as a new norm added in the assessment for fitness for use, with risk evaluated for both confined animal feeding operation animals, water resources and the environment.

Observations in clinical investigations at intensive animal production systems added to the understanding of water quality problems that have arisen from the target water quality guideline approach of the previous 1996 guidelines. This led to increasing recognition that induced deficiencies and hypo-osmotic challenges pose significant challenges to animal production and the focus shifted from a toxicological endpoint to one which addresses the current science of a range of deficiencies, adequacy to excess. Crucially, this allows for a more informed decision to be made regarding the most suitable water quality for specific animal production systems and prevents water quality planning limits from being unnecessarily strict or from water users over-treating water resources.

The inclusion of multiple ingestion routes is essential to reducing the previous observations of false positives and false negatives in terms of target water quality ranges and predicted adverse effects, and is a key component to being able to manipulate the correct system inputs to enable optimal utilisation of those water resources which are not classified as ideal (or insignificant risk). It follows that significant updates were required which involved comprehensive literature surveys on each constituent and variable.

To cater for these aspects several additional options were provided in the user options in the DSS.

Finally, it was recommended that the DSS include a section on Risk Communication in order to ensure that the correct information type is communicated where applicable. Since the objective is to achieve acceptable risk and not to remove all risk and provide safe water quality, it must be communicated that some risks are acceptable, can be mitigated, and for the specific intended purpose, remain fit for use.

The correct communication of the concept of “acceptable risk” is thus vital, and possibly critical in the case of the Rural Communal Animal Production Systems in which dual impacts to community health may apply.

The final aspect central to the DSS was a monitoring requirement. Site-specific risk factors may themselves not only yield seasonal changes, but in the context of animal production systems these changes may be on-going in the form of genetic improvements (e.g. pig production with over 60% of breeding stock replaced per year with advanced genetics), nutritional changes (often driven by changing market prices in feed input components), and management or market-related targets (e.g. exposure time in a feedlot based on grading prices/demand).

Monitoring is therefore required and the inclusion of an intra-DWS data base connectivity remains a strong recommendation in order to include compliance monitoring submissions (which can and should occur for confined animal feeding operations for both generally authorised water use activities and those operating under a Water Use Licence) which are external (user-based) and internal (National Monitoring Programme.

KEY UPDATES AND MODELLING CHANGES

Whilst providing a fundamental central source code reference document, the WIRRDs required modelling changes and updates to animal performance inputs as the animal production system targets have changed dramatically over time. The guideline effect concentration ranges were updated to reflect new information on kinetics and dynamics in addition to being adapted to include dietary factors and new effect statements. Where applicable by water quality constituents (WQCs), the WIRRD tables were updated to replace the initial “no adverse effects” statement with a range of deficiency statements to accurately reflect the essentiality and potential positive effect of the constituent presence in the water source.

This key change from the 0 mg/L = safe or no adverse effect concept to the recognition of deficiencies and marginal deficiencies before the adequacy range accords with the current recognition of essentially or the probability of a beneficial response on supplementation.

This change was the most fundamental required to align the WIRRD with the objective of optimal water resource utilization by not creating the incorrect impression in the user that a low or zero concentration is the target, both from a management types of effect approach and water resource objective perspective.

The choice of WQCs to be included in the WIRRD as opposed to a TWQR-system or Single-trigger value system, and the applicable limits thereto, were also to be updated. The list of WQC and analytical methods were updated to include current protocols and new procedures available, notably, endocrine disrupting chemicals bioassays, and Contaminants of Emerging Concern (COCs).

The WIRRDs were redesigned and compiled with new modelling calculations so new table types, columns and rows, were developed. This was also done in a manner to enable the WIRRDs to be manipulated by not just user defined site-specific input, but also to adjust them according to a Source, Pathway and Receptor approach and in so doing enable the risk assessment to occur as per the approach adopted. The detail on how the WIRRDs is used to perform risk assessments at the different Tier levels are presented in the technical support information.

Updates were also made to the data capturing guides as these are a key component that guide the user in terms of site-specific detail required in order to arrive at a risk-based assessment.

There are two fundamentally different uses of the DSS. Contrary to the typical existing exposure scenario approach (assessing exposure effects to a given water quality to an existing animal production system), a “preferred option” approach was also included. The existing format was updated to provide a tiered entry selection option page, with further subsets therein possible as next level choices within each tier. Existing water quality input requirements were also restructured to alert the user to provide the required analytical information for all guideline application levels and tiers. Critically, this is also modelled to include simultaneous risk assessments and proposed solutions for multiple water sources as opposed to a single water quality result set for one water quality source.

- These updates were effected to the following:
    - Water Quality Constituents:
        - Bromide; Fluoride; Nitrate; Selenium; Total Dissolved Solids and Disinfection By-products
    - Animal Types:
        - Cattle (beef and dairy); Sheep; Pigs and Poultry
    - Adverse Effect additions:
        - Hypo-osmotic effects; EDC effects; DBP effects; Deficiencies and Induced-deficiencies

- Linking multiple water sample data files in terms of chemistry in order to calculate the required blending options to arrive at an acceptable risk level was viewed as a key practical function required, with the Specific-WQGIS differing from the generic application level in that the final acceptable reference value is a Risk Index Value (RIV) based on the outcome of the WIRRD and corresponding site-specific data inputs.
    - This facility was expanded to include calculations performed on the same sample location but over seasonal monitoring inputs. This is viewed as essential to obtain not simply a risk-based assessment on a single water resource sample input, but more correctly, the average of the water quality constituent concentrations that result in a mean exposure over a season or time period.
    - Given the stochastic nature of water chemistry and observations of monitoring data from animal production systems, this update to the model is significant and facilitates the formulation or a risk-based statement which accurately reflects the consequences following exposure as the concentration changes may be vast in comparison to WIRRD turnover rows.

- A user entry was added into a *.wqs file of water quality data and clinical biochemistry data as the input fields of clinical problems linked to animal production are frequently the starting point of water quality investigations.
    - Whilst a *.wqs Risk-based output identifies relevant PHCCs and COCs linked to the site-specific exposure scenario, many adverse outcomes cannot be predicted. Reasons for this would include simultaneous exposure to multiple PHCCs and COCs with a wide range of possible outcomes with current constituent-focused assessments unable to adequately predict this (so called “cocktail-effect”).
    - Exposure to EDCs and combined effects with other on-site challenges (e.g. infectious diseases and sub-clinical deficiencies) are other potential sources of idiopathic problems experienced in animal production systems.
    - Thus, the initial DSS output may not list the clinical effects experienced, whilst if a clinical problem is observed and investigated the entry thereof may highlight a different assessment matrix in terms of possible water quality related causative factors.
        - This also highlights the potential value in using the *wqs files generated by the system to bring new information to the field of water quality.
        - In practice the tendency to provide water that was closer to the zero mg/L range for all WQCs (as implied by the TWQR approach in the 1996 guidelines) has led to significant production and health related problems relevant to high performing production animals (e.g. wet litter, ascites, pressure diuresis, poor FCR, cardiovascular and fluid dynamic challenges).
        - It was thus be kept as a potential output of the DSS that information generated may be compiled to identify trends in terms of effects on the applicable norms due to water quality, both spatially and temporally.

It should be noted that the key WIRRD updates generate a large amount of modelling calculations, with just the updated tables for Animal Type = Sheep addressed for the WQCs selenium, fluoride, nitrate and bromide for the following categories generating approximately 70 tables, with only one provided for illustrative purposes below:

Specific-Central WIRRD for Livestock Type = Sheep Categories:
Ewes – maintenance
Ewes – Mature Breeding
Ewes – Mature Early Gestation
Ewes – Mature Late Gestation
Ewes – Mature Early Lactation
Ewes – Mature Mid Lactation
Ewes – Mature Late Lactation

Growing Ewe Lambs – yearlings at 40% of mature weight

Growing Ewe Lambs – Breeding

Growing Ewe Lambs – Early Gestation

Growing Ewe Lambs – Late Gestation

Growing Ewe Lambs – Early Lactation

Growing Ewe Lambs – Mid Lactation

Growing Ewe Lambs – Late Lactation

Growing Rams – at 40% of mature weight

Rams – Maintenance

Rams – Pre-breeding

Table 1: Updated Specific-Central WIRRD for Livestock Type = Sheep; Category = Ewes – Mature Early Gestation; WQC = Selenium

User Specific Input			Ingestion*	Water Quality Constituent^					
LW (kg)	DMI (kg/d)	TWI (L/d)	WIR ($L/kg^{0.82}/d$)	mg $Se/kg^{0.82}/d$^^					
				A (0-[])	B [A]-[B]	C [B]-[C]	D [C]-[D]	E [D]-[E]	F >[E]
50.8	1.183	3.579	0.1428	[0.0056] 0.000808	[0.0133] 0.00190	[0.0666] 0.00952	[0.9328] 0.13329	[3.331] 0.47606	>0.4760
61.0	1.345	4.202	0.14437	[0.00547] 0.00079	[0.0113] 0.00163	[0.0597] 0.00819	[0.7945] 0.11471	[2.837] 0.40971	>0.4097
71.21	1.492	4.770	0.14436	[0.00534] 0.000772	[0.01] 0.00144	[0.05] 0.00721	[0.7] 0.10105	[2.5] 0.36090	>-0.3609
81.419	1.644	5.348	0.1452	[0.00525] 0.000762	[0.0089] 0.00129	[0.0445] 0.00646	[0.6231] 0.09054	[2.225] 0.32336	>0.3233
91.62	1.787	5.908	0.1454	[0.00516] 0.000752	[0.00807] 0.00117	[0.0403] 0.00587	[0.5651] 0.08218	[2.018] 0.29352	>0.2935

*Adapted from NRC requirement tables (NRC, 2007).
^Values adjusted for column A as per factorially derived selenium nutrient requirements.
^^Where columns A to F relate to guideline effect concentration ranges as follows:
A = minimum required for production. WIR results below the corresponding value = positive response on supplementation.
B = adequacy for production. WIR results within A-B may show a positive response on supplementation.
C = upper limit for safe water use. WIR results within B-C unlikely to yield positive response on supplementation.
D = risk of chronic selenosis. Risk of excess exposure if additional supplementation provided.
E = chronic selenosis with no additional ingestion pathways.
F = chronic to acute selenosis

RISK CALCULATION METHODOLOGIES

Guidelines must still present to the water user a source of information which allows them to determine the water quality requirements for the applicable water use and the design must ensure that the application thereof does not have an adverse impact on water resources or the environment in which the water use occurs.

At a fundamental level a risk-based guideline must provide both an analysis and management statement of risk. This approach differs significantly from the previous approaches adopted in that the output is not a statement on the quality required to present without risk (as with the Target Water Quality Range approach), but rather as a method to arrive at an *acceptable risk level*. In order to do this the guidelines must fundamentally progress from being concentration-based (mg/L) to ingestion-based (mg/kg body weight/day).

A risk-based approach effectively implies that different water quality may be fit for use for the same water user (water use type) in a different setting (site or location). As the scope of guideline application includes multiple water source types ranging from municipal to surface water, the guidelines must allow water users to make informed decisions relating to water quality, noting that this does not mean that risk is managed by only manipulating water to arrive at a suitable quality, but recognising that user and site-specific factor manipulation may also achieve an acceptable risk level.

For animal production systems this manipulation extends to the animal production system and its components and may include the selection of different animal types (e.g. ruminant or non-ruminant), production systems (breeding or growing) and site-specific settings (grazing or total mixed ration and environmentally controlled housing settings) and other pertinent risk factor alterations.

The hazard and risk estimates are also scientifically based and described in such a manner that new scientific information may be appropriately inserted into subsequent DSS updates. It follows that the more detailed the site-specific input and science behind the risk methodologies the more accurate (or focussed) the risk management strategies formulated will be.

Furthermore, the entire process remains a guideline process which by definition is not the application of an inflexible standard to a different set of sites. Thus, the DSS is supposed to *guide* the user which implies that it must do more than generate a guideline confined to a statement on risk following exposure, but it must also assist in the identification of key risk factors, which are by their very nature site-specific. It is relevant to note that this approach accords with the widely adopted source, pathway and receptor analysis for hazardous chemical investigations and represents a multidisciplinary approach to what is a complex field.

As the risk-based model is fundamentally an analysis of risk enabling the management thereof, it may be considered in design to equate to data flow. The overall product comprises a three-tiered system with increasing data flow noted with higher tiers. A brief description is provided below:

Table 2: An overview of the Tiered Assessment System

Tier 1	Tier 2	Tier 3
Most generic (and by implication the most conservative) approach to risk guidance. Minimum user input required and simple output provided. Simplified generic conservative assumptions used and totally reliant on the default datasets (worst case exposure). Does not involve rigorous calculation methodology.	Moderately site-specific, requiring some skills, but largely uses pre-defined water use scenarios and limited site characterization choices with common field observation and or measurement input required from the user for scenarios manipulation. Rule-based output interpretation.	The most site-specific guidance. A risk assessment protocol, requiring highly skilled input and output interpretation. Allows for the adjustment of the algorithm and reference data. Default site-specific component options that can be changed to suit site specific circumstances (more specific models and parameters).

The model in which these tiers are contained is termed a Constituent Ingestion Rate Risk Assessment model (CIRRA) and provides the user with an initial choice between two guideline application levels (GAL), a Generic-WQGIS and a Specific-WQGIS with the central basis of CIRRA a Water Ingestion Rate Reference Document (WIRRD) for both the Generic and Specific GALs. The calculation methodology for specific animal types and specific WQCs for the WIRRDs are presented in detail in the research project deliverables.

The main output of the Generic GAL is a list of Potentially Hazardous Chemical Constituents (PHCC) and a list of Constituents of Concern (COC) which are supported by links to additional supporting documentation on the constituents in question and a Data Capturing Guide to assist with obtaining the site-specific information required to progress to the next tier. The main output of the Specific-WQGIS is also a list of PHCCs and COCs, but this is supported by several WQGIS calculation outputs for each constituent. These outputs provide the calculations in a number of formats, differentiating between risk from water alone to that for water and other ingestion routes and relevant site-specific factors. The calculation results are provided in two side-by-side screens, one excluding system factors and the other including them. The calculation results thus highlight the difference in ingestion rate (compared to the reference document value) for the water sample quality alone and for the water sample quality including the risk assessment with site-specific data inputs, with the system factors listed and the corresponding index factor values included and listed as either antagonistic or synergistic.

The risk factors listed and potentially manipulated may be allocated to Source, Pathway and Receptor data inputs or requirements, with either a “Setting” defined or a “Trigger” factor applied. These form the fundamental risk methodology applications with the ability to increasingly include site-specific data from a wide variety of fields, ranging from geochemistry to clinical biochemistry.

A vast array of different assessment methodologies is employed in the risk assessment modelling, ranging from the use of extensive reference documentation (including Mineral Reference Documentation on animal nutrition) to user specific or user defined inputs. A basic calculation example between a WIRRD and a User input is highlighted below:

- User input handling example 1:

  Rule: If User defined data input is:

  Livestock Type = sheep

  Category = ewes – maintenance

  Live weight value – LW (kg) = unknown

  Dry Matter Intake – DMI (kg/d) = unknown

  Total Water Intake – TWI (L/d) = 4.0

  Selenium Water Sample Result (mg/L) = 0.01

  Then:

  Use Central Reference Row LW = 71.21

  Water Ingestion Rate – WIR (L/kg$^{0.82}$/d) = 0.12105

  Calculated Ingestion Rate Value – IRV (mg WQC/ kg$^{0.82}$/d) = 0.001210

  Assessment Report:

  Result >Column B value [0.00111] < Column C value [0.005549]

  Column B = true [report]

  Add Note! = [IRV calculated for LW = 71 kg]

  IRV variance from Ref Doc = +9%

In summary, the derived or user defined site-specific DMI and/or TWI is then converted to a water ingestion rate (WIR) per day, in L/kg metabolic mass using the exponent LW$^{0.82}$ with the central live weight row taken as the central reference value (for the Generic GAL). The WIRRD thus provides a core reference document whereby the effect of site-specific variables on these input factors (live weight, DMI and TWI) and resultant water quality constituent ingestion rate (WIR) and corresponding column specific anticipated effects, may be taken into account.

There are inputs which are directly linked to the WIRRD tables such as actual DMI and TWI measurements on the site, and there are those which influence a variety of factors ranging from effects on these input variables and factors other than these variables, for example altitude and the risk to fluoride toxicity.

Site-specific variables in addition to the production system detail are then used as risk factors which adjust the values as required, with these being cumulative to either increase or decrease the WIR or IRV and the final risk assessment taken as the sum of the variances from the applicable source code reference value. The inclusion of these variables as factors assists to identify key variables that alter the outcome of exposure to a given concentration and are thus additionally, as risk factors, identifiable variables which could potentially be manipulated to alter the final outcome following exposure to a specific water quality constituent concentration. The general risk factor categories used are:

- Set User Selections:
  - Animal Specific Production System Factors (e.g. livestock breed)
  - Environmental Specific Factors (e.g. altitude)
- Variable Site Data:
  - Nutritional Specific Factors
  - Palatability
- Source, Pathway and Receptor Conditions

The methodology catering for the handling of these risk factor categories is presented in detail in the technical support information. The DSS presents the user with several different results screen tabs which are specific for these different risk factor categories and include both system and non-system factors and provide statements on risk for water alone and water with feed (total exposure), in addition to which the calculation results are presented for the defined norms. The ability for the user to create dummy *.wqs files and manipulate those risk factors which are able to be manipulated permits the evaluation of the risk factor mitigation measures which are doable with the final risk level selected a function of the WQC type of effect and corresponding impact on production.

Lastly, the objective of the DSS to provide guidance by estimating risk, highlighting the applicable risk factors and providing a method for attempting to reduce them to an acceptable risk level, with this achieved by the use of the variance approach. The assessment result presented is designed to adopt a more precautionary approach which is the advocated approach for risk assessments when health based and developmental endpoints are concerned. It is also advocated with respect to EDCs noting that the end effect may not be linked to a slope factor as for carcinogens, or a reference dose for toxicity, but rather to a relatively small dose based more on the timing and receptor involved during the exposure. By way of example the following is provided:

- Assume the site-specific risk factors triggered are:
  - Antagonistic
    - 1.1
    - 1.1
  - Synergistic
    - 0.9
    - 0.9

Thus:

$[(\text{WTR RF})^2 + (\text{PS RF})^2) + (\text{ETF RF})^2 + (\text{PSE RF})^2)]/n$

$[(1.1)^2 + (1.1)^2) + (0.9)^2 + (0.9)^2)]/4 = 1.01$

IRV = $(1)^2/1 = 1$

Variance = +1%

Thus, even though the risk factors applicable would appear to be equally synergistic and antagonistic they do not cancel each other out to provide a final IRV estimate equal to the WIRRD IRV value of 1 ([1.1 + 1.1 +0.9 +0.9]/4), but instead provide a risk estimate value which is greater than 1. This implies some risk to be present and may thus be considered to provide an estimate that would err on the conservative side and thus accord with the precautionary approach advocated.

THE DECISION SUPPORT SYSTEM

The objective of the DSS to provide guidance by estimating risk, highlighting the applicable risk factors and providing a method for attempting to reduce them to an acceptable risk level (using the variance approach described earlier). The prototype DSS provides an overview of the user interface aspects and is presented as a standalone deliverable to be experienced in conjunction with this summary final report. It should be appreciated that the DSS does not present the detailed risk assessment methodology to the user, but instead provides access thereto via help files and supporting reference documentation, with the focus on assisting the user to navigate through the tiers with the intention of progressing from one tier to the next.

In addition to accommodating the risk-based approach and tiered levels, a new programming language for the proposed DSS modelling was needed and the new source code generation required on the operational version should have due consideration for the intra- and external data base connectivity aspects for the DWS. The increased link between the applicable Section 21 activities of the NWA as they apply to confined animal feeding operations, and water quality guidelines, is viewed as an essential requirement in the updates required to the DSS model. This can be risk-based by including local background conditions to enable statements to be made on surface and groundwater quality conditions, to influence water quality limits or recommendations for wastewater activities, and guide catchment management site-specific water quality objectives. What has been developed is thus a prototype with these requirements in mind.

When considered from a programming perspective, the objectives of the DSS may thus be considered to be the following:

- To provide a flexible management tool for decision making purposes concerning water quality for animals to a wide user group with a user-friendly interface;
- To provide a means for incorporating site-specific information in risk assessment for animal watering;
- To provide supporting information regarding the various components and their interactions in biological systems required for decision making; and
- To provide a water quality guideline system than can be updated as new information becomes available.

Details on the system data flow, generic and specific GALs and different tiers are provided in the technical support information, with only some key data flow aspects highlighted in the following figures (not the actual DSS screens), with Figure 1 an indication of the opening selection options, Figure 2 an example of the user detail input/selection and Figure 3 an example of a results screen.

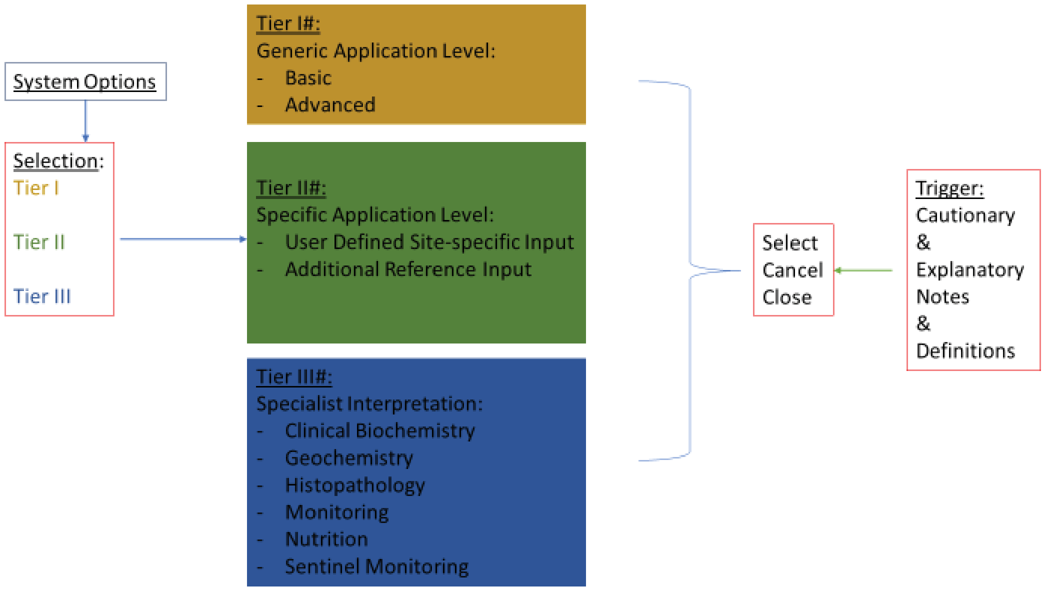

Figure 1: User input additions – Application types

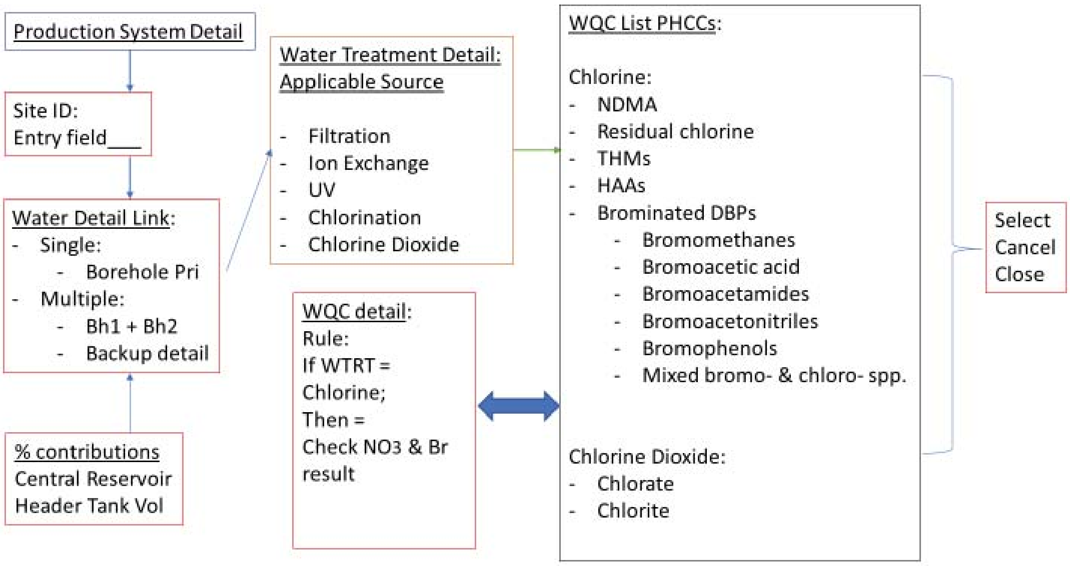

Figure 2: User input additions – Selection = Water Detail – Treatment

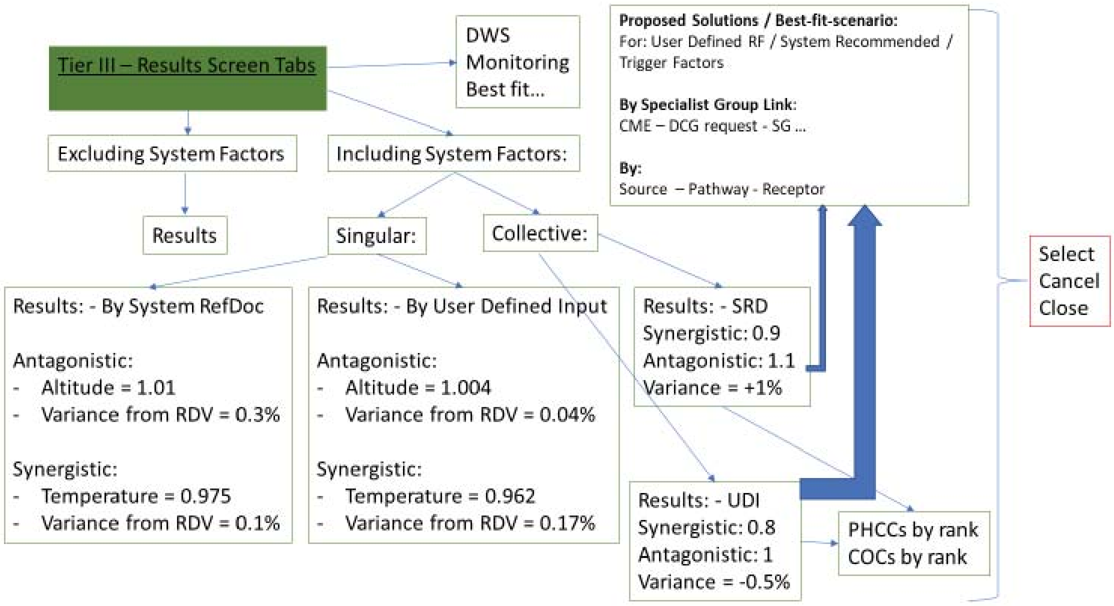

Figure 3: Results screen: Tier III

The key norms which are addressed are highlighted in Table 3 below with detail on these (e.g. types of effects and mitigation options) enabled when the user selects a PHCC or COC.

Although this report and the prototype DSS provide an overview of the user interface aspects, in the absence of a working software system (complete with source code, reference documentation and modelling algorithms), there are several issues which cannot be achieved or demonstrated.

The ability to guide the user through pop-up notes to try system-recommended approaches, or to apply user-defined or selected approaches is a key aspect of functionality which does what the risk-based guidelines are intended to do, namely offer guidance. This aspect may only be fully appreciated with an actively operating DSS.

Lastly, there are several additional functionalities which are not demonstrated, specifically the linkages to external relational data bases and the ability to collect and import data using new methodologies, for instance applications from mobile devices. It should be acknowledged that many farming activities, from plant production to animal housing systems, can be controlled by external or remote devices.

Table 3: Norms and corresponding effect applicable to Animal Watering

Norm	Effects

Animal Health	• Drinking:
	  ○ Toxicological effects
	  ○ Palatability effects
	  ○ Endocrine effects
	  ○ Carcinogenic effects
	• Inhalation:
	  ○ Disinfection By-product effects
	• Medication:
	  ○ Vaccine effects

Animal Watering System	• Production and Replacement effects:
	  ○ Biofilm
	  ○ Chemical corrosion
	  ○ Biological corrosion
	  ○ Encrustation
	  ○ Scaling sediment
	• Wastewater effects:
	  ○ Wash water
	  ○ Flushing
	  ○ Biosecurity uses

Animal Product Quality	• Consumption effects
	  ○ Maximum Accepted Limit
	  ○ Multi route scenarios (rural communal)
	• Product quality effects
	  ○ Residue compliance
	  ○ Product attributes

Environmental	• Water provision effects
	  ○ Habitat effects
	  ○ Sacrifice zone effects
	• Biodegradable wastewater irrigation
	  ○ Water resource effects
	  ○ Crop quality effects
	  ○ Crop production effects
	  ○ Soil effects

CONCLUSION

The intention of the guideline update is to present a final product that provides a series of tiered assessment levels to support a greater diversity of guideline use which facilitate more accurate risk-based assessments on the fitness for use of water for animal watering. The fundamental objective is to assist decision making by improving the science behind the assessments. The driving motivation behind the development of a DSS is to improve the accuracy with which water quality effects are predicted and assessed, which are key requirements to enabling the existing water quality challenges in South Africa to be addressed and water resources to be more optimally utilised.

The DSS developed provides guidance by estimating risk, highlighting the applicable risk factors and providing a method for attempting to reduce them to an acceptable risk level. This has been accomplished by numerous changes to the previous Constituent Ingestion Rate Risk Assessment model with a new modelling approach developed and presented in the form of a DSS.

Whilst several new methodologies have been employed in the risk assessment process, the tiered approach linked to a source, pathway and receptor adjustment system, is one of the key new processes by which much needed specialist input from multidisciplinary fields may be incorporated. Uncertainty still exists, however, and is similar to other recognised source, pathway and receptor assessment uncertainty factors, including:

- Source factors:
  - Inaccurate sampling
  - Lack of sufficient sampling
  - Analytical limitations and errors
  - Incomplete selection of required constituents
- Pathway factors:
  - Inherent uncertainty in the predictions and estimates made.
  - Lack of sufficient sampling
  - Analytical limitations and errors
  - Trend analysis with future prediction uncertainty due to both predictive uncertainty and variables beyond control (e.g. seasonal influences)
- Receptor factors:
  - Extrapolation accuracy between types and categories
  - Lack of sufficient sampling
  - Analytical limitations and errors
  - Incomplete selection of required constituents
  - Low predictive accuracy for low-probability events
  - Outcome of multiple exposure scenarios (constituent-constituent interactions)
- Reference Data:
  - A lack of appropriate reference data for source, pathway and receptor aspects.

Whilst it is thus appreciated that uncertainties exist, the WIRRD approach and basis of looping sample assessments with increasingly higher tier applications based on the acquisition of more targeted site-specific information, does assist in lowering the uncertainty. As noted previously, the high number of normal parameters reflective of the performance of the animals within the production system does assist in evaluating the accuracy of the risk statements provided, noting that proactive management remains a key requirement as subclinical adverse effects may not be routinely detected, be irreversible, and result in significant commercial losses.

Whilst the focus is initially water quality, it is again stressed that without due regard for total exposure, site-specific factors and water resource objectives, the guidelines will fail to the achieve meaningful mitigation and thus risk-factor reduction required to use water resources more efficiently.

RECOMMENDATIONS

Going forward, the key research needs are:

- To complete the source code programming in order to include the risk assessment methodology and calculations to yield a fully functional (operational) DSS.
- To update the supporting information reference documentation, for all applicable WQCs and derived parameters, site-specific data bases (animal nutrition and soil) and contaminants of emerging concern (notably EDCs including bromide).
- To include the wildlife application and update the methodology to include the best fit for multiple variables including wildlife types, water quality and presentation preferences, habitat immediate and surrounding and both primary and secondary physiological thirst signals (water dependency, mobility and behaviour).
- To include the rural communal animal production system application and update the methodology accordingly to include dual exposures incorporating domestic and household crop irrigation aspects.
- The DSS itself requires:
    - A series of child-parent software programs to be linked, notably between the water quality and types of effects data generated and the DWS-linked compliance monitoring and enforcement data bases.
    - A central administrator that receives, processes and directs information between five Specialist Groups:
        - Analytical Group
        - Animal Health Group
        - Geochemistry Group
        - Community Health Group
- A focus area of the DSS developed thus far has been primarily for commercial confined animal feeding operations, however, a key strategic application area is required in order to improve the management of water resources in rural animal production systems.
    - This is viewed as a key requirement to enable sustained water resource management in rural communal agricultural systems and to address community-dependent risk factors that may range from agricultural productivity (i.e. community funded communal agricultural projects) to safe household food preparation of high-risk agricultural products.

The departure from a concept of a “safe” concentration strategy which is not only prohibitively costly, but also contrary to the current National Water Resource Strategy (2013), to one in which risk-reduction measures aimed at arriving at an “acceptable risk level”, is not only scientifically more defensible, but also more practical and cost-effective and a need currently experienced by the agricultural water use sector.

In closing, a significant advantage is to be found in many animal production systems over other water users (for example Domestic and Irrigation) in the ability to control and thus manipulate key inputs, from diet, environmental housing conditions to specific physiological exposure scenario selections, thus allowing for risk factor manipulation to a greater extent. In addition to the potential value towards food security, assessing complex water quality issues such as EDCs, and towards sentinel use to guide human health investigations, the DSS for Animal Watering presents an opportunity to test the fundamentals of a risk-based approach in a water user group for which less confounding factors exist and more cause and effect data is obtainable with which to assess and evaluate the accuracy of the risk assessment and risk mitigation methodology employed.

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LIST OF ABBREVIATIONS

Abbreviation	Definition
ADI	Average daily intake
COCs	Constituents of Concern
CFIA	Canadian Food Inspection Agency
CIRRA	Constituent Ingestion Rate Risk Assessment
DBP	Disinfection by-product
DM	Dry Matter
DMI	Dry Matter Intake
DSS	Decision Support System
DWS	Department of Water and Sanitation
EDC	Endocrine Disrupting Chemicals
FCR	Food Conversion Ratio
FWI	Free Water Intake
GAL	Guideline Application Levels
GEV	Guideline effect value
IRV	Ingestion Rate Value
LW	Live weight
MINRD	Feed Base Reference Document
NRC	National Research Council
PHCC	Potentially Hazardous Chemical Constituents
PS RF	Production System Risk Factor
RF	Risk Factor
SAWQGs	South African Water Quality Guidelines
SDAEF	Specific Derived Acute Excess Factor
SDAF	Specific Derived Adequacy Factor
SDCEF	Specific Derived Chronic Excess Factor
SDRF	Specific Derived Requirement Factor
SMNRF	Specific Minimum Nutrient Requirement Factor
TWI	Total Water Intake
TWQR	Target Water Quality Range
US EPA	United States Environmental Protection Agency
WHO	World Health Organisation
WIR	Water Ingestion Rate
WIRRD	Water Ingestion Rate Reference Document
WQC	Water Quality Constituent
WQGIS	Water Quality Guideline Index System
WRC	Water Research Commission

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1. INTRODUCTION

1.1. Background

The Department of Water and Sanitation's South African Water Quality Guidelines (SAWQGs) for Fresh Water (Second Edition) published in 1996 has been a significant contribution to water resource management in South Africa, reflecting the scientific thinking at the time it. Subsequently, the decision support function of water quality guidance has grown and become more complex. Increased scientific understanding of the complexity of water ecosystems and adaptive management processes has led to new ways of managing water quality. Traditional scientific and management approaches may not deal well with contemporary water quality issues. Since the evolvement of water resource management within South Africa, the SAWQGs have become decision support tools rather than just a list with limits.

Both application and scope issues has made it necessary to re-examine the philosophical basis used for determining and applying water quality guidelines. The need for a quantifiable assessment system to judge fitness for use and suitability of water quality that moves beyond simple numeric values, that provides an assessment in terms of the nature of the resource and the nature of the water user, has been identified.

In 2008, a national review by the Department of Water and Sanitation (DWS) recognized the need for the development of South African Risk-based Water Quality Guidelines, leading to the following three phased approach being planned:

Phase 1: Development of philosophy
Phase 2: Application of philosophy and development of prototype guidelines
Phase 3: Development of tools for higher-tier site-specific guidelines

The process progressed to the completion of Phase 1 producing a Needs Assessment and Philosophy document (DWS, 2008). The following specific issues were listed at the time as requirements in order to support the evolution in water resource management in South Africa and specifically the extended water quality assessment and guidance needed:

- National Water Act:
  - The promulgation of the National Water Act (No. 36 of 1998) after the 1996 SAWQ guidelines led to some fundamental changes in the DWS approach to water resource management with the requirement for a single philosophical basis for detailed decision making throughout the DWS deemed prudent, largely to enable new guidelines to also be used as resource quality objectives.

- Use of a risk-approach as a common basis for linking new guidelines with risk-based approaches in other management areas.

- Since the 1996 guidelines were published, newer science and guideline practices are available, and the South African guidelines are consequently outdated.

- Additional water uses and water quality variables are considered important with the existing guidelines thus requiring extensions to accommodate them.

- It has been recognized that in the target water quality range approach the 1996 guidelines may result in an assessment of fitness for use which was either too lenient or to stringent.
    - Risk-based guidelines would enable the move from a generic level guideline to a more site-specific approach which would cater for these different outcomes.

The outcomes of the Phase 1 investigation had highlighted the necessity to extend the application of the water quality guidelines and the significance of producing a software decision tool to support the decision processes. The proposed decision support would need to relate to the assessment of fitness for use and numerical water quality objective setting in, primarily, freshwater resources.

It was noted that a key fundamental of the development of risk-based guidelines was to allow for the integrative nature of sustainable development, with a risk-based approach increasingly favoured in resource management, addressing complex issues ranging from the presence of multiple and interacting stressors to improved risk communication.

A key fundamental objective that was addressed during the formulation of the Needs Assessment and Philosophy document was noting that the concept of “acceptable risk” needed to be adopted by the user audience of the risk-based guidelines, from water resource managers to the actual water users, in order to allow for informed decisions to be made concerning water use that were sustainable.

This is arguably the most important concept to adopt, as it represents a significant departure from the previous versions of the South African Water Quality Guidelines (DWAF 1996) in which a “desired state” of a Target Water Quality Range was the goal and generally construed to imply a “no adverse effect” state.

The new goal may thus be stated as to adequately describe the outcome of a water use under a specific context in a manner which enables a more realistic decision to be reached regarding either accepting some degree of adverse outcomes or reducing the risk factors identified to an acceptable level.

In light of these recommendations of the Phase 1 outcomes, the Water Research Commission (WRC) initiated an overarching project that has seen the commissioning of a series of projects to develop risk-based approaches for water quality guidelines per user group, encompassing phase 2 of the process. The water quality guidelines need to be applied in manner that support site specificity and be based on a risked philosophy. It should further provide for a tiered assessment approach that caters for the level of use and degree of complexity of the output and specifically be presented as a software-based decision support tool.

1.2. Project Approach

This project addresses the 'Development of a Risk-based Approach for assessing Animal Watering and Aquaculture Water quality Guidelines' as part of the series. It attempts to present new approaches that will expand the scope of water quality guidelines in terms of how they are presented, applied and decision support that is provided to the user.

It is central to the theme of adopting a risk-based approach to appreciate the shortcomings of the previous guideline Target Water Quality Ranges (TWQRs) approach. These were determined per constituent by assuming lifelong exposure and incorporate a margin of safety. The TWQRs were set as equal to the no-effect range which is defined as the concentration at which the presence of the constituent would have no known or anticipated effect on the fitness of the water for the intended use. However, while this approach provides guidelines that are easy to use and have wide scale application, certain shortcomings have been identified, including:

- The limited range of constituents. The 1996 version contains some common constituents that were of local importance at the time. However, it has become necessary for a wider range of constituents to be included.
- Limited site-specificity. There is some guidance on chemical interactions that influence bioavailability, but procedural guidance for the application of the guidelines to site-specific issues is limited.
- The guidelines have been misapplied, probably unintentionally, e.g.
    - For a specific constituent, the numbers pertaining to various users are used as if their contexts in the guidelines are interchangeable, e.g. aesthetic guidance numbers are used in direct comparison with acute effect numbers – with clearly unwarranted consequences.
    - There appears to be confusion about interpretation of terminology such as the "Target Water Quality Range", "Chronic Effect Value" and "Acute Effect Value".
    - Guidelines verses standards.
- They are generic and conservative in nature (one size fits all).
- They are limited in terms of local relevance, much of it has been based on international databases.
- While simple, being generic they are over-simplified thereby compromising wide functionality.
- Critically, the adoption of a concentration-based mg/L methodology results in an overly-conservative assessment in the guideline derivation with an ingestion-based assessment significantly more accurate in estimating the types of effects following exposure.

The objective of the project was thus to develop a risk-based approach for animal watering with the process focusing primarily on refining and extending the approach and methodology and not on producing a fully functional decision support system. The project aims included:

- A revision and update of the constituent ingestion rate risk assessment approach for livestock watering.
- Selection of relevant water quality variables and animal watering categories (up to a maximum of 5 livestock types).
- Building upon the approach to guideline formulation related to types (e.g. account for site specific risk factors; water intake, user specific ingestion).
- A systematic review of relevant literature to identify and critically appraise best available evidence and new information sources.
- Refinement of the quantification methodologies for quantifying the risk-based on new information and scientific evidence.
- Refinement and extension of the Constituent Ingestion Rate Risk Assessment decision support system that is piloted as the proposed approach.

Since the current endeavour was to develop "risk-based" guidelines, it is necessary to clearly delineate the scope and nature of the risk that is being referred to. The definitions of risk vary considerably.

Risk is a statistical concept defined as the expected likelihood or probability of undesirable effects resulting from a specified exposure to known or potential environmental concentrations of a material. A material is considered safe if the risks associated with its exposure are judged to be acceptable (EPA Victoria, 2004).

A risk is posed when there is a source, a potential exposure pathway and a receptor (receiving environment, for example, animals, fish: the so-called "population at risk"). It is important to note that risk is not a concentration, dose, other value-based point, or even non value-based levels. Risk is the probability that a particular adverse effect occurs during a stated period of time (DWAF, 2005). Risk-based can therefore be defined as recognising the risk factors in giving effect to risk objectives.

The new goal of 'acceptable risk' may thus be stated as to adequately describe the outcome of a water use under a specific context in a manner which enables a more realistic decision to be reached regarding either accepting some degree of adverse outcomes or reducing the risk factors identified to an acceptable level.

Fitness for use water is dependent on its composition in relation to its intended use, implying that site specificity is necessary so that decision making on water fitness for use can be assessed accurately based on its character and context of the intended use.

The intention with the update of the guidelines is that the final product provides a series of tiered assessment levels that supports a greater diversity of guideline use and facilitates the decision making (DWAF, 2008), with the difference between the tiers lying primarily in the degree of site-specificity required to produce an output.

Tier 1	Tier 2	Tier 3
Most generic (and by implication the most conservative) approach to risk guidance. Minimum user input required and simple output provided. Simplified generic conservative assumptions used and totally reliant on the default datasets (worst case exposure). Does not involve rigorous calculation methodology.	Moderately site-specific, requiring some skills, but largely uses pre-defined water use scenarios and limited site characterization choices with common field observation and or measurement input required from the user for scenarios manipulation. Rule-based output interpretation.	The most site-specific guidance. A risk assessment protocol, requiring highly skilled input and output interpretation. Allows for the adjustment of the algorithm and reference data. Default site specific component options that can be changed to suit site specific circumstances (more specific models and parameters).

The risk-based water quality guidelines were to be presented as a software decision support system (DSS) allowing assessments to be performed in generic and site-specific contexts. A DSS would offer the advantage of improving the way in which the guidelines are used because the focus will be directly on supporting decisions in specific contexts; by retaining the scientific rigour rather than producing simple numeric guidance.

For the purposes of this project the development of the DSS as part of the risk-based approach for animal watering water quality guidelines has been done through a prototype demonstrator system.

A previous Water Quality Guideline Index System (WQGIS) software program developed for the WRC, the Constituent Ingestion Rate Risk Assessment (CIRRA) software, was used as a point of departure. CIRRA demonstrated through several WRC research projects that more needed to be done to find a way to utilise water which presented with water quality which was not ideal and contained significant potentially hazardous chemical constituents (PHCCs) and constituents of concern (COCs). Additional objectives were thus noted as operational objectives, these being:

- To identify the correct questions that needed to be asked by the user in order to guide the user in formulating a risk assessment.
- To provide the user with a platform in which key risk factor inputs could be altered with the modelling in effect allowing the user to select or define the range of mitigation options required to arrive at an acceptable final outcome.

In order to provide perspective to the changes in animal watering guidelines and references to the various CIRRA models developed, the following brief overview of work already undertaken prior to the commencement of this research project.

Table 4: Previous undertaken in the development of the Animal Watering Risk-based Guidelines Approach

Document	Key aspects
DWAF 1993. South African Water Quality Guidelines. Volume 4. Agricultural Use. 1st Edition. 84 - 134.	• Change from effluent standard to receiving water quality objective approach. • Based on WRC research project yielding two categories of potentially hazardous water quality constituents, those with a high incidence of occurrence and those with a low incidence. • Departure from previous 1974 Adelaar limited table of anecdotal guidelines. • Introduction of Fitness for Use concept and target guideline range.
DWAF 1996. South African Water Quality Guidelines. Volume 5. Agricultural Use: Livestock Watering. 2nd Edition.	• Introduction of additional Norms for Livestock Water Use. • Based on Target Water Quality Range (TWQR) approach (no adverse effect range) and types of effects with increasing concentration. • Addition of livestock categories included and significantly more constituent specific supporting information provided to assist the user of the guidelines.
Casey NH, JA Meyer, CB Coetzee and WA van Niekerk 1996. An Investigation into the Quality of Water for Animal Production. Water Research Commission Report No. 301/1/96. Pretoria.	• Report highlighting the general failure of most subterranean water sources in South Africa to meet the required target ranges, with key water quality constituents identified as having a high research priority. • The need to develop locally derived guidelines based on ingestion and palatability aspects in the form of an index presented. • Experimentation results presented noting detail on interactions between water quality constituents and potential for mitigation of some toxic potentially hazardous chemical constituents (PHCCs) providing insight into false negatives and positives observed with TWQR approach. • Research noting EDC issues linked to inorganic chemistry exposure. • Key research needs of increased water quality constituent monitoring noted.
Casey, NH and JA Meyer 1996. Interim water quality guidelines for livestock watering. WRC Report TT 76/96. Pretoria	• Interim guidelines released to accommodate local research results relevant to South African conditions. • Key shortcomings of the 1996 DWAF guidelines presented. • Alternative interpretations of the TWQR provided. • Water quality constituents placed in three categories of incidence in the aquatic environment. • Increased expert opinion included in types of effects outside of TWQR and livestock production systems and physiological states expanded.
Casey NH, JA Meyer and CB Coetzee, 1998a. *An Investigation into the Quality of Water for Livestock Production with the Emphasis on Subterranean Water and the Development of a Water Quality Guideline Index System. Volume 1: Development and modelling.* Water Research Commission Report No. 644/1/98. Pretoria.	• Introduction of a Water Quality Guideline Index System (WQGIS) with two application levels, namely Generic and Specific. • Focus on a wider user group audience including veterinarians and animal scientists. • Based fundamentally on water turnover rate as a water ingestion rate reference document (WIRRD) and differing site-specific production system factors on final outcome following exposure, allowing for different WQC concentrations to be derived for different live weights within specific production animal types.

Document	Key aspects
Casey NH, JA Meyer and CB Coetzee, 1998b. *An Investigation into the Quality of Water for Livestock Production with the Emphasis on Subterranean Water and the Development of a Water Quality Guideline Index System. Volume 2: Research results*. Water Research Commission Report No. 644/2/98. Pretoria.	• Presented as a software program for data capturing and calculation support in a user-friendly document-driven Windows application, allowing for updates in terms of data base connectivity. • Introduction of Potentially Hazardous Constituent (PHC) and Constituent of Concern (COC) approach. • Research presented on mitigation effects on water resources containing PHCs and COCs. • Water quality constituents linked to a WIRRD, TWQR, or a Trigger-value approach, with rationale provided. • Production System Detail captured enabling different livestock systems, breeds and categories to be catered for. • Statements generated to assist with recognised water quality constituent-water quality constituent interactions. • WQ GIS supported by several water quality trials in different production animals addressing key PHCs and palatability aspects. • Inclusion of Wildlife as an additional user group presented, with a departure from "livestock" watering towards "animal" watering advocated. • Need to incorporate significantly different South African local geochemical anomalies in a risk-assessment approach detailed.
Casey NH and JA Meyer, 2001. Volume 1: An Extension to and Further Refinement of a Water Quality Guideline Index System for Livestock Watering: Rural Communal Livestock Production Systems and Wildlife Production Systems. Water Research Commission Report No. 857/1/01. Pretoria. Casey NH, JA Meyer and CB Coetzee, 2001. Volume 2: An Extension to and Further Refinement of a Water Quality Guideline Index System for Livestock Watering: Poultry Production Systems and Water Quality for Ostrich Production. Water Research Commission Report No. 857/2/01. Pretoria.	• This research highlighted the need for a multidisciplinary approach to exposure scenarios for agricultural water use in rural communal production systems, in which human health endpoints are influenced by water quality via pathways involving irrigation, animal products and effects of local geochemical anomalies on community health. • Specific aspects pertaining to the different animal production systems in South Africa were addressed, highlighting specific user needs for intensive commercial production systems compared to extensive systems, and concerns for the impacts of mitigation interventions for animal health in dual-use scenarios with rural communities. • The use of animal production systems to provide key risk-assessment inputs for community health in these shared rural communal livestock production systems was advocated. • Additional observations were presented for wildlife production systems and challenges in managing water quality for both conservation areas and wildlife ranching enterprises. • Detail for the Constituent Ingestion Rate Risk Assessment (CIRRA) approach was presented, with additional specific inputs to the environmentally controlled housing systems typical of intensive poultry production systems. • The importance of the role played by local geochemistry on water quality and export product quality requirements was also noted.

Document	Key aspects
Casey NH and JA Meyer 2006. The Application of Risk Assessment Modelling in Groundwater for Humans and Livestock in Rural Communal Systems. Water Research Commission Report No. 1175/1/06. Pretoria. DoA Reports, 2006-2007. Department of Agriculture. Directorate Water Use and Irrigation Development. Project: Analyse Borehole Water for Domestic Use and Livestock Watering throughout the Republic of South Africa. Report Numbers: 022005/01/54; 032005/02/26; 052005/04/90; 062005/04/90; 072005/05/85; 082005/06/18; 082005/07/87; 092005/08/57; 072006/09/127 & 01IR2006/11/15).	• The use of CIRRA Version 2.03 to assess water quality related hazards and risks for humans and livestock in rural communities within rural communal production systems, leading to a Hazard Management tool for Rural Water Sources. • This approach increased the input capability of key specialist groups, namely, Analytical, Animal Health, Geochemistry, Community Health and Rural Implementation and Monitoring. • The main process adopted accorded with hazard and risk assessment phases, namely, Hazard Identification, Exposure Assessment, Toxicity and Risk Assessment and, finally, a Risk Management Strategy Phase. • An implementation model on a National scale for the system was presented. • The inclusion of the most recent new groundwater monitoring results from the Department of Agriculture nationwide project investigating inorganic chemistry in subterranean water resources provided for agricultural use (irrigation and animal) and rural community use highlighted the challenge facing the DWS as custodians of South Africa's water resources in ensuring that the quality thereof is fit for the recognized water uses. • The seriousness of the endpoint effects to community health in the areas investigated was highlighted as an area that warranted research attention and priority.
Numerous WRC reports on EDCs, including: K5/999; K5/1915 & K5/1956.	• Detail concerning EDCs as a key local and international focus area in terms of water quality and fitness for use.
Development of SA Risk-based Guidelines 2007. DWAF Project No: 2006-445	• Phase 1 of the project addressing the Needs Assessment and Philosophy. • Proposals were provided for increasing the Risk-based approach to the existing fundamentals of the CIRRA platform. • An outcome of the workshops was the need for a decision-support software tool and a generic guideline set, with the CIRRA platform required to be significantly simplified for users that may not be specialists in the field of animal production (veterinarians and animal scientists).

When considered from a programming perspective, the objectives of the WQGIS may be considered to be:

- To provide a flexible management tool for scission making purposes concerning water quality for livestock to a wide user group
- To provide a means for incorporating site-specific information in risk assessment for livestock watering
- To provide supporting information regarding the various components and their interactions in biological systems required for decision making
- To provide a water quality guideline system than can be updated as new information becomes available.

These programming objectives were met by:

- Modelling water quality guidelines on a livestock type site-specific basis
- Demonstrating principles of water quality and livestock production relationships
- Developing a software program that:
    - Is user friendly in a document-driven Windows application
    - Has a large data capturing capacity
    - Has a large data administration capacity
    - Can perform a large number of background calculations
    - Is able to manage a large help text file
    - Can connect to existing databases
- Providing the user with two water quality guideline systems:
    - A Generic-WQGIS
    - A Specific-WQGIS

The platform thus chosen at the time to achieve these operational objectives was a computer simulation model as a decision support system that could provide a user interface in a familiar and easy to use document driven Windows application program, and this research project presents a reworked version thereof both in terms of risk assessment methodology and the user interface design.

The new norms which were developed for this project are presented in Table 5.

Table 5: Norms and corresponding effect applicable to Animal Watering

Norm	Effects
Animal Health	• Drinking: ○ Toxicological effects ○ Palatability effects ○ Endocrine effects ○ Carcinogenic effects • Inhalation: ○ Disinfection By-product effects • Medication: ○ Vaccine effects
Animal Watering System	• Production and Replacement effects: ○ Biofilm ○ Chemical corrosion ○ Biological corrosion ○ Encrustation ○ Scaling sediment

Norm	Effects

Animal Product Quality	• Consumption effects
	  ○ Maximum Accepted Limit
	  ○ Multi route scenarios (rural communal)
	• Product quality effects
	  ○ Residue compliance
	  ○ Product attributes

Environmental	• Water provision effects
	  ○ Habitat effects
	  ○ Sacrifice zone effects
	• Biodegradable wastewater irrigation
	  ○ Water resource effects
	  ○ Crop quality effects
	  ○ Crop production effects
	  ○ Soil effects

Four core aspects were addressed in the initial CIRRA model, subsequently the requirement to include the sections relating to sub-section 21 (a), 21 (b), 21(e), and 21(g) of the National Water Act (Act No 36 of 1998) was also recognised, leading to the core factors to thus be considered expanded to:

- Breed-specific factors
- Category-specific nutrient requirements
- Production-related factors
- Product-related health hazards and quality considerations
- Water Use and Wastewater Handling activities

The existing CIRRA model generated reports results in the following manner:

- Water PHCs and COCs
- Water and Feed PHCs and COCs
- Interactions between WQCs in the water, feed and between the water and feed.
- Site-specific factors
- Proposed solutions

The model also provides the following information to facilitate risk factor management:

- Water results by category
  - Including system factors
  - Excluding system factors
- Water and feed results by category for:
  - Including system factors

   - Water and feed ingestion
   - Feed concentrations

- Suggested constituents for analysis in the water, feed and soil
- Provision of site-specific notes on system aspects
- Provision of problem origins and proposed solution palatability calculations
- Provision of supporting information
- Capability to link to external databases.

The calculation results also allow for causative factors to be identified by displaying:

- The extent by which WQCs exceed the reference document value.
- The extent by which the ingestion of a constituent exceeds the recommended High, Toxic or Maximum Tolerable reference document values.
- Identifying system factors which are synergistic or antagonistic.

It was appreciated that not all of these could be addressed within the scope of the project for the new DSS, with only the following addressed and key reference documents updated:

- Bromide
- Fluoride
- Nitrate
- Selenium
- Selected Disinfection by-products

As this final report is a supportive document to the DSS, it should be read in conjunction with the supporting technical information (Volume 2) which provides extensive detail to the DSS and the approach, these being:

- Review of model and documentation and precursor document on update and revision undertaken.
- Risk approach fundamentals for animal watering.
- Updated constituent hazard assessment for risk approach guidelines for animal watering.
- Risk methodologies for Animal Watering.
- Decision Support System for Animal Watering.

The key aspects dealt with in Volume 2 include:

- Overview of previous DSS developed (Constituent Ingestion Rate Risk Assessment model – CIRRA) including the fundamentals thereof, need for a risk-based approach and proposals for updates to this approach and subsequent revisions required.

   - Key update aspects of the CIRRA software model, namely:

    - The determination of the fundamental components to a Risk-based approach; and
    - Updates to the existing constituent ingestion rate risk assessment model (CIRRA).

- Updated Water Ingestion Rate Reference Documentation for:
    - Water Quality Constituents: Selenium, fluoride, nitrate and bromide in:
        - Selected Livestock Types: Sheep, Beef Cattle, Pigs and Poultry.

- Updated methodologies used for the Constituent Ingestion Rate Risk Assessment Modelling and corresponding source, pathway and receptor inputs for the Generic and Specific-WQGIS application levels.

- The prototype DSS report highlighting data flow of the user interface and the methods by which the results of the data input fields are assessed and compared to the reference documentation and the similarities thereto to a source, pathway and receptor analysis typically adopted, in order to include the tiered approach.

1.3. Summary

The supporting technical information explains the fundamental objective which needed to be addressed by the user audience being the concept of "acceptable risk" and how this was enabled by a DSS for a wide user audience range, from water resource managers to the actual water users.

This is arguably the most important concept to adopt, as it represents a significant departure from the previous versions of the South African Water Quality Guidelines (DWAF, 1993 and DWAF 1996) in which a "desired state" of a Target Water Quality Range was the goal and generally construed to imply a "no adverse effect" state, whereas the new goal is to adequately describe the outcome of a water use under a specific context in a manner which enables a more realistic decision to be reached regarding either accepting some degree of adverse outcomes, or reducing the risk factors identified to an acceptable level.

Herein it is worthwhile to consider that whilst the DSS subsequently developed must have in common for all these different user groups the ability to allow for informed decisions to be made concerning sustainable water use, it also has to cater for substantially different interests.

To illustrate this the simple example of microbiological indicator organism results in source water samples compared to point of use water samples may be considered. The source results offer an indication to the water user (for example, the operator of a confined animal feeding operation) if potential hazards exist for the fitness for use concerning biofilm issues and potentially pathogenic microbes which involve two different norms, namely water distribution systems and animal health.

The results may guide the user in terms of the water treatment required but the actual acceptable risk derived will be a function of point of use samples, water treatment costs and the monitoring results of additional water quality tests (in addition to water treatment-related tests for example nitrate and other potential markers linked to elevated microbiological indicator organism results) and animal system and performance monitoring.

In this instance the source, pathway and receptors relevant include water quality as influenced by both inherent quality and the water treatment chemicals created (disinfection by-products and oxidant residuals), the water distribution (and presentation to the animal) system and the animals themselves.

Additional risks which may be of more relevance to the animal producer relate to the decision to treat the water to lower the microbiological indicator organism counts and subsequent consideration of new management issues which arise. Thus, the decision to address potential adverse effects to the animals which are directly related to the microbiological indicator organism counts may incur potential adverse effects which affect the animals that are indirectly related to the counts.

An example of this could be failure to adequately neutralize the oxidant during the administration of vaccines via the drinking water and thus reduce vaccine efficacy (water medication norm) and the failure to manage pH changes with water leaks and related adverse impacts on the production environment such as wet litter (alkaline shift and acetal degradation of rubber components of drinker nipples).

The decision to address one norm may thus affect other norms, both of which are centred around the animal production system and are more concerned with point of use effects and source characteristics.

A different perspective is, however, noted when viewed from that of a water resource manager, with subsequent compliance monitoring interpretation using the microbiological indicator organism results from the source as the primary result of interest to evaluate the source, pathway and receptor aspects as they apply to the potential for the animal production system to impact the applicable water resources. The norm applicable in this instance relates more to the environment as the receptor than the animal.

Acceptable risk for the animal producer would relate more to variables for water treatment cost, biofilm impacts on water pressure for animal drinking purposes (thus water and feed intake and drinker-line cleaning) and infection outcomes following exposure to potential pathogenic strains. The outcome may thus range from affordable *in-situ* point of use monitoring (water pressure, water intake and suspended solids monitoring) without treatment, to a significant capital expenditure for water treatment (oxidant application and disinfection) for which additional routine water tests (disinfection by-product's, residuals and treatment parameters) and receptor evaluation (clinical biochemistry and histopathology) may also be required.

For the water resource manager the risk may be influenced by the wastewater handling details for the animal production system, water use licence limits applicable, background microbiological setting of the local water resource (water management unit) with other potential discharges and water users considered and seasonal microbiological variation ranges applicable.

Although the above discussion is a simplistic example it does illustrate how the DSS must cater for different perspectives in the water quality input data evaluated and how the final evaluation of "acceptable risk" may be made on different source, pathway and receptor considerations.

The link between the different needs of these diverse DSS user groups is that both relate to the requirement for a water resource to be appropriately managed for the sustainable use thereof. The animal producer thus has no desire to have the animal production operations ultimately impact the water resources negatively, just as the water resource manager requires the fitness of use to be maintained for the water uses applicable within the water management unit or broader catchment.

Despite the differences noted, the primary benefit in adopting a risk-based approach and thus moving towards a site-specific approach is that the pressure to move water resource management and related activities in a direction of unrealistic and ever lowering water quality constituent concentrations is avoided, this being achieved as the presence of a potentially hazardous constituent in terms of detection at a specific concentration (or count) alone is increasingly acknowledged to not imply an adverse effect, but more accurately a potential hazard that can be manipulated and appropriately managed to reduce the risk of such an outcome, this being true for the different norms applicable.

This progression from an initial water quality result to further obtain site-specific information is the key aspect that the DSS must cater for and, in addition to this, must also cater for varied user input which relates to different user groups with different norms of interest.

In this regard the previous CIRRA software was focused on the animal production system with the data input screens also largely limited to animal production information. As was discussed in previous deliverables the changes to the government schedules applicable to Section 21 activities of the National Water Act, and the current National Water Resource Strategy (2013), within the context of water scarcity, increased competition for access to water resources and increased challenges to water quality, the linking of abstraction to discharge aspects for animal production is the central theme by which water resources are managed on a sustainable basis for animal watering.

It is again stressed that the objective is not to remove all risk and provide safe water quality, but to understand that some risks are acceptable, can be mitigated, and for the specific intended purpose, remain fit for use without appreciable loss to the sustainability (and where applicable profitability) of the water use.

The key to achieving this objective is a combination of data capturing fields on the one hand, and the provision of results calculations in a manner which enables risk factor identification, quantification and manipulation on the other.

The final DSS risk-based guidelines are envisaged to be continually evolving as opposed to fixed standards (which would only be subject to changes which coincide with planned revisions). This difference is fundamental to achieving guidelines which firstly remain applicable as animal production systems continually improve and, secondly, assist with on-going water resource protection. This aspect should be noted as it is not inherently demonstrated for the prototype DSS.

2. KEY UPDATES AND MODELLING CHANGES

2.1. Introduction

The reality of water quality having to be used which does not comply with local or international recommended limits within an environment characterised by a wide range of animal production systems, increasingly including those with a production setting where advances in animal genetics, housing, nutrition, health management and production systems have yielded high level performance targets as a fundamental component to commercial viability, have led to the recognition in South Africa and elsewhere internationally, that a concentration-based mg/L target approach is insufficient with which to effectively achieve the production system fitness for use needs.

Whilst South African production systems and types of water quality challenges are indeed specific to the local geochemical and production environment, this challenge is not unique to South Africa, as observed in the review of available literature on water quality for livestock by Olkowski (2009):

> "It is important to understand the complex nature of biological responses of animals, in particular those that are genetically selected for high production traits. In this context, it is imperative that the high metabolic demand associated with constantly increasing production goals is taken into consideration in assessment of water quality standards, especially in the face of the increasing complexity of water contaminants."
>
> "There is a noticeable insufficiency of recent information on many aspects of water quality issues in contemporary livestock selected for superior performance characteristics. Without cooperative research using today's high-performance genetics, interpretation of water quality data is problematic at minimum."

The following three key aspects are noted in current water quality guidelines for animals:

- Most focus on water provision aspects which are continually updated in terms of new technology and products to provide water drinking systems with the correct pressure and method for specific production systems (e.g. piggeries and poultry houses).

- They stem primarily from three key sources, namely the National Academy of Sciences (NAS) (1974), the Council of Agricultural Science and Technology (1974) and the Canadian Council of Resource and Environment Ministers (1987) and continue to present with significant shortcomings and outdated interpretations.

- They are accompanied by advisories which appear to arise from a setting in which alternative water sources are readily available (often not the case locally) and appear increasing distant from the human drinking water guidelines internationally which demonstrate clear trends of increasing water quality constituent lists and lower acceptable concentrations.

Whilst the risk-based approach philosophy is not repeated here, it is noteworthy to highlight the key aspects which include a tiered-approach wherein a generic assessment is progressively moved towards a site-specific assessment in which increased accuracy of source, pathway and receptor components allow for the identification, and thus mitigation option formulation, of key risk factors.

This departure from a concept of a "safe" concentration strategy which is not only prohibitively costly, but also contrary to the current National Water Resource Strategy (Ed 2 2013-2018), to one in which risk-reduction measures aimed at arriving at an "acceptable risk level", is not only scientifically more defensible, but also more practical and cost-effective.

2.2. Key Aspects Addressed

The following key aspects were described in the research project for the CIRRA model requiring updates and an approach revision:

- Whilst significant animal production system variation is found *between* animal types, the fundamental inputs to the main commercial system types have little variation between key inputs and may be viewed as "low variation common input variables".
  - As an example, a broiler production site for a specific breed may have several production facilities across South Africa in different spatial settings, yet all follow the same production targets and inputs in terms of genetics, veterinary care, nutrition (formulation and diet types) and controlled environment settings.
    - The primary variable with the most variation in these otherwise predominantly "low variation common input variables" is water quality.
      - Although air quality may play a role the potential air quality hazards that could potentially differ between sites, are typically managed within environmentally controlled intensive systems within narrow margins.
  - It thus follows that updates are required for:
    - New animal production systems which have seen significant changes to the "low variation common input variables" since the previous CIRRA versions, including new genetics, housing systems, approaches to disease management and advances in nutrition.
      - In addition to the system options provided for the various livestock type production systems and categories presented in the CIRRA model, this

also relates to the source reference documentation for key aspects of the CIRRA model, namely:

- Water ingestion rate reference document (WIRRD)
- Feed Data Base Reference Document (MINRD)

  - This is a crucial aspect that must be addressed, as noted in the review by Olkowski (2009) the generally regarded "safe" levels may be a gross underestimation of the total dietary burden in today's commercial systems, this being true for a wide range of water quality constituents, from relatively non-toxic water quality constituents like calcium to those with a narrow margin between essentiality and toxicity such as selenium.

- As the potential list of constituents applicable is beyond the scope of this project, it was proposed that the project focus on updating the key reference documents for the following water quality constituents:

  - Bromide
  - Fluoride
  - Nitrate
  - Selenium
  - Selected Disinfection by-products

- Management goals are required for both water resource management aspects and animal production system requirements and animal watering should thus not be considered in isolation of other water users.

  - As noted in the later WRC reports on additions to the CIRRA model, agricultural use of water for irrigation and animal purposes often occurs simultaneously.

  - The rural communal production and subsistence systems versions of CIRRA addressed those scenarios in which water was used for domestic purposes, irrigation of village, community or household crops, and for animal watering. The scarcity of alternative resources in these settings requires a combined approach in the consideration of appropriate constituents and endpoints applicable, noting the precautionary approach required when dealing with community health hazards.

        - It follows that updates are required in terms of the new knowledge subsequently gained in terms of water quality and community health.

            - Specific reference is made here to the WRC EDC programme and the WRC Project on agricultural chemicals (Meyer *et al*., 2014 and Dabrowski, 2015).

    - In order to not only allow for sustainable long-term animal production but also compliance monitoring requirements, the inclusion of guidelines addressing water quality constituents and their effects on biodegradable industrial wastewater activities must also receive attention.

- Due to increasing recognition that induced deficiencies and hypo-osmotic challenges pose significant challenges to animal production, the focus has to also shift from a toxicological endpoint to once which addresses the current science of a range of deficiencies, adequacy to excess.

    - This inclusion of multiple ingestion routes is crucial to reducing the previous observations of false positives and negatives in terms of target water quality ranges and predicted adverse effects and is a key component to being able to manipulate the correct system inputs to enable optimal utilisation of those water resources which are not classified as ideal (or insignificant risk).

    - It follows that significant updates are thus required which involves comprehensive literature surveys on each constituent and variable.

- The core factors to be considered should be expanded to be:

    - Breed-specific factors
    - Category-specific nutrient requirements
    - Production-related factors
    - Product-related health hazards and quality considerations
    - Water Use and Wastewater Handling activities

- The Generic-WQGIS needs to be adapted to provide more dietary and performance settings with the estimate, albeit still on a concentration-based guideline, nonetheless more accurate and fundamentally different from the 0 – x mg/L TWQR philosophy which is demonstrably not appropriate for commercial animal production systems.

- Extensions to the user groups and production system types within the Specific-WQGIS are also required.

- Attention needs to also be given to aligning the applicable and non-applicable aspects of the SANS 241 standards in animal production systems in areas where shared use occurs (e.g. those operations using municipal water).

    - The inclusion of a detailed section on the appropriate water treatment methods available to the animal production industry and chemistry applicable to interactions between inherent water chemistry and applied oxidants it also a key aspect that must be addressed in the risk-based guidelines as this is frequently noted to be a source of significant adverse endpoint effects in practice.

- When the application of the CIRRA model was considered by the DWS during Phase 1 of the Development of Risk-based Water Quality Guidelines, the model was recommended to be housed at the WRC as an access point for specialist groups wishing to use the software and contribute to the data being generated, with yearly reviews and updates suggested.

    - As this did not transpire and considering the time-lapse between the 2007 Needs Assessment and Philosophy report and the commencement of this project it will require that a new programming language and application be sought.

    - Given the array of options currently available this may open up different formats of access and data base connectivity for a wider range of potential users.

    - Linking multiple water files from CIRRA to enable best blending options for multiple water sources on the same registered property (or animal production system) to align the separate water sample inputs with applicable site-specific scenario solutions.

    - Crucially, this could and should link to internal DWS monitoring data bases and as a key potential user group of the information captures and assessments generated, the water files from CIRRA can serve as an input towards a range of DWS functions, from water quality planning limits in water management areas, water volume allocation for agricultural sector users, to potential wastewater load calculations.

It should also be noted that whilst the use of the term “livestock” to categorise the water use sector is frequently used, it is technically more accurate to use the term “animal” as water users in South Africa include sectors in addition to farm animals, such as wildlife, which although in certain instances may be breed in captivity as “confined animal feeding operations”, primarily include game ranches and private reserves.

Lastly, whilst the previous CIRRA system was developed in conjunction with the target user audience it was noted that a less "intimidating" user interface could be developed. Given that the updates and results generated in the form of risk-based guidelines for this project inherently require more calculations and results to be presented, the manner in which this was done formed a significant part of the DSS prototype developed. By way of example, below are examples of some of the previous CIRRA user interface screens (generic input, site-specific detail and results screens) which the reader should compare to the prototype DSS update as part of this project.

These screen shots provide an indication of the general flow of the DSS, namely data input, evaluation and reporting. Subsequent CIRRA versions added additional generation of Data Capturing Guides (printable sheets which were generated for specific livestock types and categories) in order to assist with this process for users not familiar with animal production and additional linkages between specialist groups, for example, nutritionists and pathologists. These changes were in essence attempts to move towards a Tier III level in which specialist user groups were increasingly catered for, and it should be noted to also confirm suspected risks by clinical biochemistry assessments.

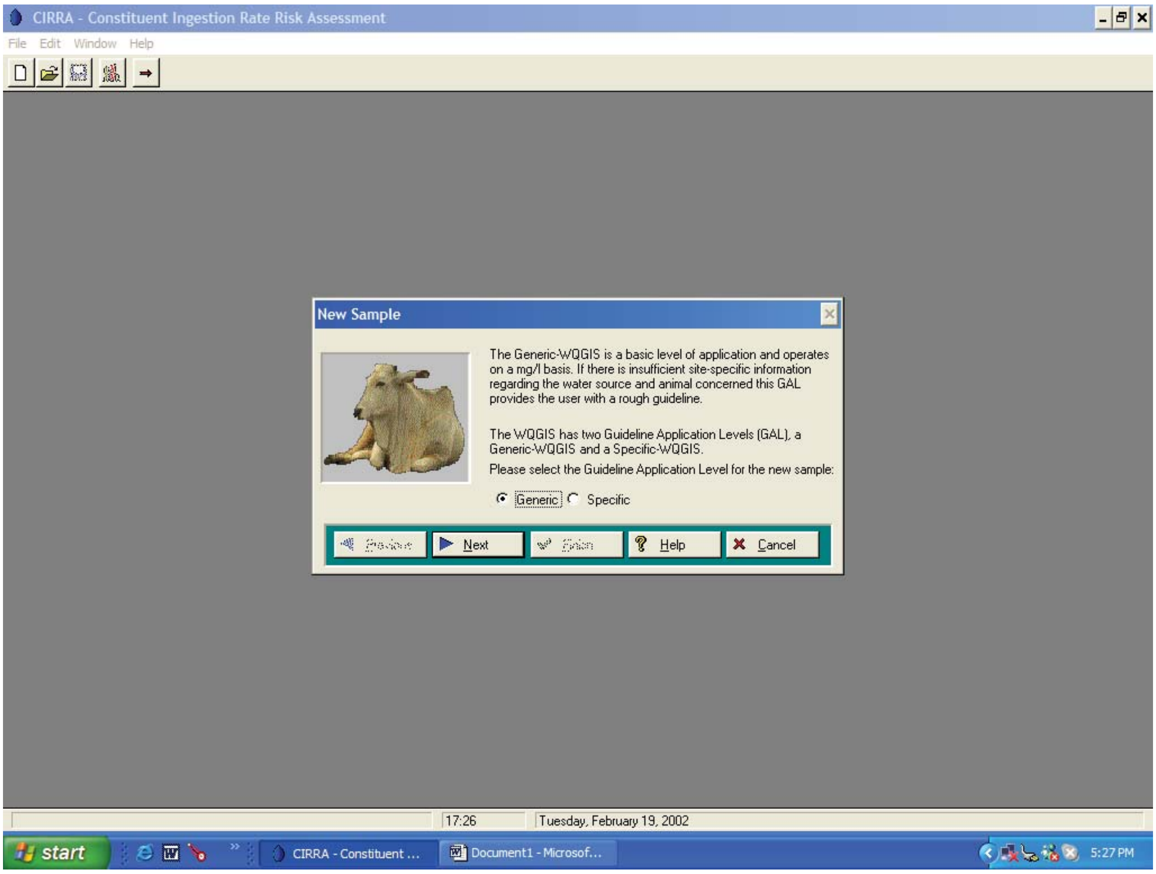


Figure 4: Opening Guideline Application-Level options with cautionary notes

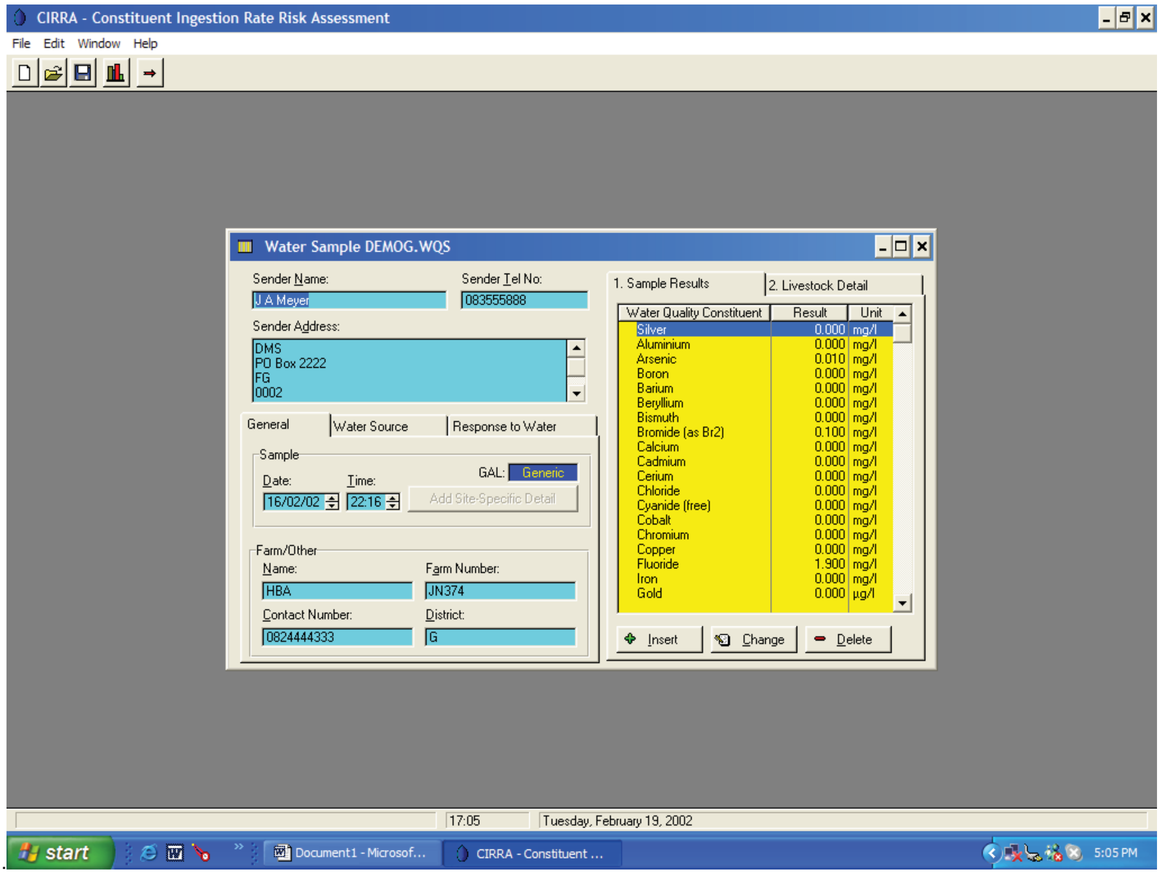


Figure 5: Opening interface for sample detail

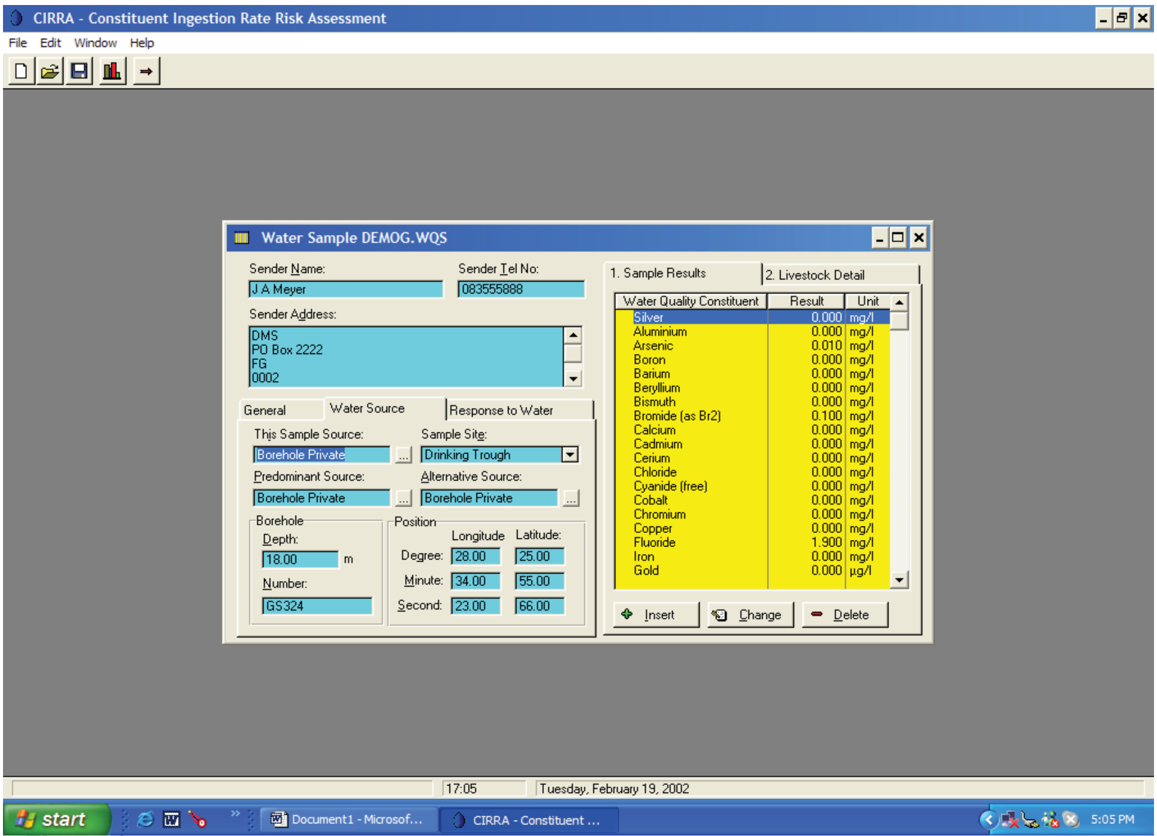


Figure 6: Expansion of Water Source Tab

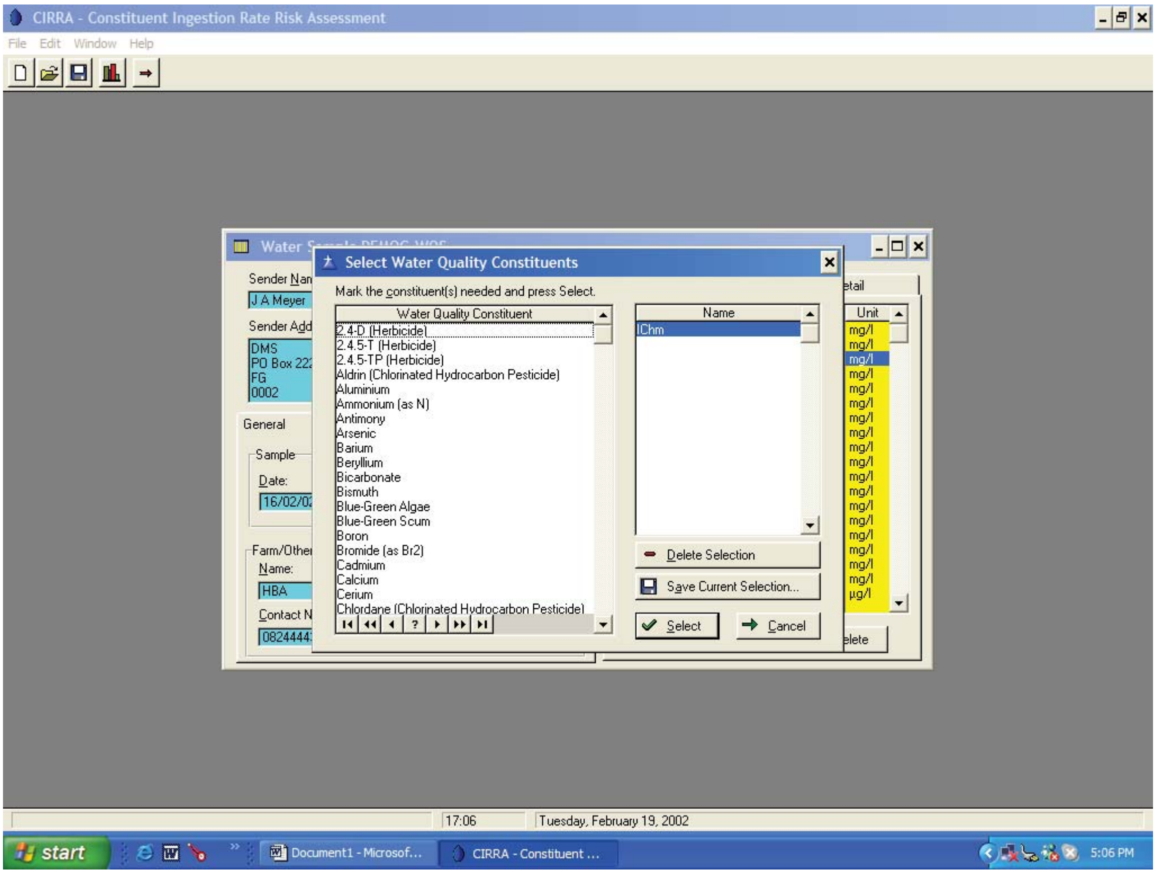


Figure 7: Expansion of Water Quality Constituent List Selection Tab

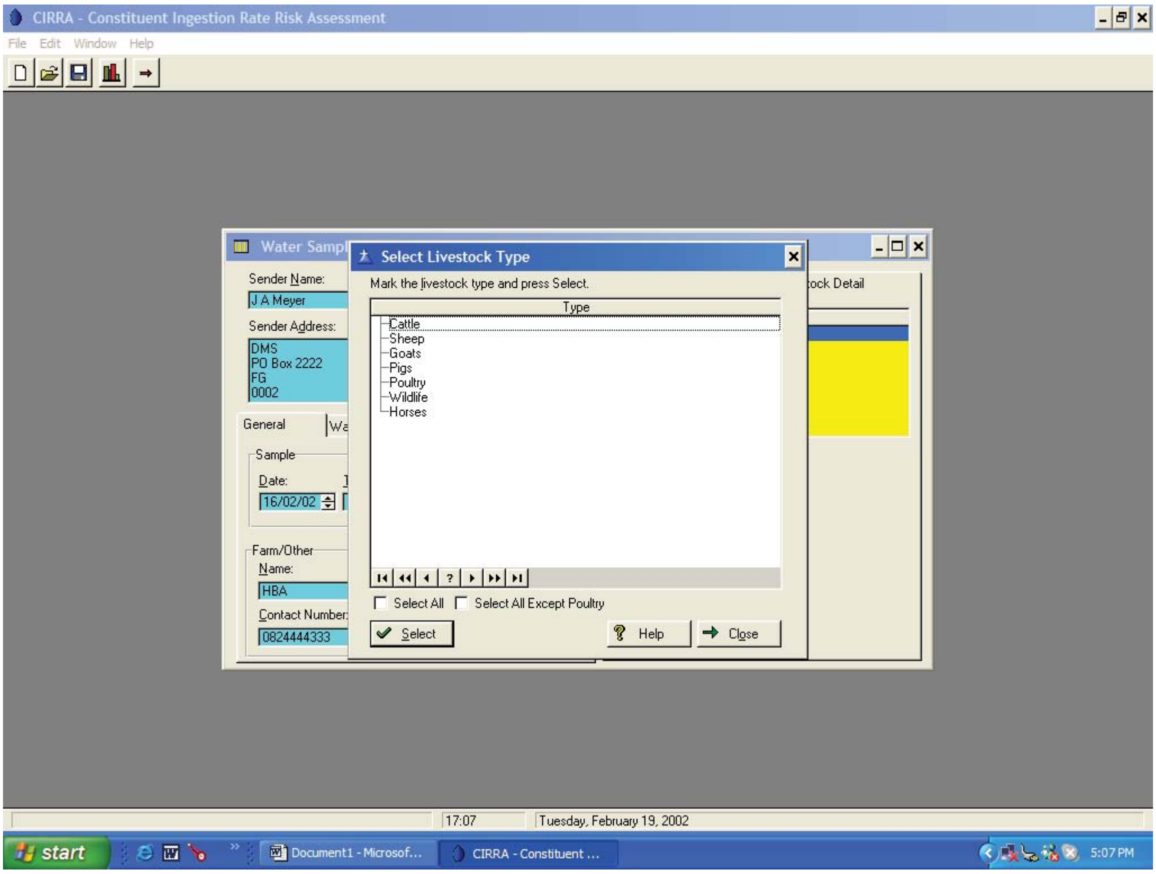


Figure 8: Expansion of Generic Livestock Detail Selection Tab

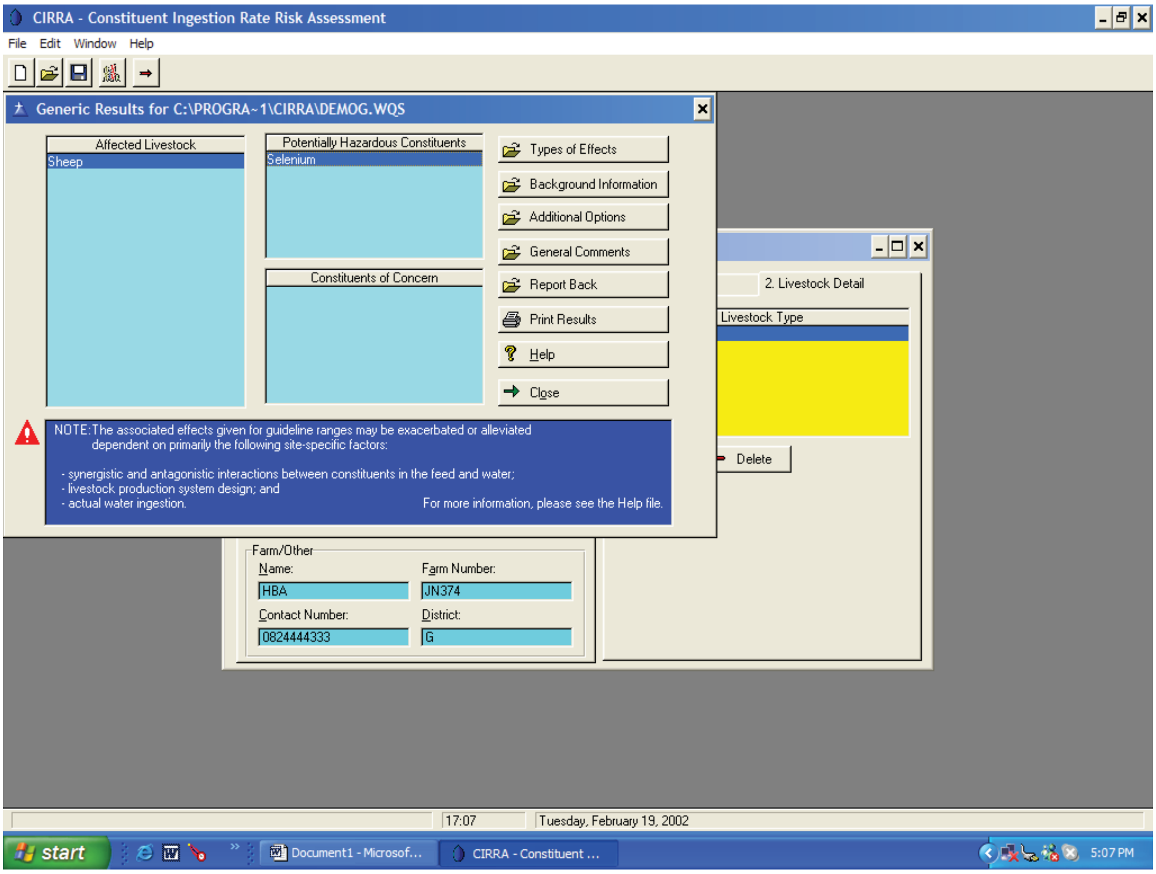


Figure 9: Results screens by animal type for Generic GAL

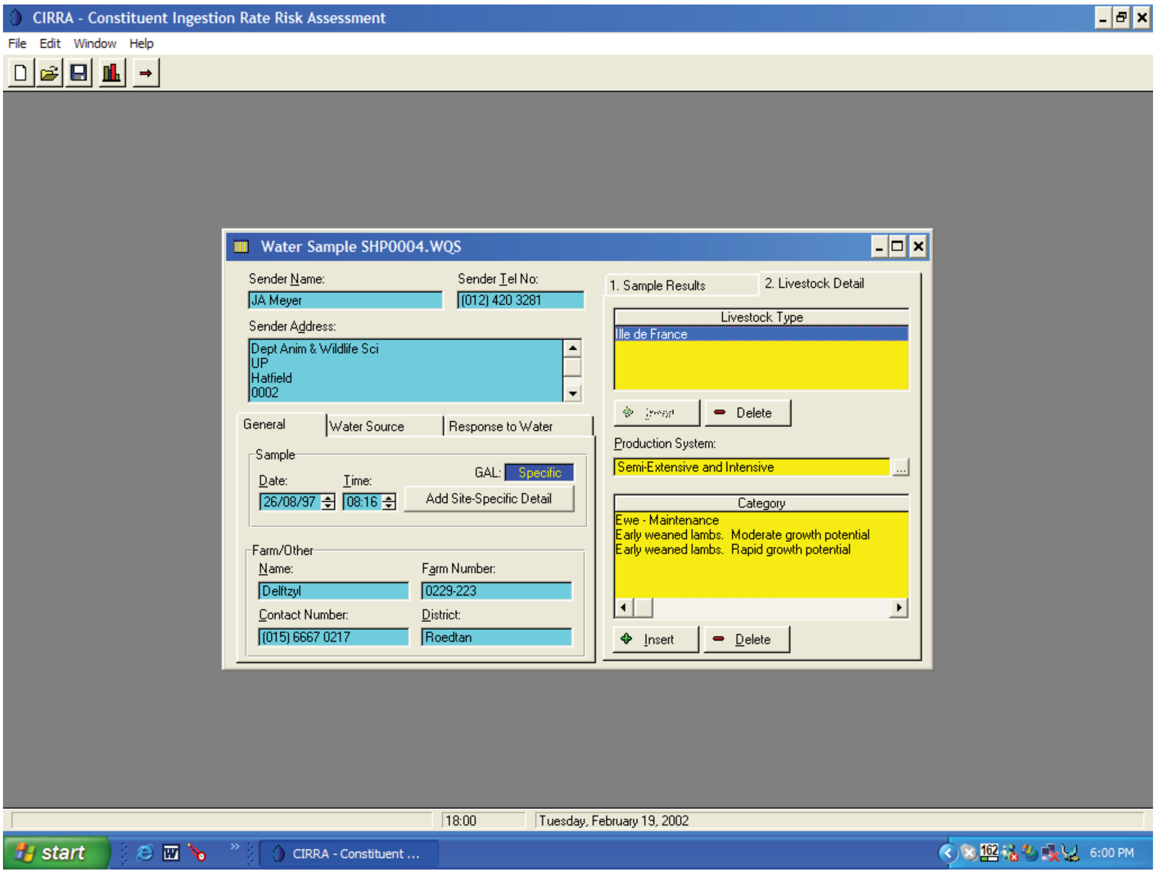


Figure 10: A Specific GAL sample – note the activation of the Add Site-Specific Detail button

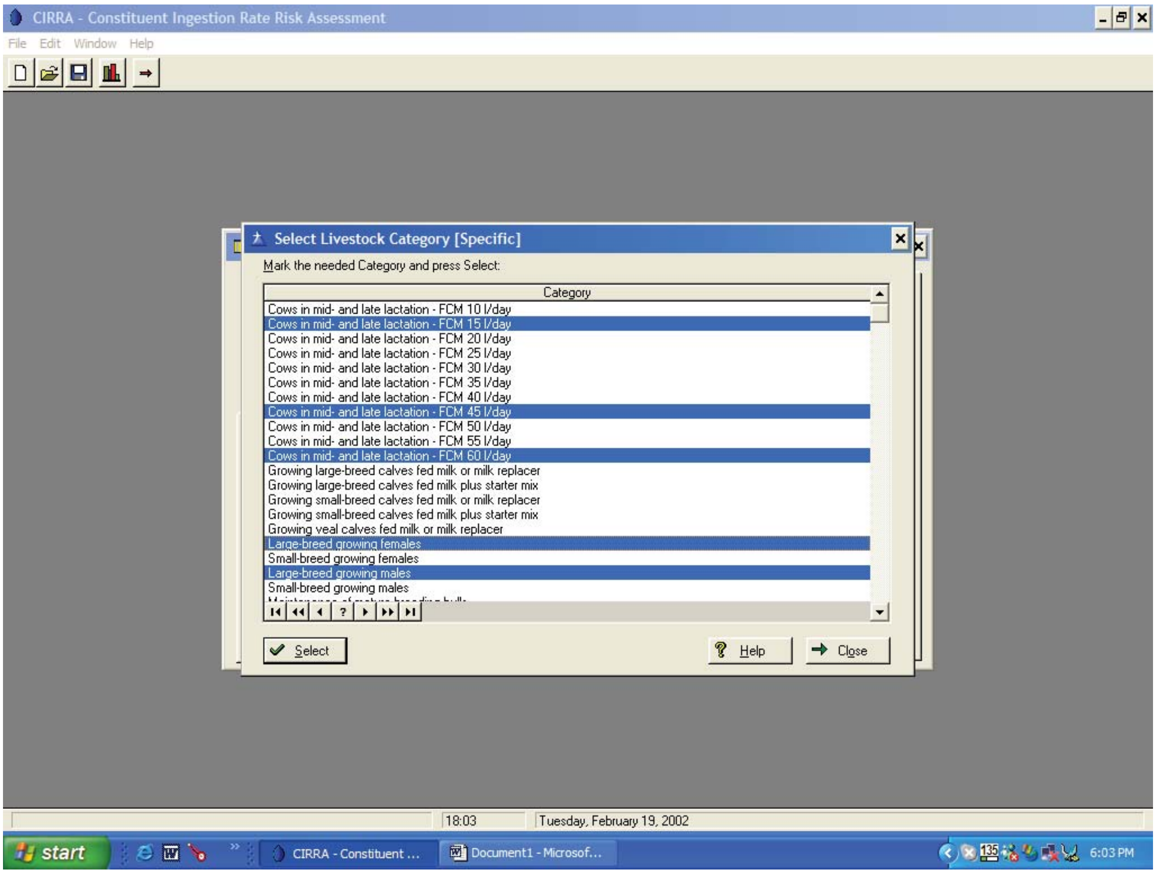


Figure 11: A Specific GAL sample – Dairy specific categories and selection method

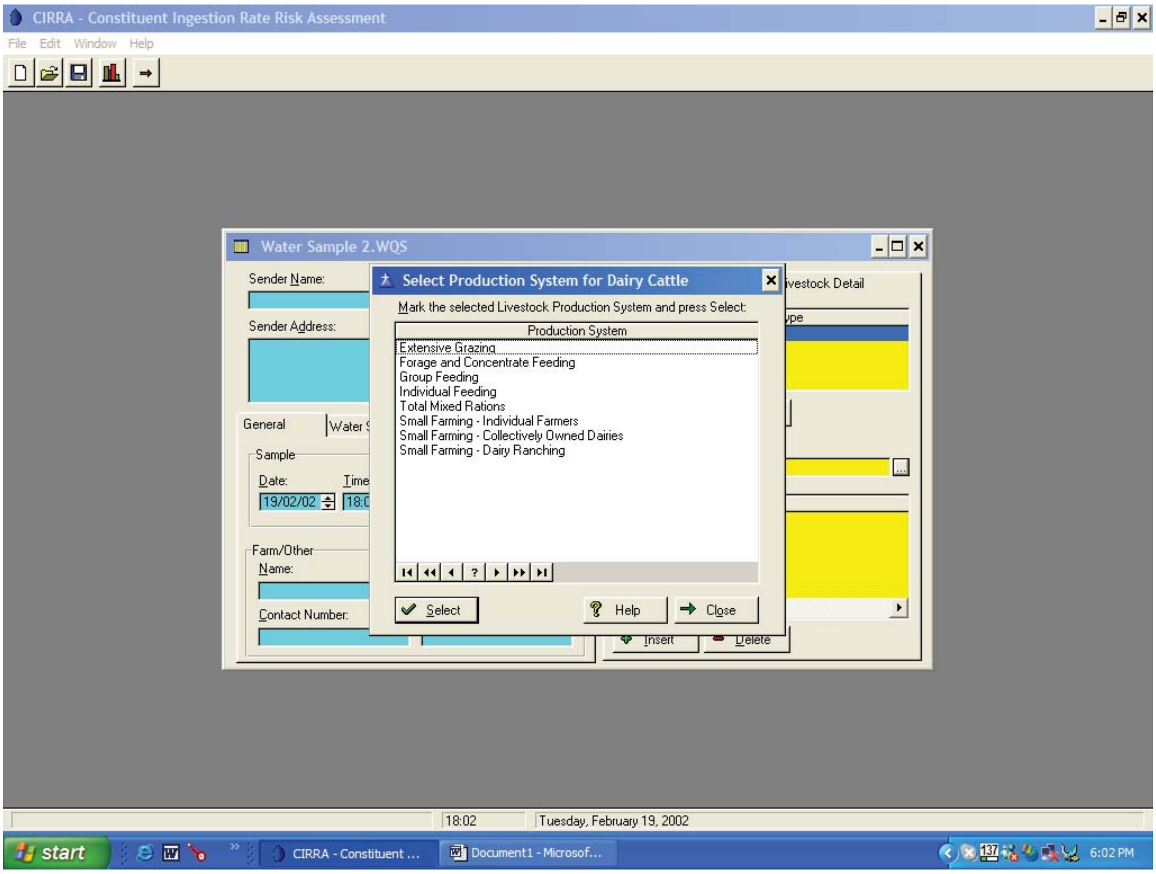


Figure 12: A Specific GAL sample – Dairy specific production systems

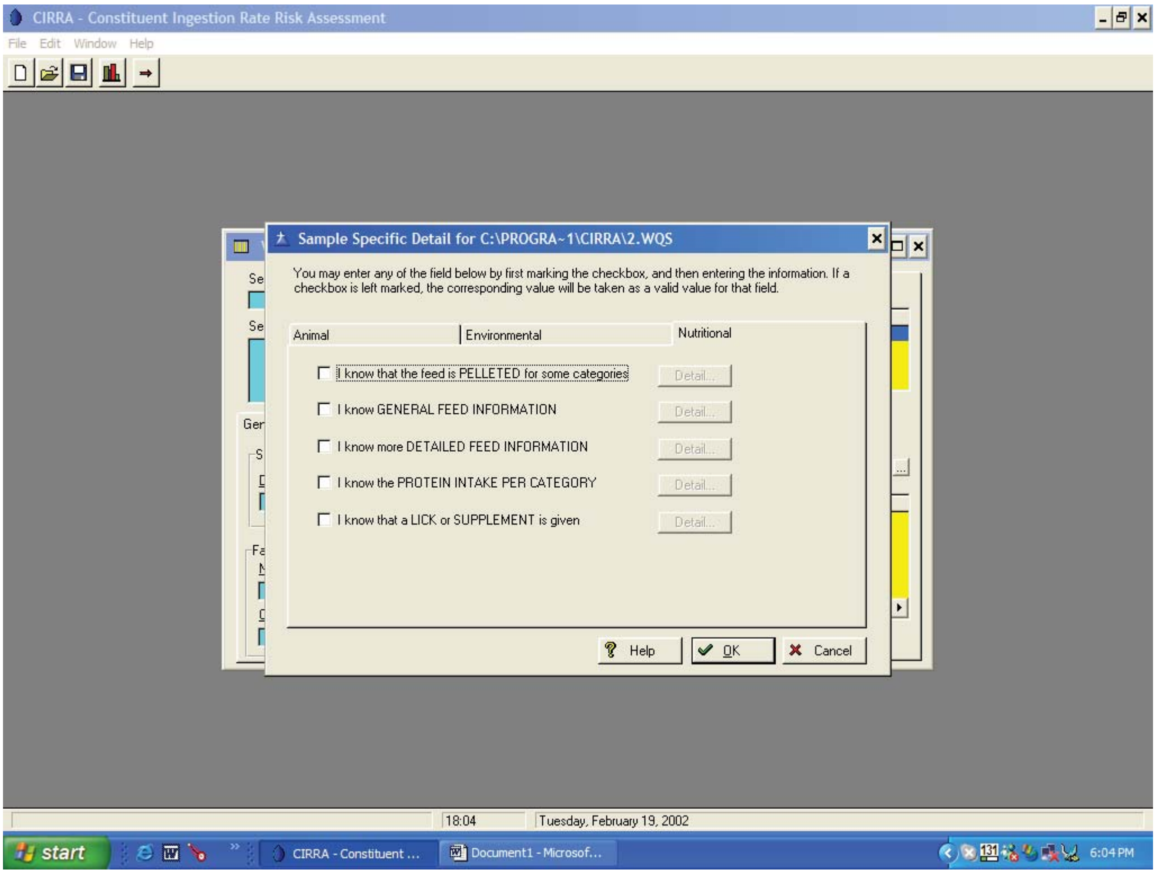
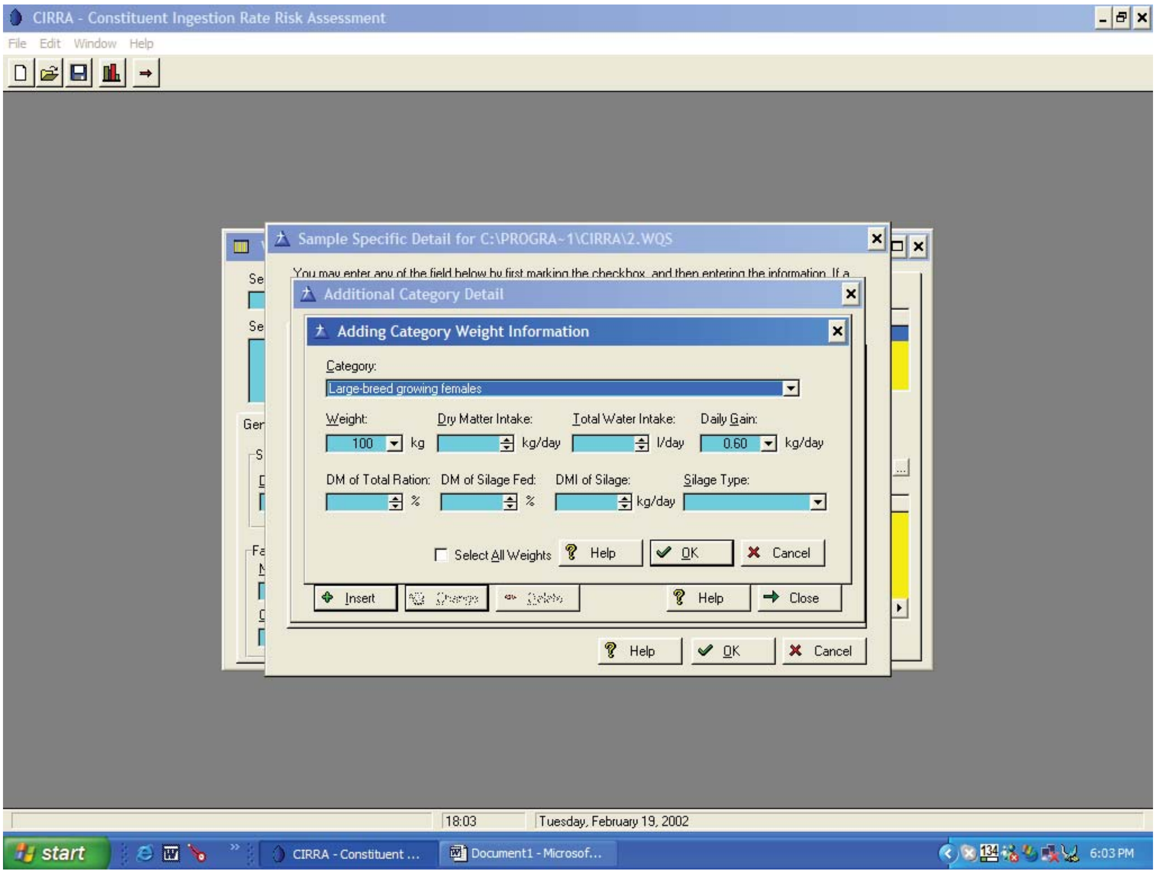


Figure 13: Specific GAL – Dairy specific – Add site-specific Detail – category.



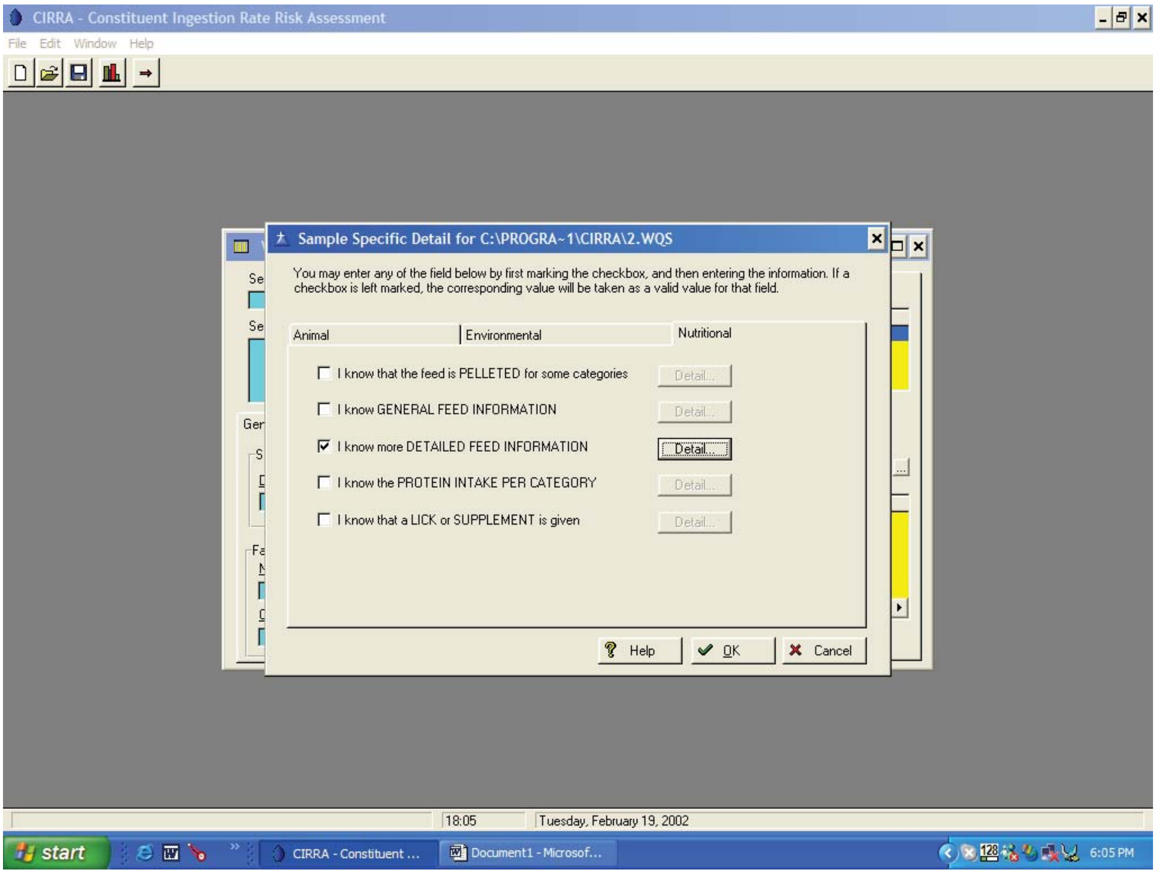


Figure 14: Dairy specific – Add site-specific Detail – Feed – Specific1

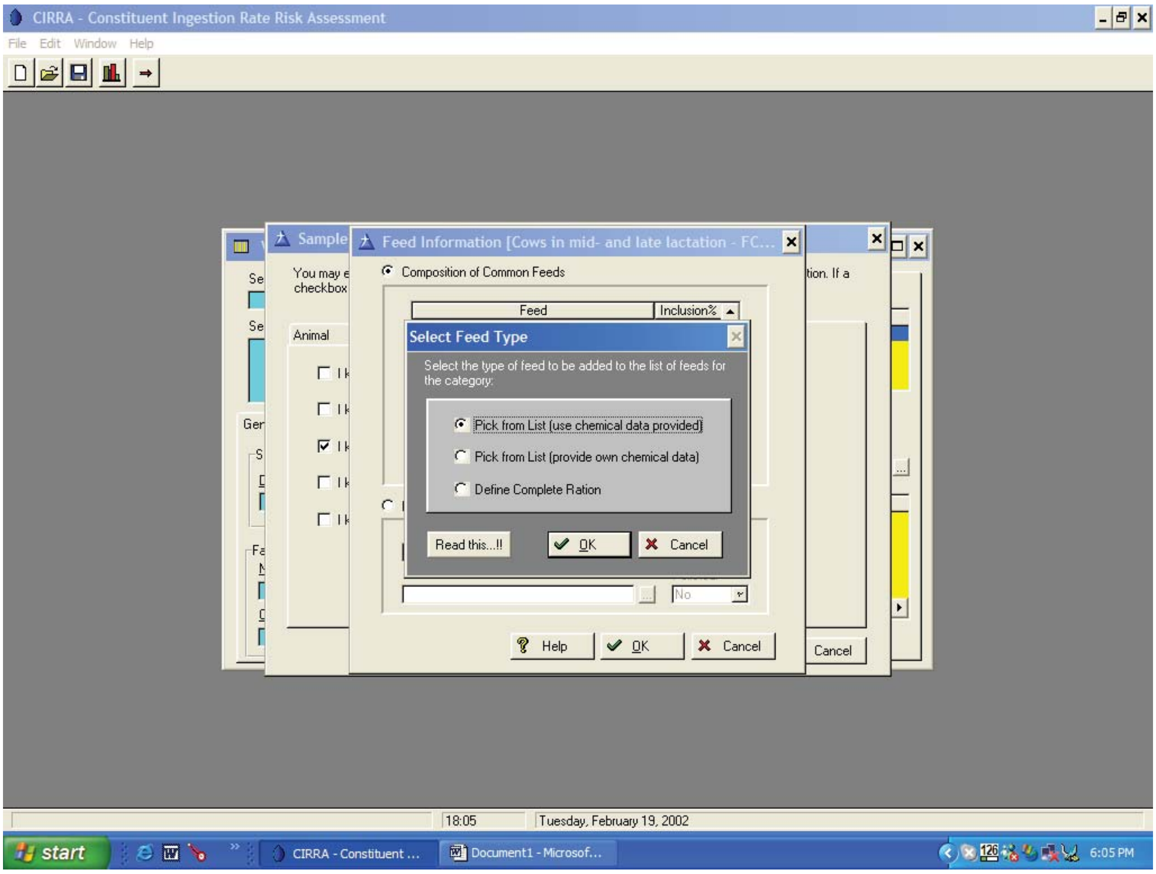
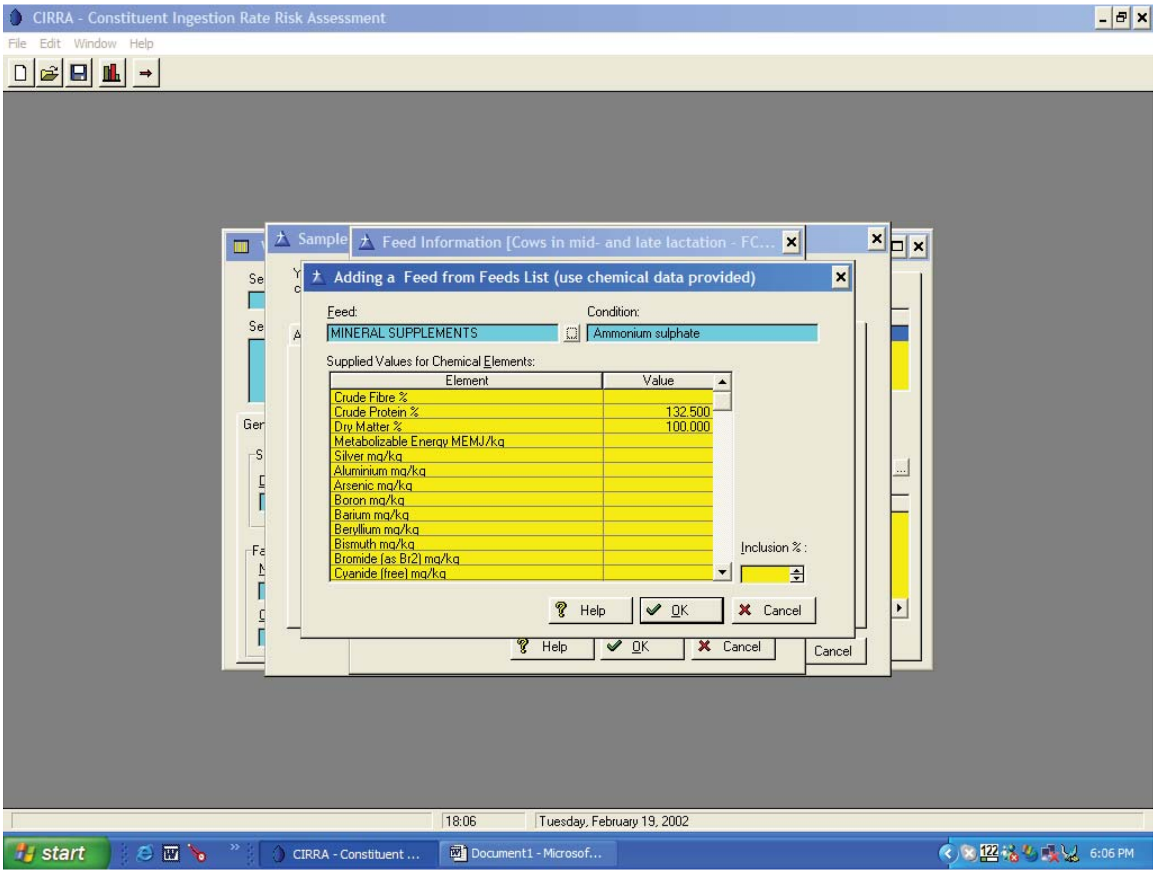


Figure 15: Dairy specific – Add site-specific Detail – Feed – Specific 3



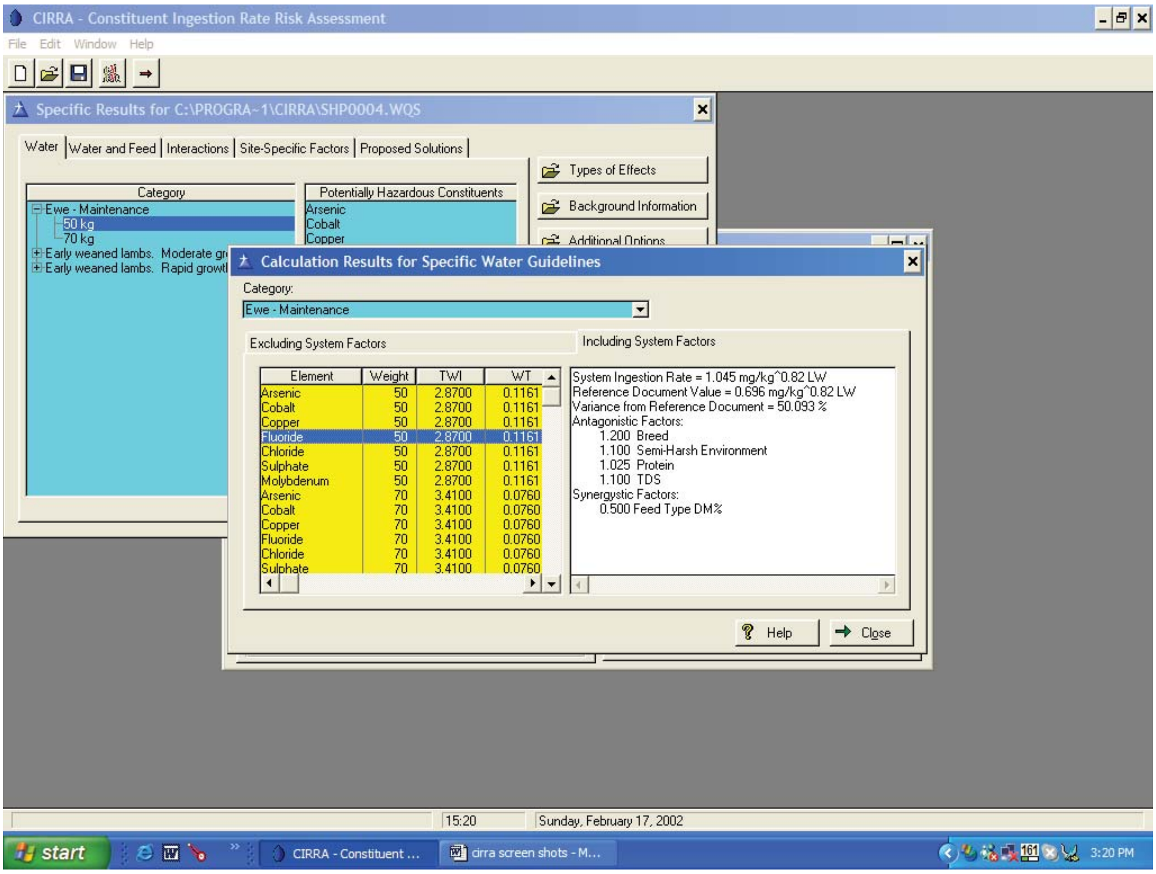


Figure 16: Specific Application Level – Sheep – Results screen5

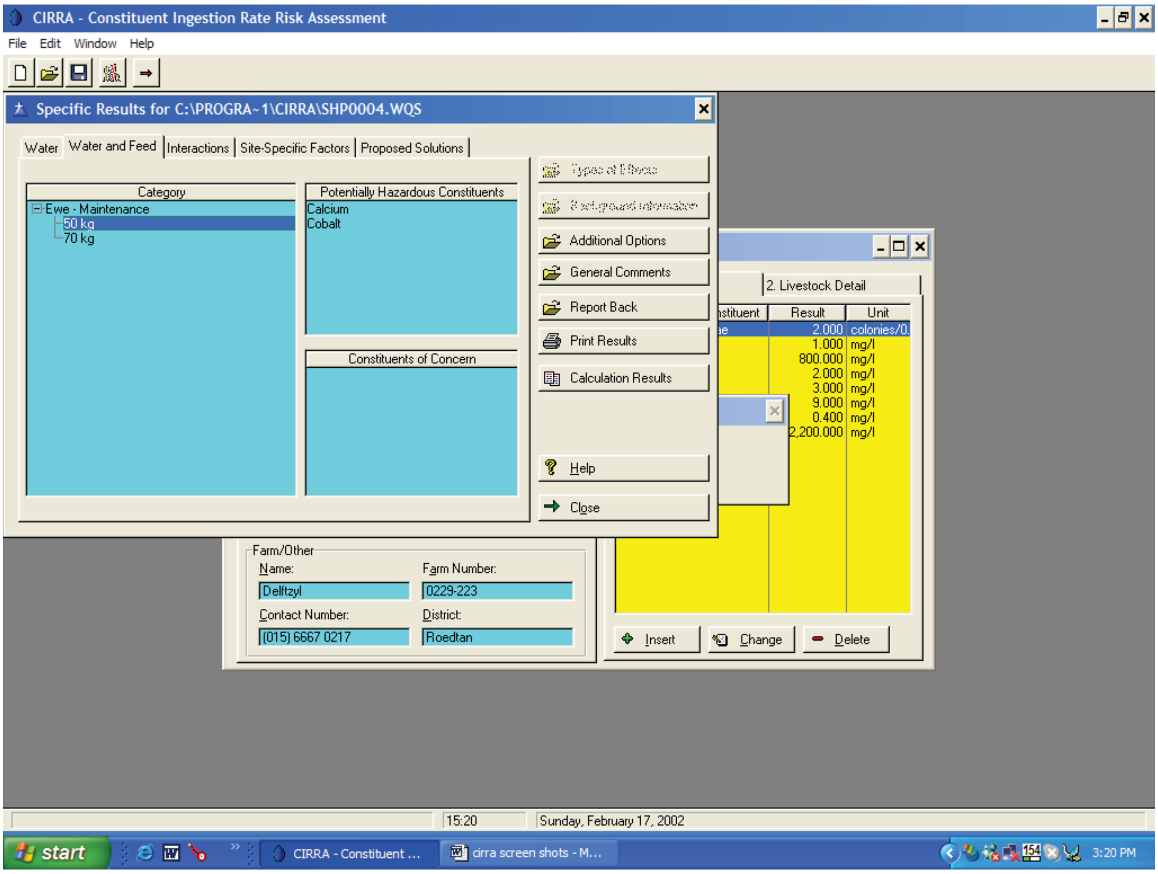


Figure 17: Specific Application Level – Sheep – Results screen6

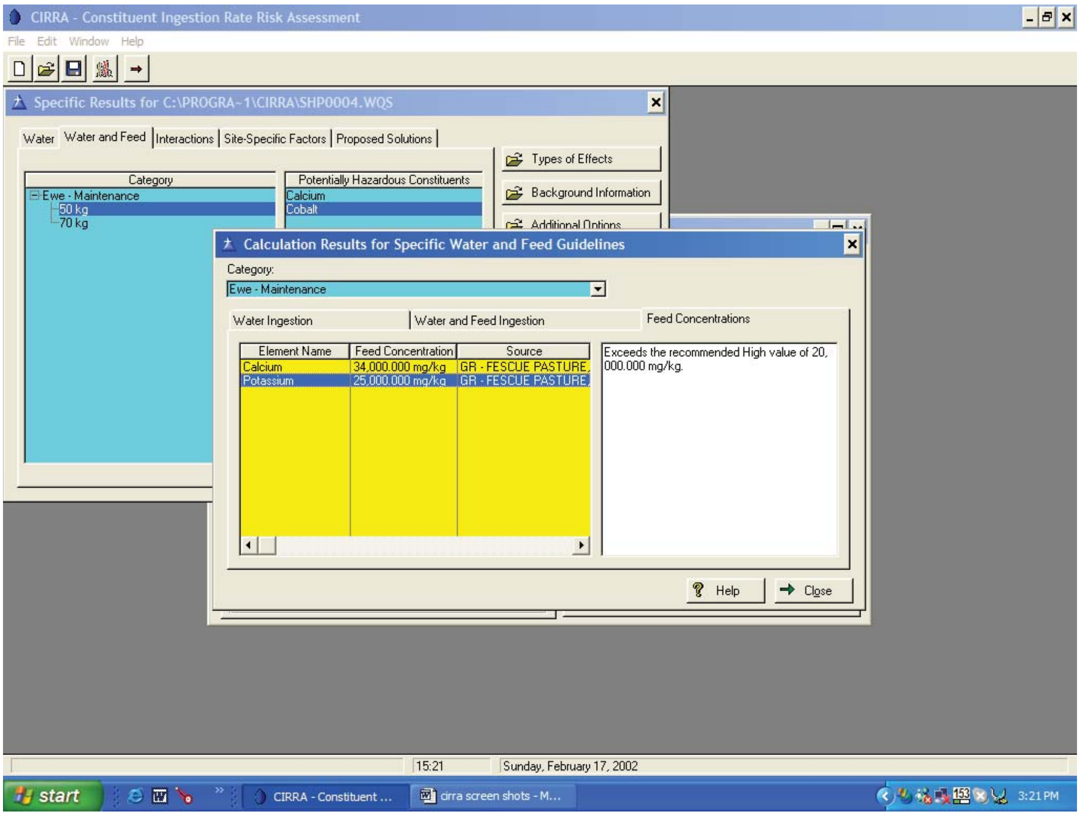


Figure 18: Specific Application Level – Sheep – Results screen8

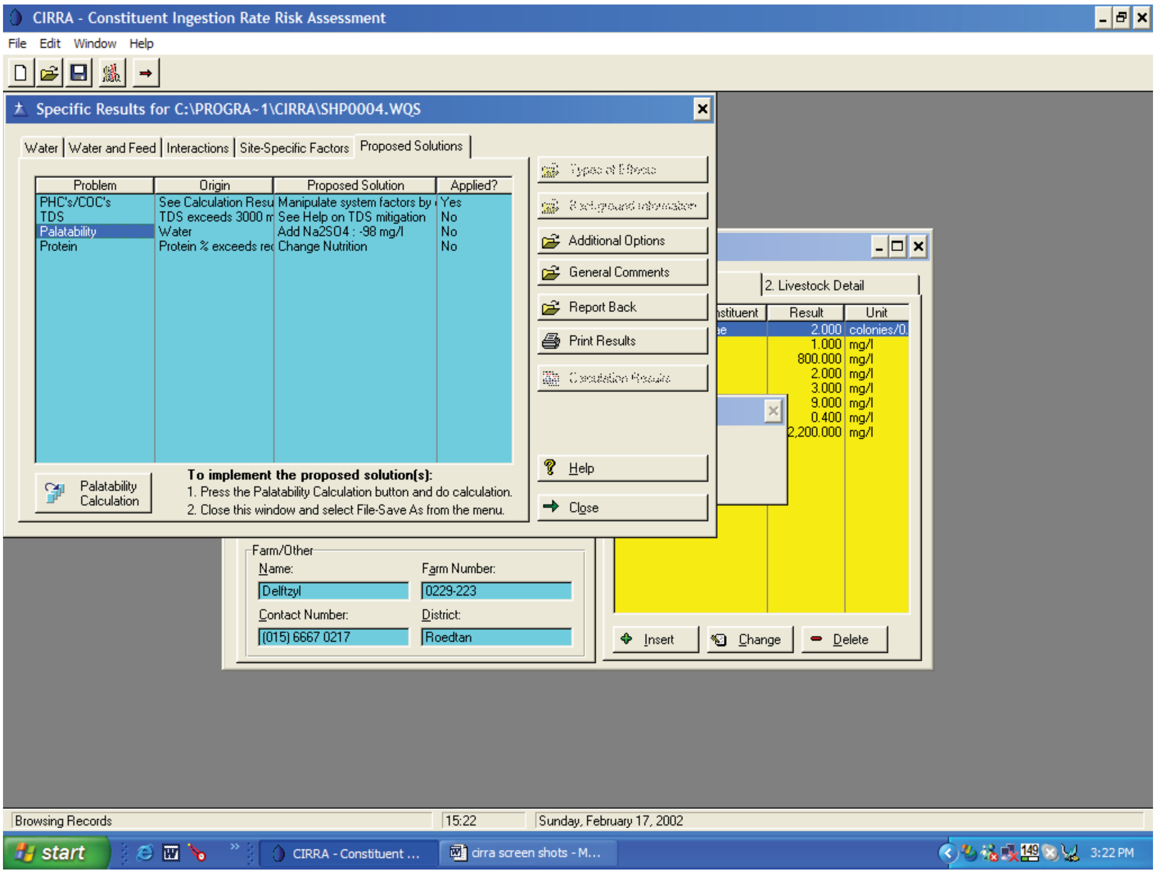


Figure 19: Specific Application Level – Sheep – Results screen11

3. RISK METHODOLOGIES AND CALCULATION PROCEDURES

3.1. Water Ingestion Rate Reference Document

The central component to the CIRRA model is a water ingestion rate reference document (WIRRD). Which provides for a more accurate physiological approach to fitness for use assessment as the guideline thus derived is not based on a fundamentally flawed assumption of an average intake per body weight per day from water as it typically the approach for domestic water quality guidelines, but on a more accurate calculation of actual water intake.

The difficulty in deriving accurate assessments on ingestion of a water quality constituent at a given concentration in humans was highlighted in deliverable and it follows that such variations will be magnified in animals given the vast array of animal types (with different physiological cooling mechanisms), production system types (intensive to extensive), environments (cold to hot) and level of production (e.g. low to high yielding milk production in dairy cattle).

The WIRRD is thus a key component of the CIRRA model as it provides a derived (or measured) total water intake (TWI) which is then converted to a water ingestion rate (WIR) per day, in L/kg metabolic mass using the exponent $LW^{0.82}$ for water turnover. The primary reason for selecting this method as opposed to simply a WI approach is that different livestock types in different production environments have different water turnover rates, influenced by live weight, energy production, thermoregulation and other factors.

The use of the exponent in the WIRRD is motivated by the generally drier South African environment under which animal production occurs. The use of additional factors to the basic WIRRD caters for the other recognised effects such as temperature on water turnover rate (WTR). For the physiological detail pertaining to this approach the reader is referred to the WRC Reports 644/1/98 and 301/1/96 (Casey *et al*., 1996 and Casey *et al*., 1998a).

The Specific-WQGIS effectively provides a data capturing model for each livestock type, yielding a vast number of Water Ingestion Rate Reference Documents (WIRRD). The previous CIRRA model had the following per WQC for the Livestock Type: Sheep: 16 WIRRDs; Total = 336 WIRRD tables for sheep being accommodated by the source code. The tables presented for this research project expanded this to 17 WIRRD tables per constituent.

The corresponding WIRRD tables calculate livestock type, category, live weight, dry matter intake (DMI), total water intake (TWI) and water ingestion rate (WIR) specific guidelines on a per WQC basis, using recognised reference sources for nutrient requirements and production parameters in the derivation of the category list and table content (applicable regression formula for the specific livestock types). The derived TWI is then converted to a WIR per day, in L/kg metabolic mass using the exponent

$LW^{0.82}$ for water turnover. The primary reason for selecting this method as opposed to simply a WI approach is that different livestock types in different production environments have different water turnover rates, influenced by live weight, energy production, thermoregulation and other factors.

It is stressed that these values are based on the minimum requirements to sustain normal health, production and performance, with the WIRRD thus based on conservative estimate and the safety factors inherent in the published nutrient requirement tables are passed on to the WIRRD. As the fundamental source document of the CIRRA model, the WIRRD values produced in the guideline effect concentration ranges (A to F, see Table 6 for example) may:

- Be altered to include updates to the field of knowledge per constituent and animal type

- Be then inserted into risk-assessment index calculations which recognise those site-specific factors that alter the water concentration at which a given constituent will cause an adverse effect, thus modifying WIRRD by including those site-specific variables such as, breed, livestock production system, environmental and nutritional.

The WIRRD thus provides a core reference document whereby the effect of these variables on the WI and resultant water quality constituent ingestion rate and anticipated effects, may be taken into account.

Modifying factors are used to adjust the values as required, with these being cumulative to either increase or decrease the WIR. The inclusion of these variables as factors assists to identify key variables that alter the outcome of exposure to a given concentration. The Specific-WQGIS caters for this by giving the user the choice to calculate the risk by using two formats, one with and one without system factors.

As more user specific information is entered a Specific-WQGIS is enabled in which the entry fields are marked and prompted as *required fields* in order for the user to continue. This allows for the WIRRD and additional site-specific risk factors to be included in the assessment.

In order to reach the Tier III assessment, the user is required to make subsets of the water sample file in which the identified PHCCs and COCs final outcome is manipulated by user input changes, for example, to the physiological category of exposure (e.g. breeding cattle to beef cattle feedlot for trigger differential fluoride guideline effect concentration ranges to the WIRRD).

As these manipulations allow the user to create “dummy” water sample files with the objective of manipulating the risk factors in order to arrive at an acceptable risk level, they do require increasing skill in terms of understanding the fields relating to animal physiology, management, nutrition and health care.

Even within the Specific-WQGIS there are varying levels of skill required depending on the user environment applicable (e.g. rural communal systems to wildlife production systems). Increasingly, outputs may be of an instructional nature, for example, “obtain whole blood thyroxine values to evaluate potential thyroid dysfunction”.

The Specific-WQGIS also includes clinical data information capturing screens which allow for outputs to be made in terms of diagnostics (e.g. capillary haemoglobin concentrations and iron-deficiency disorders).

There are also two fundamentally different uses of the CIRRA model. Contrary to the typical existing exposure scenario approach (assessing the effects of exposure to a given water quality to an existing animal production system), a “preferred option” approach may be adopted.
Thus, an existing water resource quality risk-based approach may be entered with the request for the model to produce a best-fit animal production system type. This can also range from a best-fit to a ranking of high risk to low risk production system options.
The values in the WIRRD tables provided below were mainly derived as follows:

- Live weight value - LW (kg):
    - Adapted from NRC requirement tables (NRC, 2007)
    - Central Row LW value adopted as Central LW value.
    - LW [Ranges] = as per physiological category by livestock type and production stage
- Dry Matter Intake – DMI (kg/d):
    - Adapted from NRC requirement tables (NRC, 2007)
- Total Water Intake - TWI (L/d):
    - Applicable regression equations used (Forbes, 1968; Holter & Urban, 1992; Murphy 1992).
        - TWI = 3.86(DMI) – 0.99
- Water Ingestion Rate – WIR (L/kg$^{0.82}$/d):
    - Where a^n = LW$^{0.82}$
    - WIR = (TWI)/(LW$^{0.82}$)
- Column A Guideline Effect Value (GEV) =
    - WQC and Livestock Type and Livestock Category Specific Minimum Nutrient Requirement Factor (SMNRF = 0.020628 for Selenium), and
    - GEV = (DMI * SMNRF)/TWI
        - Column A Ingestion Rate Value - IRV (mg WQC/ kg$^{0.82}$/d)
            - GEV * WIR
- Column B Guideline Effect Value (GEV) =
    - WQC and Livestock Type and Livestock Category Specific Derived Requirement Factor (SDRF = 0.036673 for Selenium)
    - GEV = (SDRF/TWI)

- Column B Ingestion Rate Value - IRV (mg WQC/ kg$^{0.82}$/d)
  - GEV * WIR

- Column C Guideline Effect Value (GEV) =
  - WQC and Livestock Type and Livestock Category Specific Derived Adequacy Factor (SDAF = 0.183365 for Selenium)
  - GEV = (SDAF/TWI)
    - Column C Ingestion Rate Value - IRV (mg WQC/ kg$^{0.82}$/d)
      - GEV * WIR
- Column D Guideline Effect Value (GEV) =
  - WQC and Livestock Type and Livestock Category Specific Derived Chronic Excess Factor (SDCEF = 2.56711 for Selenium)
  - GEV = (SDCEF/TWI)
    - Column D Ingestion Rate Value - IRV (mg WQC/ kg$^{0.82}$/d)
      - GEV * WIR
- Column E Guideline Effect Value (GEV) =
  - WQC and Livestock Type and Livestock Category Specific Derived Acute Excess Factor (SDAEF = 9.168252 for Selenium)
  - GEV = (SDAEF/TWI)
    - Column E Ingestion Rate Value - IRV (mg WQC/ kg$^{0.82}$/d)
      - GEV * WIR

Examples of updated WIRRDs for the same physiological category but different WQCs are provided in Table 6 to Table 9:

Table 6: Updated Specific-Central WIRRD for Livestock Type = Sheep; Category = Ewes – maintenance; WQC = Selenium

User Specific Input			Ingestion*	Water Quality Constituent^					
LW (kg)	DMI (kg/d)	TWI (L/d)	WIR (L/kg$^{0.82}$/d)	mg Se/kg$^{0.82}$/d^^					
				A (0-[])	B [A]-[B]	C [B]-[C]	D [C]-[D]	E [D]-[E]	F >[E]
50.8	0.92	2.599	0.1037	[0.0061] 0.000634	[0.0141] 0.001464	[0.0705] 0.007319	[0.9876] 0.102476	[3.5272] 0.365984	>0.36598
61.0	1.07	3.142	0.1079	[0.0058] 0.000629	[0.01167] 0.00126	[0.0583] 0.006299	[0.8168] 0.088193	[2.9174] 0.314974	>0.31497
71.21	1.20	3.667	0.1109	[0.005488] 0.000624	[0.01] 0.00111	[0.05] 0.005549	[0.7] 0.077687	[2.5] 0.277452	>0.27745
81.419	1.32	4.132	0.1120	[0.005488] 0.000615	[0.008874] 0.000994	[0.0443] 0.004971	[0.6211] 0.069606	[2.285] 0.248594	>0.24859
91.62	1.45	4.612	0.1135	[0.00537] 0.00061	[0.0079] 0.000903	[0.0397] 0.004513	[0.5565] 0.063182	[1.9875] 0.22565	>0.2256

*Adapted from NRC requirement tables (NRC, 2007).

^Values adjusted for column A as per factorially derived selenium nutrient requirements.

^^Where columns A to F relate to guideline effect concentration ranges as follows:

A = minimum required for production. WIR results below the corresponding value = positive response on supplementation.

User Specific Input			Ingestion*	Water Quality Constituent^					
LW (kg)	DMI (kg/d)	TWI (L/d)	WIR (L/kg$^{0.82}$/d)	mg Se/kg$^{0.82}$/d^^					
				A (0-[])	B [A]-[B]	C [B]-[C]	D [C]-[D]	E [D]-[E]	F >[E]

B = adequacy for production. WIR results within A-B may show a positive response on supplementation.

C = upper limit for safe water use. WIR results within B-C unlikely to yield positive response on supplementation.

D = risk of chronic selenosis. Risk of excess exposure if additional supplementation provided.

E = chronic selenosis with no additional ingestion pathways.

F = chronic to acute selenosis

Table 7: Updated Specific-Central WIRRD for Livestock Type = Sheep; Category = Ewes – maintenance; WQC = Fluoride

User Specific Input			Ingestion*	Water Quality Constituent^					
LW (kg)	DMI (kg/d)	TWI (L/d)	WIR (L/kg$^{0.82}$/d)	mg F/kg$^{0.82}$/d^^					
				A (0-[])	B [A]-[B]	C [B]-[C]	D [C]-[D]	E [D]-[E]	F >[E]
50.8	0.92	2.599	0.1037	[0.1101] 0.0.11429	[0.9856] 0.102276	[1.4108] 0.146393	[2.821] 0.292787	[8.046] 0.87836	>0.8783
61.0	1.07	3.142	0.1079	[0.1048] 0.011325	[0.8153] 0.088021	[1.1669] 0.125989	[2.333] 0.25198	[7.001] 0.75593	>0.7559
71.21	1.20	3.667	0.1109	[0.1013] 0.01242	[0.6986] 0.077535	[1.0] 0.110980	[2] 0.022196	[5.999] 0.66588	>0.6658
81.419	1.32	4.132	0.1120	[0.0988] 0.011079	[0.6169] 0.069471	[0.8874] 0.099437	[1.774] 0.19887	[5.324] 0.59662	>0.5966
91.62	1.45	4.612	0.1135	[0.0968] 0.011	[0.5554] 0.063059	[0.7950] 0.090259	[1.590] 0.18052	[4.770] 0.54115	>0.5411

*Adapted from NRC requirement tables (NRC, 2007).

^Values adjusted for column A as per derived uncontaminated control (normal) nutrient exposures.

^^Where columns A to F relate to guideline effect concentration ranges as follows:

A = derived minimum required for production. WIR results below the corresponding value = may indicate a positive response on increased exposure.

B = adequacy for production. WIR results within A-B unlikely to show a positive correlation to fluorosis.

C = upper limit for safe water use. WIR results within B-C may yield a negative response to increased dietary exposure.

D = risk of chronic fluorosis. Risk of excess exposure if additional supplementation provided.

E = risk of chronic fluorosis with no additional ingestion pathways.

F = chronic to acute fluorosis

Table 8: Updated Specific-Central WIRRD for Livestock Type = Sheep; Category = Ewes – maintenance; WQC = Nitrate

User Specific Input			Ingestion*	Water Quality Constituent^					
				mg $NO_3/kg^{0.82}/d$^^					
LW (kg)	DMI (kg/d)	TWI (L/d)	WIR ($L/kg^{0.82}/d$)	A (0-[])	B [A]-[B]	C [B]-[C]	D [C]-[D]	E [D]-[E]	F >[E]
50.8	0.92	2.599	0.1037	[9.301] 0.964-9	[62.07] 6.4413	[126.9] 13.1751	[211.6] 21.9588	[311.8] 32.3528	>32.352
61.0	1.07	3.142	0.1079	[8.857] 0.95628	[51.34] 5.5434	[105.0] 11.3388	[175.04] 18.8982	[257.9] 27.8436	>27.843
71.21	1.20	3.667	0.1109	[8.554] 0.94934	[44] 4.8831	[90] 9.9882	[150] 16.6471	[221] 24.5267	>24.526
81.419	1.32	4.132	0.1120	[8.349] 0.93558	[39.04] 5.3752	[79.86] 8.9492	[133.1] 14.9155	[196.1] 21.9175	>21.917
91.62	1.45	4.612	0.1135	[8.181] 0.92883	[34.98] 3.9714	[71.55] 8.1232	[119.2] 13.5388	[175.7] 19.9473	>19.947

*Adapted from NRC requirement tables (NRC, 2007).

^Values adjusted for column A as per derived adaptation via rumen nitrite reductions.

^^Where columns A to F relate to guideline effect concentration ranges as follows:

A = derived minimum required for adaptation. WIR results below the corresponding value may indicate an insufficient adaptation and no risk for nitrite toxicity.

B = adequacy for rumen adaptation and protection from nitrite toxicosis. WIR results within A-B unlikely to show a positive correlation to nitrite hazards.

C = upper limit for safe water use. WIR results within B-C may yield a negative response to increased dietary exposure and hold the potential for endocrine disruption.

D = risk of nitrite toxicosis and additional endocrine endpoints. Risk of adverse effects from excessive exposure if additional supplementation provided and in scenarios with insufficient adaptation.

E = risk of nitrite toxicity with no additional ingestion pathways.

F = potential for acute nitrite toxicosis

Table 9: Updated Specific-Central WIRRD for Livestock Type = Sheep; Category = Ewes – maintenance; WQC = Bromide

User Specific Input			Ingestion*	Water Quality Constituent^					
				mg $Br/kg^{0.82}/d$^^					
LW (kg)	DMI (kg/d)	TWI (L/d)	WIR ($L/kg^{0.82}/d$)	A (0-[])	B [A]-[B]	C [B]-[C]	D [C]-[D]	E [D]-[E]	F >[E]
50.8	0.92	2.599	0.1037	[0.01180] 0.001225	[0.1269] 0.013175	[1.269] 0.13175	[2.469] 0.25618	[3.5272] 0.36598	>0.3659
61.0	1.07	3.142	0.1079	[0.01124] 0.001214	[0.1050] 0.011339	[1.050] 0.11339	[2.042] 0.22048	[2.9174] 0.31497	>0.3149
				[0.01085]	[0.09]	[0.9]	[1.75]	[2.5]	

User Specific Input			Ingestion*	Water Quality Constituent^					
				mg Br/kg$^{0.82}$/d^^					
LW (kg)	DMI (kg/d)	TWI (L/d)	WIR (L/kg$^{0.82}$/d)	A (0-[])	B [A]-[B]	C [B]-[C]	D [C]-[D]	E [D]-[E]	F >[E]
71.21	1.20	3.667	0.1109	0.001205	0.009988	0.09988	0.19421	0.27745	>0.2774
81.419	1.32	4.132	0.1120	[0.01059] 0.001187	[0.0798] 0.008949	[0.7986] 0.08949	[1.552] 0.17401	[2.2185] 0.24859	>0.2485
91.62	1.45	4.612	0.1135	[0.01038] 0.001179	[0.0715] 0.008123	[0.7155] 0.08123	[1.391] 0.15795	[1.9875] 0.22565	>0.2256

*Adapted from NRC requirement tables (NRC, 2007).

^Values adjusted for column A as per derived uncontaminated exposures.

^^Where columns A to F relate to guideline effect concentration ranges as follows:

A = derived normal exposure. WIR results below the corresponding value suggest insignificant risk to toxicity and DBP concerns.

B = marginal risk for adverse effects due to bromide and for bromide related DBPs.

C = potential adverse effects due to bromide and significant risk for bromide related DBPs. Potential beneficial response to increased dietary supplementation for induced trace element deficiencies and thyroid dysfunction.

D = significant adverse endocrine endpoints and induced trace element deficiencies. Significant risk for bromide related DBPs. Increased dietary supplementation for induced trace element deficiencies and thyroid dysfunction recommended.

E = increasing risk for adverse endocrine endpoints and induced trace element deficiencies. Significant risk for bromide related DBPs. Increased dietary supplementation for induced trace element deficiencies and thyroid dysfunction essential.

F = risk significant for all adverse outcomes including direct bromide toxicity with no additional exposure pathways.

Whilst column A generally represents a nutritional requirement or potential benefit on supplementation, should dietary analytical inputs by the user trigger elevated dietary values, these columns can shift accordingly. Thus, total exposure is catered for to the column values by adjusting the column designation in accordance with total exposure reference values (shift left or right as indicated by total exposure setting).

Additional central reference row allocation may be shifted towards a lower live weight for those categories for which the adjusted ratio of TWI to column reference values yields the same WIR reference result. This is due to the same central live weight values for different categories (e.g. early lactation and growing ewe lambs and breeding) which would result in a similar reference value being generated.

Thus, the same TWI can be obtained for different categories despite having differing physiological stages, an issue which could easily arise in adjusted TWI values based on ambient temperature. In order for the tables to accommodate this the alternate selection strategy for the central reference row would be adjusted on a site-specific flock or herd basis, noting that across production system environments direct comparisons between DMI and TWI would not be valid, but within environments correctly varying WIR reference values would be generated.

3.2. Water Quality Constituents

The central requirement reference value is consistent within physiological modes (e.g. pregnancy) but differs between modes (e.g. growth versus adult maintenance). The source thereof is again a function of the specific water quality constituent in terms of function at the corresponding physiological stage. Thus, selenium requirements might incur an upwards adaptation for reproduction, whereas fluoride might incur a lower adaptation due to concerns for subclinical adverse effects (e.g. testicular spermatogenic concerns in poultry). Sensitive stages during a category may also be water quality constituent specific, as is the case for fluoride and ameloblast developmental stages.

As noted with selenium (Table 6), some column A to F reference values may be influenced by norms other than production, notably consumer exposure factors. Selenium also offers an additional change required in instances where total exposure is elevated and concerns for the norm of wastewater quality and subsequent environmental impacts are applicable (this has already been factored into dietary requirement limits in the maximum nutrient recommendations for animal feeds).

Fluoride concerns due to locally occurring geochemical anomalies have been described in previous WRC reports and deliverables, with site-specific recognition of source exposure differences linked to altitude and temperature included in the initial CIRRA model.

The methodology described above results in each LW having a specific DMI, TWI and WIR value and together with the specific column derived values award for each LW row a specific column GEV. The columns are linked to water quality constituents and Livestock Type and Livestock Category specific statements and thus differ for physiological stages and production phases and described mode of action for the applicable constituent.

It is thus noteworthy that whilst in other approaches (e.g. 1996 DWAF guidelines) the water quality *guideline* concentration limits typically remain unchanged, the WIRRD GEVs change with the physiological stages within LW ranges for the same animal, this being a function of variables such as the different production stage.

The resultant final IRV is thus specific to each LW within a Livestock Type, Category, and WQC selection. The comparisons thus made between the WQC analytical data input and the IRV yield the initial variance reported on. Since these values are typically not based on an observational range within an animal production system and all animals within a category typically have the same WQC exposure value, the variance result provided is calculated as a percentage variance from the IRV and not as a true statistical variance.

It is, however, possible that higher Tier III data inputs include a sub-sample of these values which would enable an actual observational data set to be compiled for a specific animal production system category which will afford the ability to calculate standard deviations, variances and also comparisons between sites using a coefficient of variance method.

It is noteworthy that for different categories there may be similar derived values within a WQC, this being a function of the central derivation value, notably for Column A values, with fluoride above an example as the same fluoride requirement factor (a nutritional requirement value linked to age and developmental aspects) is used. The final WIRRD value used in the risk assessment is still different for the different categories as the WIR value will differ according to the differing LW, ADI and TWI values.

For some water quality constituents, a different column factor will apply which links to the comments on the risk corresponding to each column. In some instances, the approach may be the same despite different *nutrient* requirements (or no demonstrated essentially), as is the case for nitrate, where there is not a specific *nutrient requirement per se,* but nonetheless continual exposure is desired to mitigate for nitrite toxicosis by enabling rumen microbes to establish viable populations which can reduce nitrite to ammonia.

For this to occur exposure to low level nitrate is a precursor, thus a *nitrate requirement* can still be considered to exist. As this applies to ruminant physiology it would not be true for all livestock types and is thus livestock type specific. It is once again stressed that the value of the WIRRD methodology adopted is that the ability to mitigate against nitrate related adverse health endpoints relies on a more accurate assessment of nitrate ingestion, and not a nitrate concentration for which ingestion (thus dose ingestion and nitrite toxicity) may vary significantly between the categories within a livestock type.

In some instances, the derivation values are influenced by routine analytical detection limits, with bromide being an example thereof. Whilst future research and analytical detection limits, or more specifically, limits of quantification, may yield a more accurate approach, the current observations of naturally occurring values and ranges in which adverse effects have been observed determine the initial column values.

Additionally, as is noted in the following chapter, water quality constituents such as bromide which may yield other disinfection by-product concerns (thus additional water quality constituent data input requirements) which would prompt methodology in which the disinfection by-product results may be at stricter limits than the initial water quality constituent (bromide) column values. This is obviously specific to a disinfection by-product (as in the current SANS 241 concentration limits) which is (as noted in the corresponding WHO chemical fact sheets) largely influenced by analytical and *treatment* capabilities.

3.3. Calculation Examples

In order to highlight the assessment performed between the WIRRD and different user inputs, a few calculation examples are provided next.

- User input handling example 1:

Rule: If User defined data input is:

Livestock Type = sheep

Category = ewes – maintenance

Live weight value - LW (kg) = unknown

Dry Matter Intake – DMI (kg/d) = unknown

Total Water Intake - TWI (L/d) = 4.0

Selenium Water Sample Result (mg/L) = 0.01

Then:

Use Central Reference Row LW = 71.21

Water Ingestion Rate – WIR (L/kg$^{0.82}$/d) = 0.12105

Calculated Ingestion Rate Value - IRV (mg WQC/ kg$^{0.82}$/d) = 0.001210

Assessment Report:

Result >Column B value [0.00111] < Column C value [0.005549]

Column B = true [report]

Add Note! = [IRV calculated for LW = 71 kg]

IRV variance from Ref Doc = +9%

- User input handling example 2.1:

Rule: If User defined data input is:

Livestock Type = sheep

Category = ewes – maintenance

Live weight value - LW (kg) = 51.0

Dry Matter Intake – DMI (kg/d) = unknown

Total Water Intake - TWI (L/d) = 2.599

Selenium Water Sample Result (mg/L) = 0.045

Then:

Use Corresponding LW Reference Row LW = 50.8

Water Ingestion Rate – WIR (L/kg$^{0.82}$/d) = 0.1037

Calculated Ingestion Rate Value - IRV (mg WQC/ kg$^{0.82}$/d) = 0.00466

Assessment Report:

Result >Column B value [0.001464] < Column C value [0.007319]

Column B = true [report]

IRV variance from Ref Doc = [+218% Col B Ref Doc & -36% Col C Ref Doc]

- User input handling example 2.2:

Rule: If User defined data input is:

Livestock Type = sheep

Category = ewes – maintenance

Live weight value - LW (kg) = 61.0

Dry Matter Intake – DMI (kg/d) = unknown

Total Water Intake - TWI (L/d) = 3.142

Selenium Water Sample Result (mg/L) = 0.045

Then:

Use Corresponding LW Reference Row LW = 61.0

Water Ingestion Rate – WIR (L/kg$^{0.82}$/d) = 0.1079

Calculated Ingestion Rate Value - IRV (mg WQC/ kg$^{0.82}$/d) = 0.004855

Assessment Report:

Result >Column B value [0.00126] < Column C value [0.006299]

Column B = true [report]

IRV variance from Ref Doc = [+285% Col B Ref Doc & -23% Col C Ref Doc]

- User input handling example 2.3:

Rule: If User defined data input is:

Livestock Type = sheep

Category = ewes – maintenance

Live weight value - LW (kg) = 71.0

Dry Matter Intake – DMI (kg/d) = unknown

Total Water Intake - TWI (L/d) = 3.667

Selenium Water Sample Result (mg/L) = 0.045

Then:

Use Corresponding LW Reference Row LW = 71.0

Water Ingestion Rate – WIR (L/kg$^{0.82}$/d) = 0.1109

Calculated Ingestion Rate Value - IRV (mg WQC/ kg$^{0.82}$/d) = 0.00499

Assessment Report:

Result >Column B value [0.00111] < Column C value [0.005549]

Column B = true [report]

IRV variance from Ref Doc = [+349% Col B Ref Doc & -10% Col C Ref Doc]

- User input handling example 2.4:

Rule: If User defined data input is:

Livestock Type = sheep

Category = ewes – maintenance

Live weight value - LW (kg) = 82.0

Dry Matter Intake – DMI (kg/d) = unknown

Total Water Intake - TWI (L/d) = 4.13

Selenium Water Sample Result (mg/L) = 0.045

Then:

Use Corresponding LW Reference Row LW = 81.4

Water Ingestion Rate – WIR (L/kg$^{0.82}$/d) = 0.1120

Calculated Ingestion Rate Value - IRV (mg WQC/ kg$^{0.82}$/d) = 0.00504

Assessment Report:

Result >Column C value [0.004971] < Column D value [0.069606]

Column C = true [report]

IRV variance from Ref Doc = [+1.3% Col C Ref Doc & -93% Col D Ref Doc]

- User input handling example 2.5:

  Rule: If User defined data input is:

  Livestock Type = sheep

  Category = ewes – maintenance

  Live weight value - LW (kg) = 81.0

  Dry Matter Intake – DMI (kg/d) = unknown

  Total Water Intake - TWI (L/d) = 4.6

  Selenium Water Sample Result (mg/L) = 0.045

  Then:

  Use Corresponding LW Reference Row LW = 91.62

  Water Ingestion Rate – WIR (L/kg$^{0.82}$/d) = 0.1135

  Calculated Ingestion Rate Value - IRV (mg WQC/ kg$^{0.82}$/d) = 0.0051

  Assessment Report:

  Result >Column C value [0.004513] < Column D value [0.0631]

  Column C = true [report]

  IRV variance from Ref Doc = [+13% Col C Ref Doc & -92% Col D Ref Doc]

These user input examples highlight how the same WQC concentration result yields different risk assessment statements for the *same* physiological category (ewes in maintenance) even assuming no site-specific changes to the reference value inputs. The reverse is also true (refer to user examples 3.1-3.3 below), namely that different system inputs can yield the same risk assessment statements for *different* WQC concentration results within the same LW range across different production categories.

This WIRRD capability is specifically of value in animal production systems which separate different physiological groups by production stage (a common occurrence) and where DMI and TWI change due to water and non-water factors (e.g. water palatability compared to environmental temperature, ration composition and feeding method).

Furthermore, it highlights that a particular water resource may be unsuitable in terms of the risk posed for a specific animal production system category, but suitable for another, within a livestock type. This has the practical application of allowing a producer to allocate water resources to lower risk categories between water resources available on a site. In many cases this is the situation producers are confronted with, namely, different water quality observed in multiple water resources on a production site (farm/portions).

This implies that allocation may not necessarily be confined to a toxicological mechanism, as was explained in previous deliverables for fluoride and developmental adverse effects (ameloblast stage) and allocation of high-risk concentrations to only growing system scenarios where eruption has already occurred and the exposure period is sufficiently short to limit the adverse effects on skeletal end points (e.g. feedlot). Allocation may thus be used to find the best-fit scenario in terms of animal production system, livestock type and category for a given water quality, or alternatively, for a selection of varying water quality resources available.

Whilst not elaborated here, an additional functionality of the WIRRD would thus be to also explore the fitness for use of a given water resource quality to various Livestock Types *prior* to the commencement of the animal production system. This is a practical application used currently in the siting of breeder and grower units in the piggery sector and thus becomes a factor in the planning stage of a proposed confined animal feeding operation (thus in the EIA application and BA phases).

- User input handling example 3.1:

  Rule: If User defined data input is:

  Livestock Type = sheep
  Category = ewes – mature breeding
  Live weight value - LW (kg) = 71.0
  Dry Matter Intake – DMI (kg/d) = 1.32
  Total Water Intake - TWI (L/d) = 4.14
  Selenium Water Sample Result (mg/L) = 0.7

  Then:

  Use Corresponding LW Reference Row LW = 71.0
  Water Ingestion Rate – WIR (L/kg$^{0.82}$/d) = 0.1252
  Calculated Ingestion Rate Value - IRV (mg WQC/ kg$^{0.82}$/d) = 0.0877

  Assessment Report:

  Result >Column D value [0.0877]
  Column D = true [report]

- User input handling example 3.2:

  Rule: If User defined data input is:

  Livestock Type = sheep
  Category = ewes – maintenance
  Live weight value - LW (kg) = 71.0
  Dry Matter Intake – DMI (kg/d) = unknown
  Total Water Intake - TWI (L/d) = 4.10
  Selenium Water Sample Result (mg/L) = 0.63

  Then:

  Use Corresponding LW Reference Row LW = 71.0

Water Ingestion Rate – WIR (L/kg$^{0.82}$/d) = 0.1240

Calculated Ingestion Rate Value - IRV (mg WQC/ kg$^{0.82}$/d) = 0.07812

Assessment Report:

Result >Column D value [0.077687]

Column D = true [report]

- User input handling example 3.3:

Rule: If User defined data input is:

Livestock Type = sheep

Category = ewes – late gestation

Live weight value - LW (kg) = 71.0

Dry Matter Intake – DMI (kg/d) = unknown

Total Water Intake - TWI (L/d) = 5.55

Selenium Water Sample Result (mg/L) = 0.77

Then:

Use Corresponding LW Reference Row LW = 71.0

Water Ingestion Rate – WIR (L/kg$^{0.82}$/d) = 0.16795

Calculated Ingestion Rate Value - IRV (mg WQC/ kg$^{0.82}$/d) = 0.1292

Assessment Report:

Result >Column D value [0.1292]

Column D = true [report]

As noted in the data flow section the results are provided for several sets of calculations. These include water alone and water plus feed exposures, and variance from the IRV with and without site-specific factors. Where site-specific factors are applicable to the calculations the corresponding value for each is provided, with antagonistic factors noted as a positive addition (increase in IRV and thus risk) synergistic factors as a negative addition.

In summary, the derived or user defined site-specific DMI and/or TWI is then converted to a water ingestion rate (WIR) per day, in L/kg metabolic mass using the exponent LW$^{0.82}$ with the central live weight row taken as the central reference value, specifically for the Generic GAL. The WIRRD thus provides a core reference document whereby the effect of site-specific variables on these input factors (live weight, DMI and TWI) and resultant water quality constituent ingestion rate (WIR) and corresponding column specific anticipated effects, may be taken into account.

There are inputs which are directly linked to the WIRRD tables such as actual DMI and TWI measurements on the site, and there are those which influence a variety of factors ranging from effects on these input variables and factors other than these variables, for example altitude and the risk to fluoride toxicity.

Thus far the primary rules for the methodology behind the WIRRD tables and user specified input values relevant to the final reference values generated have been described. The effects of site-specific factors relative to these tables and the subsequent methodology for recognising these adjustments in the assessment process are presented next.

3.4. Effect of Site-specific Factors

Whilst the calculated IRV may be viewed as a central reference value for each of the column specific risk statements with subsequent increases or decreases therein altering risk accordingly, site-specific variables in addition to the production system detail may be used as risk factors which adjust the values as required, with these being cumulative to either increase or decrease the WIR or IRV and the final risk assessment taken as the sum of the variances from the applicable source code reference value.

The inclusion of these variables as factors assists to identify key variables that alter the outcome of exposure to a given concentration and are thus additionally, as risk factors, identifiable variables which could potentially be manipulated to alter the final outcome following exposure to a specific water quality constituent concentration.

An example of an *animal production specific factor* would be the recognition that different breeds have different water turnover rates which are reflective of the adaptation of the breed to a specific environment, with corresponding Risk Factor adjustments applied across breeds and breed-production system fit (detailed later in WIRRD modelling).

An example of a *site-specific variable factor* would be temperature, with increases therein increasing the ingestion rate and corresponding WIR result (also detailed later in WIRRD modelling). These factors are used to modify the final IRV to which comparisons are made to the central source code WIRRD IRV, with this methodology elaborated on below.

It is again stressed that the Specific-WQGIS caters for these modifications by giving the user the choice to calculate the risk by using two formats, one with and one without system factors. As more user specific information is entered a Specific-WQGIS is enabled in which the entry fields are marked and prompted as *required fields* in order for the user to continue. This allows for the WIRRD and additional site-specific risk factors to be included in the assessment.

Even within the Specific-WQGIS there are varying levels of skill required depending on the user environment applicable (e.g. rural communal systems to wildlife production systems). Increasingly, outputs may be of an instructional nature, for example, “obtain whole blood thyroxine values to evaluate potential thyroid dysfunction”.

The Specific-WQGIS also includes clinical data information capturing screens which allow for outputs to be made in terms of diagnostics (e.g. capillary haemoglobin concentrations and iron-deficiency disorders).

The inclusion of site-specific factors is handled differently in terms of modifications to the WIRRD and various actions triggered by the DSS, examples being alerting the user to cautionary notes or generating items required for the Data Capturing Guide. As previously described the Data Capturing Guide is usually reflective of a progression from lower to higher Tier levels and thus from initial non-expert user data entry to increasingly diverse and specialised data inputs.

As is described in below the risk factors applied are categorised differently, primarily in recognition that some are more fixed than others and thus less likely to be manipulated. For example, although the Livestock Type could possibly be changed it is usually not the objective of the assessment.

In some instances, for example wildlife breeding, the animal type can however be changed fairly easily. Some factors cannot be altered, for example altitude, whilst others may be changed depending on the production system, for example, temperature may be fixed in extensive systems but manipulated within a range in intensive environmentally controlled housing systems. In some sites soil composition may be fixed and non-variable, but on other sites a variety of different soil types may be present.

Factors which may be altered relatively dramatically include the ration composition and type, and as many different types of ration may be provided on a single site (to different livestock type categories on a site), is viewed more as a variable input than a fixed input. Although water quality is initially viewed as a fixed variable, in addition to stochastic variability, the ability to change the quality by the addition of chemical treatments (or water treatment processes) renders it fairly easy to manipulate. This category allocation system is thus not a rule but a general category allocation which also assists with the Source Pathway and Receptor settings detailed later.

The general risk factor categories used are:

- Set User Selections:
  - Animal Specific Production System Factors (e.g. Livestock Breed)
  - Environmental Specific Factors (e.g. altitude)

- Variable Site Data:
  - Nutritional Specific Factors
  - Palatability

- Source, Pathway and Receptor Conditions

There are also two fundamentally different uses of the CIRRA model. Contrary to the typical existing exposure scenario approach (assessing the effects of exposure to a given water quality to an existing animal production system), a “preferred option” approach may also be adopted.

Thus, an existing water resource quality risk-based approach may be entered with the request for the model to produce a best-fit animal production system type. This can also range from a best-fit to a ranking of high risk to low- risk production system options. This may also be catered for in the “Proposed

Solutions" generated by the DSS and the application of selected options. The User selected "routines" may be used to create a series of *.wqs files which may be altered in various formats to represent potential production system scenarios.

An example of the two types of Set User Selections is provided below.

The following Animal Specific Production Factors are provided to illustrate the methodology adopted for Livestock Type = Sheep:

Animal Specific Production Factor 1

- Rule: Breed specific Water Turnover Rate
  - If Livestock Type = Sheep and
    - Breed = x then:
      - Apply the corresponding Risk Factor to the WIR column.
        - Where:
          - Breed = WTR RF
          - Afrino = 0.9
          - Blackheaded Persian = 0.8
          - Dohne Merino = 1.1
          - Dormer = 1.0
          - Dorper = 0.9
          - Ille de France = 1.2
          - Indigenous = 0.8
            - Pedi; Damara; Namaqua-Afrikaner
          - Karakul = 0.8
          - Merino = 1
          - SA Mutton Merino = 1
          - Van Rooy = 0.8
          - Vandor = 0.8

Example of WTR rule:

Rule: If User defined data input is:

Livestock Type = sheep

Breed = Dorper

Category = ewes – maintenance

Live weight value - LW (kg) = 71.0

Dry Matter Intake – DMI (kg/d) = unknown

Total Water Intake - TWI (L/d) = 3.66

Selenium Water Sample Result (mg/L) = 0.05

Then:

Use Corresponding LW Reference Row LW = 71.0

Applicable Breed WTR RF = 0.9

(WIR * WTR RF) = WIR* 0.9 = 0.1109*0.9 = 0.09981 ($L/kg^{0.82}/d$)

Calculated Ingestion Rate Value - IRV (mg WQC/ $kg^{0.82}$/d) = 0.004994145

<u>Assessment Report</u>:

Results:

Standard Results without system factors (system factor not true) =

Column C = True

Value [0.005549]

Result with system factor (system factor = true) =

Column B = True

Value = 0.004994145<CRV for IRV of 0.005549

Results statement:

Synergistic Site-specific Factor = Water Turnover Rate = 0.9

Variance from Ref Doc Value = -9.99%

Thus, due to the better water turnover rate applicable to the physiology of breed, which is a Synergistic factor, the same WQC concentration yields a lower risk assessment statement.

It is noteworthy that since this is an animal specific production factor the adjustment is made to the WIR column value and not the IRV. For those risk factors which are *site-specific factors* (such as altitude) the risk factor adjustment would be made to the IRV. The difference is illustrated below as:
Example of WTR rule application difference (animal specific compared to site-specific):

<u>Rule</u>: If User defined data input is:

Livestock Type = sheep

Breed = Dorper

Category = ewes – maintenance

Live weight value - LW (kg) = 71.0

Dry Matter Intake – DMI (kg/d) = unknown

Total Water Intake - TWI (L/d) = 3.66

Selenium Water Sample Result (mg/L) = 0.05

Then:

Use Corresponding LW Reference Row LW = 71.0

Applicable Breed WTR RF = 0.9

IF APPLIED TO IRV then:

(IRV * WTR RF) = WIR* 0.9 = 0.005549*0.9 = 0.09981 (L/$kg^{0.82}$/d)

Calculated Ingestion Rate Value - IRV (mg WQC/ $kg^{0.82}$/d) = 0.004994136

<u>Assessment Report</u>:

Results:

Standard Results without system factors (system factor not true) =

Column C = True

Value [0.005549]

Result with system factor (system factor = true) =

Column B = True

Value = 0.004994136<CRV for IRV of 0.005549

Results statement:

Synergistic Site-specific Factor = Water Turnover Rate = 0.9

Variance from Ref Doc Value = -10.0%

The percentage difference shows that a slightly greater advantage is derived from applying the Risk Factor rule to the IRV compared to the WIR value, in this case 0.00499145 compared to 0.004994136. Since these are summed as variances (demonstrated later) the difference is considered relevant.

<u>Animal Specific Production Factor 2</u>

- Rule: Breed specific <u>Production System Factor</u>
    - If Livestock Type = Sheep and
        - Breed = x and
        - Production System = Extensive; Semi-extensive and Intensive: Intensive, then:
            - Apply the corresponding Risk Factor to the WIR column.
                - Where:
                    - Breed & PSF RF:
                    - Afrino + Ext= 1
                    - Afrino + Semi-Ext = 1
                    - Afrino + Int = 0.9
                    - Blackheaded Persian & Ext = 1
                    - Blackheaded Persian & Semi-Ext = 1
                    - Blackheaded Persian & Int = 0.9
                    - Dohne Merino & Ext = 1
                    - Dohne Merino & Semi-Ext = 1
                    - Dohne Merino & Int = 0.9
                    - Dormer & Ext = 1.1
                    - Dormer & Semi-Ext = 1
                    - Dormer & Int = 0.9
                    - Dorper & Ext = 1
                    - Dorper & Semi-Ext = 1
                    - Dorper & Int = 0.9
                    - Ille de France & Ext = 1.2
                    - Ille de France & Semi-Ext = 1.1
                    - Ille de France & Int = 1
                    - Indigenous & Ext = 1

- Indigenous & Semi-Ext =1
- Indigenous & Int =0.9
- Karakul & Ext = 1
- Karakul & Semi-Ext = 1
- Karakul & Int = 0.8
- Merino & Ext = 1
- Merino & Semi-Ext = 1
- Merino & Int = 0.9
- SA Mutton Merino & Ext = 1.1
- SA Mutton Merino & Semi-Ext = 1
- SA Mutton Merino & Int = 0.9
- Van Rooy & Ext = 1
- Van Rooy & Semi-Ext = 1
- Van Rooy & Int = 0.8
- Vandor & Ext = 1
- Vandor & Semi-Ext = 1
- Vandor & Int = 0.8

Example of PS RF rule:

Rule: If User defined data input is:

Livestock Type = sheep

Breed = Dorper

Production System = Extensive

Category = ewes – maintenance

Live weight value - LW (kg) = 71.0

Dry Matter Intake – DMI (kg/d) = unknown

Total Water Intake - TWI (L/d) = 3.66

Selenium Water Sample Result (mg/L) = 0.05

Then:

Use Corresponding LW Reference Row LW = 71.0

Applicable Breed WTR RF = 0.9

Applicable Breed PSF RF = 1.0

(WIR * WTR RF) = WIR* 0.9 = 0.1109*0.9 = 0.09981 (L/kg$^{0.82}$/d)

Calculated Ingestion Rate Value - IRV (mg WQC/ kg$^{0.82}$/d) = 0.004994145

(WIR * PS RF) = WIR* 1 = 0.1109*1.0 = 0.1109 (L/kg$^{0.82}$/d)

Calculated Ingestion Rate Value - IRV (mg WQC/ kg$^{0.82}$/d) = 0.005549

Assessment Report:

Results:

Standard Results without system factors (system factor not true) =

Column C = True

Value [0.005549]

Result with system factor (system factor = true) =

Column B = True

Value = 0.004994145<CRV for IRV of 0.005549

Results statement:

Synergistic Site-specific Factor = Water Turnover Rate = 0.9

Variance from Ref Doc Value = -9.99%

The example used above notes that the Production System Risk Factor, having a value of 1, does not result in any further change to the calculated result or system risk factors to be listed. Where multiple risk factors are applicable and where the RF does not equal 1 these factors may vary from having a synergistic to an antagonistic effect and are handled thus as variances as demonstrated below.
Example of multiple RF rule:

<u>Rule</u>: If User defined data input is:

Livestock Type = sheep

Breed = Blackheaded Persian

Production System = Intensive

Category = ewes – maintenance

Live weight value - LW (kg) = 71.0

Dry Matter Intake – DMI (kg/d) = unknown

Total Water Intake - TWI (L/d) = 3.66

Selenium Water Sample Result (mg/L) = 0.05

Then:

Use Corresponding LW Reference Row LW = 71.0

Applicable Breed WTR RF = 0.8

Applicable Breed PSF RF = 0.9

(WIR * WTR RF) = WIR* 0.8 = 0.1109*0.8 = 0.0887848 (L/kg$^{0.82}$/d)

Calculated Ingestion Rate Value - IRV (mg WQC/ kg$^{0.82}$/d) = 0.00443924

(WIR * PS RF) = WIR* 0.9 = 0.1109*0.9 = 0. 0.09981 (L/kg$^{0.82}$/d)

Calculated Ingestion Rate Value - IRV (mg WQC/ kg$^{0.82}$/d) = 0.004994145

Then:

Variance: [sum of squares]/n

$[(0.00443924)^2 + (0.004994145^2]/2$

= [(0.000019706 +0.00002494148)]/2 = 0.0000223237

Comparison to IRV: $(0.005549)^2$ = 0.00003079184 =

-27.5%

<u>Assessment Report</u>:

Results:

Standard Results without system factors (system factor not true) =

Column C = True

Value [0.005549]

Result with system factor (system factor = true) =

Column B = True

Value = 0.0000223237<CRV for IRV of 0.00003079184

Results statement:

Synergistic Site-specific Factor = Water Turnover Rate = 0.8

Variance from Ref Doc Value = -19.99%

Synergistic Site-specific Factor = Production System = 0.9

Variance from Ref Doc Value = -18.9%

It should be noted that the same combined variance from the IRV is obtained if the RF values triggered are compared as per the same variance formula:

$[(WTR\ RF)^2 + (PS\ RF)^2)]/n$

$[(0.8)^2 + (0.9)^2)]/2 = 0.725$

$IRV = (1)^2/1 = 1$

Variance = -27.5%

As provided above, the results page provides for the IRV including system factor variance comparison individually as the objective is for the User to identify the individual risk factor contributions to the final result. Manipulation thereof will still need to be performed using the same methodology noted above as the cumulative effect is different in terms of variance obtained than simply using an average thereof (singular variances were 19.9 and 18.9%, but cumulative system variance 27.5%).

The following <u>Environmental System Factors</u> are provided to illustrate the methodology adopted for Livestock Type = Sheep:

<u>Environmental System Factor 1</u>

- Rule: Altitude 1
  - User defined input for Altitude = >900 m AMSL
  - If Livestock Type = Sheep and
    - WQC = Fluoride
      - Apply the corresponding Risk Factor to the WIR column.
        - Where:
          - WQC = F & A1 RF = 1.1

Example of A1 rule:

<u>Rule</u>: If User defined data input is:

Livestock Type = sheep

Breed = Dorper

Category = ewes – maintenance

Live weight value - LW (kg) = 71.0

Dry Matter Intake – DMI (kg/d) = unknown

Total Water Intake - TWI (L/d) = 3.66

Fluoride Water Sample Result (mg/L) = 0.91

Then:

Use Corresponding LW Reference Row LW = 71.0

Applicable A1 RF = 1.1

(WIR * A1 RF) = WIR* 1.1 = 0.1109*1.1 = 0.12199 (L/kg$^{0.82}$/d)

Calculated Ingestion Rate Value - IRV (mg WQC/ kg$^{0.82}$/d) = 0.11101

Assessment Report:

Results:

Standard Results without system factors (system factor not true) =

Column B = True

Value [0.100919]

Result with system factor (system factor = true) =

Column C = True

Value = 0.11101>CRV for IRV of 0.1109

Results statement:

Antagonistic Site-specific Factor = Altitude = 1.1

Variance from Ref Doc Value = +0.03%

Thus, due to the adverse effect of altitude on respiratory and renal function in which renal tubular transport curves are altered with a lowered excretion rate and higher urinary tubular fluid F reabsorption. This physiological mechanism is specific to fluoride toxicology and noted as an antagonistic, with the same WQC concentration yielding a lower risk assessment statement at a lower altitude.

The designation of “A1” to the rule is to differentiate between the actual altitude, which is provided and a derived altitude, designated as A2. The derived altitude is taken from the either the coordinates of the sample, district, or other location which links the location to a geographical location with an altitude range thus derived. The A2 risk statement would differentiate between the two and request the actual altitude to be obtained as part of the Data Capturing Guide request.

Environmental System Factor 2

- Rule: Temperature 1
    - User defined input for Temperature = value in º C provided
    - If Livestock Type = Sheep and
        - WQC = x
            - Apply the corresponding equation to the WIRRD TWI column:
                - Where:
                    - TWI = DMI(0.18T) + 1.25(DMI)

- Where T = (min T +max T)/2
    - Observed as a weekly average, and
    - DMI as per WIRRD reference or User defined input
        - Recalculate IRV

Example of Temperature 1 rule:

Rule: If User defined data input is:

Livestock Type = sheep

Breed = Dorper

Category = ewes – maintenance

Live weight value - LW (kg) = 71.0

Dry Matter Intake – DMI (kg/d) = unknown

Total Water Intake - TWI (L/d) = unknown

Fluoride Water Sample Result (mg/L) = 0.65

Temperature Input A = weekly data set [17-35; 19-38; 21-41; 15-41; 12-22; 11-23; 12-28]

Then:

Use Corresponding LW Reference Row LW = 71.0

Applicable T1 RF = 23.85

New TWI = 6.6516

($TWI/LW^{0.82}$) = WIR = 0.20129 ($L/kg^{0.82}/d$)

Calculated Ingestion Rate Value - IRV (mg WQC/ $kg^{0.82}/d$) = 0.1308

Assessment Report:

Results:

Standard Results without system factors (system factor not true) =

Column A = True

Value [0.0728]

Result with system factor (system factor = true) =

Column C = True

Value = 0.1308>CRV for IRV of 0.1109

Results statement:

Antagonistic Site-specific Factor = Temperature

Variance from Ref Doc Value = +17.8%

By way of comparison, a different temperature data set is used but the same WQC concentration:

Second example of Temperature 1 rule:

Rule: If User defined data input is:

Livestock Type = sheep

Breed = Dorper

Category = ewes – maintenance

Live weight value - LW (kg) = 71.0

Dry Matter Intake – DMI (kg/d) = unknown

Total Water Intake - TWI (L/d) = unknown

Fluoride Water Sample Result (mg/L) = 0.65

Temperature Input A = weekly data set [11 -21; 11-24; 12-24; 14-24; 12-21; 9-19; 9 -18]

Then:

Use Corresponding LW Reference Row LW = 71.0

Applicable T1 RF = 16.35

New TWI = 5.0316

($TWI/LW^{0.82}$) = WIR = 0.15226 ($L/kg^{0.82}/d$)

Calculated Ingestion Rate Value - IRV (mg WQC/ $kg^{0.82}/d$) = 0.0983

Assessment Report:

Results:

Standard Results without system factors (system factor not true) =

Column A = True

Value [0.072]

Result with system factor (system factor = true) =

Column B = True

Value = 0.0983>CRV for IRV of 0.07753

Results statement:

Antagonistic Site-specific Factor = Temperature

Variance from Ref Doc Value = +26.7%

The two temperature data sets demonstrate that the TWI reference values are conservative estimates (as is the case for the WHO Drinking Water Standards) and that the influence of temperature on increasing the IRV is significant. In the first example the temperature data set was obtained from Cradock whilst in the second from Belfast, both for the same week.

In the Belfast case, whilst the temperature value does increase the IRV calculated it is insufficient to increase the risk statement to that for Column C. However, it is noteworthy that with the location correlation to altitude an additional risk factor is applicable as per the Altitude rule. The final effect of these two factors combined would be:

Rule: If User defined data input is:

Livestock Type = sheep

Breed = Dorper

Category = ewes – maintenance

Live weight value - LW (kg) = 71.0

Dry Matter Intake – DMI (kg/d) = unknown

Total Water Intake - TWI (L/d) = unknown

Fluoride Water Sample Result (mg/L) = 0.65

Temperature Input A = weekly data set [11 -21; 11-24; 12-24; 14-24; 12-21; 9-19; 9 -18]

Altitude 2 = Derived altitude from sample location = > 900m AMSL

Then:

Use Corresponding LW Reference Row LW = 71.0

Applicable T1 RF = 16.35

New TWI = 5.0316

(TWI/LW$^{0.82}$) = WIR = 0.15226 (L/kg$^{0.82}$/d)

Applicable A2 RF = 1.1

(WIR * A1 RF) = WIR* 1.1 = 0.15226*1.1 = 0.167486 (L/kg$^{0.82}$/d)

Calculated Ingestion Rate Value - IRV (mg WQC/ kg$^{0.82}$/d) = 0.10886

<u>Assessment Report</u>:

Results:

Standard Results without system factors (system factor not true) =

Column A = True

Value [0.072]

Result with system factor (system factor = true) =

Column B = True

Value = 0.10886>CRV for IRV of 0.07753

Results statement:

Antagonistic Site-specific Factor = Temperature

Variance from Ref Doc Value = +40.4%

The altitude factor is only applicable to the WQC Fluoride and thus the Temperature rule would be applied to all constituents, but the PHCC fluoride would generate a risk statement with a greater variance from the reference document than without this factor.

Note, however, that the calculated IRV would trigger a Column C risk statement if the concentration of fluoride returned a relatively small increase of only 0.015 mg/L (from 0.65 to 0.665 mg/L) as demonstrated below:

<u>Rule</u>: If User defined data input is:

Livestock Type = sheep

Breed = Dorper

Category = ewes – maintenance

Live weight value - LW (kg) = 71.0

Dry Matter Intake – DMI (kg/d) = unknown

Total Water Intake - TWI (L/d) = unknown

Fluoride Water Sample Result (mg/L) = 0.665

Temperature Input A = weekly data set [11 -21; 11-24; 12-24; 14-24; 12-21; 9-19; 9 -18]

Altitude 2 = Derived altitude from sample location = > 900m AMSL

Then:

Use Corresponding LW Reference Row LW = 71.0

Applicable T1 RF = 16.35

New TWI = 5.0316

($TWI/LW^{0.82}$) = WIR = 0.15226 ($L/kg^{0.82}/d$)

Applicable A2 RF = 1.1

(WIR * A1 RF) = WIR* 1.1 = 0.15226*1.1 = 0.167486 ($L/kg^{0.82}/d$)

Calculated Ingestion Rate Value - IRV (mg WQC/ $kg^{0.82}/d$) = 0.11137

<u>Assessment Report</u>:

Results:

Standard Results without system factors (system factor not true) =

Column A = True

Value [0.072]

Result with system factor (system factor = true) =

Column B = True

Value = 0.11137>CRV for IRV of 0.11098

Results statement:

Antagonistic Site-specific Factor = Temperature

Variance from Ref Doc Value = +0.3%

This is a critical demonstration of site-specific risk factors which collectively alter the risk estimated with a correspondingly small change in the water quality constituent concentration resulting in a different risk scenario. The reader is referred to the research project deliverables for more detail pertaining to the other Set User Selection methodology.

The methodology for other adjustments, for example, Variable Site Data, are described in detail in the research project deliverables and not covered in great detail here. It is, however, stressed that at the outset the DSS was designed to contain significant nutritional information as the formulation of specific rations for animals extends to those which are Livestock Type, Breed, category, physiological and live weight specific. One of the primary reasons for this is that the diet fed represents ca. 70% of the production costs and accordingly much research has been undertaken to ensure the content and formulation are able to provide the required nutrients to achieve the genetic potential within a defined production system setting. Vast reference data sheets are available and were embedded in the initial CIRRA versions, with the user thus able to select the pasture or ration type from the data base provided.

Since most feed manufacturing companies test the rations sold on a regular basis to ensure quality and formulation accuracy the input of actual data is typically feasible and not necessarily a cost deterrent to the input thereof to the DSS user.

It should be appreciated that the complexities extend to more than just variable constituent ingestion rates (with significant influences on both dynamics and kinetics), but also to complex inter-nutrient interactions and digestibility factors. On a more fundamental basis the correlation between feed intake and water intake is a crucial one with increasing genetic potential requiring corresponding increases in both feed and water intakes. It should lastly be noted that at the higher Tier levels specialist interpretation for viable manipulation of the diet to accommodate water-borne PHCCs and COCs in the form of a nutritionist specialising in ruminant or monogastric feeds would be required.

3.5. Source Pathway Receptor Approach

As with the source, pathway and receptor approach, the fundamentals of a risk-based approach are similar in principle to establishing the hazards and then risks posed by hazardous substances in the environment. Whilst a water quality constituent is not inherently viewed as a hazardous substance the objective of water quality guidelines, and more specifically risk-based guidelines, is to identify the set of conditions under which a given concentration may result in an adverse effect.

In this approach the concept of a Potentially Hazardous Chemical Constituent (PHCC) is thus applicable and the generally accepted source, pathway and receptor stage approaches to the assessments are applicable. It would also thus be applicable to note that there is a fourth stage in the risk-based guideline approach, namely the management of the risks identified, typically referred to as Risk Management Strategies.

This is the fundamental approach adopted by the WIRRD in the DSS in both the use of user specific input, reference documentation, calculations and corresponding methodology in the assessments performed and in the reporting methods for the results obtained. In many respects the assessment of the inputs is a source characterisation which requires site description, samplings, chemical analysis, and an overall assessment of the site which for this user group implies an assessment of the animal production system.

The pathways aspect requires an application of the behaviour of the constituents within the site and this consequently extends to more than just the presence thereof in the water resource, but in soil and other pathways, notably feed. The affected Receptors are the animals themselves and, more accurately, this implies that the pharmaco-kinetics and pharmaco-dynamics of these substances within the animal applicable is deterministic. It has to be acknowledged in this aspect that the Receptor is a controlled receptor for the vast majority of exposures with animal husbandry techniques capable of having control over a large number of exposures in terms of source, pathway and receptors, applicable to both concentration and duration.

It is again stressed that the risk-based guidelines cater for a variety of norms, these having been described previously. Within the WIRRD approach detailed earlier it was noted that the adjustments are made on two key levels, firstly to the Results calculation and comparison with the central reference WIRRD, and secondly, to the central reference WIRRD itself. The central reference WIRRD is compiled in a similar manner to the WHO Drinking Water Standards in the sense that certain assumptions are made, these pertaining to the user and the environment (e.g. body weight, water intake and temperature in the WHO scenario), however, the setting for the WIRRD is obviously more complex given the host of animal types, breeds and production system specifics applicable.

To cater for this a source, pathway and receptor setting is defined for the WIRRDs with trigger factors also set as either assumptions or user defined input fields. The following examples for Livestock = Sheep, Category Ewes – maintenance for WQC = Selenium were provided as examples thereof.

Table 10: Example of a Specific-WIRRD for Livestock Type = Sheep; Category = Ewes – maintenance; WQC = Selenium; Column A

Site-specific conditions – Column A^^		
Source setting: Column A = - no organic dietary selenium supplementation. - soil concentrations ,0.005-2 mg/kg DM.	**Pathway setting:** Column A = - temperature < 16 degrees Celsius	**Receptor setting**: Column A = Production parameters = set reference values
Source Trigger Factors Column A = - soil < 2 mg/kg DM - forage < 1 mg/kg DM - geographical location = selenium deficient area	**Pathway Trigger Factors** Column A = - temperature < 16 degrees Celsius	**Receptor Trigger Factors** Column A = - blood = 500-900 nmol/l; serum = 250-500 nmol/L - liver = 350-450 mg/kg FW; muscle = 300-400 mg/kg FW
^^ the statements in the columns relate to the WIRRD guideline effect values provided in Table 6.		

Table 11: Example of a Specific-WIRRD for Livestock Type = Sheep; Category = Ewes – maintenance; WQC = Selenium; Column C

Site-specific conditions – Column C^^		
Source setting: Column C = - organic dietary selenium supplementation - forage Se 5-15 mg/kg DM	**Pathway setting:** Column C = - temperature 16-22.5 degrees Celsius	**Receptor setting**: Column C = Production parameters = set reference values

Site-specific conditions – Column C^^		
- soil concentrations 0.02 – 3.7 mg/kg DM. - geographical location = seleniferous area		
Source Trigger Factors Column C = - soil >0.02 mg/kg DM - dietary Se 3-5 mg/kg DM - forage > 5 mg/kg DM	**Pathway Trigger Factors** Column C = - temperature >16 degrees Celsius	**Receptor Trigger Factors** Column C = - blood Se = 0.2-0.3 mg/L; serum Se = 2.0-3.0 mg/L - liver Se = 10 -15 mg/kg FW; fleece Se = 4-6 mg/kg FW
^^ the statements in the columns relate to the WIRRD guideline effect values provided in Table 6.		

Table 12: Example of a Specific-WIRRD for Livestock Type = Sheep; Category = Ewes – maintenance; WQC = Selenium; Column D

Site-specific conditions – Column D^^		
Source setting: Column D= - organic dietary selenium supplementation - dietary Se>5 mg/kg DM - soil concentrations >3.7 mg/kg DM.	**Pathway setting:** Column D = - temperature > 22.5 degrees Celsius	**Receptor setting**: Column D = Production parameters = set reference values
Source Trigger Factors Column D = - soil >1200 mg/kg DM - forage > 15 mg/kg DM - diet > 5 mg/kg DM - geographical location = seleniferous area	**Pathway Trigger Factors** Column D = - temperature >22.5 degrees Celsius	**Receptor Trigger Factors** Column D = - blood = >0.3 mg Se/L; serum = >3.5 mg Se/LL - liver = >15 mg/kg FW mg/kg FW; fleece Se >6 mg/kg DM
^^ the statements in the columns relate to the WIRRD guideline effect values provided in Table 6.		

Table 13: Updated Specific-Central WIRRD for Livestock Type = Sheep; Category = Ewes – maintenance; WQC = Selenium

User Specific Input			Ingestion*	Water Quality Constituent^					
				mg Se/kg$^{0.82}$/d^^					
LW (kg)	DMI (kg/d)	TWI (L/d)	WIR (L/kg$^{0.82}$/d)	A (0-[])	B [A]-[B]	C [B]-[C]	D [C]-[D]	E [D]-[E]	F >[E]
50.8	0.92	2.599	0.1037	[0.0061] 0.000634	[0.0141] 0.001464	[0.0705] 0.007319	[0.9876] 0.102476	[3.5272] 0.365984	>0.36598
				[0.0058]	[0.01167]	[0.0583]	[0.8168]	[2.9174]	

User Specific Input			Ingestion*	Water Quality Constituent^					
				mg Se/kg$^{0.82}$/d^^					
LW (kg)	DMI (kg/d)	TWI (L/d)	WIR (L/kg$^{0.82}$/d)	A (0-[])	B [A]-[B]	C [B]-[C]	D [C]-[D]	E [D]-[E]	F >[E]
61.0	1.07	3.142	0.1079	0.000629	0.00126	0.006299	0.088193	0.314974	>0.31497
71.21	1.20	3.667	0.1109	[0.005488] 0.000624	[0.01] 0.00111	[0.05] 0.005549	[0.7] 0.077687	[2.5] 0.277452	>0.27745
81.419	1.32	4.132	0.1120	[0.005488] 0.000615	[0.008874] 0.000994	[0.0443] 0.004971	[0.6211] 0.069606	[2.285] 0.248594	>0.24859
91.62	1.45	4.612	0.1135	[0.00537] 0.00061	[0.0079] 0.000903	[0.0397] 0.004513	[0.5565] 0.063182	[1.9875] 0.22565	>0.2256

*Adapted from NRC requirement tables (NRC, 2007).

^Values adjusted for column A as per factorially derived selenium nutrient requirements.

^^Where columns A to F relate to guideline effect concentration ranges as follows:

A = minimum required for production. WIR results below the corresponding value = positive response on supplementation.
B = adequacy for production. WIR results within A-B may show a positive response on supplementation.
C = upper limit for safe water use. WIR results within B-C unlikely to yield positive response on supplementation.
D = risk of chronic selenosis. Risk of excess exposure if additional supplementation provided.
E = chronic selenosis with no additional ingestion pathways.
F = chronic to acute selenosis

The tables above demonstrate how the source, pathway and receptor approach allows for a setting to be defined with corresponding trigger values for each column. This implies that multidisciplinary fields can be brought into the WIRRD at the entry level thereof without having to ensure a Tier III application. Simply put, the expertise that exists in fields that apply to the different Sources, Pathways, and Receptors, such as geochemistry, physiology and clinical biochemistry, may be included in the derivation and corresponding IRVs generated in the WIRRD methodology.

This allows for updates to be effected as new clinical information becomes available, or as additional source, pathway and receptor settings can be defined with corresponding trigger factors. In terms of handling the WIRRD it is thus also possible to adjust the Results Reporting column to reflect the appropriate Source, Pathway and Receptor data provided, or that which was requested following the compilation of this required entry field data in the Data Capturing Guide generated.

This is a key aspect that is required for another practical reason, this being that in many cases there does not exist sufficient descriptions of exposure outcomes, this being due to a lack of research, confounding factors, multiple endpoints being involved for multiple PHCCs and COCs. As was described in previous deliverables this is a reality in domestic drinking water guidelines as it is for livestock guidelines, with the significant impact of a simple "specialist opinion" – derived Uncertainty Factor having been demonstrated in terms of altering the guideline concentration proposed.

Stated differently, this implies that the preceding calculations may be based on user data input such as WQC concentrations, feed concentrations, production system specifics, etc., as described and yield a Results Report for the assessment for which a corresponding outcomes statement applies to one column, yet it may also be possible that another data input source (e.g. clinical biochemistry) may yield a different column statement due to a trigger factor altering the applicable setting.

This means that the user may be given a system results and variance from the reference document but will also be alerted to a result for the Source, Pathway and Receptor setting applicable, in which it is noted that the setting either is assumed (in the absence of user defined inputs) or derived based on user defined inputs, which may differ. Thus, the WIRRD calculations may yield a Column C result but a clinical biochemistry test may yield a Column B or D result.

This feature and associated outcome are an asset to the system as it provides a means for incorporating a form of final outcome assessment (e.g. histopathology) following exposure and in reality removes much of the uncertainty which is inherent in the Source, Pathway and Receptor analysis applicable. This source, pathway and receptor set of conditions are therefore either an Uncertainty Factor alert or a Validation of Effect which is reported to the user.

The value in the WIRRD results report would remain true as it would highlight those synergistic and antagonistic factors which *could* have conceivably been instrumental in the final Source, Pathway and Receptor data provided. On this point is must again be stated that the factor value awarded as described in the preceding sections is an assessment methodology for which numeric quantification may be increasingly refined. Thus, the inclusion of source, pathway and receptor data in the form of the settings and trigger values presented, is a means for either validating or obtaining over time more accurate Risk Factor values.

It is noteworthy that the temperature setting used is 22.5 ºC and not 16ºC (as in the WHO approach) as this is deemed to be more relevant to South African animal production systems, noting that similar adjustments to the WHO approach have been adopted elsewhere. Adjustments are made to the applicable columns according to the user defined temperature within the central reference row, as demonstrated in Table 14.

Rule: Temperature Adjustment to Pathway Setting:

<u>Temp (ºC)</u>	<u>RF</u>
22.5	1
↑1ºC	0.975

Where, adjustment is made to the Guideline Effect Value, and IRV is recalculated.

Table 14: Adjusted Central Reference Row for Specific-Central WIRRD for Livestock Type = Sheep; Category = Ewes – maintenance; WQC = Selenium & Temperature = 25.5ºC

User Specific Input			Ingestion*	Water Quality Constituent^					
				mg Se/kg$^{0.82}$/d^^					
LW (kg)	DMI (kg/d)	TWI (L/d)	WIR (L/kg$^{0.82}$/d)	A (0-[])	B [A]-[B]	C [B]-[C]	D [C]-[D]	E [D]-[E]	F >[E]
71.21	1.20	3.667	0.1109	[0.005086] 0.000564	[0.0092] 0.0010278	[0.0463] 0.0051394	[0.648] 0.071952	[2.317] 0.25697	>0.25697

*Adapted from NRC requirement tables (NRC, 2007). ^Values adjusted for column A as per factorially derived selenium nutrient requirements. ^^Where columns A to F relate to guideline effect concentration ranges as follows: A = minimum required for production. WIR results below the corresponding value = positive response on supplementation. B = adequacy for production. WIR results within A-B may show a positive response on supplementation. C = upper limit for safe water use. WIR results within B-C unlikely to yield positive response on supplementation. D = risk of chronic selenosis. Risk of excess exposure if additional supplementation provided. E = chronic selenosis with no additional ingestion pathways. F = chronic to acute selenosis

The source, pathway and receptor approach also has application to those water quality constituents which do not typically result in adverse health effects directly, but primarily in induced deficiencies or altered tolerance to excesses. An example would be the Cu: S: Mo interactions specific to ruminants with cattle and sheep also presenting with different tolerances to deficiency and toxicity trigger exposure values. This is an important aspect as in many cases these nutrients are included at high concentrations in the rations formulated in order to ensure antagonisms do not lower availability of essential elements and thus adversely affect production.

This practice may impact norms of wastewater quality and soil nutrient status and the corresponding WIRRD should therefore be accordingly adjusted when synergistic and/or antagonistic settings apply as these would have the effect of potentially altering the ration formulation and thus permitted final water quality constituent concentration which would result in an acceptable risk level being reached. An example of these settings for Sheep and the WQC Cu are provided below in Table 15 to Table 17 to demonstrate the user inputs required.

Table 15: Example of a Specific-WIRRD for Livestock Type = Sheep; Category = Ewes – maintenance; WQC = Copper; Column A

Site-specific conditions – Column A^		
Source setting: Column A= - exposure to Mo and S - exposure to Fe - Soil Cu <0.3 mg/kg - Soil Mo >0.1 mg/kg	**Pathway setting:** Column A = - temperature < 22.5 degrees Celsius	**Receptor setting**: Column A = Production parameters = set reference values
Source Trigger Factors Column A = - herbage Cu: Mo <1.0 - roughage Cu: Mo <0.5 & Dietary Sulphur > 2 g/kg DM & Dietary Mo < 8 mg/kg DM - Diet Fe: Cu < 50	**Pathway Trigger Factors** Column A = - temperature < 22.5 degrees Celsius	**Receptor Trigger Factors** Column A = - Liver Cu < 100 µmol/kg DM - Serum Cu < 3 µmol/L - Blood Cu < 6 µmol/L - Hair / Wool Cu < 31 µmol/kg DM

Site-specific conditions – Column A^		
- Diet Cu Herbage <6; Roughage <4 mg/kg DM - Soil Cu <0.3 mg/kg - Soil Mo >0.1 mg/kg		
^^ the statements in the columns relate to the WIRRD guideline effect values provided in the corresponding Cu WIRRD table.		

Table 16: Example of a Specific-WIRRD for Livestock Type = Sheep; Category = Ewes – maintenance; WQC = Copper; Column B

Site-specific conditions – Column A^		
Source setting: Column A= - exposure to Mo and S - exposure to Fe - Soil Cu ca. 13 mg/kg - Soil Mo 0.1-20 mg/kg	**Pathway setting:** Column A = - temperature < 22.5 degrees Celsius	**Receptor setting**: Column A = Production parameters = set reference values
Source Trigger Factors Column A = - herbage Cu: Mo 1.0-3.0 - roughage Cu: Mo 0.5-2.0 & Dietary Sulphur > 2 g/kg DM & Dietary Mo < 8 mg/kg DM - Diet Fe: Cu 50-100 - Diet Cu Herbage 6-8; Roughage 4-6 mg/kg DM - Soil Cu ca. 13 mg/kg - Soil Mo 0.1-20 mg/kg	**Pathway Trigger Factors** Column A = - temperature < 22.5 degrees Celsius	**Receptor Trigger Factors** Column A = - Liver Cu 100-300 μmol/kg DM - Serum Cu 3-9 μmol/L - Blood Cu 6-10 μmol/L - Hair / Wool Cu 31-62 μmol/kg DM
^^ the statements in the columns relate to the WIRRD guideline effect values provided in the corresponding Cu WIRRD table.		

Table 17: Example of a Specific-WIRRD for Livestock Type = Sheep; Category = Ewes – maintenance; WQC = Copper; Column C

Site-specific conditions – Column A^		
Source setting: Column A= - exposure to Mo and S - exposure to Fe - Soil Cu >114 mg/kg - Soil Mo <20 mg/kg	**Pathway setting:** Column A = - temperature < 22.5 degrees Celsius	**Receptor setting**: Column A = Production parameters = set reference values
Source Trigger Factors Column A = - herbage Cu: Mo >3.0 - roughage Cu: Mo >2.0 & Dietary Sulphur > 2 g/kg DM & Dietary Mo < 8 mg/kg DM - Diet Fe: Cu >100 - Diet Cu Herbage > 8; Roughage >6 mg/kg DM - Soil Cu >114 mg/kg - Soil Mo <20 mg/kg	**Pathway Trigger Factors** Column A = - temperature < 22.5 degrees Celsius	**Receptor Trigger Factors** Column A = - Liver Cu >300 µmol/kg DM - Serum Cu >9 µmol/L - Blood Cu >10 µmol/L - Hair / Wool Cu >62 µmol/kg DM
^^ the statements in the columns relate to the WIRRD guideline effect values provided in the corresponding Cu WIRRD table.		

Finally, the Precautionary Approach methodology was noted earlier and is a key approach enabled with the use of the variance calculation performed. Linking the variances to the recognised classification nomenclature and colours, as adopted in the other risk-based water quality guidelines, is recommended for the DSS results screens. These would effectively move from Blue, to Green, to Yellow, to Red and finally to Purple, equating to Ideal, Good, Marginal Risk, Significant Risk and Unacceptable Risk. These would correspond to the various columns on a per water quality constituent basis, as some column A values would not be ideal due to the recognition of deficiency challenges.

4. PROTOTYPE DECISION SUPPORT SYSTEM DESIGN

The prototype DSS design presented as the outcome of this project reflect the various changes and updates related to modelling and corresponding calculations discussed in the previous sections and support technical information document. Since these are not viewable in the User Interface it should be appreciated that the bulk of the changes effected are not visible. As described earlier the key update required to the previous CIRRA version was to adjust the User Interface to one which is more user-friendly and which encourages the progression from Tier I to Tier II. This is best viewed by engaging with the prototype DSS provided with this final report.

An overview of the system flow is provided below hereafter figures attending to the core changes to the DSS functionality are provided.

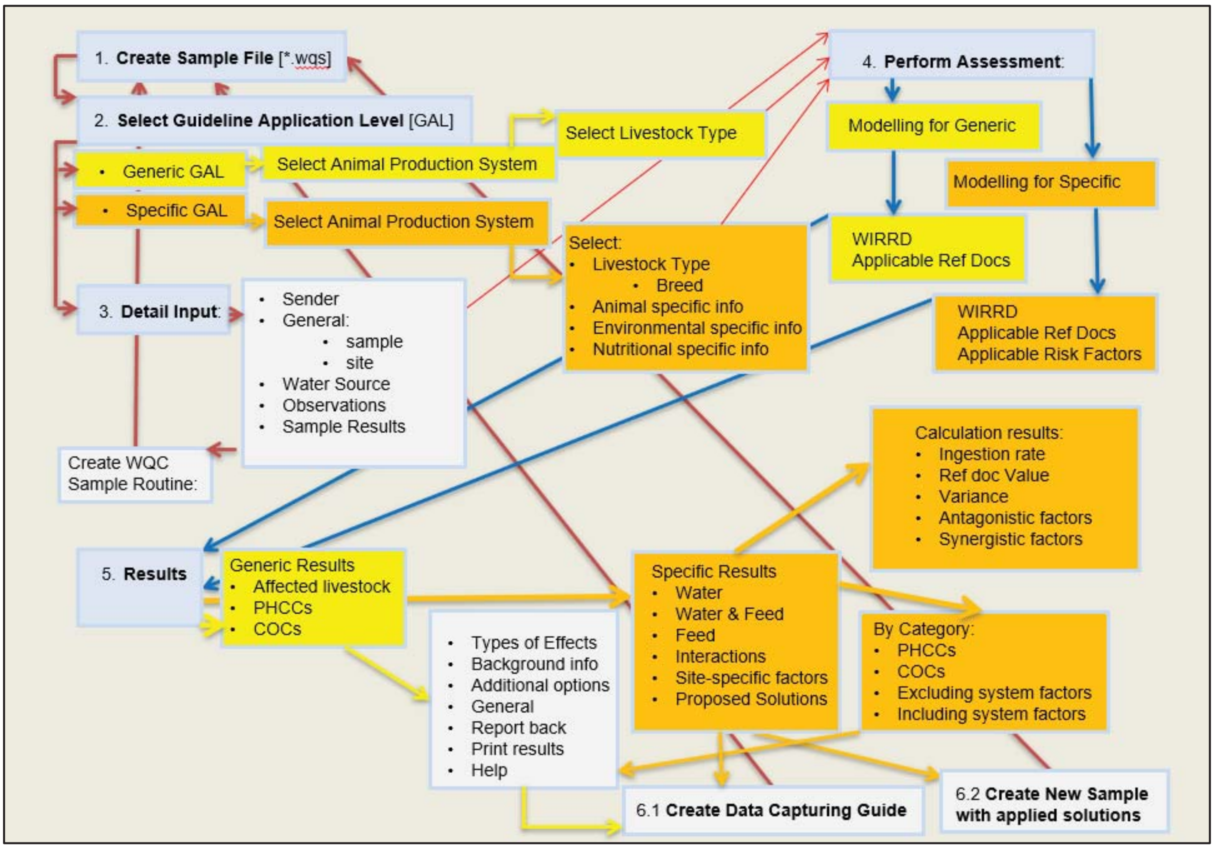


Figure 20: System data flow

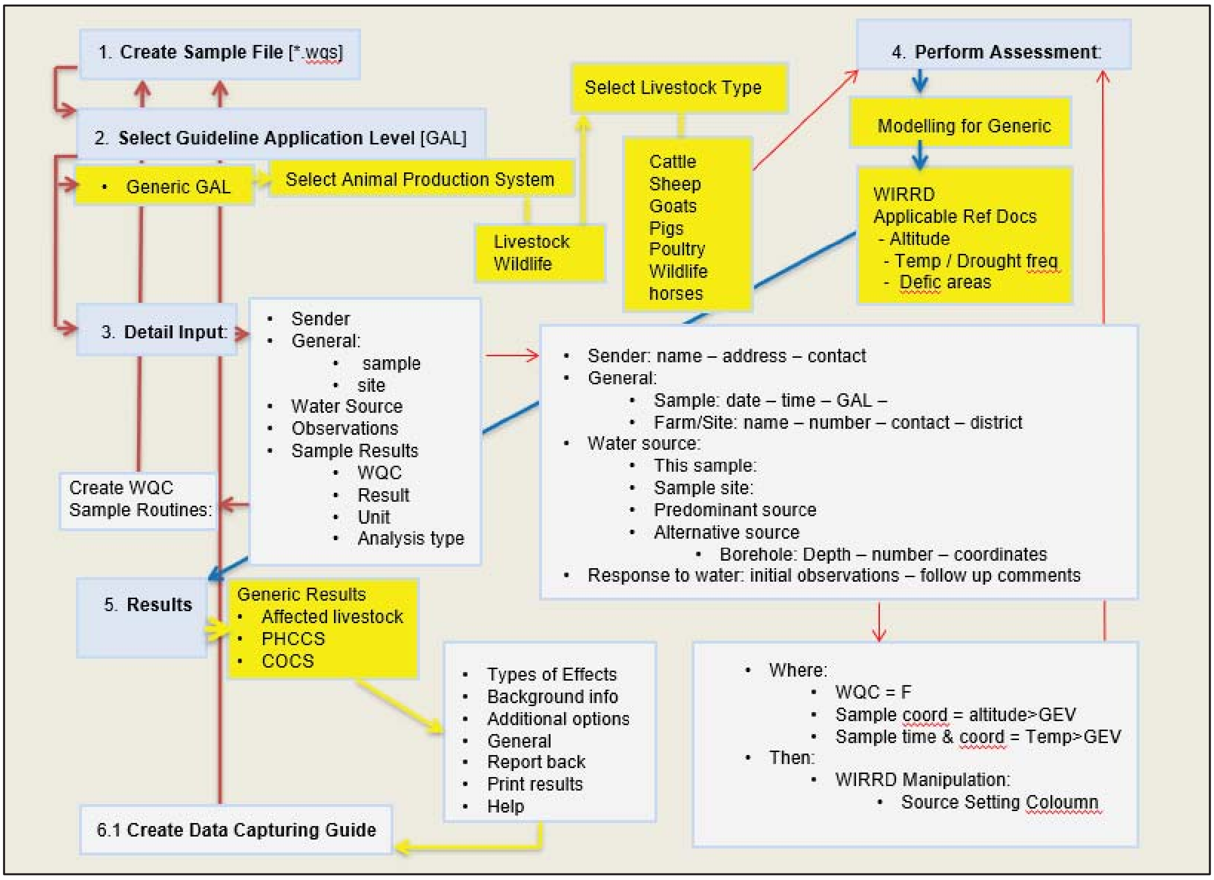


Figure 21: Generic system overview

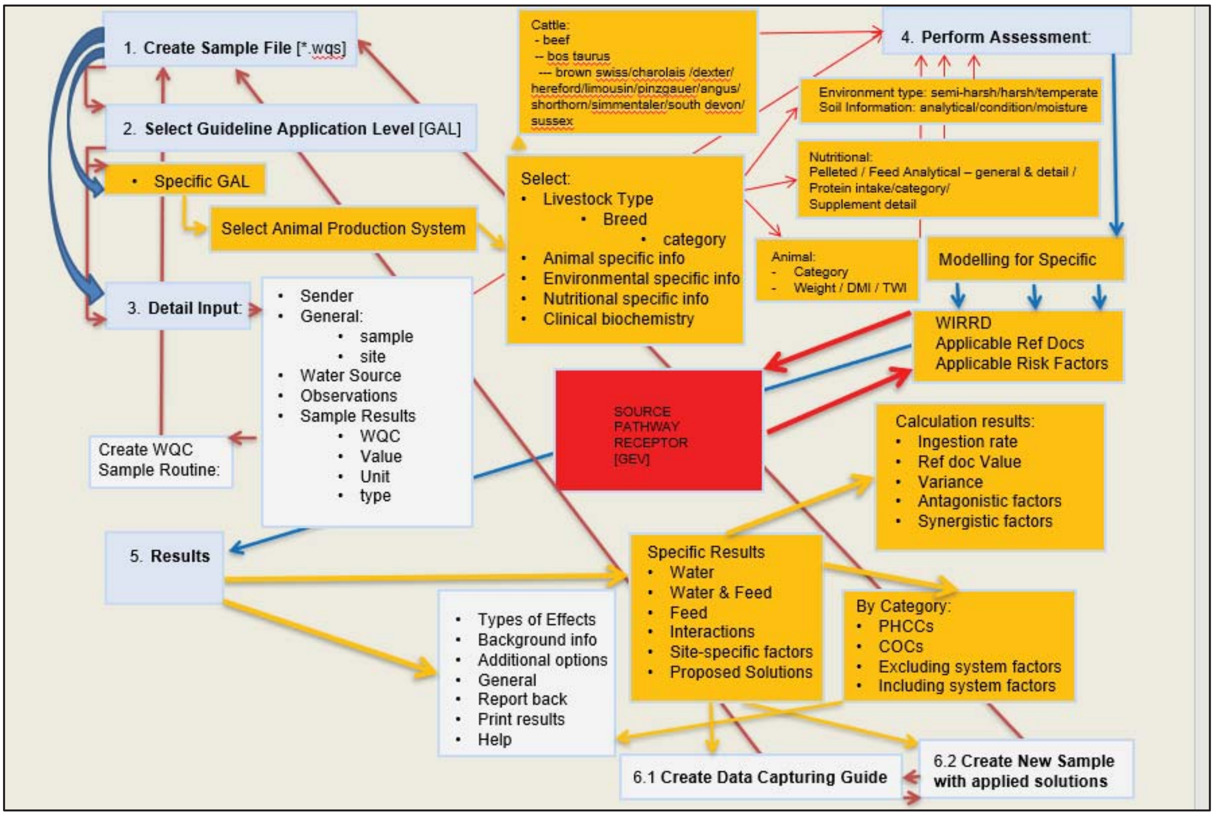


Figure 22: Specific system overview

It should be noted that a key change in moving from Tier I to higher tiers is not only the increase in data inputs (from reference documentation and user defined site-specific inputs) but also the ability to review final exposure to multiple water resources. This aspect (and others) is essential to reflect typical animal production system dynamics and thus enable the DSS to have more meaningful impact.

- Tier I indicate that little information is known and the assessment focusses on the presence and concentration of water quality constituents in the water – this is also termed a “Generic” approach.
- Tier II requires additional information inputs for the animal exposed (e.g. type, physiology), production system (e.g. type and level of production), nutrition (e.g. diet and intake) and the environment (e.g. soil, temperature, location and altitude).
- Tier III allows for more specialist information to be considered which may include a variety of expert fields, ranging from geochemistry to clinical biochemistry.

As the system moves from Tier I to Tier III the focus moves from a potential hazard assessment towards a risk assessment. The risk assessment process also focusses increasingly on the key risk factors applicable and possible mitigation measures to reduce the risk present. The fundamental difference between a Tier I and a Tier III assessment is that due to the low site-specific detail known a Tier I assessment is more conservative in nature, whereas more information input allows for the Tier III assessment to be a more realistic statement on the probability for certain types of effects to occur.

4.1. Introductory aspects to the DSS

The following figures highlight the introduction aspects to the DSS.

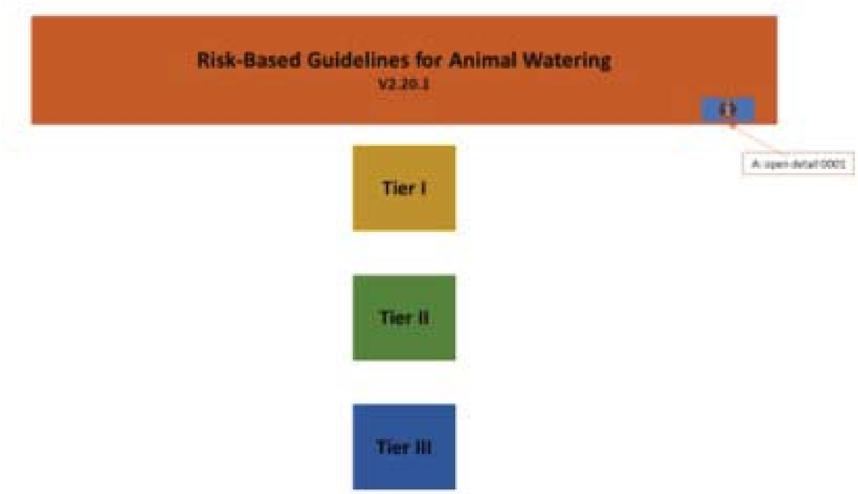


Figure 23: Opening User Interface

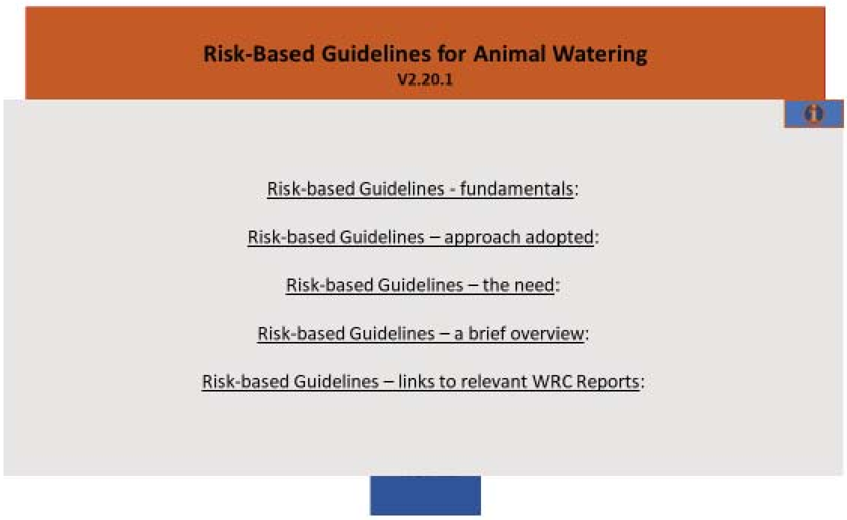


Figure 24: User Interface Introductory aspects offered

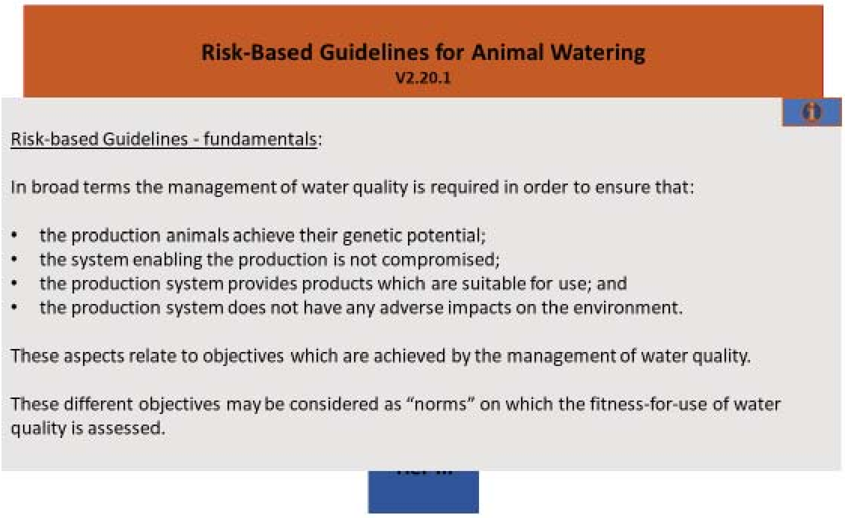


Figure 25: User Interface – Fundamentals content 1

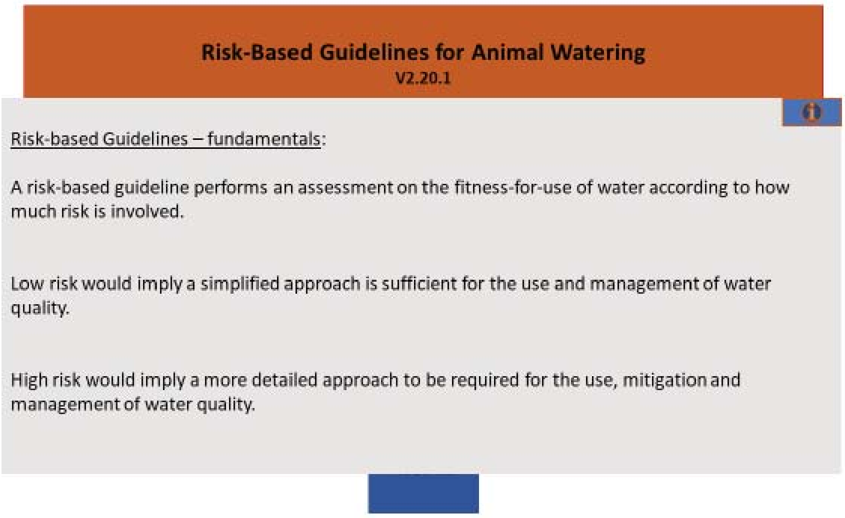


Figure 26: User Interface – Fundamental content 2

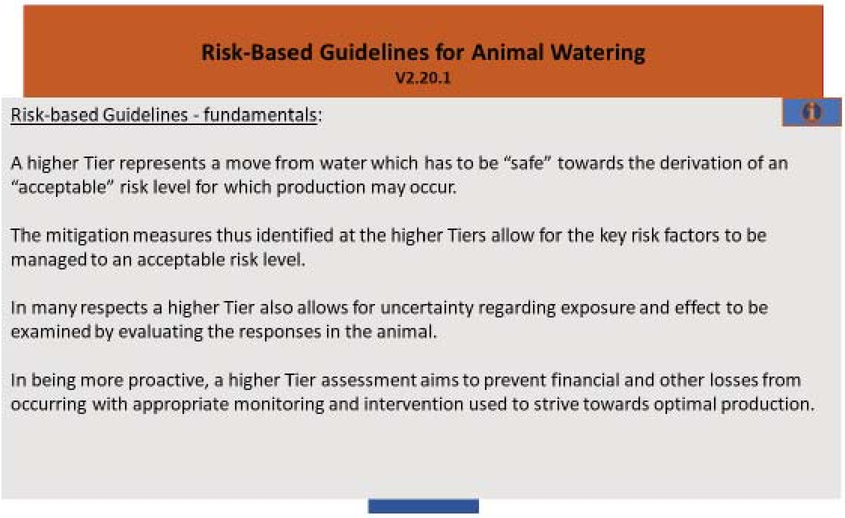


Figure 27: User Interface – Fundamental content 3

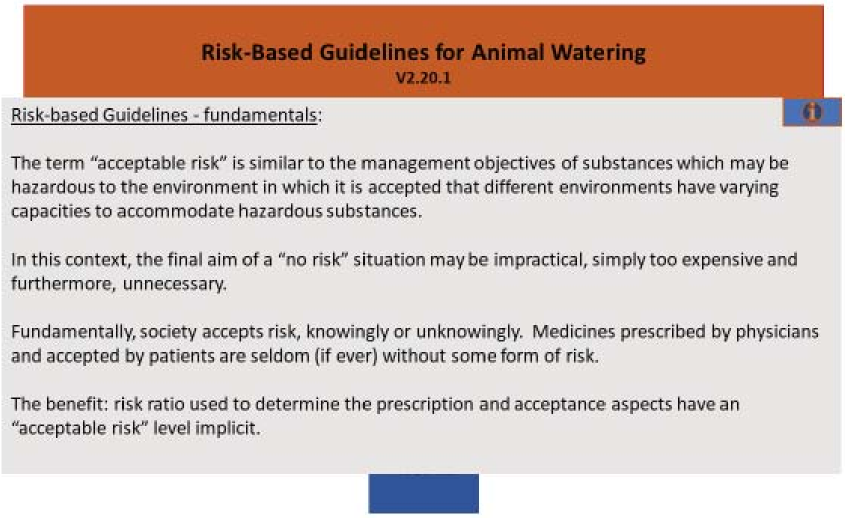


Figure 28: User Interface – Fundamental content 4

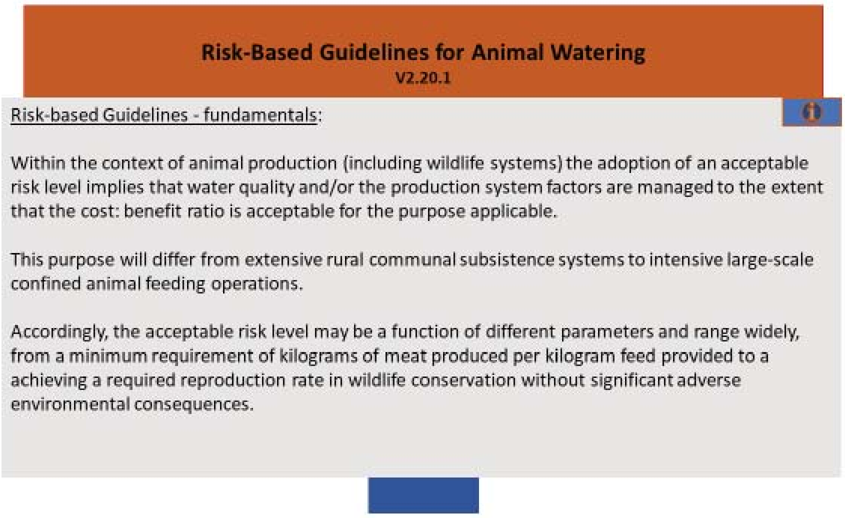


Figure 29: User Interface – Fundamental content 5

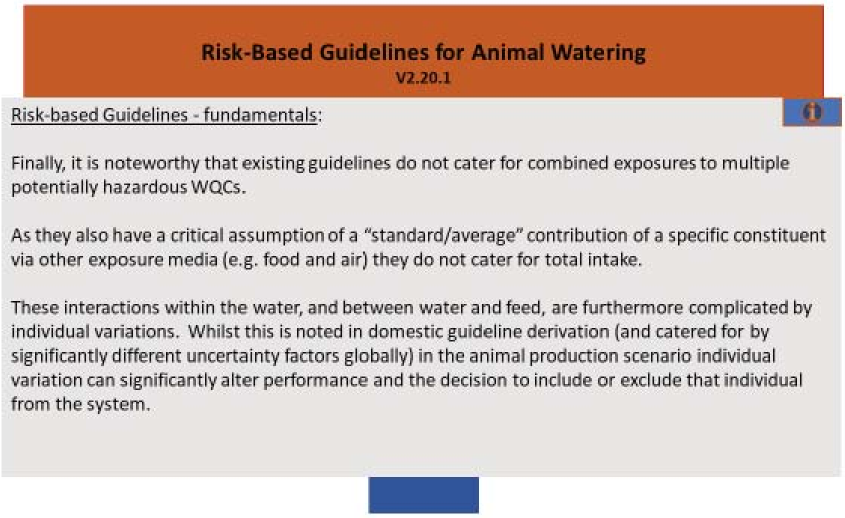


Figure 30: User Interface – Fundamental content 6

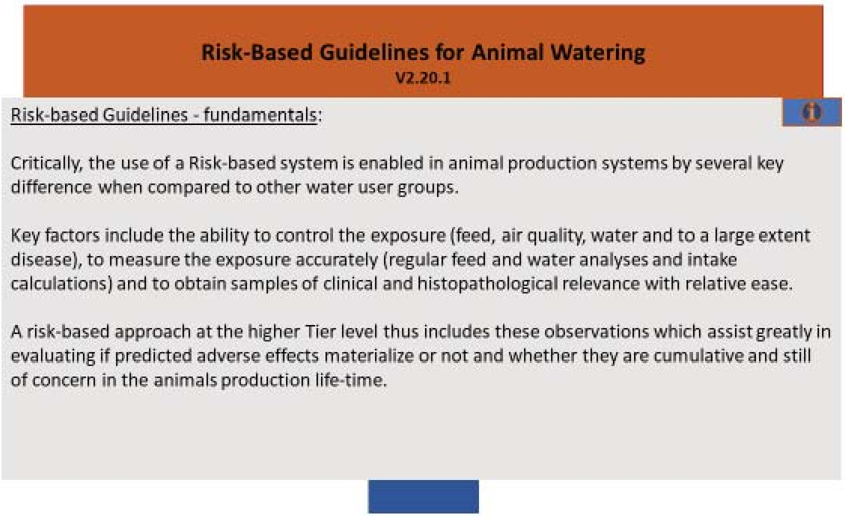


Figure 31: User Interface – Fundamental content 7

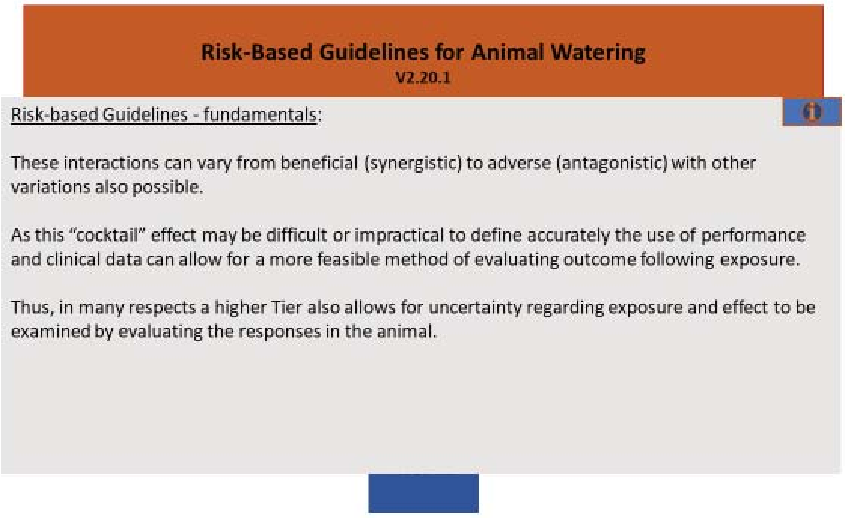


Figure 32: User Interface – Fundamental content 8

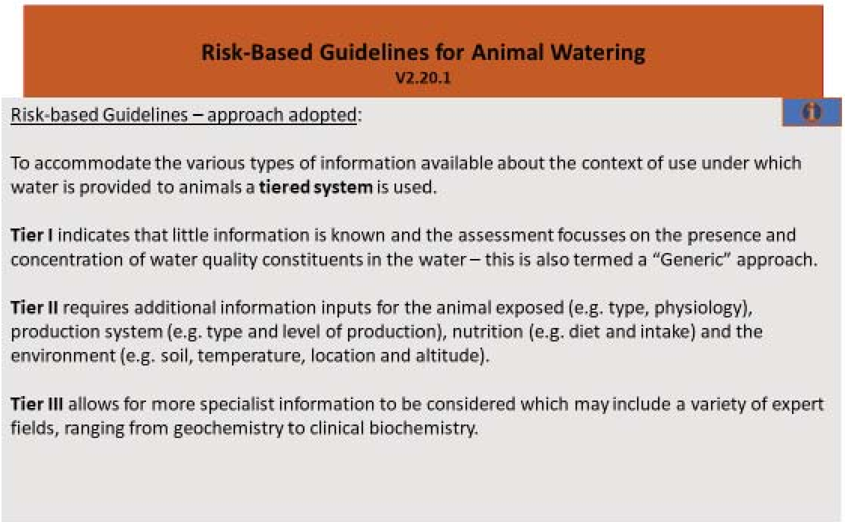


Figure 33: User Interface – Approach Adopted 1

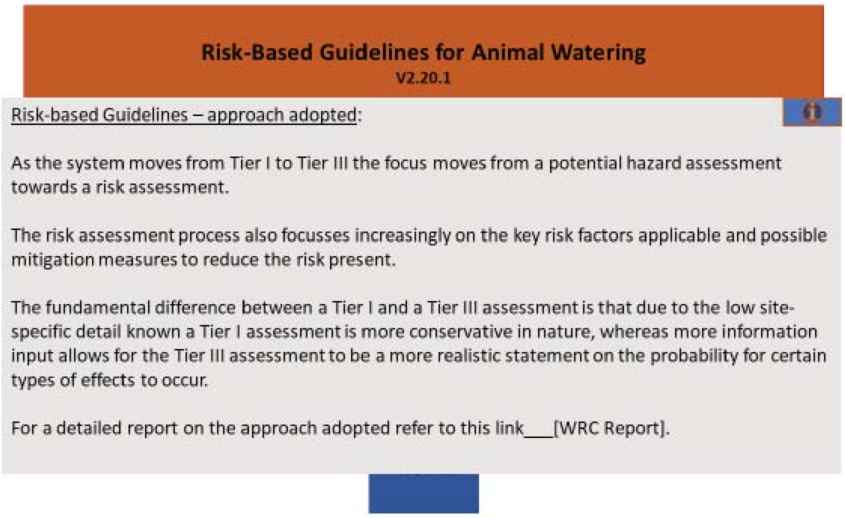


Figure 34: User Interface – Approach Adopted 2

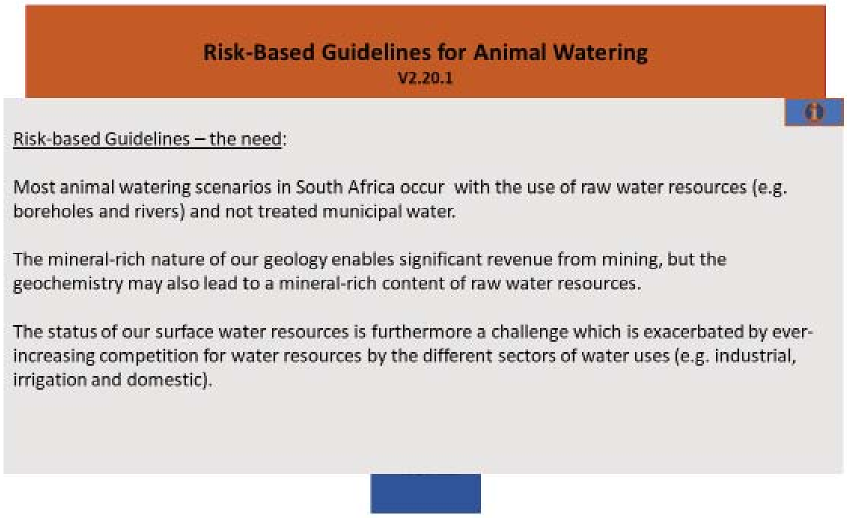


Figure 35: User Interface – The need 1

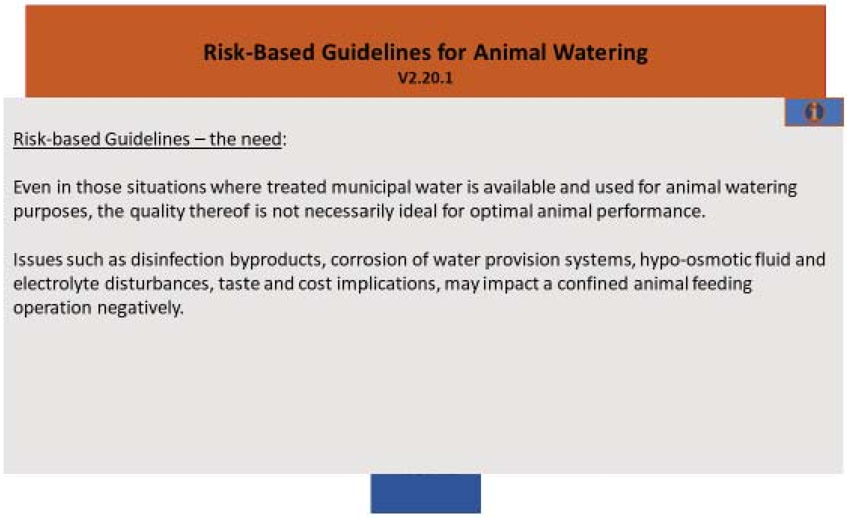


Figure 36: User Interface – The need 2

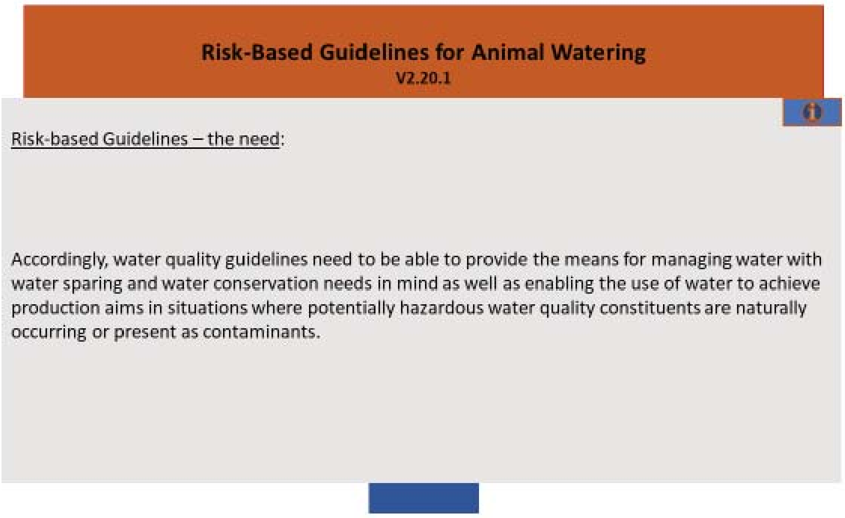


Figure 37: User Interface – The need 3

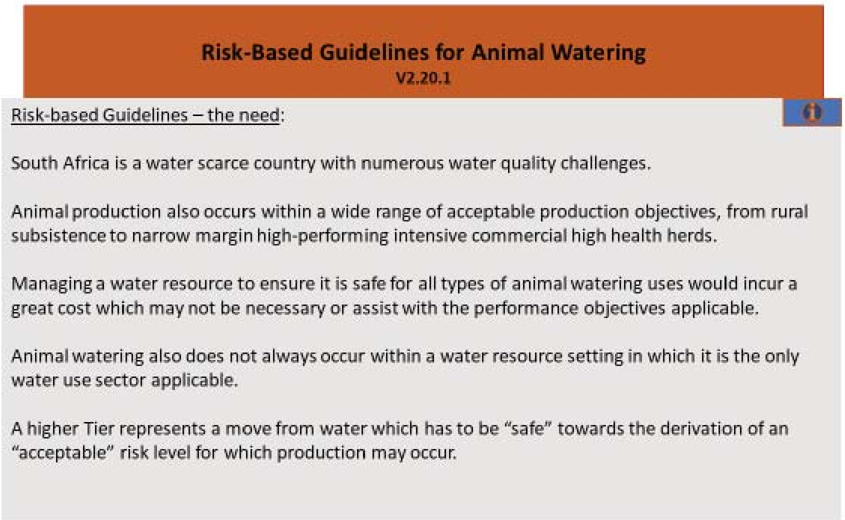


Figure 38: User Interface – The need 4

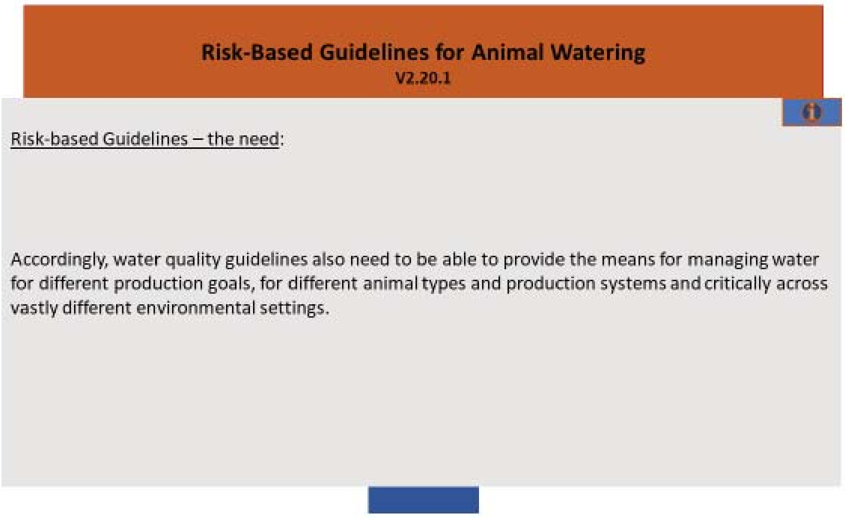


Figure 39: User Interface – The need 5

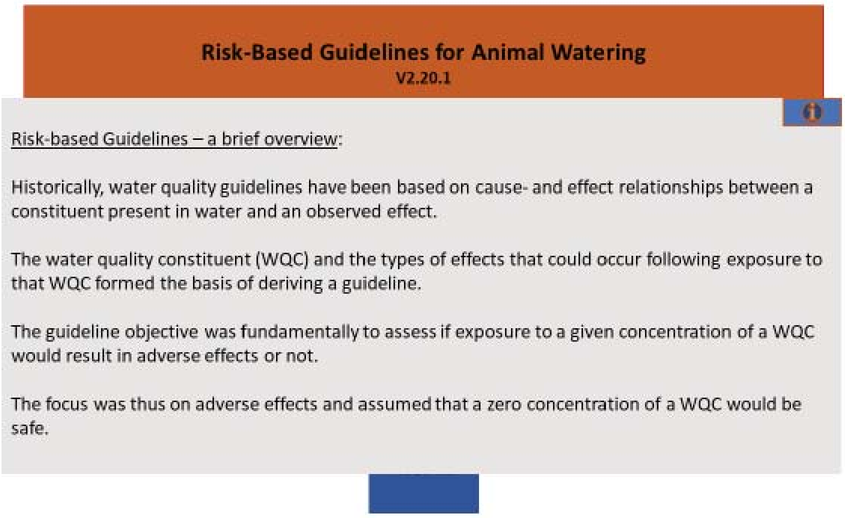


Figure 40: User Interface – Brief overview 1

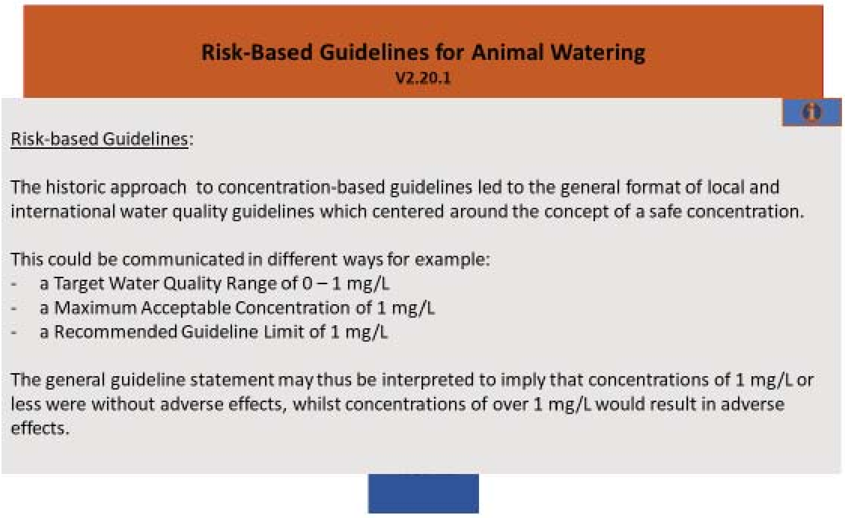


Figure 41: User Interface – Brief overview 2

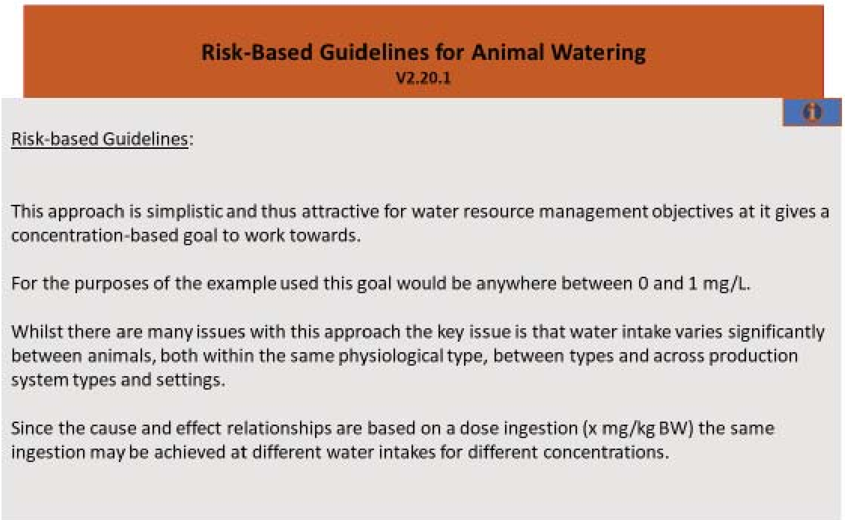


Figure 42: User Interface – Brief overview 3

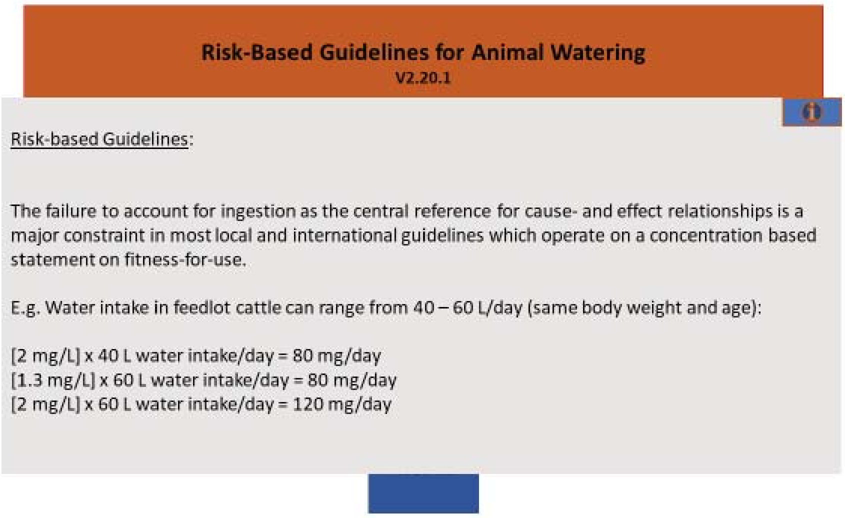


Figure 43: User Interface – Brief overview 4

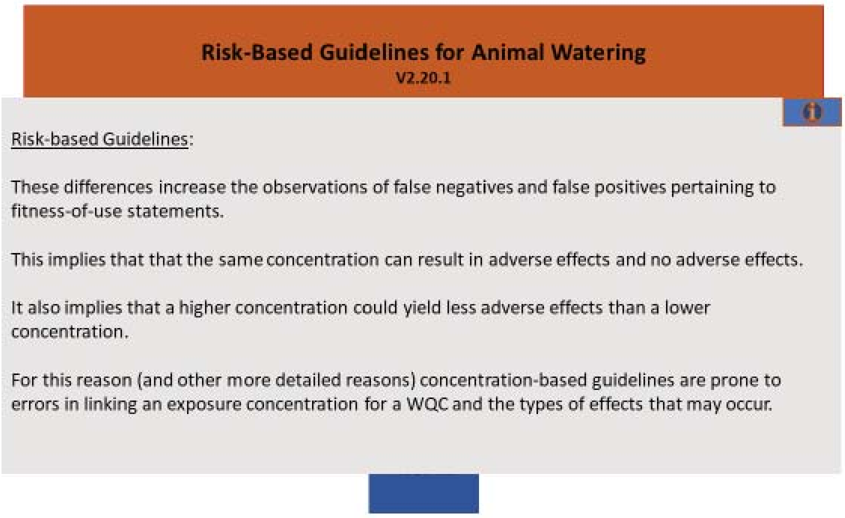


Figure 44: User Interface – Brief overview 5

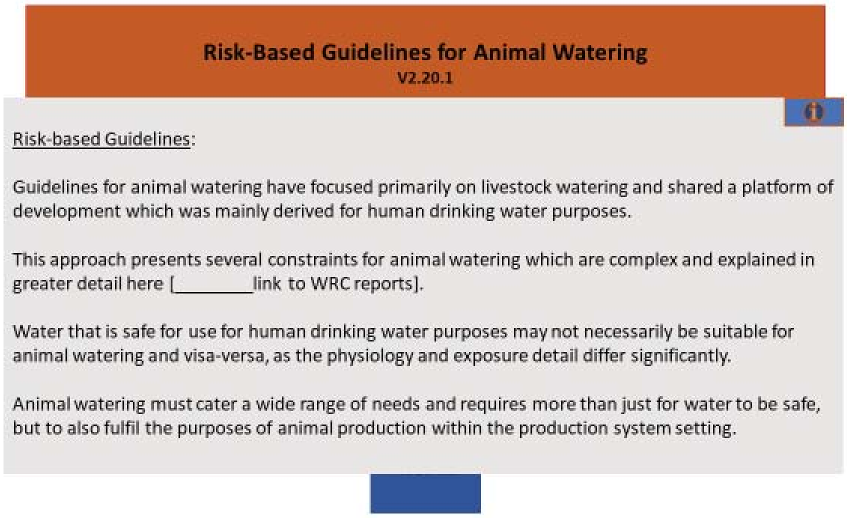


Figure 45: User Interface – Brief overview 6

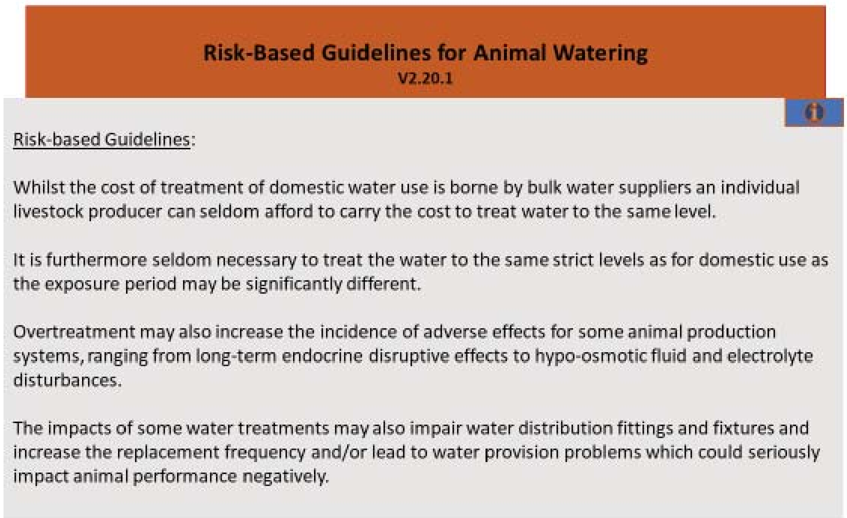


Figure 46: User Interface – Brief overview 7

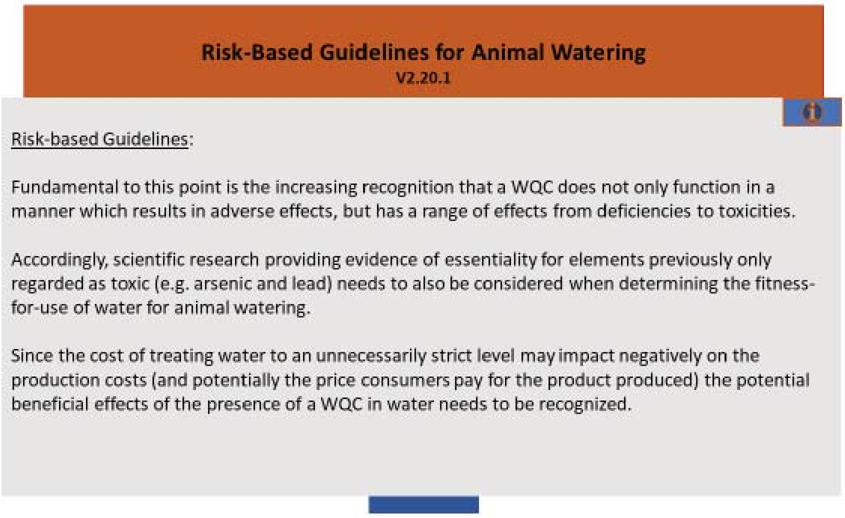


Figure 47: User Interface – Brief overview 8

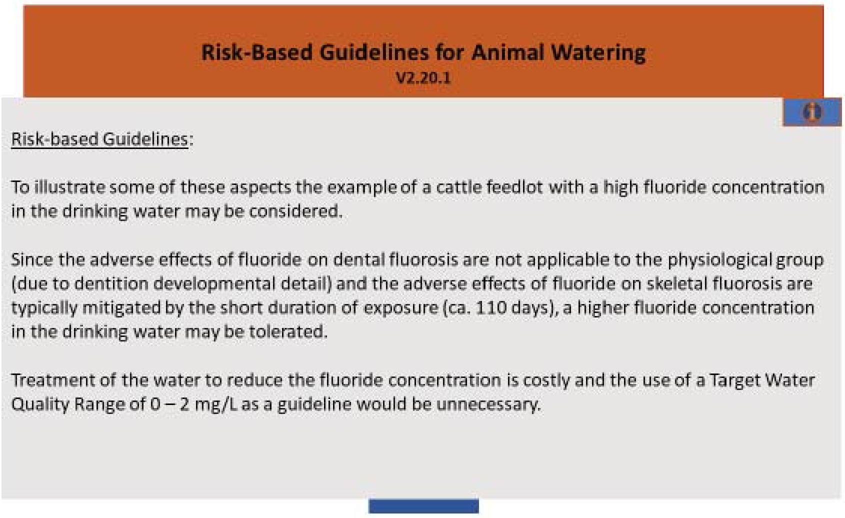


Figure 48: User Interface – Brief overview 9

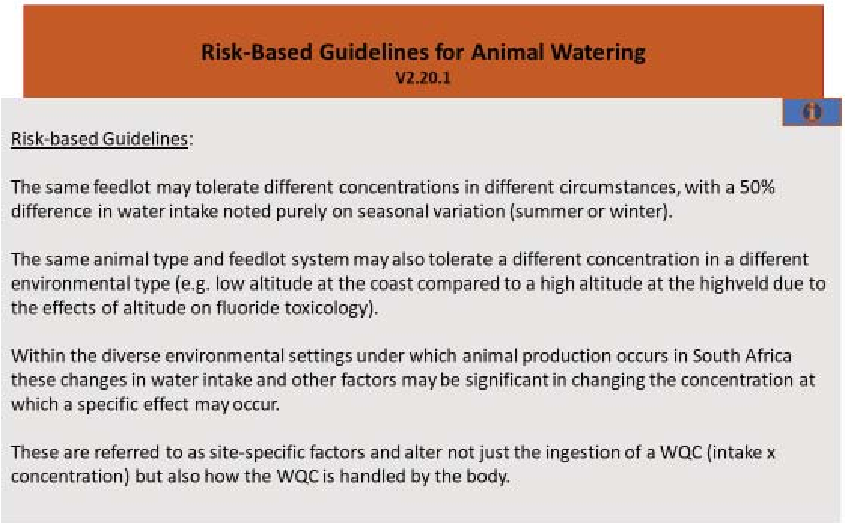


Figure 49: User Interface – Brief overview 10.

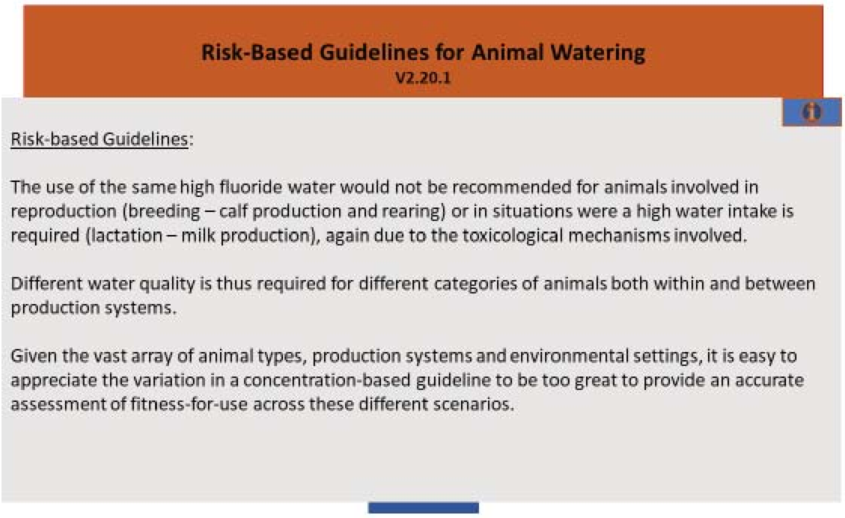


Figure 50: User Interface – Brief overview 11

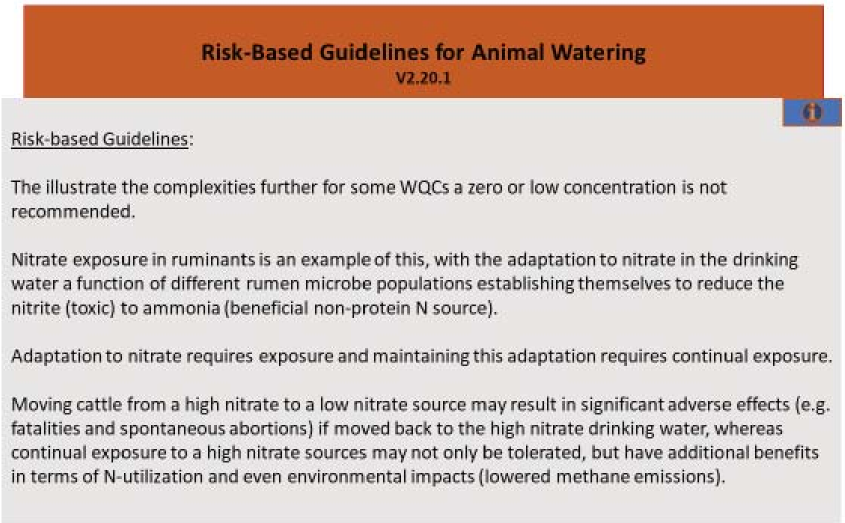


Figure 51: User Interface – Brief overview 12

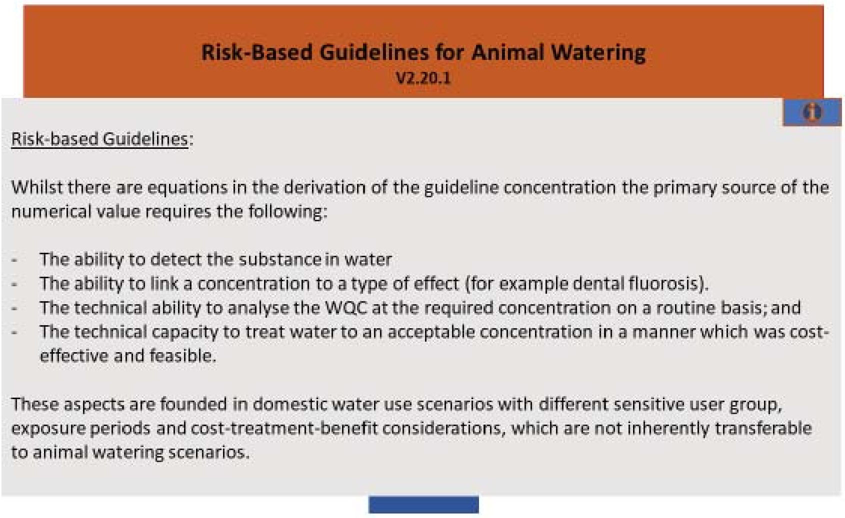


Figure 52: User Interface – Brief overview 13

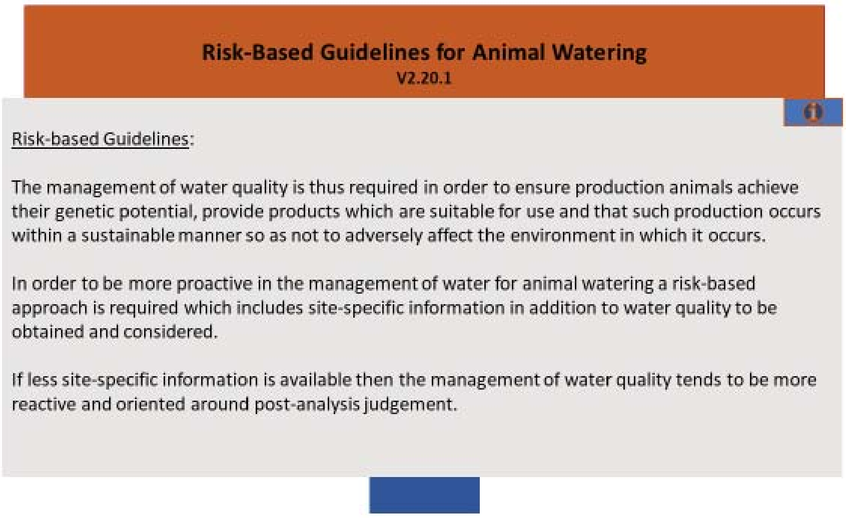


Figure 53: User Interface – Brief overview 14

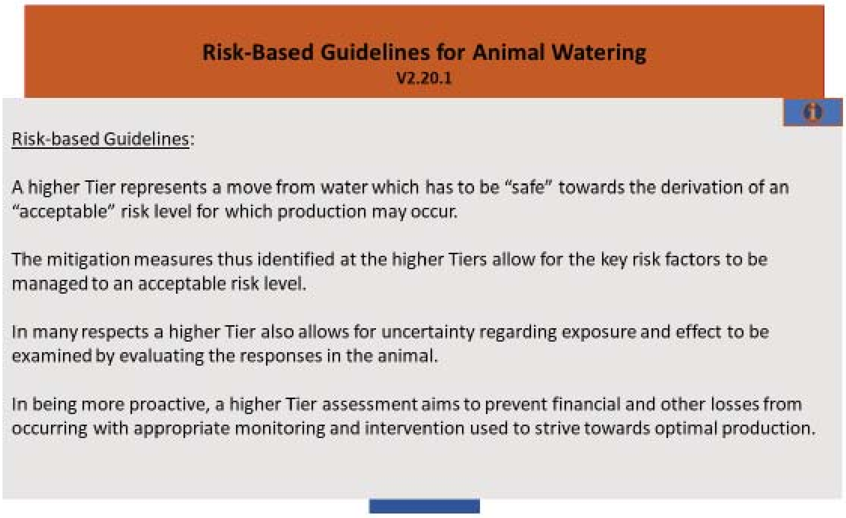


Figure 54: User Interface – Brief overview 15

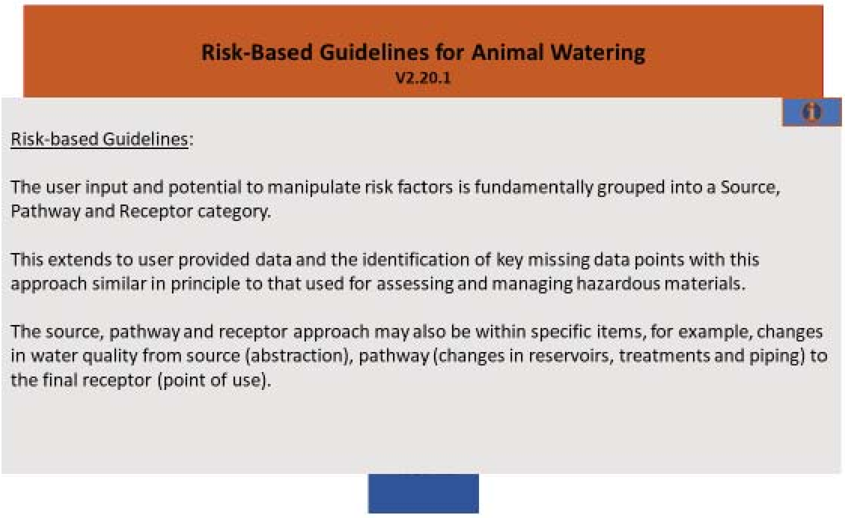


Figure 55: User Interface – Brief overview 16

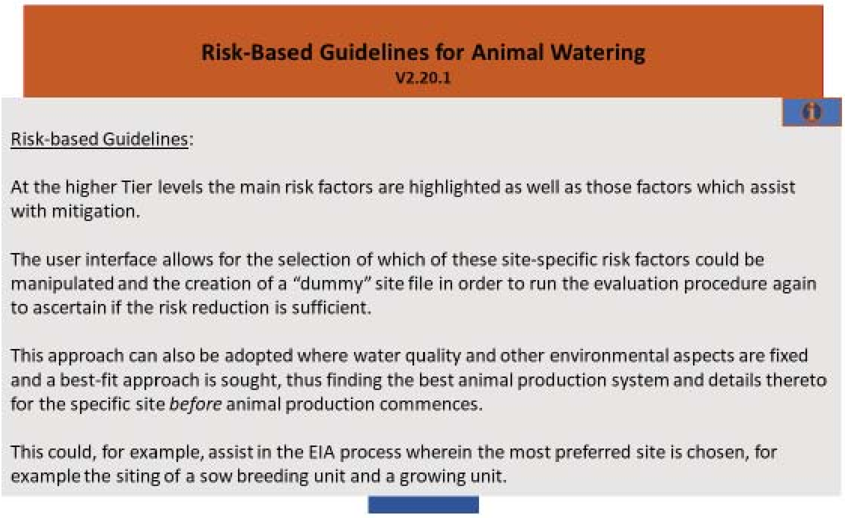


Figure 56: User Interface – Brief overview 17

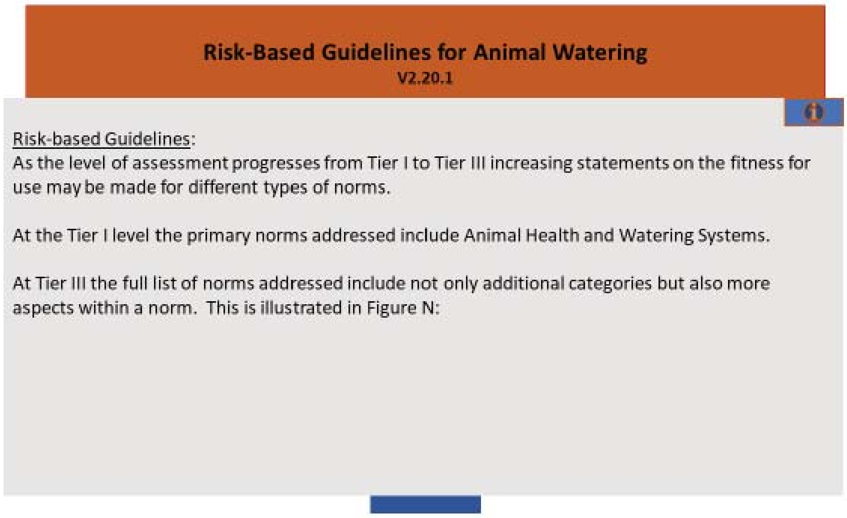


Figure 57: User Interface – Brief overview 18

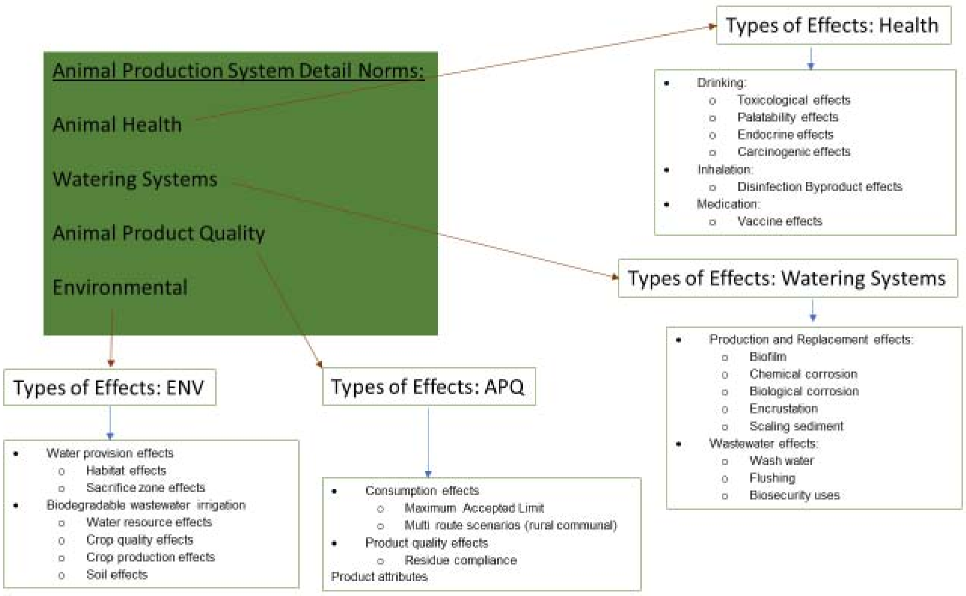


Figure 58: User Interface – Norms overview

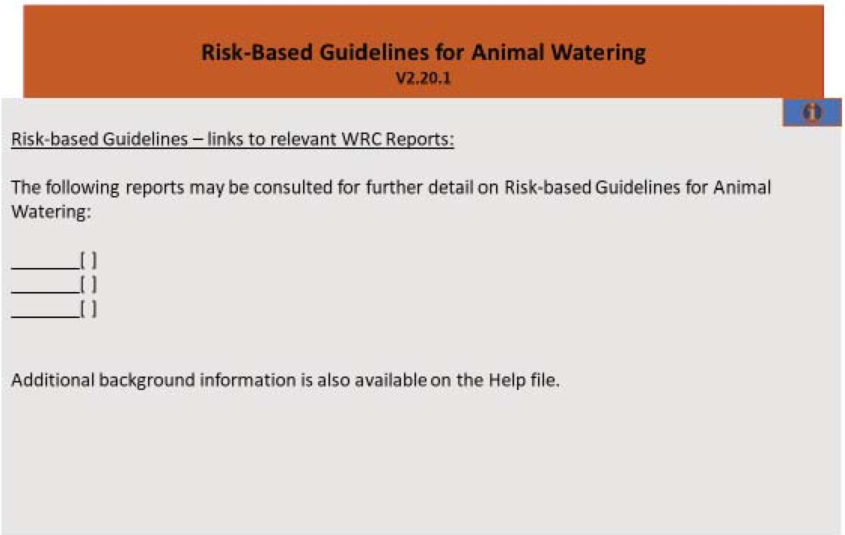


Figure 59: User Interface – WRC and reference documentation links

4.2. Tier User Interfaces in the DSS

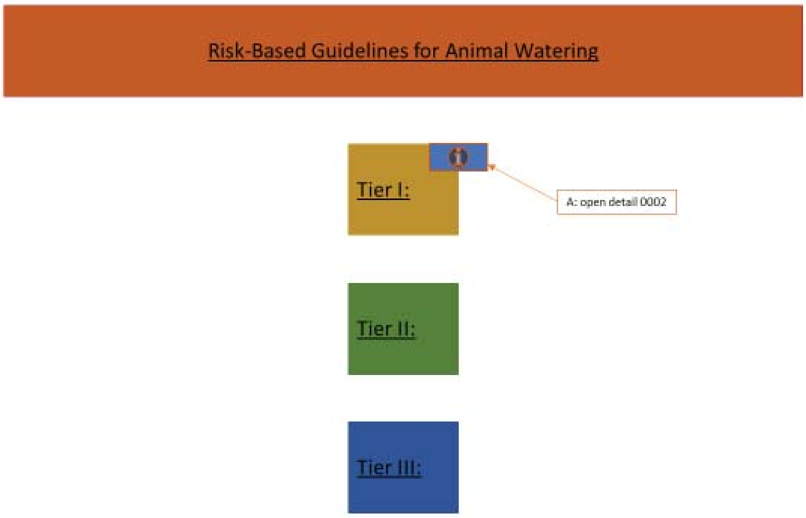


Figure 60: User Interface – Tier 1 opening

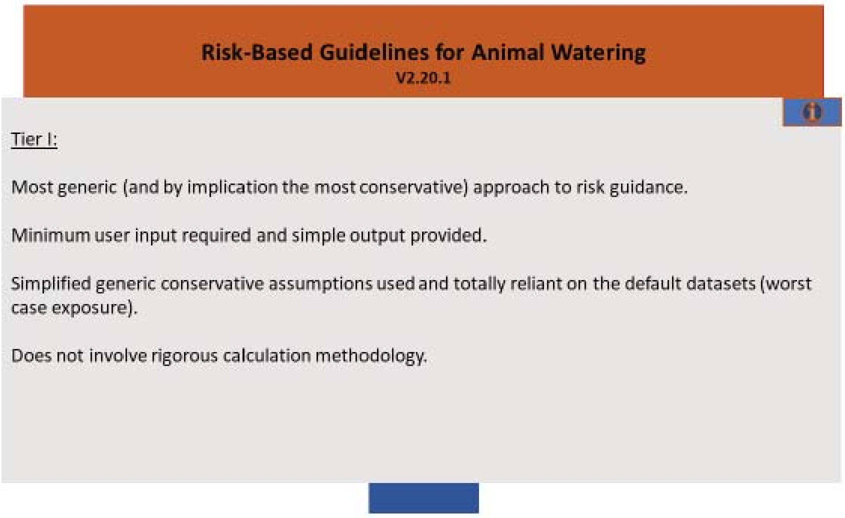


Figure 61: User Interface – Tier 1 introduction note

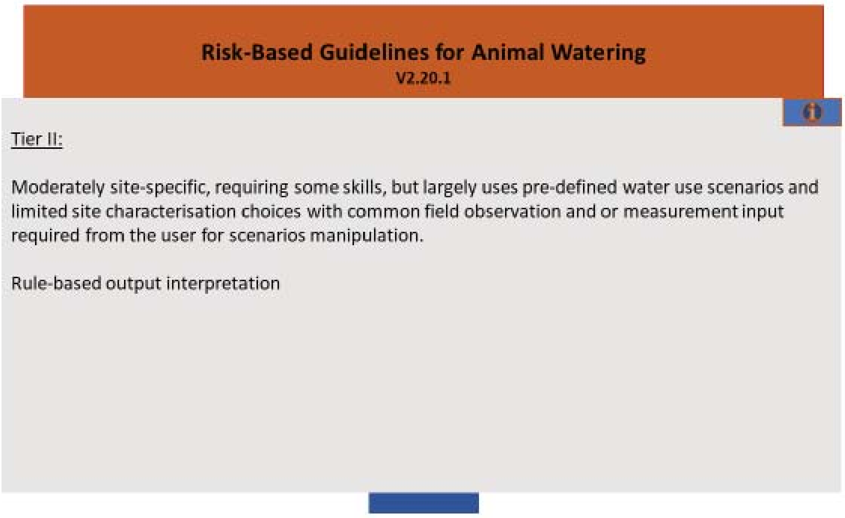


Figure 62: User Interface – Tier 2 introduction note

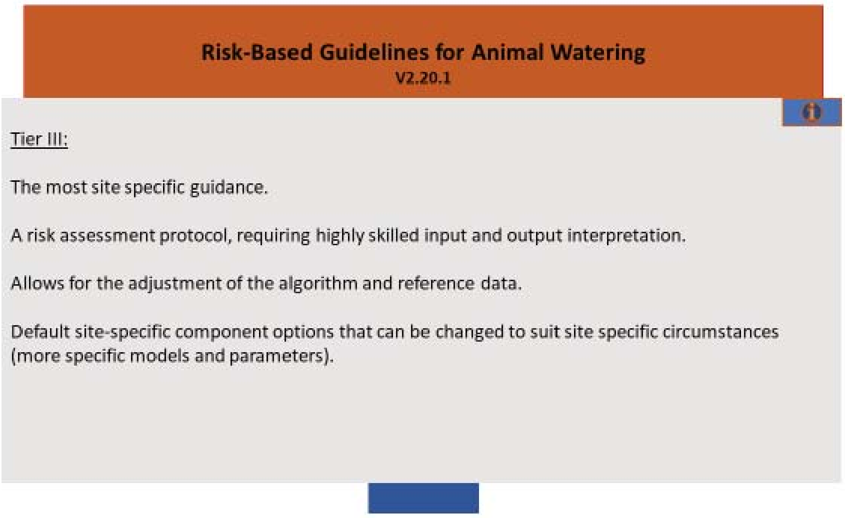


Figure 63: User Interface – Tier 3 introduction note

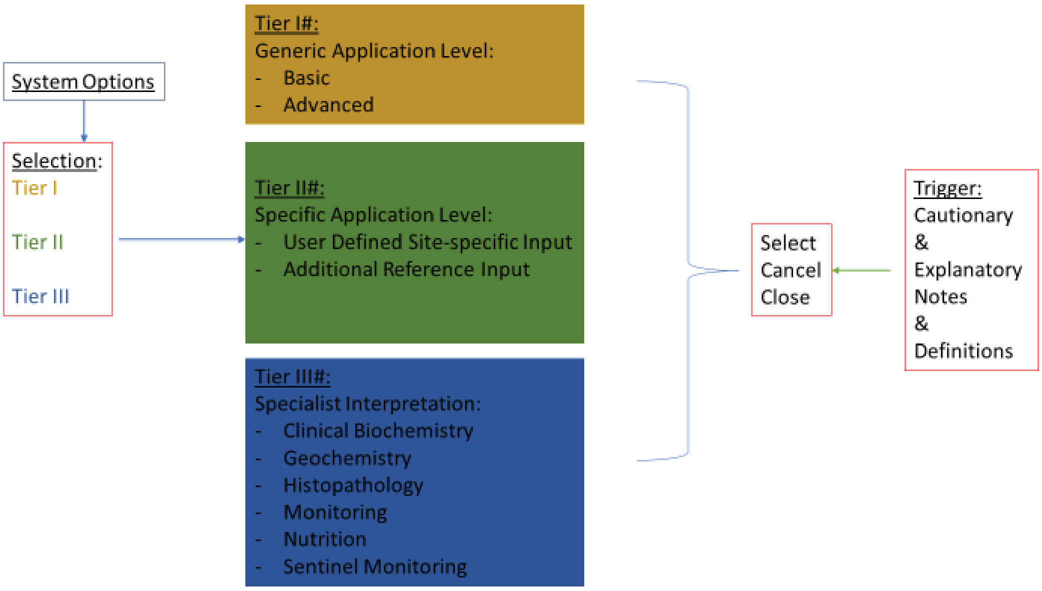


Figure 64: User Interface – Tier User Input Options

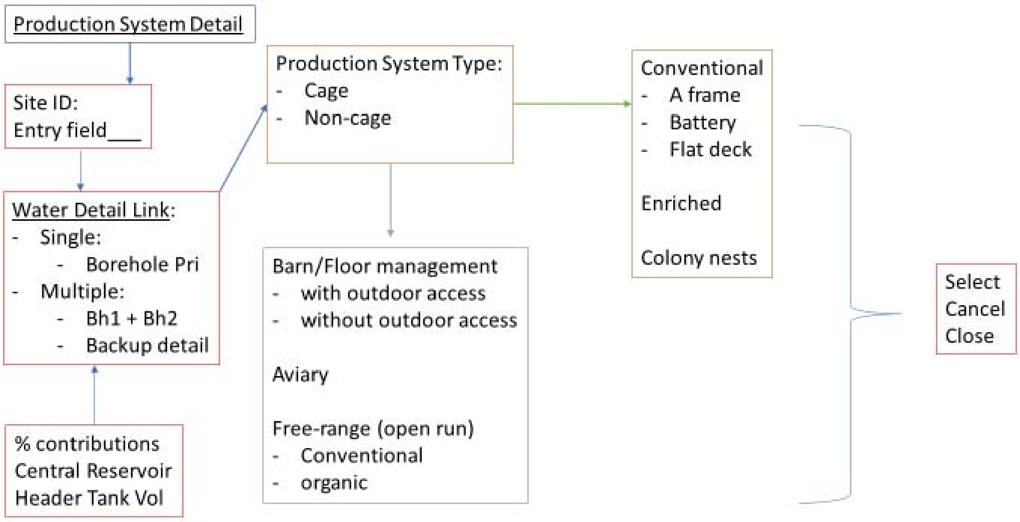


Figure 65: User Interface – Updated Production System detail by Animal Type

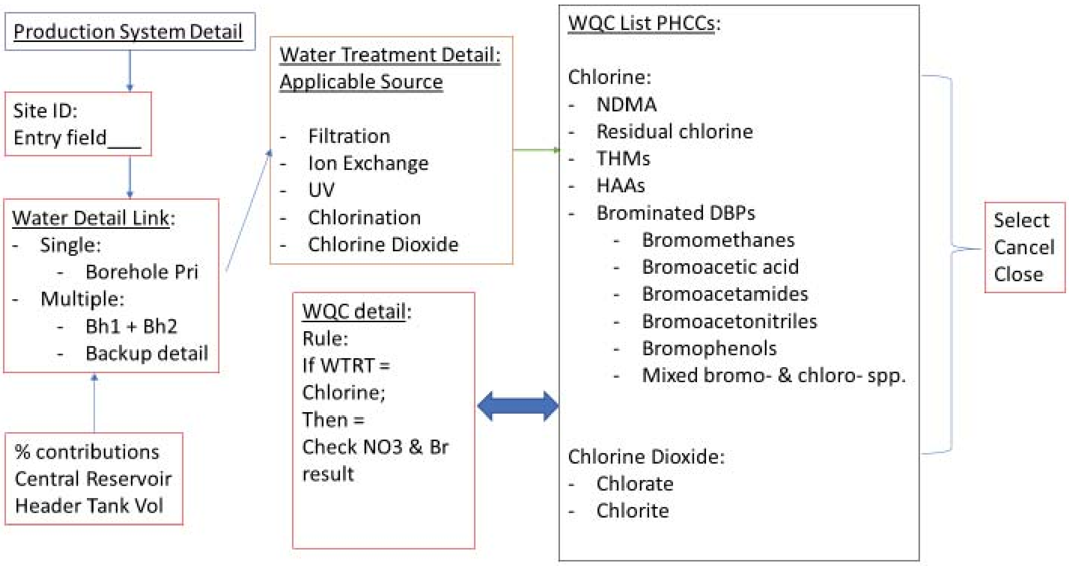


Figure 66: User Interface – Updated Water System Detail

The following figures highlight the differences in the WIRRD reference values (IRV) by means of a graphic comparison. This is provided as linking documents as supporting documentation may also highlight the central WIRRD reference material and a graphic representation may be easier for a varied user audience to assimilate.

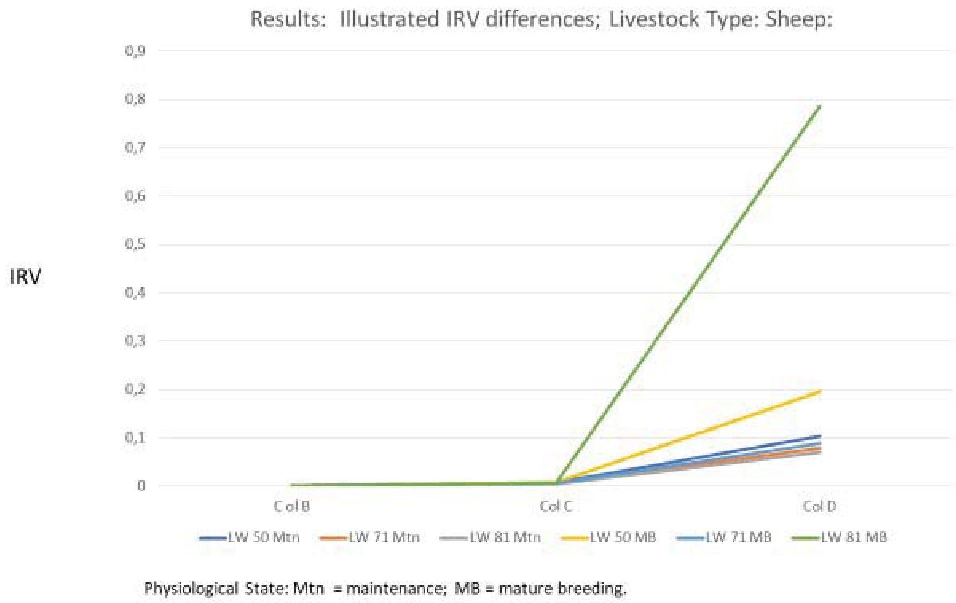


Figure 67: User Interface – Link to IRV comparison – sheep categories

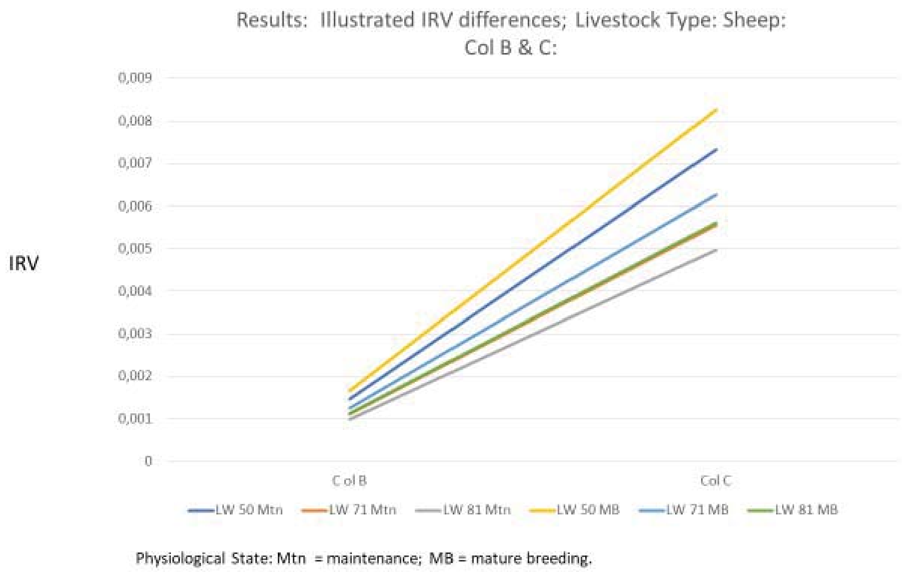


Figure 68: User Interface – Link to IRV – column B and C expanded

The following sets of figures highlight some of the user interface screens and data flows for Tier I, Tier II and Tier III respectively, with the DSS prototype referred to for more detail. Many of the changes effected are to cater for a different (simplified) user interface compared to the previous CIRRA software with improved data separation screens and tabs employed.

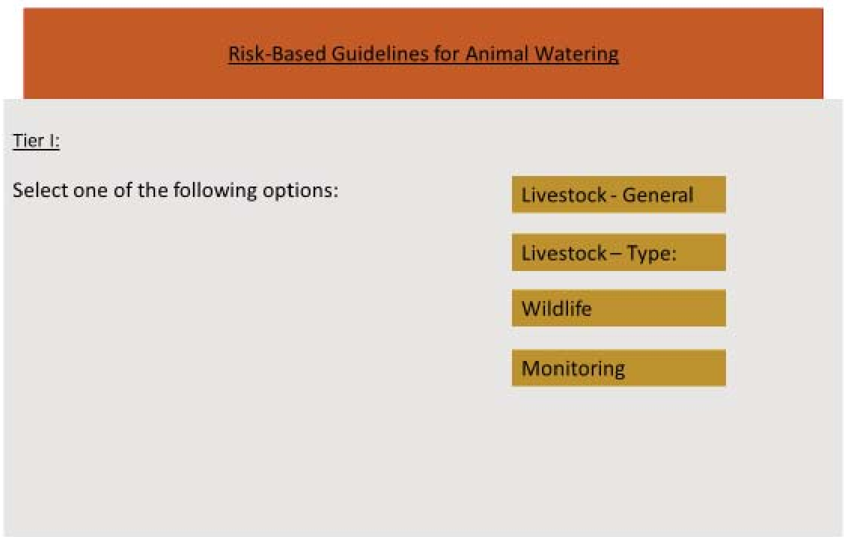


Figure 69: User Interface Tier I option example 1

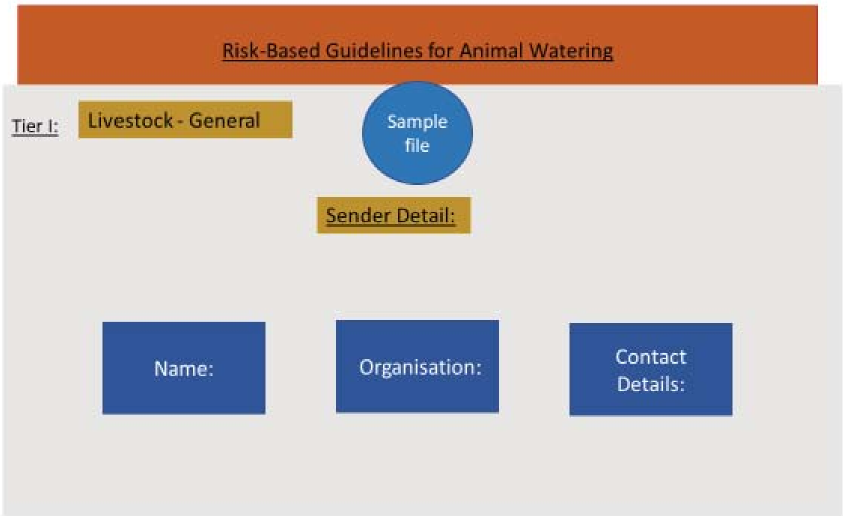


Figure 70: User Interface Tier I option 2

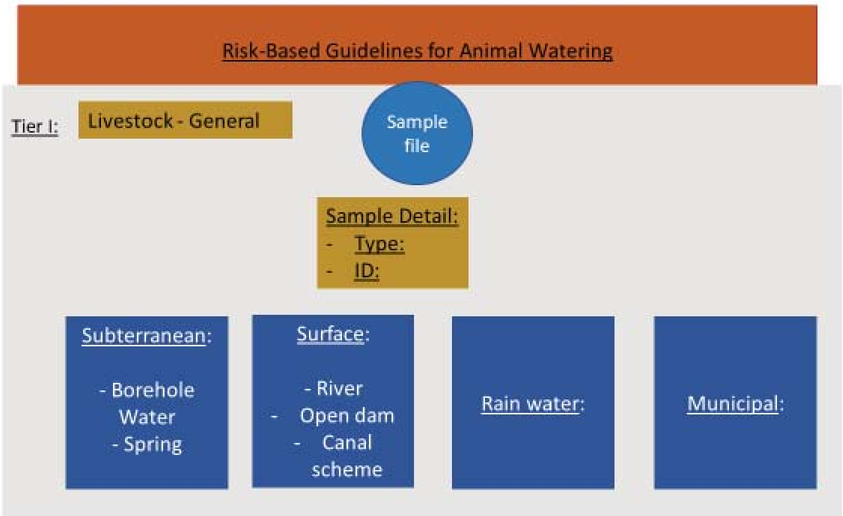


Figure 71: User Interface Tier I option 3

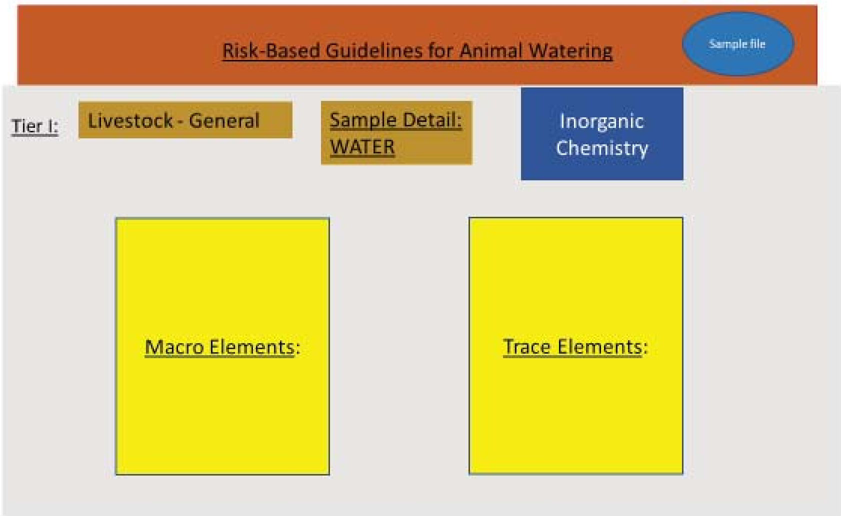


Figure 72: User Interface Tier I option 4

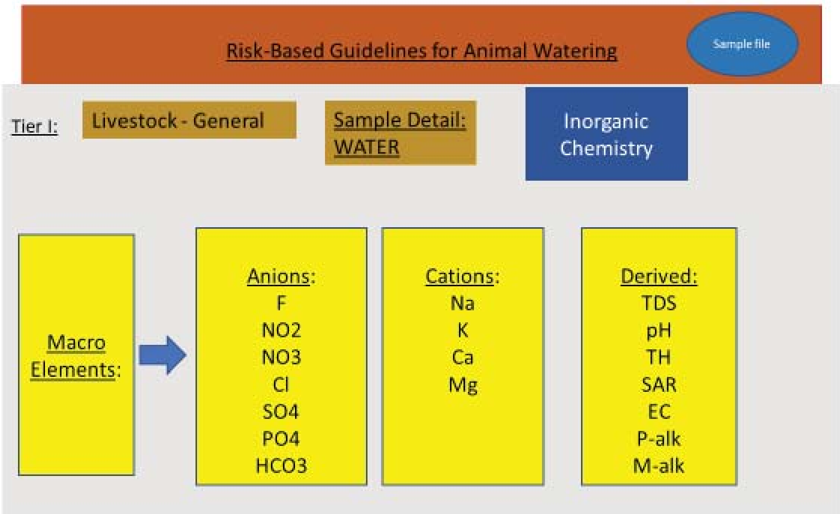


Figure 73: User Interface Tier I option 5

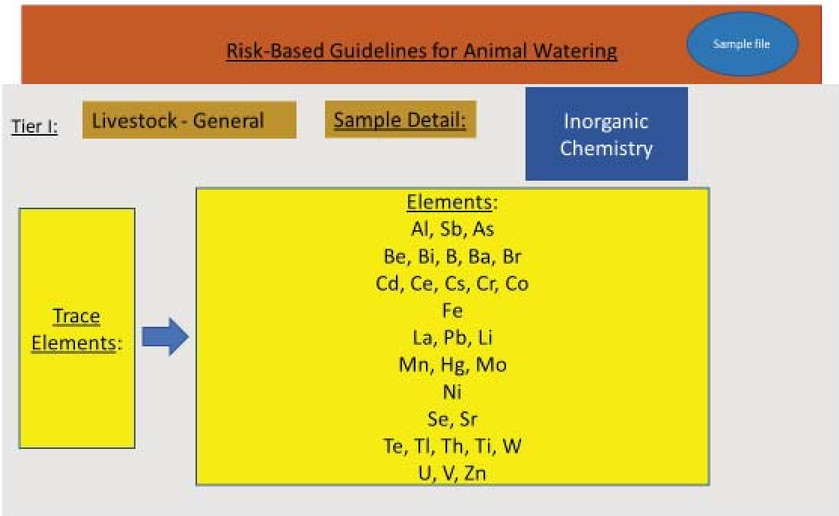


Figure 74: User Interface Tier I option 6

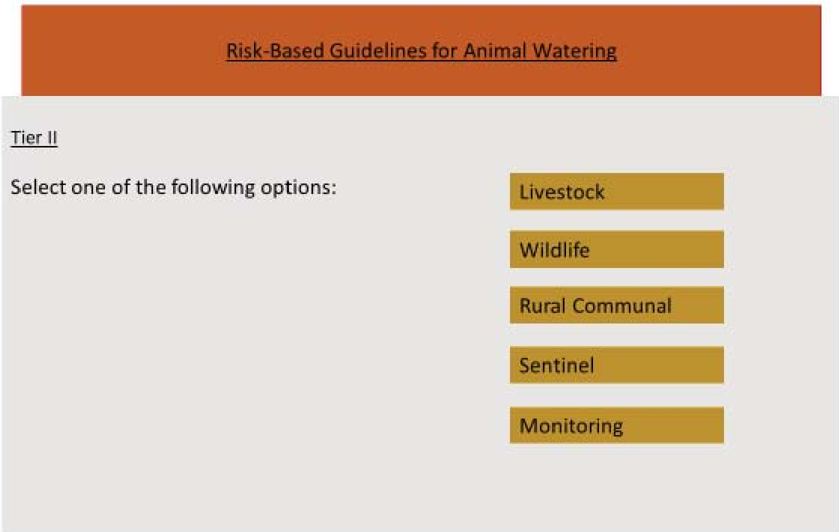


Figure 75: User Interface Tier II option 1

Figure 76: User Interface Tier II option 2

Figure 77: User Interface Tier II option 3

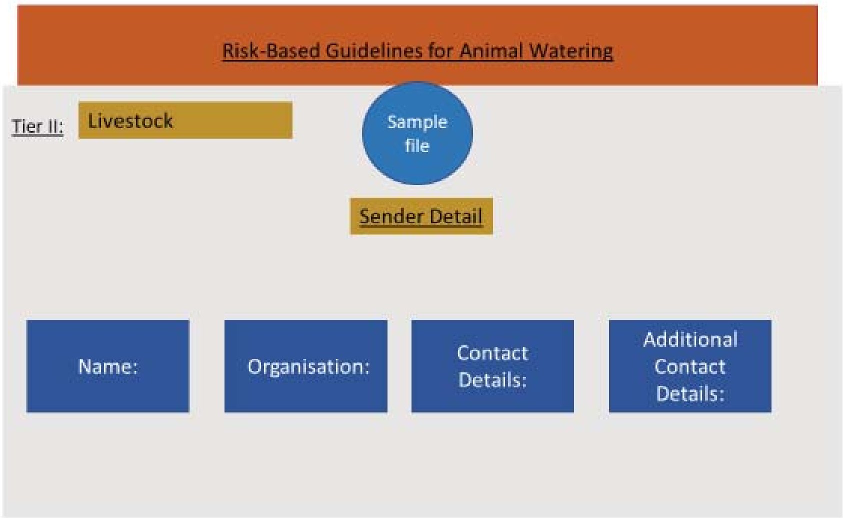


Figure 78: User Interface Tier II option 4

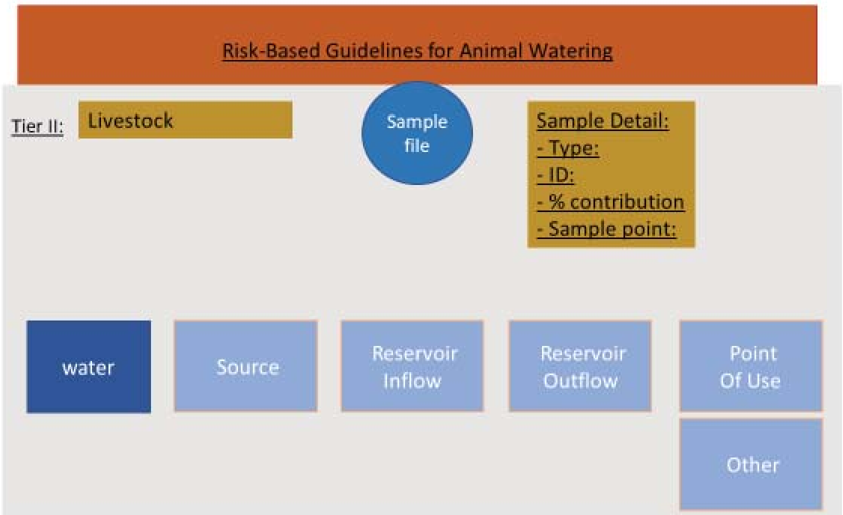


Figure 79: User Interface Tier II option 5

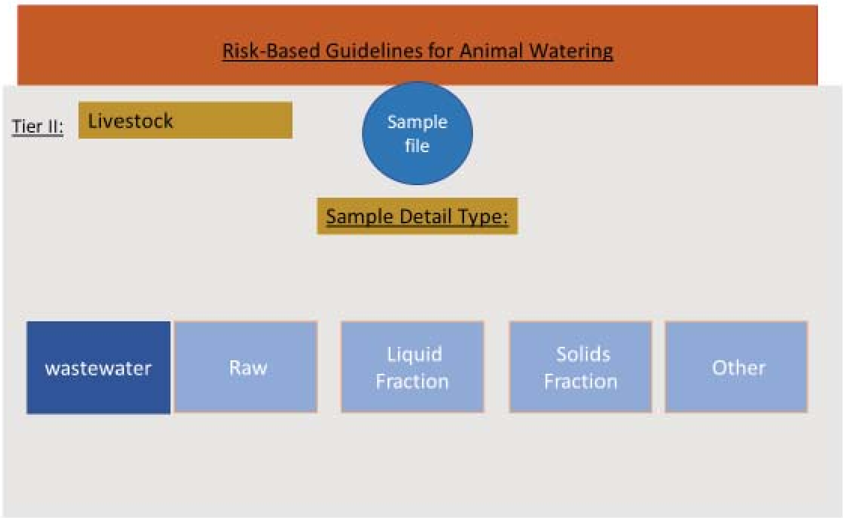


Figure 80: User Interface Tier II option 6

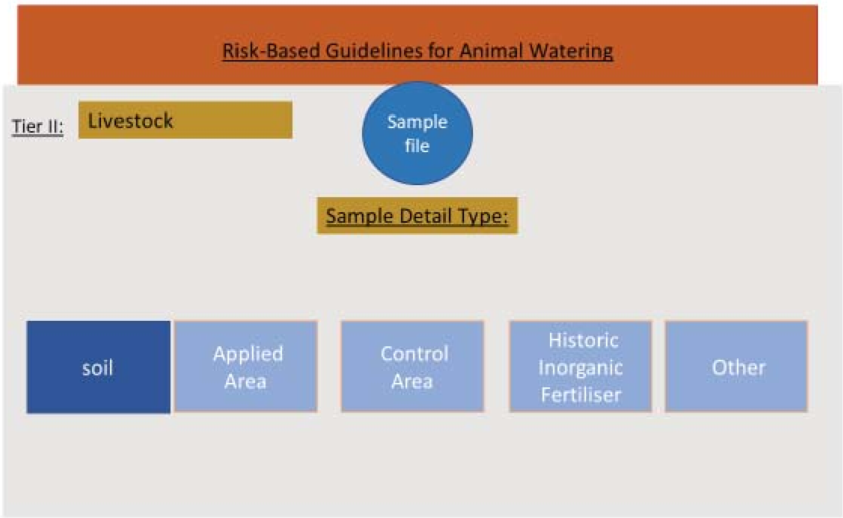


Figure 81: User Interface Tier II option 7

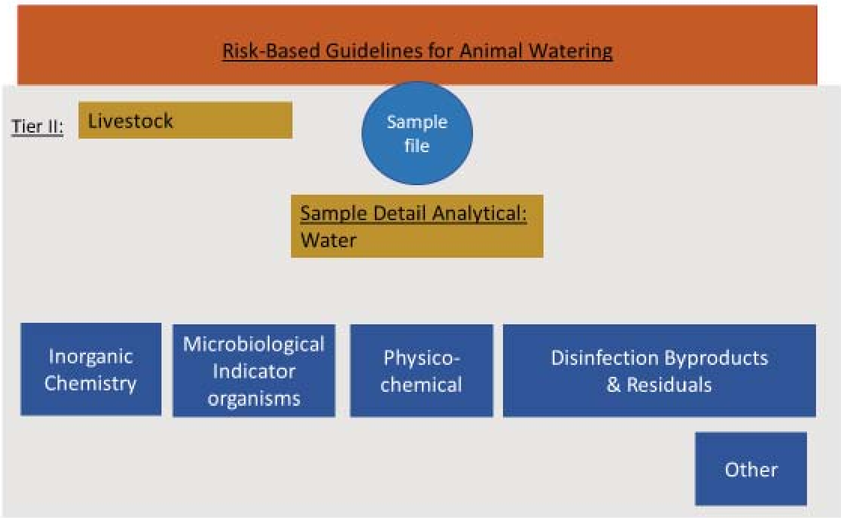


Figure 82: User Interface Tier II option 8

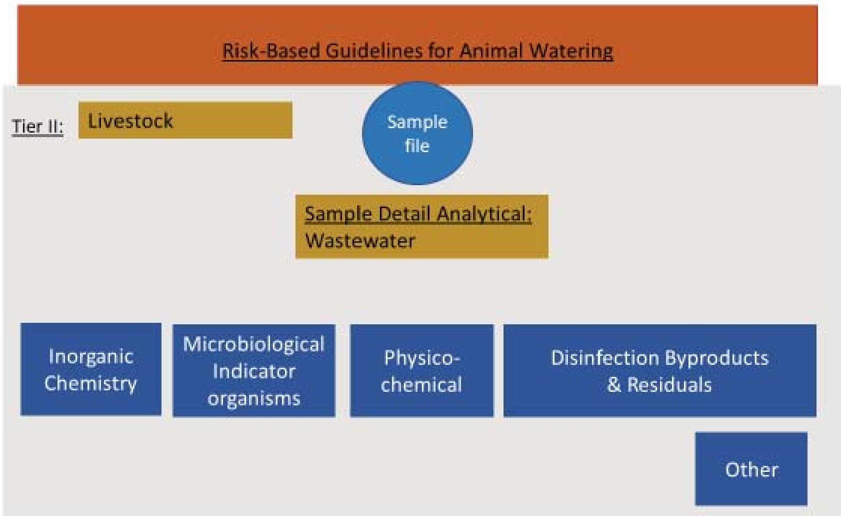


Figure 83: User Interface Tier II option 9

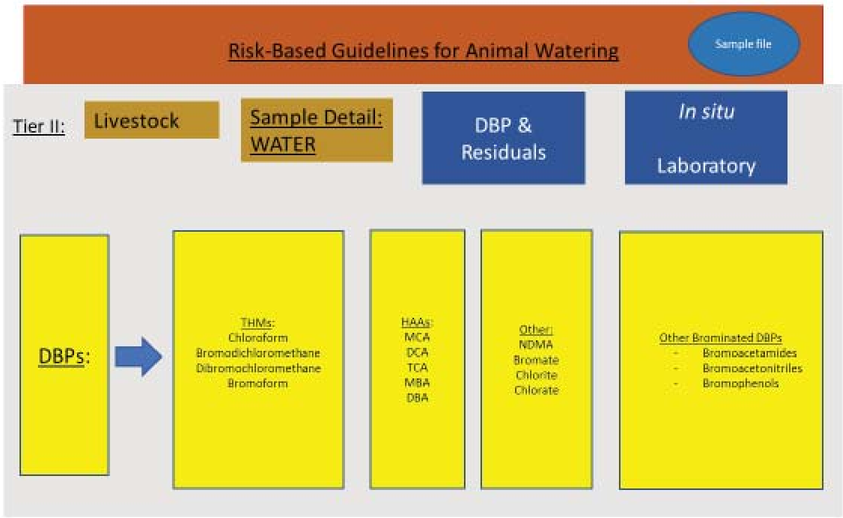


Figure 84: User Interface Tier II option 10

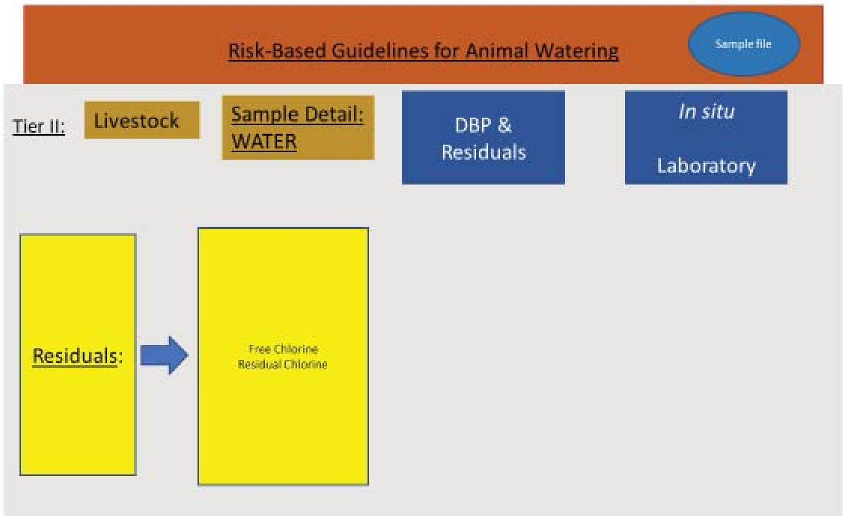


Figure 85: User Interface Tier II option 11

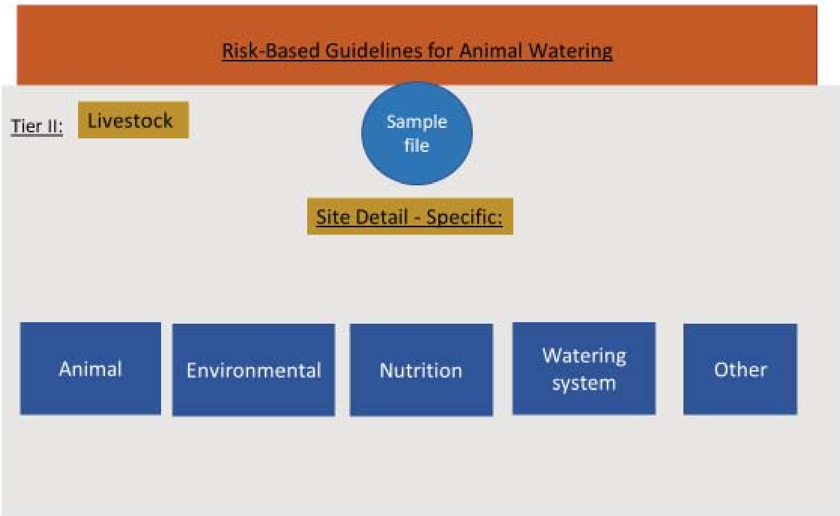


Figure 86: User Interface Tier II option 12

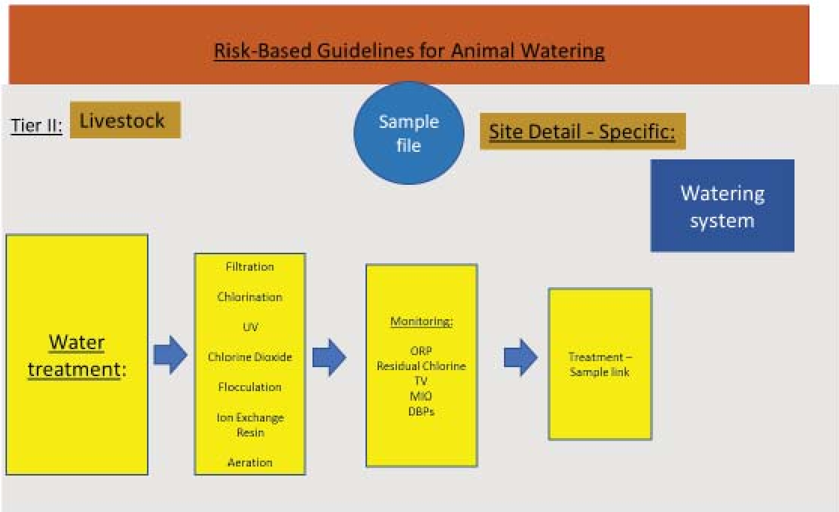


Figure 87: User Interface Tier II option 13

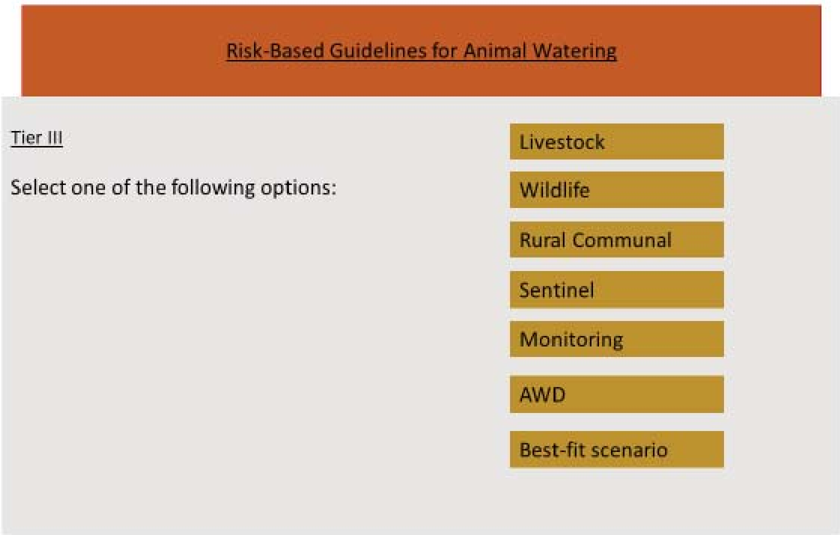


Figure 88: User Interface Tier III option 1

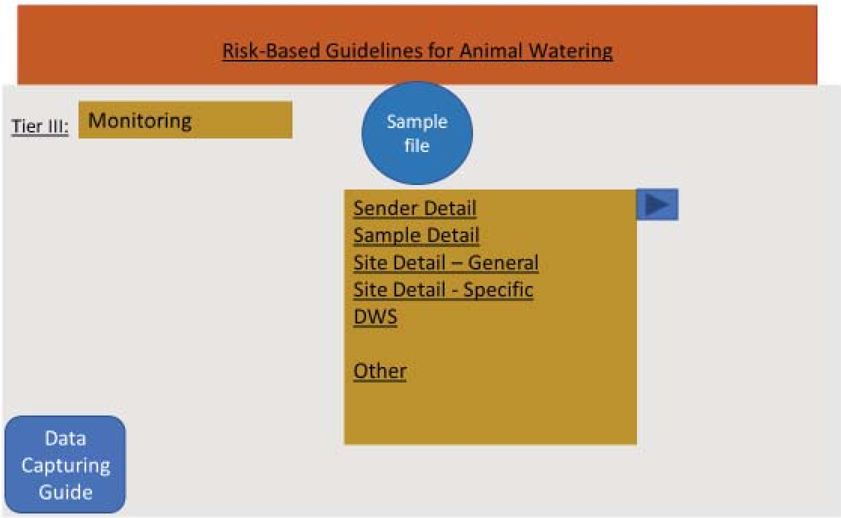


Figure 89: User Interface Tier III option 2

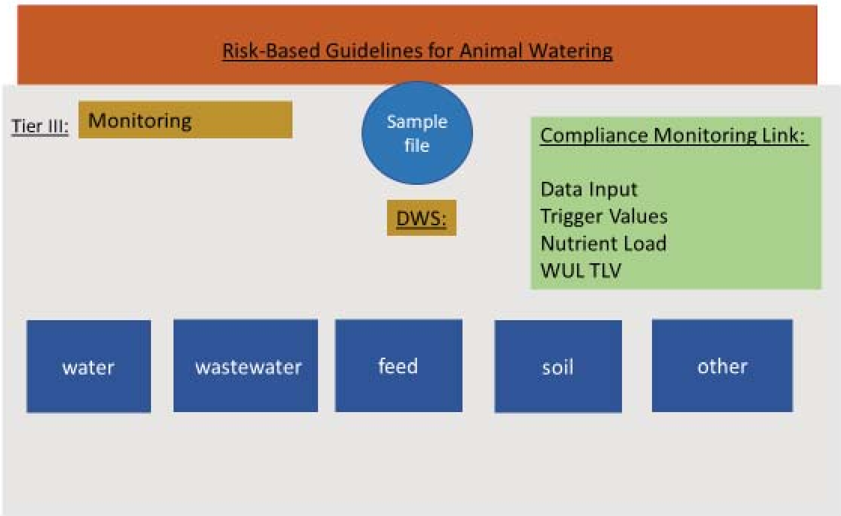


Figure 90: User Interface Tier III option 3

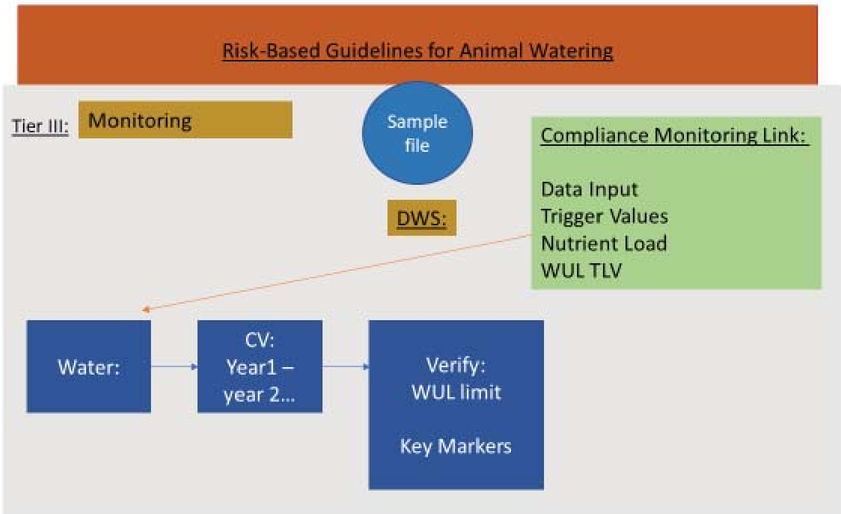


Figure 91: User Interface Tier III option 4

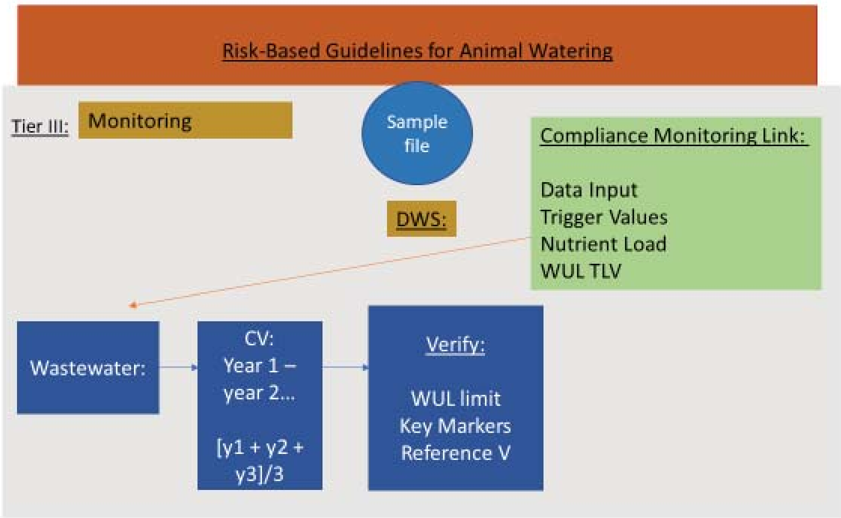


Figure 92: User Interface Tier III options 5

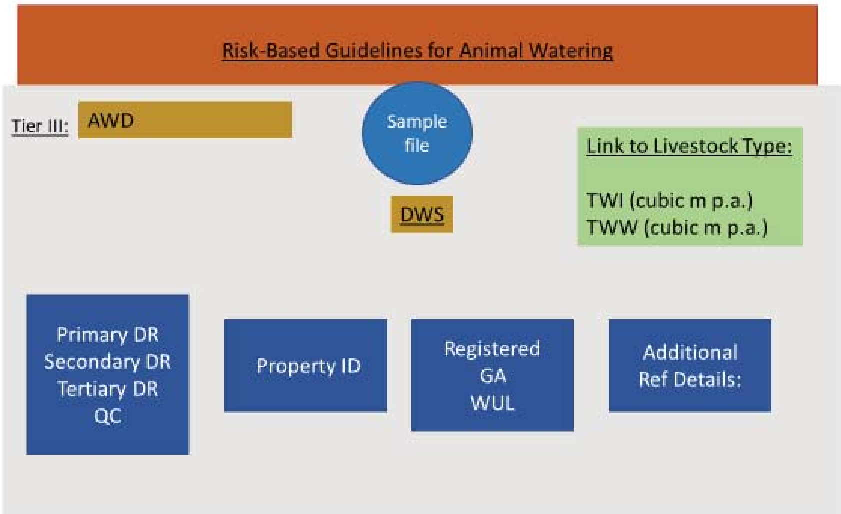


Figure 93: User Interface Tier III option 6

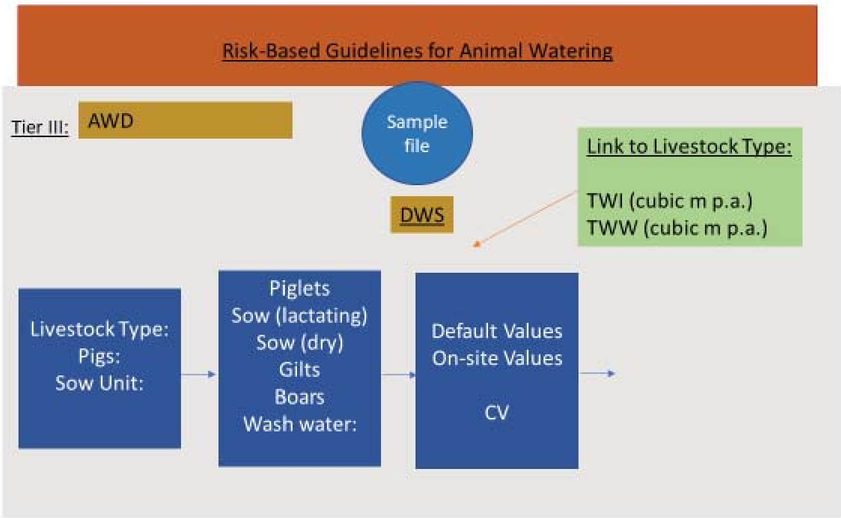


Figure 94: User Interface Tier III option 7

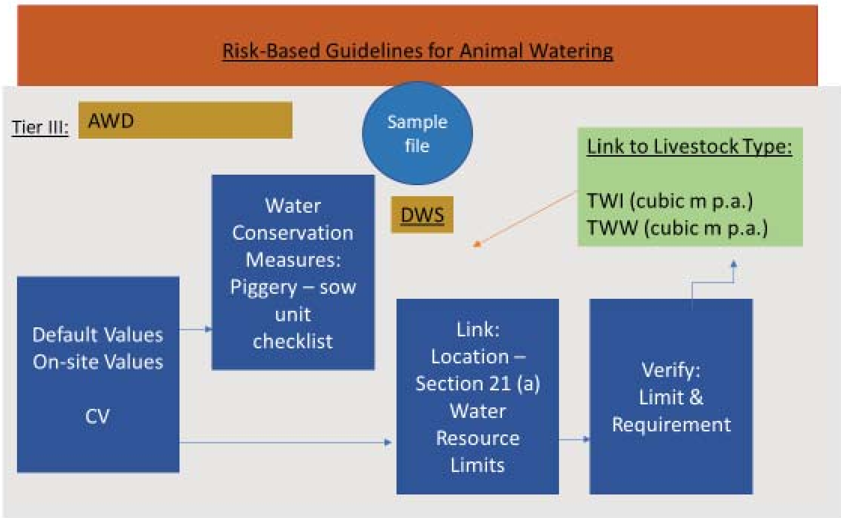


Figure 95: User Interface Tier III option 8

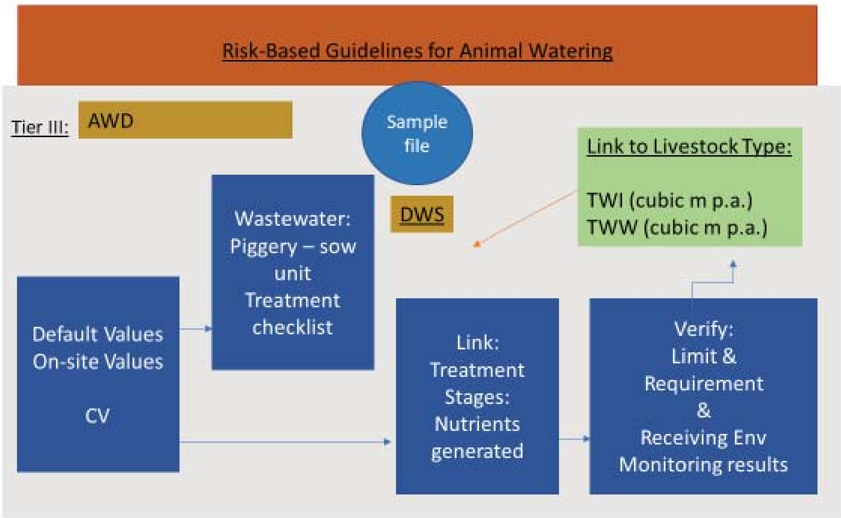


Figure 96: User Interface Tier III option 9

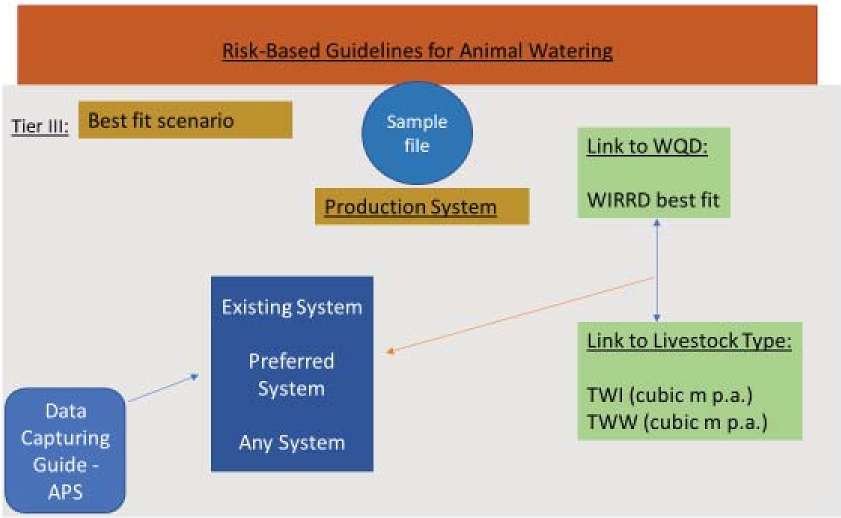


Figure 97: User Interface Tier III option 10

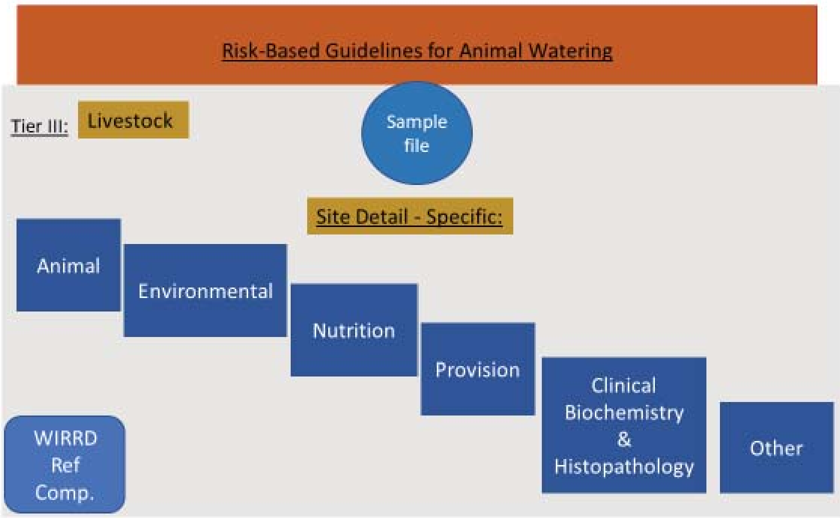


Figure 98: User Interface Tier III option 11

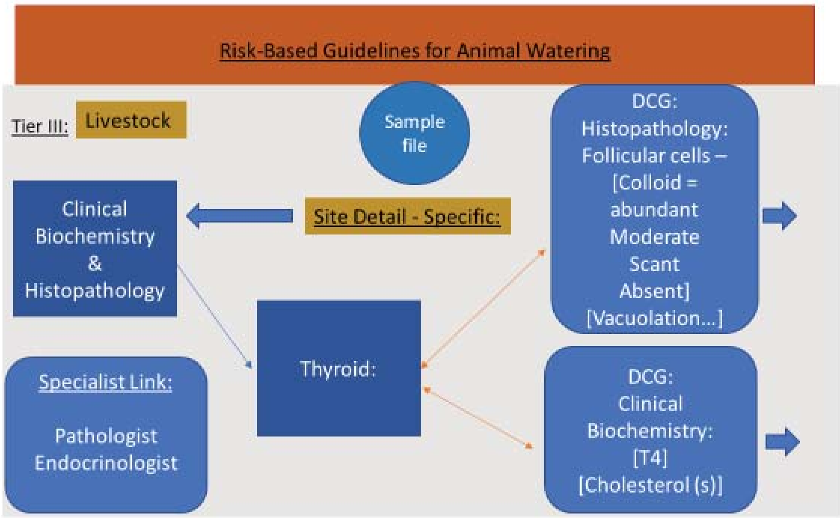


Figure 99: User Interface Tier III option 12

The next set of figures highlight the user interface for the Results screens for the various tiers with the initial images providing an overview thereof. It is again stressed that the detail in terms of variance reporting and the creating of several options of dummy sample files to test risk factor reduction outcomes has been described in the previous deliverables and remains a key benefit in the risk-based DSS approach for multiple water and animal user options.

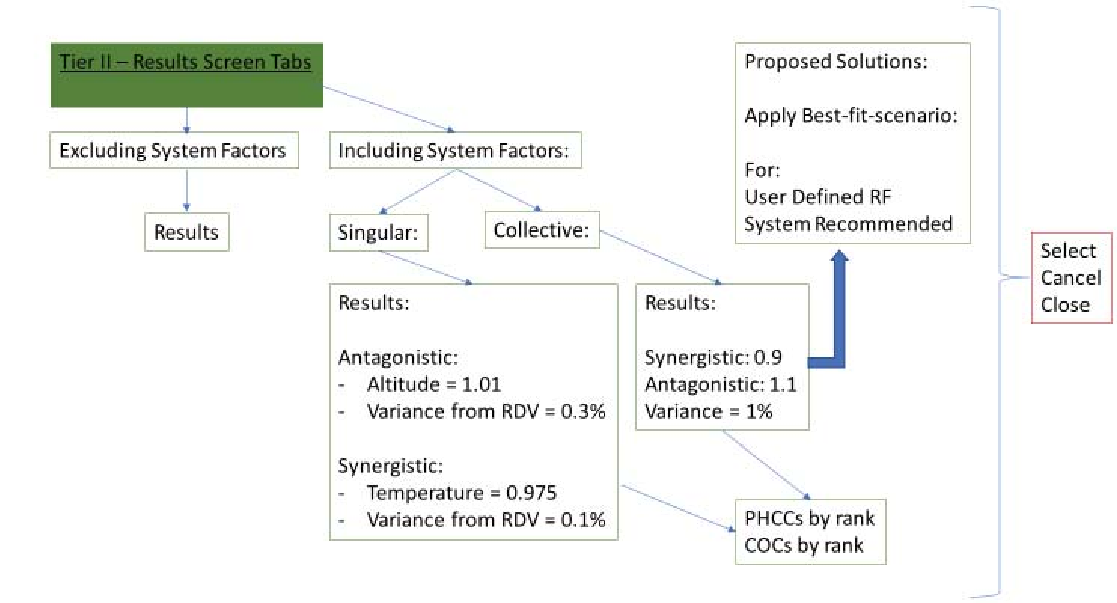


Figure 100: User Interface – results overview – Tier II

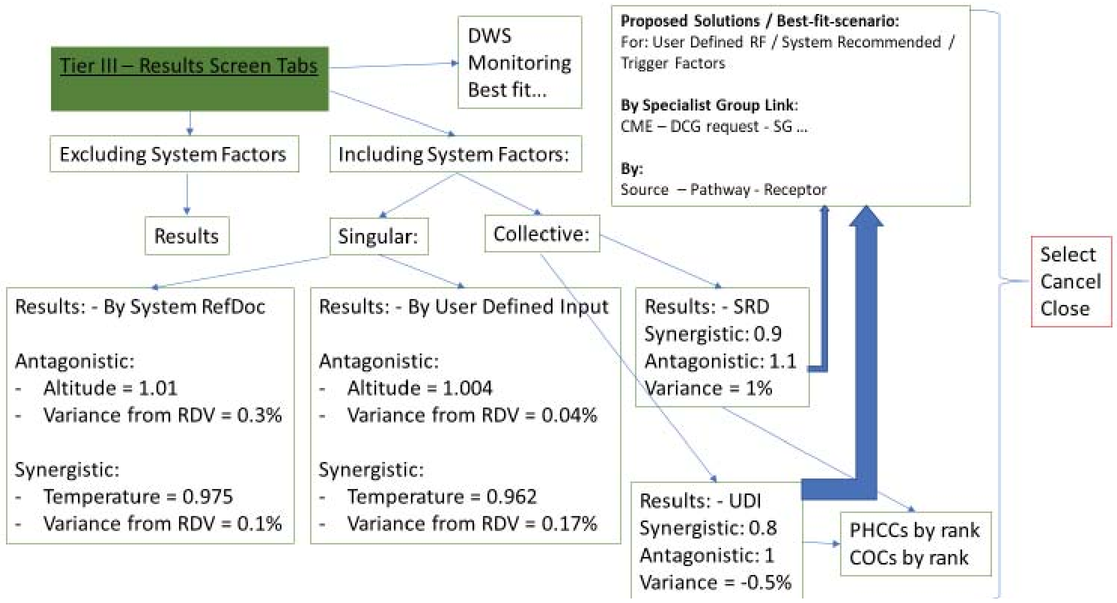


Figure 101: User Interface – results overview – Tier III

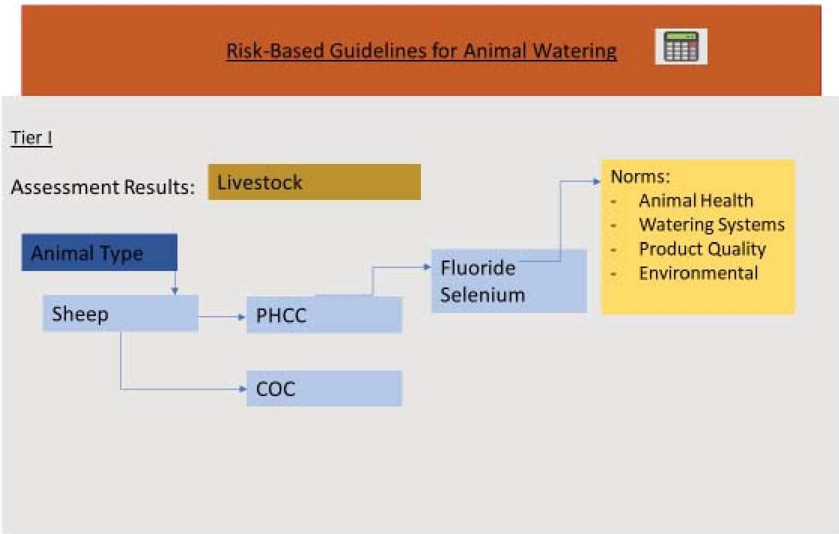


Figure 102: User Interface – Tier I results screen 1

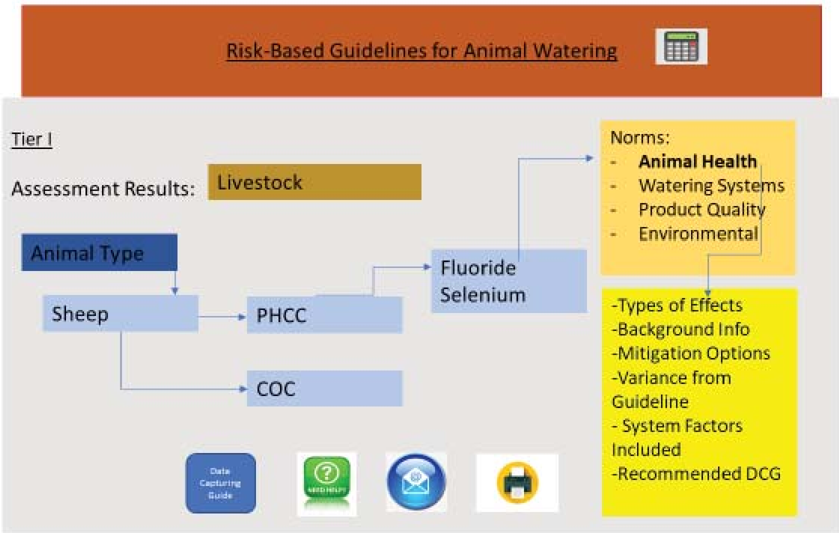


Figure 103: User Interface – Tier I results screen 2

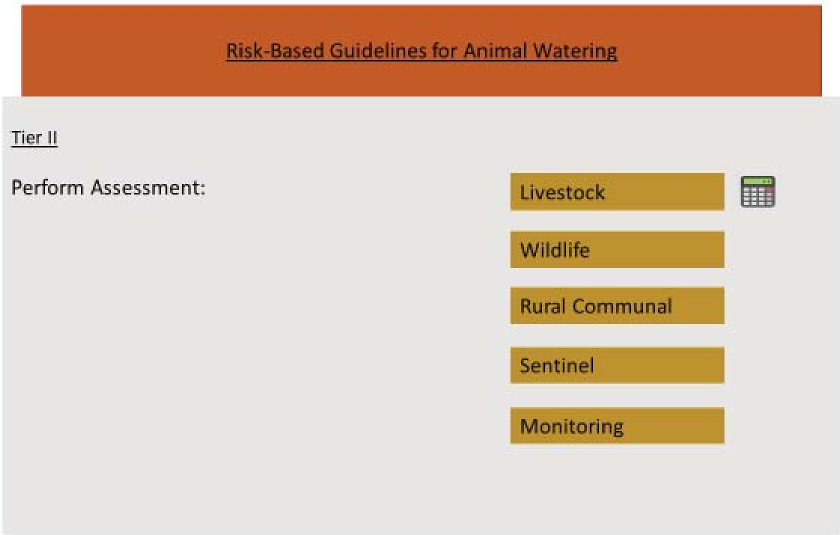


Figure 104: User Interface – Tier II results screen 1

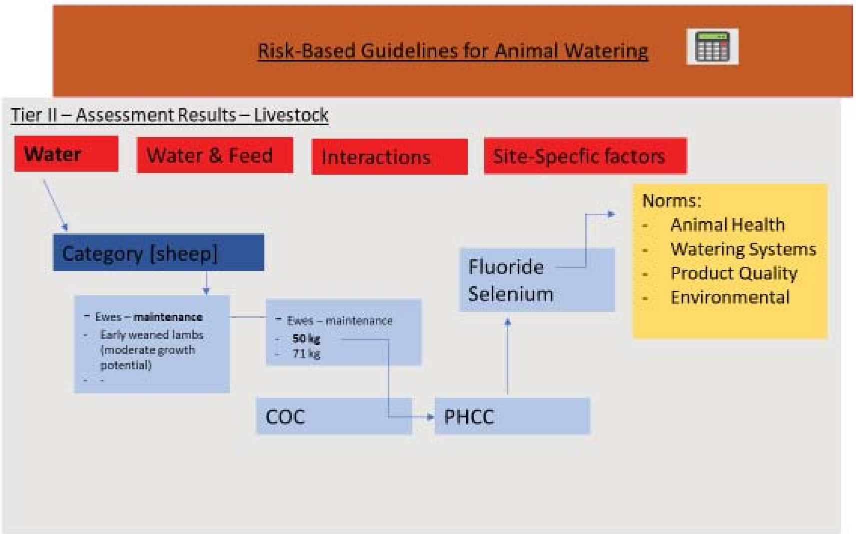


Figure 105: User Interface – Tier II results screen 2

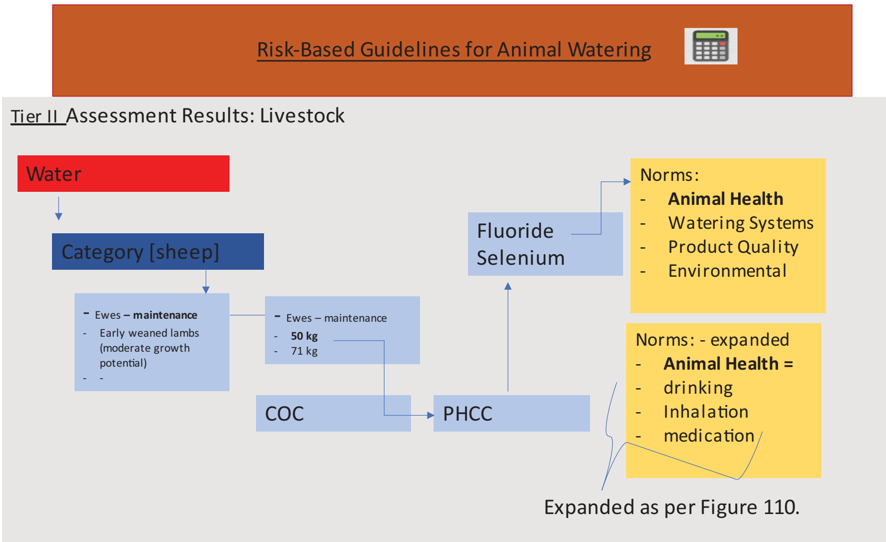


Figure 106: User Interface – Tier II results screen 3

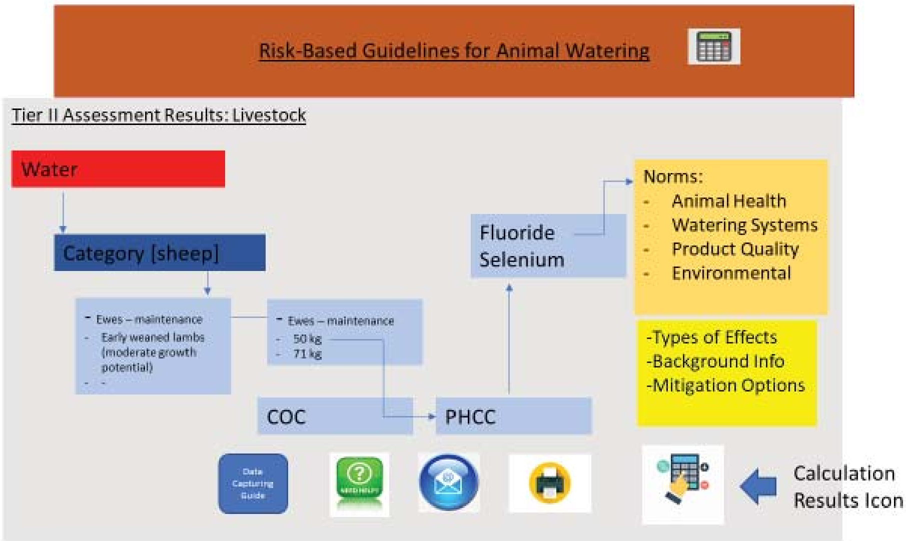


Figure 107: User Interface – Tier II results screen 4

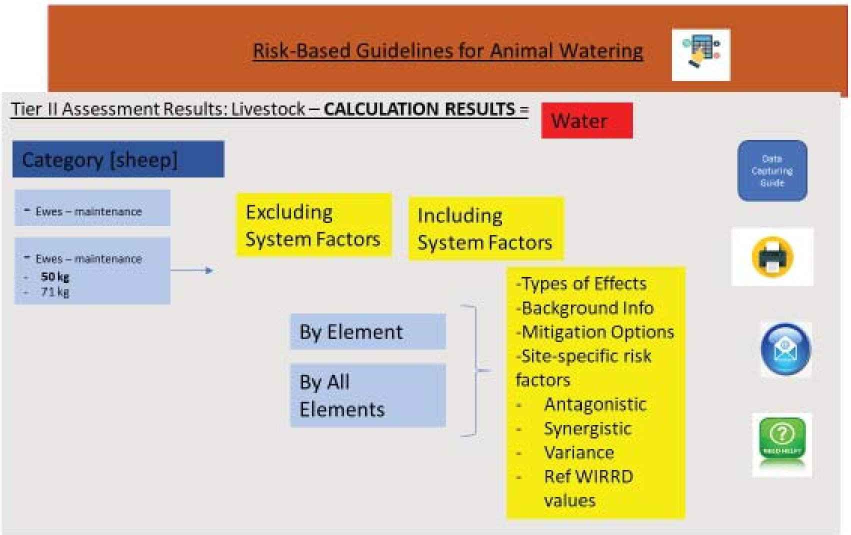


Figure 108: User Interface – Tier II results screen 5

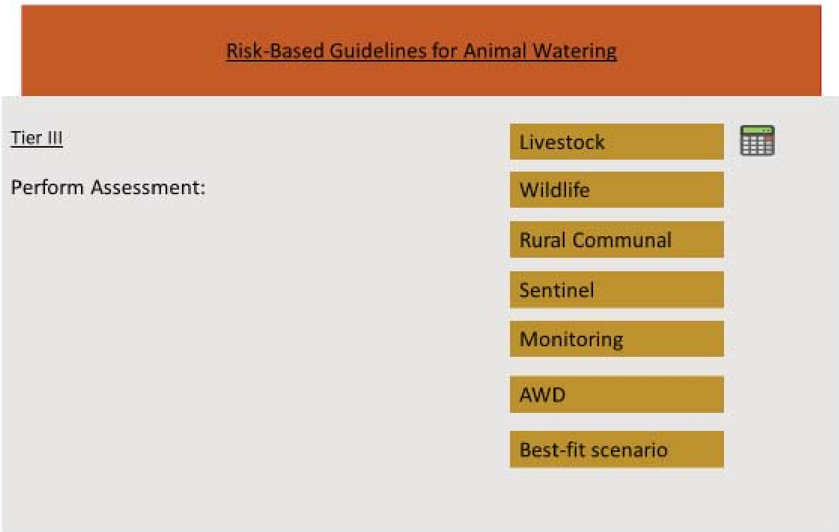


Figure 109: User Interface – Tier III results screen 1

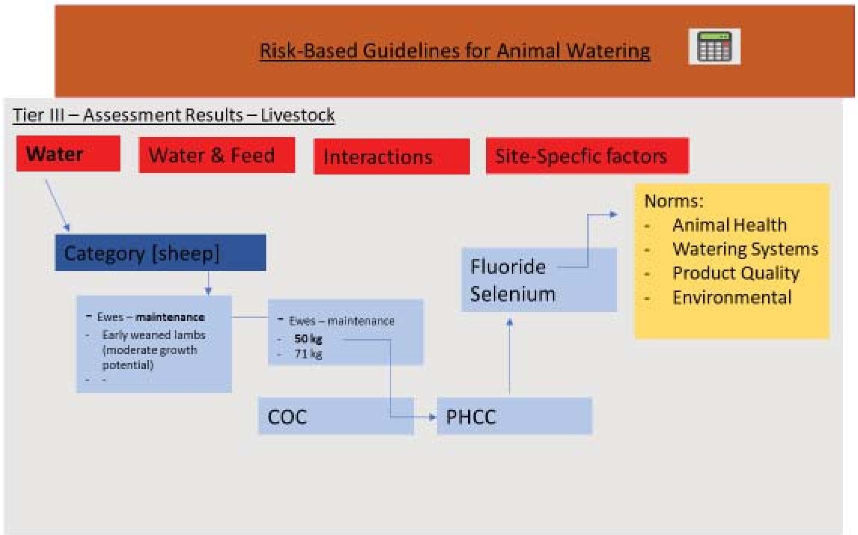


Figure 110: User Interface – Tier III results screen 2

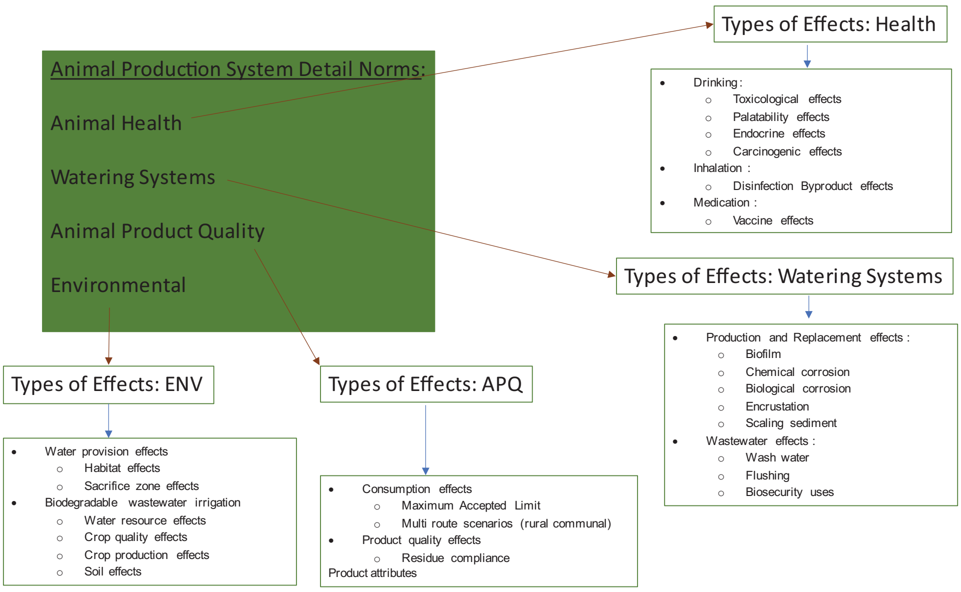


Figure 111: User Interface – Tier III results screen 3

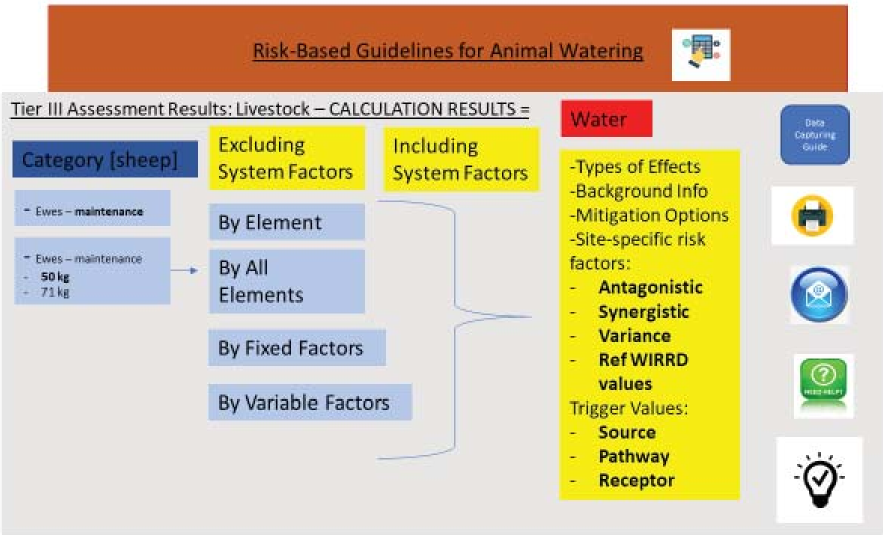


Figure 112: User Interface – Tier III results screen 4

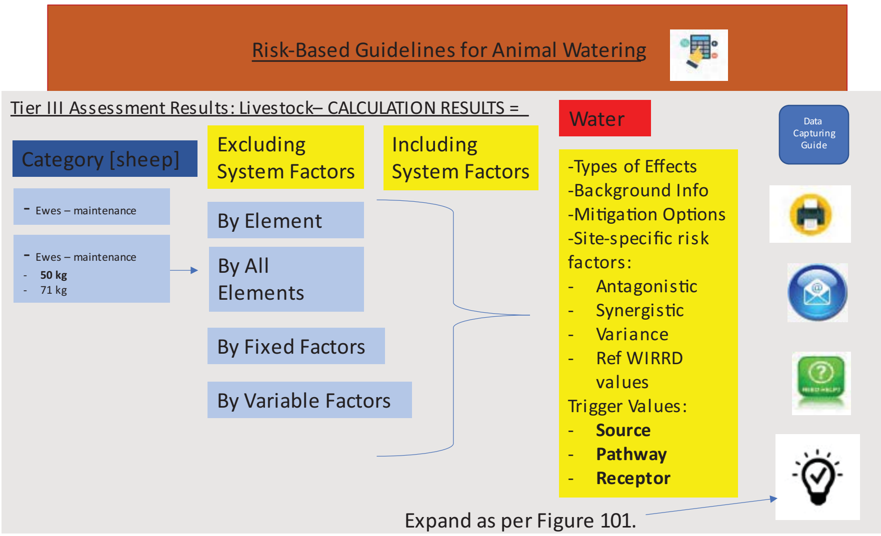


Figure 113: User Interface – Tier III results screen 5

4.3. Towards a fully functioning DSS

Although the prototype DSS provides an overview of the user interface aspects, in the absence of a working software system (complete with source code, reference documentation and modelling algorithms), there are several issues which cannot be achieved or demonstrated.

The objective of the DSS to provide guidance by estimating risk, highlighting the applicable risk factors and providing a method for attempting to reduce them to an acceptable risk level. The ability to guide the user through pop-up notes to try system-recommended approaches, or to apply user-defined or selected approaches is a key aspect of functionality which does what the risk-based guidelines are intended to do, namely offer guidance. This aspect may only be fully appreciated with an actively operating DSS.

There are several additional functionalities which are also not demonstrated, specifically the linkages to external relational data bases and the ability to collect and import data using new methodologies, for instance applications from mobile devices. It should be acknowledged that many farming activities, from plant production to animal housing systems, can be controlled by external or remote devices.

In addition to the extensive reference documentation previously coded into the CIRRA software newer site-specific data inputs are available which are also linked to management software and thus other DSSs. Incorporating these will be production system type and category specific but will nonetheless be a viable method of including vast amounts of production system information into the assessments performed.

The incorporation of Tier III specialist activities is of major benefit in reducing uncertainty and offers a cost-effective approach to assessing the final outcome following exposure in animals to multiple potentially hazardous chemical constituents and constituents of concern from multiple exposure sources, pathways and receptors. The ability to evaluate the outcomes of water-quality risk-based directed guidance via clinical biochemistry and histopathology is increasingly used in practice to investigate the outcomes without having to identify all the complexities applicable. This step enables more targeted interventions and data capturing guides to be compiled which is a more cost-effective approach and an ever-increasingly important consideration.

The ability to also include water quality investigation information towards both compliance monitoring and national database generation should be noted as a fundamental requirement towards achieving the stated objectives of the National Water Act (Act No. 36 of 1998) and a functional DSS as intended would easily cater for this and assist greatly in reducing the uncertainties which exist with individual sample or production system investigations.

As detailed earlier, whilst the focus is initially water quality, it is again stressed that without due regard for total exposure, site-specific factors and water resource objectives, the guidelines will fail to the achieve meaningful mitigation and thus risk-factor reduction required to use water resources more efficiently.

5. CONCLUSION AND RECOMMENDATIONS

The need for changes to be made to the water quality guideline format from the previous 1993 and 1996 South African Water Quality Guidelines for Agricultural Use, Livestock Watering, was acknowledged with subsequent changes in philosophy and the recognition of the complexities relating to fitness for use leading to the need for a risk-based approach to water resource management.

It is prudent to reflect that water resource quality data and clinical challenges experienced in the animal production sector have supported this need for a risk-based approach as a viable means to effectively manage the available water resources for the agricultural sector users and achieve the objective of optimal utilisation of available water resources.

The reality of water quality having to be used which does not comply with local or international recommended limits within an environment characterised by a wide range of animal production systems, increasingly including those with a production setting where advances in animal genetics, housing, nutrition, health management and production systems have yielded high level performance targets as a fundamental component to commercial viability, have led to the recognition in South Africa and elsewhere internationally, that a concentration-based mg/L target approach is insufficient with which to effectively achieve the production system fitness for use needs.

It is also increasingly apparent that the link between water activities, from abstraction, storage to wastewater generation and subsequent storage and beneficial reuse, has to be embraced by both the competent authorities and the agricultural water users. The foundation of this link lies in a greater understanding of the impact on the fitness for use by impacts on the water resources available, with this link sharing a common basis in the analytical monitoring data required to both assess fitness for use and resource impacts, but nonetheless requiring the water quality guidelines to have a more diverse user audience.

The intention of the guideline update conducted for this research project is to present a final product that provides a series of tiered assessment levels to support a greater diversity of guideline use which facilitate more accurate risk-based assessments on the fitness for use of water for animal watering. The fundamental objective is to assist decision making by improving the science behind the assessments. The driving motivation behind the development of a DSS is to improve the accuracy with which water quality effects are predicted and assessed, which are key requirements to enabling the existing water quality challenges in South Africa to be addressed and water resources to be more optimally utilised.

The DSS developed provides guidance by estimating risk, highlighting the applicable risk factors and providing a method for attempting to reduce them to an acceptable risk level. This has been accomplished by numerous changes to the previous Constituent Ingestion Rate Risk Assessment model with a new modelling approach developed and presented in the form of a DSS.

Whilst several new methodologies have been employed in the risk assessment process, the Tiered approach linked to a Source, Pathway and Receptor adjustment system, is one of the key new processes by which much needed specialist input from multidisciplinary fields may be incorporated.

Uncertainty still exists, however, and is similar to other recognised source, pathway and receptor assessment uncertainty factors, including:

- Source factors:
    - Inaccurate sampling
    - Lack of sufficient sampling
    - Analytical limitations and errors
    - Incomplete selection of required constituents

- Pathway factors:
    - Inherent uncertainty in the predictions and estimates made.
    - Lack of sufficient sampling
    - Analytical limitations and errors
    - Trend analysis with future prediction uncertainty due to both predictive uncertainty and variables beyond control (e.g. seasonal influences)

- Receptor factors:
    - Extrapolation accuracy between types and categories
    - Lack of sufficient sampling
    - Analytical limitations and errors
    - Incomplete selection of required constituents
    - Low predictive accuracy for low-probability events
    - Outcome of multiple exposure scenarios (constituent-constituent interactions)

- Reference Data:
    - A lack of appropriate reference data for Source, Pathway and Receptor aspects

Whilst it is thus appreciated that uncertainties exist, the WIRRD approach and basis of looping sample assessments with increasingly higher Tier applications based on the acquisition of more targeted site-specific information, does assist in lowering the uncertainty. As noted previously, the high number of normal parameters reflective of the performance of the animals within the production system does assist in evaluating the accuracy of the risk statements provided, noting that proactive management remains a key requirement as subclinical adverse effects may not be routinely detected, be irreversible, and result in significant commercial losses.

Whilst the focus is initially water quality, it is again stressed that without due regard for total exposure, site-specific factors and water resource objectives, the guidelines will fail to the achieve meaningful mitigation and thus risk-factor reduction required to use water resources more efficiently.

Recommendations

The key research needs going forward are:

- To complete the source code programming in order to include the risk assessment methodology and calculations to yield a fully functional (operational) DSS.
- To update the supporting information reference documentation, for all applicable WQCs and derived parameters, site-specific data bases (animal nutrition and soil) and contaminants of emerging concern (notably EDCs including bromide).
- To include the Wildlife application and update the methodology to include the best fit for multiple variables including wildlife types, water quality and presentation preferences, habitat immediate and surrounding and both primary and secondary physiological thirst signals (water dependency, mobility and behaviour).
- To include the Rural Communal Animal Production System application and update the methodology accordingly to include dual exposures incorporating domestic and household crop irrigation aspects.
- The DSS itself requires:
    - A series of child-parent software programs to be linked, notably between the water quality and types of effects data generated and the DWS-linked compliance monitoring and enforcement data bases.
    - A Central Administrator that receives, processes and directs information between five Specialist Groups:
        - Analytical Group
        - Animal Health Group
        - Geochemistry Group
        - Community Health Group
- A focus area of the DSS developed thus far has been primarily for commercial confined animal feeding operations, however, a key strategic application area is required in order to improve the management of water resources in rural animal production systems.
    - This is viewed as a key requirement to enable sustained water resource management in rural communal agricultural systems and to address community-dependent risk factors that may range from agricultural productivity (i.e. community funded communal agricultural projects) to safe household food preparation of high-risk agricultural products.

It is relevant to note that the departure from a concept of a “safe” concentration strategy which is not only prohibitively costly, but also contrary to the current National Water Resource Strategy (DWS, 2013) to one in which risk-reduction measures aimed at arriving at an “acceptable risk level”, is not only scientifically more defensible, but also more practical and cost-effective and a need currently experienced by the agricultural water use sector.

In closing, a significant advantage is to be found in many animal production systems over other water users (for example Domestic and Irrigation) in the ability to control and thus manipulate key inputs, from diet, environmental housing conditions to specific physiological exposure scenario selections, thus allowing for risk factor manipulation to a greater extent.

Thus, in addition to the potential value towards food security (by improving animal production on a more efficient and sustainable water use basis) and human health (via the use of animal production systems as sentinels to guide community health studies relating to complex water quality challenges such as endocrine disrupting chemicals), the DSS for Animal Watering presents an opportunity to test the fundamentals of a risk-based approach in a water user group for which less confounding factors exist and more cause and effect data is obtainable with which to assess and evaluate the accuracy of the risk assessment and risk mitigation methodology employed.

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