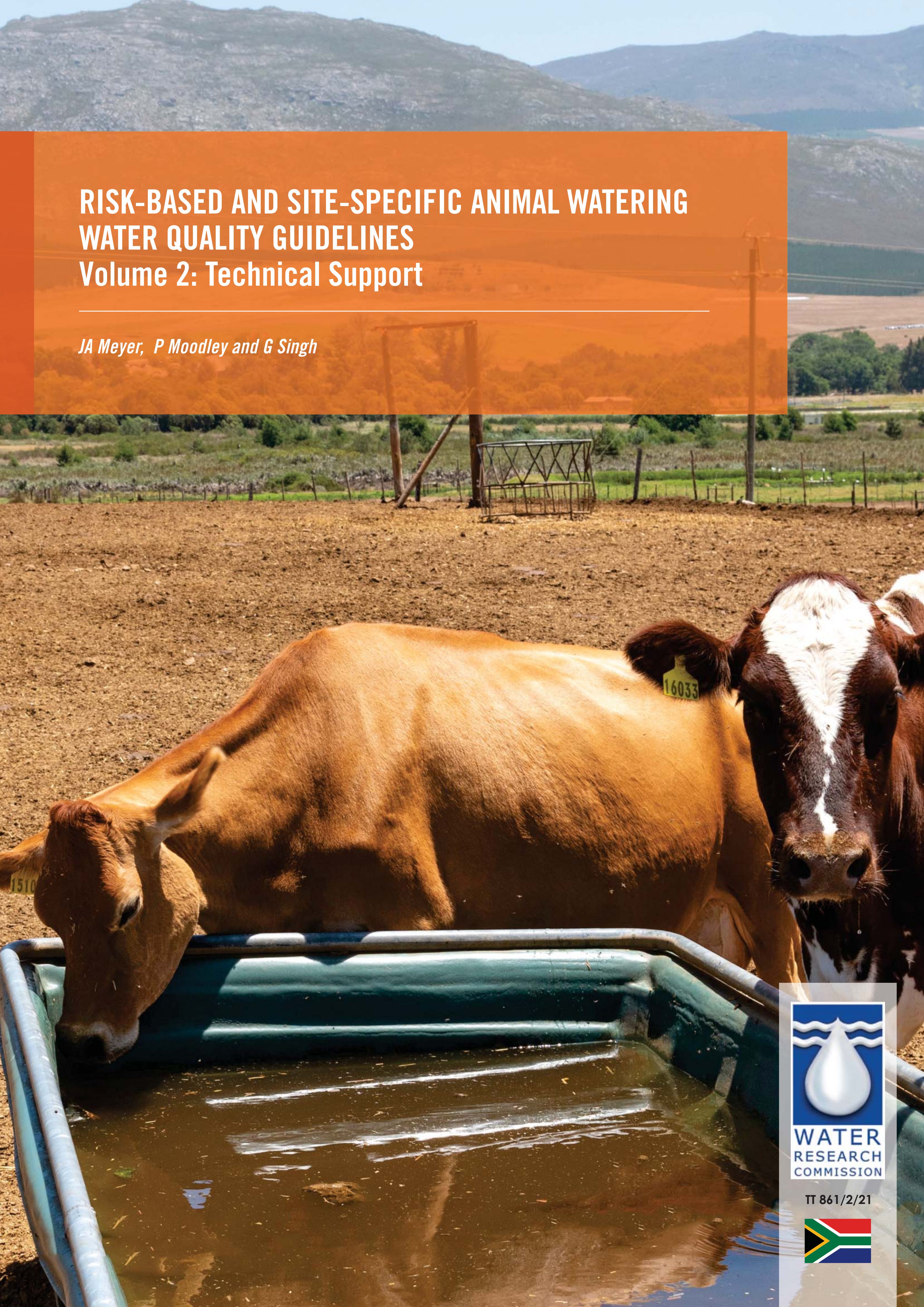
RISK-BASED AND SITE-SPECIFIC ANIMAL WATERING WATER QUALITY GUIDELINES
Volume 2: Technical Support

JA Meyer, P Moodley and G Singh



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

Volume 2: Technical Support

Report to the
Water Research Commission

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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 1: Decision Support System* (**WRC Report No. TT 861/1/21**)
- *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 presents 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 and Volume 2: Technical Support Information (this report).

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 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 occurs 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 database 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

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, is 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:

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 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:

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

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

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

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, with only some key data flow aspects highlighted in this report. The key norms which are addressed are highlighted in the table 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.

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
CFIA	Canadian Food Inspection Agency
CIRRA	Constituent Ingestion Rate Risk Assessment
COCs	Constituents of Concern
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 National Water Act (Act No.36 of 1998) emphasises on the need to protect our freshwater ecosystems, which are under threat because of pollution from many sources. Being a water scarce country, water resources in South Africa requires careful management in order to enable provision of basic water services and equitable allocation, while meeting the needs of inclusive economic growth without threatening the integrity of the aquatic ecosystem. Though the concept of risk management in the context of water resource management is not explicitly stipulated in the National Water Act (Act No.36 of 1998), its role in supporting decision making with regards to resource classification and fitness for use is well recognised. While there is no legal obligation requiring the use of risk approaches or risk science in water resources management, the concept of risk offers a scientifically tenable approach to assess impact of different qualities of water. Consistent with global practice, the concept of risk has been used as basis for the development of South African Water Quality Guidelines (SAWQGs) (Jooste and Claassen, 2001). As such, the 1996 SAWQG series have been used by water quality managers and water resource managers as a primary source for decision-making to judge the fitness for use of water for different purposes.

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 too 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, fresh-water 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.

This project addresses the 'Development of a Risk-based Water Quality Guidelines for Animal Watering' 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.

The new envisaged guidelines would be different in different in a number of fundamental ways:

- They would be risked based (different to the 1996 guideline which was largely hazard based);
- They would allow for greater site specificity (a widely recognised limitation of the generic 1996 guidelines); and
- They would be made available primarily as a software decision tool to support decision making.

Previous recent projects have addressed risk-based water quality guidelines for the irrigation, domestic and recreational water user groups, that are aligned in terms of the philosophy and concept fundamentals, to this, the animal water (livestock) water user group guidelines. The risk-based approach to water quality guidelines for aquaculture have been developed in parallel with as part of this project. This report provides the technical support information to the risk-based approach and decision support system for animal watering.

1.2. Project Objective

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, methodology and decision support system design, 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.

1.3. Risk-based Philosophy

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.

1.4. Animal (Livestock) Watering

Water quality guideline development for livestock watering in South Africa has been an on-going process since 1990. This research (which has included a number of WRC projects) has provided a departure point for the current endeavour to develop a risk-based approach.

The 1996 guidelines, published as Volume 5: Livestock Watering (DWAF, 1996) were an improvement on the previous 1993 edition which was based on a limited number of key constituents thought to be of primary interest at the time with minimal local experimental evidence used to arrive at guideline values. The 1996 edition saw the addition of several trace elements and other constituents to the list as well as an expansion on the norms used to assess fitness for use. Expert opinion was actively gathered at the time from veterinary toxicologists and animal nutritionists in order to address several issues ranging from types of effects to exposure periods (DWA, 2008).

Subsequent to the 1993 and 1996 editions of the Department of Water and Forestry South African Water Quality Guidelines for the Volume 5 Agricultural Use: Livestock Watering, a Constituent Ingestion Rate Risk Assessment (CIRRA) software decision support system was developed for the Water Research Commission (WRC Report Series 857 & 1175).

A great deal of work has thus already been completed for animal (livestock) watering, however, several years have transpired since the process was halted and new information on the systems applicable and clinical biochemistry available needed to be included. The previous work and the CIRRA model previously developed for animal watering are discussed in this report, as well the revisions and updates and calculation methodologies required to the risk-based approach.

1.5. Risk-based Water Quality Guidelines

Guidelines reflect the scientific environment. The key components defining the nature of the envisaged revised guidelines that distinguishes it in a fundamental way from the existing 1996 guidelines are risk and site-specificity.

As a central point of departure, it should be noted that water resource quality data and clinical challenges experienced in the animal production sector have supported the DWS's adoption of 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.

South African production systems and types of water quality challenges are indeed specific to the local geochemical and production environment, however, 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 (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.

Demonstrating the current recognition that water quality is a key input to performance for commercial intensive animal production systems, many breed-specific companies (producers of superior genetic material from poultry to pigs) have developed their own in-house water quality requirements as part of the comprehensive management guides for the breeds.

A challenge with this approach locally is that these water quality requirements are developed in European countries and lack the extent of geochemical anomalies faced locally. The benefit, however, is that the operations are aware that water quality can (and should be) manipulated to achieve optimal production, as opposed to simply made “safe”, with this evolving into a field in which water quality is seen as an input variable which presents an opportunity for improving performance as opposed to only enabling it. This performance-based approach will inevitably be part of a higher-level Tier within the risk-based guideline system.

Based on the risk-based approach philosophy defined, a key aspect includes 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 (DWS, Edition 2 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.

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.

A significant advantage is thus to be found in many animal production systems over other water users 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.

International practice has shown that incorporating risk or risk-based approaches is the best water to manage and protect water resources. Thus, the need for risk-based water quality guidelines does not stem from a legal obligation, but rather from the water resource management framework that demands decision support that accounts for all contexts of water use.

The fitness for use assessment forms the core technical requirement of the guidelines. The objective of risk-based guidelines for animal watering is to provide a quantitative basis for making decisions regarding sources, pathways and receptors." The ability of the user to provide some input to the risk assessment process and contextualising the scenario, supports the proposal of presenting the guidelines as a software product rather than a static document.

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.

It is 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.

1.6. The Tiered Assessment System

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).

Each tier provides an output that has to comply with the concept of categorization. In the case where it is presented with a set of analytical data pertaining to a water sample, the output will be category of water for each user. In the case where it is presented with a desired category of water, the output is a feasible set of constituent levels for each user. The difference between the tiers lies primarily in the degree of site-specificity required to produce an output; and should not be equated to or confused with the tiers of risk assessment. All tiers must be categorised in terms of risk objectives.

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).

1.7. Prototype Decision Support System

A prototype DSS for animal watering has been developed incorporating the important features of the risk-based design and functional specifications, building on the previous CIRRA model. The tool incorporates the tiers of assessment and the qualitative and quantitative assessments to express the risks associated with animal watering through user-friendly graphical interfaces.

The risk-based methodologies are used as the basis to define the informatics of the tool 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.

Given the budget and scope of this project it should be noted that the prototype tool developed through this project does not offer a fully functioning DSS as time and funding were not made available for the required coding for the software program. Instead, the DSS provides an indication of what the system may look like from a user-interface perspective.

This final report presents technical support information to the DSS, which includes the approach development process and the risk calculation methodologies applied as the basis to define the informatics for the software application. This report consists of two volumes, Volume 1: Description of the Decision Support System and Volume 2: Technical Support (this report). Volume 2 with its supporting appendices 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.
- Overview of Decision Support System for Animal Watering.

2. APPROACH

2.1. Historic Overview

In 1990, from a livestock watering water quality guideline perspective, a combination of international guidelines and a locally derived source table were available. These were based on a limited number of water quality constituents, with the local guideline compiled mainly from anecdotal evidence and/or single non-transferrable site-specific observations, with the local guideline consisting of a total of only nine water quality constituents.

Several problems areas were encountered in the application of these guidelines. Firstly, it was most noticeable that the international guidelines shared a common source and were derived from limitations in both research and analytical information base. Secondly, it was noted that the influence of geochemistry on subterranean water resources, which form the most significant water source for livestock watering, was largely unrecognized.

This led to the vast majority of the water resources evaluated against these guidelines to present with concentration ranges which exceeded the recommended limits. These guidelines also did not provide an alternative strategy to non-compliant water quality with no clear communication of the concept of ingestion-based variances changing the outcome following exposure or the key factors leading to effects with exposure. Additionally, evidence of an ever-increasing list of water quality constituents with lower detection limits and growing recognition for adverse types of effects at lower concentration ranges was emerging, with these guidelines failing to provide guidance thereon.

Consequently, many of the problematic water quality constituents noted in subterranean water use in South Africa presented the user with little more than a simple statement that the water quality did not comply with the recommended limit, leading to significant funding from the Water Research Commission (WRC) over the following decades. This coincided with the DWS acknowledging that water resource quality in South Africa was deteriorating.

A brief overview of the key research projects and guidelines that have been developed within the South African context of agricultural water use for animal watering since 1990 is provided in the Table 1.

2.1.1. Review of the Constituent Ingestion Rate Risk Assessment Approach

From the outset of the initial 1990 WRC research project emphasis was placed on the development of guidelines that would be applicable to the local conditions under which animal watering took place and be of relevance to the varied local animal production systems found, from extensive subsistence farming to commercial intensive confined animal feeding operations.

Table 1: Previous undertaken in the development of the Livestock 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 need 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).

Meyer and Casey (2012) noted that precarious rainfall and the lack of natural perennial rivers and streams caused livestock farmers, rural farming communities and small towns to be reliant on groundwater sources, with the southern African region characterized by agro-ecological features suitable for livestock production and ranging from subtropical bush to grassland to harsh semi-desert and desert features (Tainton *et al*., 1993).

The annual average rainfall ranges from 800 mm in the east to <10 mm in the west, with the central regions having between 300 and 400 mm 90 % of the time (De Jager, 1993), with many livestock production systems consequently reliant on predominantly stable groundwater resources and a combination of highly variable surface water resources.

Prior to the DWAF 1993 guidelines limited guidance was available with which to establish the suitability of use of these water resources for livestock production and the format of the available local and international guidelines were all constructed around single-value reference criteria, typically for maximum tolerable limits or recommended maximum exposure concentrations, such as 2 mg/L for a water quality constituent, with only the norm of drinking water addressed.

These were often incorrectly referred to as “standards” and usually adopted by the Department of Agriculture to assist farmers with water quality issues, an example of which is presented in Table 2 below, which was widely used in South Africa and Namibia.

The selection of water quality constituents and corresponding values had not been considered scientifically and advice given, and conclusions drawn were largely anecdotal and in many cases the concentrations cited emanated from fundamentally flawed research with transference thereof to other animal types, production systems and environments unfounded.

Table 2: Single-value standards for water quality constituents (WQC) that were used in South Africa and Namibia (Adelaar, 1974).

Water Quality Constituents	Standard (mg/L)
Total dissolved solids	5000
Sodium	2000
Calcium	1000
Magnesium	500
Nitrate	400
Chloride	3000
Sulphate	1000
Fluoride	6
Bicarbonate	500

An example of this was noted by Casey *et al* (1996) where in the case of fluoride a single research publication led to the 6 mg/L recommendation (Van Rensburg & de Vos, 1966), but contained numerous fundamental errors. These included the failure to actually confirm point of use drinking water concentrations and thus dose ingestion rates, exposure to sub-maintenance nutrition and significant mineral-mineral interactions, including the potential addition of fluoride and an alleviator treatment to the drinking water by a mineral supplement additive which was not quantified.

Since the timing of fluoride exposure to ameloblasts is instrumental in the development of dental fluorosis, different sensitivities in livestock categories were also relevant although not detailed in the guideline. This guideline was subsequently adopted erroneously by other international and local guidelines with chronic fluorosis reportedly encountered at lower concentrations on one hand, and none observed at higher concentrations on the other, with the outcome dependent on several toxicological risk factors being present and/or variations in site-specific ingestion rates.

A second key example relates to the significantly elevated guideline of 400 mg/L for nitrate which was not clearly stated to be explicitly for nitrate as $N0_3$, and not as N, with some confusion resulting. Furthermore, the conditions under which such an elevated concentration would be tolerated was fundamentally due to the ability of specifically ruminant stock to adapt to microbial reduction of the ingested nitrate, via an additional reduction pathway of nitrite (NO_2) to ammonia in the rumen. This adaptation required on-going exposure to sustain the different rumen microbe populations.

Consequently, there were many instances where adverse effects ranging from spontaneous abortions to whole herd mortalities were reported with the introduction of new stock and/or conditions under which the adaptation was lost (e.g. drinking water concentration changes, variations in nitrate exposures from feed and water, movement of herds between different drinking points with different nitrate concentrations).

Since both fluoride and nitrate occur across South Africa in subterranean water resources at varied concentrations and received much research attention from the WRC (Tredoux *et al*., 2009), the failure of the guidelines to provide the necessary guidance was seen as a significant shortcoming.
Critically, as these guidelines were limited and concentration-based (mg/L), increasing problems were reported where adverse effects were experienced with water compliant with the limits, whilst cases were also cited where exposures to non-compliant water did not yield any apparent adverse effects.

As a consequence, different error types were reported, with numerous observations in the field challenging the validity of these recommended values. During the period of the late 1980s farmers were eligible for a conditional government subsidy on groundwater sources in designated water scarce regions, with the condition that the water had to be fit-for-use for livestock watering. The dilemma that arose from the discrepancies in the cited water quality constituents and corresponding concentrations between local and international guidelines, and the errors reported earlier, gave rise to the WRC research programme investigating water quality for livestock watering.

As the existing water quality guidelines were neither site specific nor were the types of animals, their physiological status, the environment and production systems taken into account, they were associated with a high degree of uncertainty in the outcome following exposure, and it was this uncertainty that motivated for a more accurate guideline format.

The water quality guideline development process to date has progressed to the Constituent Ingestion Rate Risk Assessment (CIRRA) model, a risk-based approach that allows for the necessary flexibility to incorporate the information fields necessary to enable a sources, pathways and receptors approach.

In summary, water quality guideline development for animal watering has been an on-going process since the commencement of the initial WRC project in 1990. This research provided a departure point for the development of the guidelines that followed, and the reader is referred to the WRC publications for further detail (Casey *et al*., 1996; Casey *et al*., 1998a; Casey *et al*., 1998b; Casey *et al*., 1998c; Casey and Meyer 2001; Casey *et al*., 2001; and Casey and Meyer 2006).

These and other WRC publications, notably those relating to the WRC Endocrine Disruptors (EDC) programme, and other non-WRC projects (e.g. Department of Agriculture and SANParks) all contributed to the current knowledge.

Key components of the CIRRA model are provided in the following sections. It should also be noted that the various versions of the model were developed between the period of 1996-2005, and that these are now also outdated. Some developmental context is also provided in here, along with current requirements in terms of the updates identified as part of this project.

2.1.2. Key Components of the Constituent Ingestion Rate Risk Assessment Approach

Following the widespread application of the DWAF 1996 guidelines numerous role-players in the South African livestock industry noted that the application of the guidelines in the varied array of animal production systems was problematic at best. It was predominantly these problems, and subsequent reactions thereto, that led to the objectives being formulated for the initial Water Quality Guideline Index System (WQGIS), (the CIRRA model),

Due to commercial producers which represent a significant part of the agricultural water use sector were already noting that the DWAF 1996 guidelines were inadequate in assessing fitness for use, outdated and that water-related costs to production were an increasing reality, a departure from the simplistic DWAF 1996 TWQR approach was identified in the late 1990s,

The objectives thus formulated for the WQGIS were (Casey *et al*., 1998a):

- Identifying the main types of livestock production systems and the water sources common to them (subterranean and surface);
- Identifying the main variables of relevance in these water sources and their effect on livestock water quality norms;
- Develop water quality constituent guidelines for the respective livestock producing systems; and
- Provide guidelines and required supporting information in a format that would find application to a wide range of users, from water quality managers of complex aquatic systems to private on-farm users.

Biological experimentation and regional water quality investigations conducted for the WRC provided the bulk of the work which contributed to the WQGIS and this generated a significant amount of reference documentation (WRC Reports 644/1/98, 644/2/98, 644/3/98, 857/1/01, 857/2/01 and 1175/1/06).

Given that this research conducted consistently demonstrated 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 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.

When considered from a programming perspective, the objectives of the WQGIS were 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.

2.1.2.1. *Norms Addressed*

The reference documentation used for CIRRA was initially selected based on the central theme of water quality for livestock production, with this being changed later to cater for animal production (and thus include wildlife categories).

The central theme of water quality applicable to livestock production systems was addressed by arriving at norms used to assess the effects of water quality. Those initially noted in the DWAF 1996 guidelines were:

Livestock Consumption Norms

- Toxicological effects
- Palatability effects

Livestock Watering System Norms

- Clogging
- Chemical corrosion
- Biological corrosion
- Encrustation
- Scaling sediment

Livestock Product Quality Norms

- Consumer health hazards
- Product quality problems

These norms have been subsequently adjusted over time with those currently considered relevant when conducting an assessment on the fitness for use presented in Table 3.

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

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

It is recognised that the approach adopted should not only address the available types of effects known and be aligned to primary prevention thereof but should also be able to cater for new and future concerns which may not yet be fully described.

The norms should thus each be elaborated upon as new information becomes available, with the decision-support tool also capable of capturing information on those norms for which key guidelines are not yet available, in the hope that future assessments may benefit from the data captured.

2.1.2.2 Production Systems Addressed

The norms detailed above allow for the guidelines to be practically, and locally, applicable to most animal production systems where four core factors are considered, namely (Heath et al., 2007):

- Breed-specific factors
- Category-specific nutrient requirements
- Production-related factors
- Product-related health hazards and quality considerations

Whilst these 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) have also been recognised.

Examples of a first and second level division of Animal Use Categories considered by the CIRRA model are provided in Table 4 and Table 5. Reasons for adopting this approach are to enable the application of the key components that significantly alter the water quality constituent concentration ranges that may be used within a range of adequacy.

Using the second level division assists in accessing breed specific parameters (milk production/day; conception rate; weaning indices, etc.) that affect water requirements and water quality constituent dose-response curves.

The guideline statements produced would thus approach total dose ingestion estimates or herd averages corrected for body weight and turnover rates.

Table 4: First level division of Animal Use Categories considered by the CIRRA model

	Commercial:
1.1	Intensive Production of products for Human consumption
1.2	Intensive Production of products not destined for Human consumption
1.3	Breeding Systems
1.4	Semi-intensive production systems
1.5	Extensive production systems
	Rural Systems:
2.1	Communal production systems
2.2	Subsistence systems
	Wildlife:
3.1	National Parks and Trans-frontier Parks
3.2	Commercial systems

Table 5: Second level division of Animal Use Categories considered by the CIRRA model

1 Commercial
1.1 Intensive Production of products for Human Consumption:
1.1.1 Cattle
1.1.1.1 Type = Dairy
1.1.1.1.1 Breed = Friesland

The CIRRA model developed include the generic-WQGIS that was initially adopted, followed by the specific -WQGIS.

Fundamental Approach for the Generic-WQGIS

A generic guideline application implies an absence of site-specific information and may be considered to be a first-tier approach to assessing fitness for use, using a mg/L or concentration-based approach. As detailed earlier this presents with several shortcomings, the main ones briefly being:

- The mg/L basis forces a more conservative estimation of the TWQR.
- They do not offer solutions for water with inherently high concentrations of PHCCs
- They do not take into account, to a large enough extent, the differing water quality and quantity requirements of animals due to:
  - Animal specific factors
  - Site-specific environmental factors
  - Nutritional factors

- Livestock production system factors
- They do not take into account the effect of short-term exposure to water quality constituents.
- They do not cater for differences in carry-over effects of PHCCs to the user of the animal products with varying exposure periods.
- They do not cater for synergistic and antagonistic interactions between water quality constituents and the environment.
- They do not base recommendations on the actual ingestion of a water quality constituent from all sources.
- They do not cater adequately for a wider range of norms.

Whilst these issues were alluded to already during the development of the 1993 and 1996 DWAF guidelines and highlighted in subsequent WRC reports relating to the research and the development of the CIRRA model, they have also been noted internationally, with water quality guidelines for livestock produced by Agriculture and Agri-food Canada by Olkowski (2009) clearly stating in the foreword that:

> "There is a noticeable insufficiency of recent information on many aspects of water quality issues in contemporary livestock selected for superior performance characteristics. Without comparative research using today's high-performance genetics, interpretation of water quality data is problematic as minimum."

Although the generic-WQGIS and previous DWAF water quality guidelines, and international guidelines, all use a water constituent concentration-based approach, the Generic-WQGIS offers an improvement by virtue of the following:

- It not only offers a single guideline value, or range from [0 – x mg/L], but also gives an indication of the possible adverse effects with increasing water quality constituent concentrations
- It offers more differentiation for livestock types
- It provides an indication of the incidence of occurrence in the water source used as typically encountered in South African treated water, groundwater and surface water sources, thereby focussing management attention on predominant problematic water quality constituent as opposed to the degree of toxicity attributed inherently to a water quality constituent.
- It alerts the user upfront to the potential errors that may occur when using a static tabulated guideline on mg/L basis
- If offers extensive supporting information.

Shortcomings of the Generic-WQGIS remain:

- Whilst more accurate estimates of water intake are included, actual water intake and hence WQC ingestion variation are not addressed
- Constituent ingestion from sources external to the water are not necessarily included
- Complex palatability factors are not addressed
- Differences in livestock type water turnover and production systems are not addressed

- Environmental and nutritional factors are not addressed.

A key aspect considered as part of this project was the viability of producing area-specific Generic Tier I guidelines and Production System Specific Generic Tier I guidelines.

These variations are addressed to an extent in section 3.6.1, however they may need to be adapted for intensive confined animal feeding operations where water intake values are constantly evolving to meet the change in genetic progress, nutrition, housing and management, all of which lead to an intake setting which can be more accurately incorporated even with a generic-concentration based approach.

In order to progress from this Tier I type generic approach, additional information inputs based on either reference type documents and/or site-specific data would be used and centre on water ingestion rate reference documents that are compiled with corrections for body weight, dry matter intake and water turnover rates, amongst other things.

This would serve as inputs to the application of hazard and risk procedures applicable to the specific production system type.

Fundamental Approach for the Specific-WQGIS

Water Ingestion Rate Reference Documents

The Specific-WQGIS effectively provides a data capturing model for each livestock type, yielding a vast number of Water Ingestion Rate Reference Documents (WIRRD). By way of example one single water quality constituent (WQC) for the Livestock Type: Sheep has 16 WIRRDs, with a total of 336 WIRRD tables for sheep being accommodated by the source code. The Specific-WQGIS has two main outputs:

- A risk assessment in which key risk factors are identified, and
- A method of manipulating the inputs to arrive at an acceptable risk level.

Examples of the application thereof to alleviate adverse WQC effects in different livestock and livestock production systems were presented in the WRC report 644/2/98 and may be referred to for experimental results.

Whilst the data inputs of actual site-specific measurements are obviously preferred, the model does rely on a significant degree of source reference documentation (e.g. pasture type nutritional detail). The basis for the Specific-WQGIS is a Livestock Type specific reference document referred to as a Water Ingestion Rate Reference Document (WIRRD). This is provided for categories for each livestock type which comprise category specific tables for key WQCs.

The 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. For some livestock types additional information is used in the calculations, for example, in dairy cattle fat corrected milk yield is included as a variable.

A variety of recognised reference sources for nutrient requirements and production parameters were used in the derivation of the category list and table content using either live weight specific DMI values or calculated DMI values, the TWI being calculated using the applicable regression formula for the specific livestock type.

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.

Body water functions as a basis for intermediary metabolism with this being related to body size, with numerous regression formulae having been published in this regard. The use of the exponent in the WIRRD is motivated by the generally drier South African environment under which livestock production occurs.

The use of additional factors to the basic WIRRD caters for the other recognised effects such as temperature on 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).

A brief example of the WIRRD for a specific category of sheep is presented in Table 6.

Table 6: Example of a WIRRD for Livestock Type = Sheep; Category = Ewes – maintenance; WQC = Selenium

Live Weight (kg)	DMI (kg/d)	TWI (ml/kg$^{0.82}$/d)	WIR (ml/kg$^{0.82}$/d)	mg Se/kg$^{0.82}$/d				
				A (0-0.02)	B (0.21-0.05)	C (0.51-0.7)	D (0.71-2.5)	E >2.5
50	1	2.87	0.116	0.00232	0.0058	0.0812	0.29	>0.29
60	1.1	3.26	0.113	0.00226	0.00565	0.0791	0.2825	>0.2825
70	1.2	3.642	0.111	0.00222	0.00555	0.0777	0.2775	>0.2775
80	1.3	4.028	0.1108	0.002216	0.00554	0.007756	0.277	>0.277
90	1.4	4.414	0.11	0.0022	0.0055	0.077	0.275	>0.275

Since site-specific factors alter the water concentration at which a given constituent will cause an adverse effect, the WIRRD can also be modified 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.

Additional modifying variable to the WIRRD thus include palatability, protein percentage, breed differences in water turnover and other environmentally specific factors. These modifying factors are effected in three ways, firstly by the use of a factor system (similar to human drinking water guidelines), secondly by use of different regression equations, and thirdly by altering the initial column value (guideline concentration ranges A-E in the example provided).

Modifying factors are thus cumulative and either increase or decrease the WIR, but it is recognised that many livestock production systems are highly variable, even between the same livestock production system breed and type (e.g. different environmentally controlled settings which are breed specific) rendering the inclusion thereof in an equation format impractical. The inclusion of these variables as factors can, however, assist managers in identifying key variables that alter the outcome of exposure to a given concentration, and for this reason still have value. 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.

Thus, some factors are included as objective measurements, for example, temperature and ration protein percentage, whilst others are set factors embedded in the program calculations. It is envisaged that as additional research information becomes available the number of equations used will increase and the number of factors used will decrease.

Other aspects are considered as equations which do not affect the WIRRD, for example, the recognised interaction between copper, molybdenum and sulphate in ruminants and the derivation of a copper utilisation coefficient.

It is also relevant to note that some water quality constituents are not suited to a WIRRD approach, for a variety of reasons. Key reasons relate to the type of effect (toxicology specifics) and insufficient guideline information with which to derive a WIRRD. These are presented in Table 7 which provides the differentiation between these WQC handling types. The generated reference documentation was presented in the WRC Report 644/3/98 (Casey *et al.,* 1998c) as a hard copy and embedded in the CIRRA software program.

Table 7: Selection of Water Quality Constituents (WQCs) and WIRRD or TWQR or single trigger guideline

WQCs with a WIRRD for: Beef cattle, dairy cattle, goats, horses, pigs and sheep.	
WQC	Al, AS, B, Cd, Cl, Cr, Co, Cu, F, Fe, Hg, Mg, Mn, Mn, Na, Ni, Pb, Se, SO4, V, Zn.
WQCs using a TWQR-system	
WQC	Rationale
Nitrate & nitrite	Adaptation of rumen microbes more important than ingestion *per se*.
Pathogens & parasites	Risk of infection with exposure alone sufficient to warrant further investigation.

WQCs with a WIRRD for: Beef cattle, dairy cattle, goats, horses, pigs and sheep.			
WQC	Al, AS, B, Cd, Cl, Cr, Co, Cu, F, Fe, Hg, Mg, Mn, Mn, Na, Ni, Pb, Se, SO4, V, Zn.		
Pesticides	Lack of guideline information on types of effects with increasing concentrations and concerns regarding consumer health implications.		
TDS	Significant palatability effects dependent on ratios between major anions and cations and not ingestion alone.		
Toxic Algae	Highly variable daily fluctuations in ingested water concentration.		
WQCs using a single trigger value			
Water Quality Constituent	Maximum Permissible Level (mg/L)	WQC	Maximum Permissible Level (mg/L)
Ammonium (as N)	0-2	Potassium	0-400
Antimony	0-00	Radium	0-0.001
Barium	0-1	Rubidium	0-5
Beryllium	0-5	Silica	0-18
Bicarbonate	0-500	Silver	0-0.05
Bismuth	0-0.5	Strontium	0-10
Bromide	0-3	Tellurium	0-0.005
Cerium	0-2	Thallium	0-0.2
Cyanide (free)	0-0.3	Thorium	0-0.5
Gold	0-0.005	Tin	0-0.2
Hardness (as $CaCO_3$)	0-300	Titanium	0-0.5
Iodide	0-10	Tungsten	0-0.5
Lithium	0-5	Uranium	0-4.4
Phosphate (as P)	0-2	Yttrium	0-0.001
	0-400	DOC (mg/L C)	0-10
	0-0.001	pH	6-9
		Turbidity	0-1 NTU

The Specific-WQGIS shares the following common elements with the Generic-WQGIS:

- Sender Information – General information
- Sampling information – General information
- Water source information – General information
- Response to water source information – General information
- Chemical analyses of water sample information
- Reporting on Types of Effects, Background and Additional Information

The model captures two information types, namely that used in risk assessment and sample evaluation results, and secondly, that use for record purposes only (e.g. sender and sampling detail). The model evaluates information regarding the water, animal and production system for each live weight within each selected category.

User input is via the provision of analytical results and the selected options in several input-dropdown tabs. Calculations are then conducted based on formulas, factors or notes provided, all of which are livestock type and category specific. The results are compared to the WIRRD which, as noted earlier, can also be modified. Comparisons are also made to a central feed data base reference document, referred to as a MINRD. The MINRD is a vast reference data base which includes the composition of key water quality constituents in various types of animal feed and forages, with the user also able to provide analytical results as an input. The results generated thus stem from comparisons to reference documents or specific input fields provided by the user. The system also offers additional calculations applicable to the proposed solution implementation and this leads to the creation of a new sample file. The user may save several of these types of files and manipulate inputs, ranging from animal type, exposure period to ration composition offered, and in so doing attempt to mitigate against the key antagonistic system factors present.

Stepwise examples of the Generic-WQGIS and Specific-WQGIS are provided in the applicable WRC reports. It was also noted when information inputs were required some extension workers in the field did not have access to computers and requested hard copies in a file in order to record information from farmers. Subsequently components of the CIRRA user interface were compiled into forms as Data Capturing Guides in order to facilitate this process.

Software Programming Detail

The system was developed using Clarion version 2.003 for Windows as the programming language (similar to both C and Pascal). This has a strong data-base orientation, and by defining the data definitions and integrity rules in a Clarion dictionary, a source code generator can generate the source code needed to enforce referential and domain integrity. The links between procedures are displayed on-screen to assist with application structure.

It was also possible to customise the system to use any relational database management system which has Open Database Connectivity (ODBC) interfacing capabilities (e.g. Microsoft Access, Sybase and SQL server versions of Microsoft, Oracle and Sybase).

The average size of a sample file (*.wqs) is ca. 12 K, thus holding 100 sample files requires around 1 Mb of space. The WQGIS.exe files require ca. 700 Kb whilst the data files component requires 3 Mb and the *.dll files require 1 Mb. At the time of provision of the system to the WRC the Help files were 1.69 Mb.

Three basic categories of Help files were offered, a WQGIS help, System Help and Supporting Information, composed with WYSI-Help Composer Version 2.202 software. The WQGIS help is divided into the Generic and Specific application levels, with the System help similar to most Windows help files for navigating a Windows environment. The Supporting Information contained text files with cross-referencing capabilities providing easily accessible information on a wide range of topics.

Updating of Supporting Information requires the replacement of certain program files, whilst updating the “Evaluation” procedure requires source code changes to the reference documents.

2.2. Main Aspects to the Decision Support System Update and Approach Revision

The following key aspects of the CIRRA model were identified 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 (the DSS), 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. However, this will not be addressed as part of this phase.

- 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.

- As presented earlier 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.

Additionally, work conducted for SANParks in the Kruger National Park, Pilanesberg and Kgalagadi National Transfrontier Park showed a significant water quality input requirement to water provision, both in terms of spatial setting, provision design and quality fit for different wildlife categories.

In conclusion it can be observed that the primary benefit in adopting both 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.

This risk-based approach allows for a more realistic fit to water quality planning limits set for specific catchments, as animal water use guidelines not only predict the outcome following exposure, but also allow for key non-water quality aspects to be identified as factors to be managed, in order to allow for sustainable water resource utilisation.

The ability to control and measure the system variable inputs and manipulate relevant risk factors in commercial animal production systems is a significant advantage that allows for a somewhat unique approach.

An additional consideration, as detailed in the WRC EDC Volume 4 Monitoring and Assessment of EDCs (WRC Project 1915) and WRC project on Pesticides and Agricultural Chemicals (WRC project 1956), is the ability to utilise confined animal feeding operations as a sentinel monitoring platform for community health risk assessment guidance. The high power of the statistical tests given the replicates and repetitions applicable towards cause and effect relationship identification within the highly controlled system and single drinking water source input, coupled to high level biosecurity sites with access to repeatable clinical and histopathological investigations with high confidence in population norm references, allows for the use of the outputs of the animal water quality assessments to potentially serve as inputs towards domestic drinking water risk assessments.

3. FUNDAMENTAL COMPONENTS OF THE RISK-BASED GUIDELINES

3.1 Fundamental Perspective

The guidelines differ in a fundamental way from the existing 1996 guidelines firstly by being ingestion rate based as opposed to a concentration-based, and secondly, by adopting a risk and site-specific approach. In addition, the structure of the guidelines is to include a tiered assessment level system that is presented and operated through a decision support system (DSS).

In adopting a risk-based approach the focus moves from regarding exposure to a water quality constituent concentration as safe due to an expectation of a "no adverse effect" at or below that stated concentration, to an acceptable risk level following exposure. This is a statistical concept defined as the expected likelihood or probability of undesirable effects resulting from a specified exposure.

In the existing guidelines the fundamental approach of a "no-adverse effect" for potentially toxic chemicals is adopted, and given the variability in ingestion and effects, the derived Tolerable Daily Intake is based on an assumed water consumption value and the most sensitive endpoint. Inevitably this leads to a conservative guideline which creates the situation when using surface and groundwater resources that few, if any, fully comply with the guideline limits set.

It should again be noted that the historic development of the versions of the Constituent Ingestion Rate Risk Assessment (CIRRA) model, detail regarding the model and rationale behind each user group component subsequently added were presented in Deliverable 1 of this project and are not repeated here. It is recommended that the reader of this report be acquainted with the Inception Report and the applicable WRC documents referred to therein.

The system developed provided the user with two water quality guideline index systems (WQGIS) to choose from:

- A Generic-WQGIS
- A Specific-WQGIS

The fundamental difference between the two is that the Generic-WQGIS uses default values in the source code whereas the Specific-WQGIS caters for actual on-site measured values as input data, thus effectively enables the change from a concentration-based statement on fitness for use to an ingestion-based site-specific risk assessment.

The main output of the Generic-WQGIS is a list of Potentially Hazardous Chemical Constituents (PHCC) and a list of Constituents of Concern (COC), supported by links to additional supporting documentation on the constituents in question (similar to the 1996 guidelines, but significantly greater in content).

In addition to the Generic-WQGIS outputs and supporting documentation, the Specific-WQGIS has two main outputs:

- A risk assessment as a Risk Index value with corresponding key risk factors are identified
- A method of manipulating the inputs (significant risk factors) to arrive at an acceptable risk level.

Although not repeated here (refer to WRC EDC Volume 4 Monitoring and Assessment) it should be noted that in principle the process is similar to a source, pathway and receptor analysis typically adopted in which the following general steps are involved:

- **Hazard Identification**: As source assessment involving tasks of:

- Sampling, monitoring, chemical and targeted constituent analysis and assessment of the data gathered.
- At the higher Tier levels additional source sampling and analysis provide more site detail and increase the degree of assessment performed. At the higher level this may thus include EDC bioassays and other screening tools.
- The outputs of this step guide the further steps in terms of the key constituents (Potentially Hazardous Chemical Constituents and Constituents of Concern).
  - This is in principle similar to the Chemical Scores obtained for carcinogens (slope factor) and non-carcinogens (reference doses).
- Appropriate source assessment allows for a more focussed Pathway assessment to be performed, with the Specific-WQGIS and corresponding site-specific data inputs (e.g. soil and diet analysis) aiding in this regard.

- **Exposure Assessment**: This estimates the magnitude, frequency, duration and route of exposure.
  - At higher Tier levels this makes less use of assumptions (as in the mg/L typical guideline approach at the Generic-WQGIS Application level) and more use of actual on-site measured data, with each step thus more accurately performed with higher Tier levels.
  - Key specifics required in this step include:
    - A more detailed description of the exposed receptor types (thus not simply livestock or cattle, but physiological subcategories linked to production status).
      - This receptor analysis is essential to identifying the key risk factors, sensitive user groups and potential acceptable risk level applicable.
    - Pathway assessment (e.g. drinking water, soil, diet and inhalation).
    - Calculating the exposure concentrations
    - Calculating ingestion rates (concentration and intake data)
  - It should be noted that each step makes use of background information and observed site data, for example Pathway analysis involves chemical release mechanisms, transformations and key point of use exposure values.
  - It should once again be appreciated that in many commercial animal production systems this differs from a more typical community approach in that the actual mean exposure concentrations can be accurately determined for significant receptor numbers.
- **Risk Assessment**
  - This is performed typically as a form of index, for example, a Hazard Index (HI = intake/reference dose) where an index value of <1.0 provides acceptable risk.
  - The CIRRA model applies risk factors in a cumulative manner to the final cumulative index obtained for all constituents.
  - It is an important albeit technical note that the index value derived does not provide a value for the probability of harm as the result of exposure, but rather quantifies the absence of effects from exposure.

In the risk-based approach the DSS also provides assistance to the user by Help files and various notes which aim to fundamentally reduce the sources of uncertainty in the assessment.

These are typically factors such as:

- Failure to adequately provide source characterisation.
- Lack of reference data, for example, where reference doses or slope factors are not available (as is the case for most chemicals) this is noted and potentially insightful clinical tests recommended to determine possible adverse outcomes linked to exposure.
- Uncertainty regarding exposure models. It should be noted that this is again a benefit in many animal production systems in which the actual duration and future potential exposure is known or can be easily validated.

Risk management is effected by identifying the key risk factors which affect the final Risk Index value. The source of the potential hazards may be inherent in the water quality and/or as a consequence or influenced adversely by site-specific risk factors. Providing the user with these numeric values allows for the management decisions to be made regarding potential mitigation thereof.
It should be appreciated that the Risk Management process is in effect based on the quantitative values provided in the Risk-based assessment, however, it is fundamentally a product of multifactorial methodologies requiring increased expert qualitative assessments (professional opinion) as the assessment moves to a higher Tier level.

Despite this judgement-based decision for Risk Management the DSS (CIRRA model) attempts to provide the user with the relevant information types so applicable expert opinion may be sought should it be required. This multidisciplinary approach is increasingly relevant (e.g. EDC effects and risk) as more information and specialisation become available in the field of water quality guidelines and specific animal production sectors.

Finally, it is a recommendation that the DSS include a section on Risk Communication in order to ensure that the correct information type is communicated where applicable. As noted in the Inception Report 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 accept 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 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.

Experience in the agricultural water use sector has repeatedly shown that in order to gain adequate insight into the risks posed monitoring is vital. Due to the stochastic nature of water quality the population of an input water quality file with corresponding water sample information is simply a single point observation of concentration values. Seasonal changes in addition to stochastic variability have to be appreciated and included as a recommendation in the Risk-based approach.

Additionally, it is true that the 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). Either way, monitoring is required and as noted prior the inclusion of an intra-DWS data base connectivity is a strong recommendation in order to include compliance monitoring submissions (which can and should occur for confined animal feeding operations for both General Authorised water use activities and those operating under a Water Use Licence) which are external (user-based) and internal (National Monitoring Programme).

3.2 Water Ingestion Rate Reference Document

The central component to the CIRRA model is a water ingestion rate reference document (WIRRD). This 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.

In deriving recommendations for domestic drinking water guidelines, Grandjean (2004) observed that workers in the field highlighted a multitude of intra- and inter-individual factors rendered deriving a recommended daily allowance for water intake that meets the needs of all impossible, noting that:

> "Given the extreme variability in water needs which are not solely based on differences in metabolism, but also in environmental conditions and activity, there is not a single level of water intake that would ensure adequate hydration and optimal health for half of all apparently healthy persons in all environmental conditions."

It was thus noted at an Estimated Average Requirement (EAR), and therefore a Recommended Dietary Allowance (RDA), could not be established, with an Adequate Intake (AI) established as the reference value for water intake for healthy U.S. and Canadian individuals and populations.

Various water intake values are noted linked to numerous variables, with temperature (region) recognised as a key variable, with water intake in L/day differing in the same 70 kg human differing from 3 L in a temperate zone to 6 L in a tropical zone.

The current WHO Guidelines for Drinking-water quality (WHO, 2011) note that in setting water quality targets "Volume of water consumed and intake from other sources should be considered when setting national standards", yet in practice the stated WHO guideline is frequently adopted as is.

The two key default assumptions in the WHO guidelines are water consumption in L/day and body weight. These are noted for an adult as 2 L per day and a body weight of an adult of 60 kg, an intake of 1 L/day and a body weight of 10 kg for children, and 0.75L/day and 5 kg for bottle-fed infants.

In the 1996 South African Water Quality Guidelines for Domestic Use it is noted that adverse effects may arise from an increase in water intake and for some constituents with a high inherent toxicity, with significant water intake increases from the default L/day for an adult noted in some occupational settings (underground miners).

There are numerous references in the international guidelines on hydration recommendations which highlight the difference between sedentary and active phases on water consumption rates linked to temperature. Variations are linked mainly to water loss through sweating (up to 1.5 L/hour) with intake increases of over four times from 20 degrees Celsius to 31 degrees Celsius noted for being at rest in shade to double this during an activity such as walking.

These highlight the difficulty in deriving accurate assessments on ingestion of a water quality constituent at a given concentration in humans 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).

To this point is should be noted that a primary management focus point in the vast majority of animal production systems is feed intake, with genetic improvements based on the ability to increase production of the product (e.g. milk or protein) with an increase in energy intake (feed intake). Since feed intake is significantly correlated to water intake this relates to a significant change in water intake at a given body weight.

A key advantage to animal production systems over human drinking guideline settings is that input variability in terms of source and content is controlled and thus limited and defined. Estimating intake of a constituent from other sources is thus typically far more accurate and readily available, largely due to the high input costs thereof (feed costs) and strict monitoring by feed manufacturing companies.
It is thus both a challenge and benefit in animal production systems that these vast differences exist, as whilst they provide for a more diverse water use sector, they allow for more complex nutrient requirements to be derived.

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.

Body water functions as a basis for intermediary metabolism with this being related to body size, with numerous regression formulae having been published in this regard. The use of the exponent in the

WIRRD is motivated by the generally drier South African environment under which livestock 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). By way of example one single water quality constituent for the Livestock Type: Sheep has 16 WIRRDs, with a total of 336 WIRRD tables for sheep being accommodated by the source code.

Examples of the application thereof to alleviate adverse water quality constituent effects in different livestock and livestock production systems were presented in the WRC report 644/2/98 and may be referred to for experimental results.

Whilst the data inputs of actual site-specific measurements are obviously preferred, the model does rely on a significant degree of source reference documentation (e.g. pasture type nutritional detail).
The basis for the Specific-WQGIS is a Livestock Type specific reference document referred to as a Water Ingestion Rate Reference Document (WIRRD). This is provided for categories for each livestock type which comprise category specific tables for key water quality constituents.

The 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. For some livestock types additional information is used in the calculations, for example, in dairy cattle fat corrected milk yield is included as a variable.

A variety of recognised reference sources for nutrient requirements and production parameters were used in the derivation of the category list and table content using either live weight specific DMI values or calculated DMI values, the TWI being calculated using the applicable regression formula for the specific livestock type.

The WIRRD thus effectively converts a stated water quality constituent guideline value from mg/L to an allowable ingestion rate in mg of that constituent per kg $LW^{0.82}$/day. A brief example of the WIRRD previously developed for a specific category of sheep is presented in Table 8.

It is noteworthy that the final calculated ingestion rate of the water quality constituent applicable to the guideline effect statement thus changes over actual Live Weight values and is not by default set at a mg/kg LW/day.

Table 8: Example of a WIRRD for Livestock Type = Sheep; Category = Ewes – maintenance; WQC = Selenium

User Specific Input			Ingestion	Water Quality Constituent				
Live Weight (LW) (kg)	DMI (kg/d)	TWI (L/d)	WIR ($L/kg^{0.82}/d$)	mg Se/$kg^{0.82}$/d^				
				A (0-0.02)	B (0.021-0.05)	C (0.051-0.7)	D (0.71-2.5)	E >2.5
50	1	2.87	0.116	0.00232	0.0058	0.0812	0.29	>0.29
60	1.1	3.26	0.113	0.00226	0.00565	0.0791	0.2825	>0.2825
70	1.2	3.642	0.111	0.00222	0.00555	0.0777	0.2775	>0.2775
80	1.3	4.028	0.1108	0.002216	0.00554	0.007756	0.277	>0.277
90	1.4	4.414	0.11	0.0022	0.0055	0.077	0.275	>0.275
^Where columns A to E relate to target water quality range to possible acute adverse effects as "guideline effect concentration ranges".								

The calculated decrease in the ingestion of the WQC X for the increased LW category differs from 26% on the LW basis to 1.8% on the metabolic water basis, providing a physiologically more accurate guideline reference value based on the relationship between metabolic rate and water turnover.
This is fundamentally similar to relating metabolic rate to oxygen turnover or kilocalories to mass 0.75. The WIRRD for each livestock type is specific to that type and the calculated allowable ingestion rates for a given WQC between livestock types using this method is more accurate, allowing for the derived value to be based on requirements which are in turn based on numerous regression equations, for example, livestock type specific growth curves.

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 E) 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. These modifications are thus necessitated when variables additional to those already catered for are applicable, either by affecting the ingestion thereof, or crucially, also the toxicity. An example of a toxicity change may be found in the case of fluoride exposure and altitude, with South African Highveld

altitudes not transferable to coastal areas in terms of the effects of changes in ventilation and perfusion ratios and renal function, all of which alter the outcome at the same concentration and ingestion rate.
Additional modifying variable to the WIRRD thus include palatability, protein percentage, breed differences in water turnover and other environmentally specific factors. These modifying factors are effected in three ways, firstly by the use of a factor system (similar to human drinking water guidelines), secondly by use of different regression equations, and thirdly by altering the initial column value (guideline effect concentration ranges A-E in the example provided).

Modifying factors are thus cumulative and either increase or decrease the WIR, but it is recognised that many livestock production systems are highly variable, even between the same livestock production system breed and type (e.g. different environmentally controlled settings which are breed specific) rendering the inclusion thereof in an equation format impractical.

The inclusion of these variables as factors can, however, assist managers in identifying key variables that alter the outcome of exposure to a given concentration, and for this reason still have value. 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.

Thus, some factors are included as objective measurements, for example, temperature and ration protein percentage, whilst others are set factors embedded in the program calculations. It is envisaged that as additional research information becomes available the number of equations used will increase and the number of factors used will decrease. Other aspects are considered as equations which do not affect the WIRRD, for example, the recognised interaction between copper, molybdenum and sulphate in ruminants and the derivation of a copper utilisation coefficient.

It is also relevant to note that some water quality constituents are not suited to a WIRRD approach, for a variety of reasons. Key reasons relate to the type of effect (toxicology specifics) and insufficient guideline information with which to derive a WIRRD. Those applicable to the previous CIRRA versions are presented in Table 9 which illustrates the differentiation between these water quality constituent handling types.

It is noted once again that these tables require an update with additional constituents recognised and new information available for incorporation (e.g. bromide, lanthanum and radionuclides).
The generated reference documentation was presented in the WRC Report 644/3/98 (Casey et al., 1998c) as a hard copy and embedded in the CIRRA software program.

Table 9: Selection of Water Quality Constituents (WQCs) and WIRRD or TWQR or single trigger guideline approaches

WQCs with a WIRRD for: Beef cattle, dairy cattle, goats, horses, pigs and sheep.	
WQC	Al, As, B, Cd, Cl, Cr, Co, Cu, F, Fe, Hg, Mg, Mn, Mn, Na, Ni, Pb, Se, SO4, V, Zn.

WQCs using a TWQR-system	
WQC	Rationale
Nitrate & nitrite	Adaptation of rumen microbes more important than ingestion *per se*.
Pathogens & parasites	Risk of infection with exposure alone sufficient to warrant further investigation.
Pesticides	Lack of guideline information on types of effects with increasing concentrations and concerns regarding consumer health implications.
TDS	Significant palatability effects dependent on ratios between major anions and cations and not ingestion alone.
Toxic Algae	Highly variable daily fluctuations in ingested water concentration.

WQCs using a single trigger value

Water Quality Constituent	Maximum Permissible Level (mg/L)	WQC	Maximum Permissible Level (mg/L)
Ammonium (as N)	0-2	Potassium	0-400
Antimony	0-0.100	Radium	0-0.001
Barium	0-1	Rubidium	0-5
Beryllium	0-5	Silica	0-18
Bicarbonate	0-500	Silver	0-0.05
Bismuth	0-0.5	Strontium	0-10
Bromide	0-3	Tellurium	0-0.005
Cerium	0-2	Thallium	0-0.2
Cyanide (free)	0-0.3	Thorium	0-0.5
Gold	0-0.005	Tin	0-0.2
Hardness (as $CaCO_3$)	0-300	Titanium	0-0.5
Iodide	0-10	Tungsten	0-0.5
Lithium	0-5	Uranium	0-4.4
Phosphate (as P)	0-2	Yttrium	0-0.001
	0-400	DOC (mg/L C)	0-10
	0-0.001	pH	6-9
		Turbidity	0-1 NTU

Whilst providing a fundamental central source code reference document, the WIRRDs do require changes and updates as the animal production targets (e.g. DMI & TWI) have changed, and the guideline effect concentration ranges need also to be adapted to include dietary factors and new effect statements.

A key change that has to be effected is the change from the 0 mg/L = safe or no adverse effect concept to the recognition of deficiencies and marginal deficiencies before the adequacy range, with this concept according with the current recognition of essentially or the probability of a beneficial response on supplementation.

This change is 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 water quality constituents to be included in the WIRRD as opposed to a TWQR-system or Single-trigger value system, and the applicable limits thereto, also require to be updated.

3.3 Site specificity

It was noted in the Inception Report that a significant deficiency of the 1996 water quality guidelines is the generic format and uniformity of application. As fitness for use water is dependent on its composition in relation to its intended use site specificity is necessary so that decision can be assessed accurately based on its character and context of the intended use.

This aligns with the recognised approaches to hazard and risk assessments, with baseline toxicological data an input to the process and not the final statement. Examples of this are to be found in some guideline statements, although they are seldom, if ever, applied.

For example, the statements in the 1996 South African Water Quality Guidelines for Domestic Use for Fluoride, the temperature correlation to an acceptable guideline value is provided and does allow for an adjustment to the Target Water Quality Range presented, yet this no-adverse effect limit of 1 mg/L is usually cited with little recognition in the field for the recommended value with an inclusion of temperature as a site-specific factor.

This is noteworthy as the derived no-adverse effect concentration of 1 mg/L for fluoride correlates to a *Maximum* daily air temperature of 16 degrees Celsius, whilst monitoring data has revealed elevated fluoride concentrations to naturally occur in many of the north and western border regions of South Africa where the maximum daily air temperature may even exceed 40 degrees Celsius, corresponding to an Optimum Fluoride concentration of only 0.5 mg/L.

It was noted in the Inception Report that the site / scenario specificity of the new guidelines is envisaged to manifest in the following ways (DWAF, 2008).

- *Nature of the water resource*: The water resource itself will determine the nature of the fate and transport behaviour of water quality constituents. For example, soft clear waters have very different characteristics from hard turbid waters. Similarly, the acidic waters in the Western Cape are naturally and fundamentally different from the rest of South Africa.
- *Multiple exposure routes (the "pathways").* It will be possible to take account of multiple routes of exposure (e.g. ingestion, dermal) of the target organism to specific water quality constituents.
- *The nature of the water user ("the receptor").* It will be possible to define water users (current or future) in considerable detail so that guidelines specific to those users can be developed (when

the necessary data are available). It is the increasingly detailed description of the water user, and implicitly or explicitly the nature of the exposure of that user to the water, that makes the envisaged guidelines “risk-based” as opposed to “hazard-based” (e.g. species, life stage, nutrition, body weight, etc.).

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Site / scenario specificity enables risk assessment to identify differences between background risk, incremental risk and thus total risk, on a more realistic basis.

The CIRRA model (the DSS) caters for site-specific data in two key formats:

- Firstly, via coded reference documentation.
  - There are several examples of this ranging from altitude to selenium deficient/excessive soil and pasture areas.
    - The altitude is derived from the user entering a water sample location (GPS coordinates) which is transposed onto a map of South Africa to obtain the height above mean sea level.
      - An example of this is in the use of a risk-factor to adjust the WIR output for fluoride in recognition of the effect of altitude on the renal clearance rate and thus concentration at which fluorosis may occur (within the designated sensitive user group).
        - Thus, if the user group selected by the user is not equal to the default setting the altitude risk factor is adjusted accordingly.
      - The use of published data on selenium-deficient soil and pasture areas within South Africa assist in two ways, namely in assessing the total exposure from selenium from non-drinking water sources and also in combining correlated mitigation options where potentially applicable (for example, adjusting Vitamin E supplementation).
  - Similar coded reference maps may be developed for a wide range of site-specific variables, such as temperature, rainfall (and pasture moisture percentage), known geophagia issues, and potentially EDC exposure (refer to WRC Project 1956 Pesticide Maps produced).
    - Potentially, the use of increased Compliance Monitoring Data and clinical reference data may be included in this manner to identify low, medium and high risk water management units.
      - It is envisaged that a seasonal component should be included with these outcomes linked to known seasonal risk periods (e.g. incidence of fluorosis and toxic algal blooms) which are thus linked to geographical position and time.
- Secondly, via actual user-selected input fields.
  - In this format the actual information available to the user is provided in the assessment file. This can include actual water intake, feed intake, targeted constituent intakes via feed analysis and other actual site-specific measurements.

- It is noteworthy that this input field is not limited to external factors affecting the user (e.g. temperature, altitude, soil quality and feed quality) but user specific detail, notably:
    - Actual intake (feed and water and where applicable soil).
    - Clinical biochemical data which may be linked to reference documentation for clear diagnostic and differential diagnostic purposes. This is viewed as a Tier III approach in which the user is directed by the DSS to obtain/request the appropriate clinical data, the results of which may also be captured in the data capturing fields and provided as a complete file to the appropriate clinician.
    -

Lastly, it should be appreciated that the site-specific input information required may also be generated in the form of a Data Capturing Guide, which could be sent to a different user/involved party to facilitate moving from a Generic-level assessment to a Specific-level assessment.

This is a key component, notably the ability to guide the user in terms of site-specific detail required in order to arrive at a risk-based assessment. In the final product it is envisaged that this data capturing guide will be linked to a monitoring platform within the DWS in which compliance monitoring data can be entered and assessments updated with monitoring data submissions (Phase 3 of project).

This should enable both the drinking-water aspect and potential impact on water resources to be assessed, thus including the norm of biodegradable industrial wastewater quality as influenced by drinking water quality. This “second” assessment may run as a separate file in the DSS or be part of the fitness for use guide provided.

Since the data capturing guide includes specific physiological categories of animals within each production system type and is based on actual water intake, additional water resource planning inputs may also be obtained from the outputs of the assessment, ranging from water volume potential water quality planning limits for management units to catchment loads from the biodegradable industrial wastewater generation from confined animal feeding operations.

It should also be considered that in many agricultural scenarios multiple water sources are available for use. Frequently it is experienced in practice that blending of the water sources is a viable solution to arrive at an acceptable risk level in terms of exposure to one or more PHCCs.

The ability to accurately assess the outcome from exposure from a single water sample quality and site-specific detail input is already the initial file-based approach, however, additional functionality should be incorporated in which selected water quality files can be combined in order to provide the user with a “best-fit” scenario.

The inclusion of these site-specific functionalities into the DSS overcomes the shortcomings of the generic nature of the 1996 guidelines, as well as facilitates more informed decision making related to water resource use and management (DWAF, 2008).

3.4 The Tiered Assessment System

The intention with the update of the guidelines was 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).

Each tier provides an output that has to comply with the concept of categorization. In the case where it is presented with a set of analytical data pertaining to a water sample, the output will be category of water for each user.

In the case where it is presented with a desired category of water, the output is a feasible set of constituent levels for each user. The difference between the tiers lies primarily in the degree of site-specificity required to produce an output; and should not be equated to or confused with the tiers of risk assessment. All tiers must be categorised in terms of risk objectives. An overview is provided in Table 10 with more detail included in the Volume 1 report.

Within the Tiers outlined in Table 10 there are also Tier subsets in the DSS (CIRRA model). The CIRRA model applies the Tier 1 approach outlined in Table 10 as a Generic-WQGIS file. The user has two options to enter this Tier. Firstly, a file is created with user information captured to the level of information that is available. The user is prompted for responses to selections made upfront for a Generic-WQGIS or a Specific-WQGIS, with a brief pop-up information screen highlighting the input requirements for each. If a selection for the Specific-WQGIS is made, a pop-up note draws the user's attention to the fact that this requires site-specific information to proceed.

Table 10: 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 characterisation 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).

Once in the Generic-WQGIS the user can make various selections ranging from animal production system to breed. If the user does not have the information with which to make a selection, the option “other” or “not known” is provided, which reverts the assessment to an increasingly conservative concentration-based approach.

Within the Generic-WQGIS the user has the ability to generate a Data Capturing Guide in order to acquire the information needed to arrive at a more detailed assessment. An example would be being able to select between a ruminant (e.g. cattle or sheep) or non-ruminant (e.g. poultry) for nitrate-nitrite toxicity guidelines.

Additional information fields that allow the Generic “Tier I” approach to move increasingly towards a Tier II assessment are provided in the Data Capturing Guide, and effectively this creates a Tier II assessment which may be regarded as an entry level Tier II assessment as it still does not require of the user to have any animal science or veterinary skills, but simply to enter more site-specific information pertaining to the user type and location.

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 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 approach is a fundamental input towards rural communal animal production systems in which poorer quality water is matched to both the least risk exposure model or towards guidance on whether the animal products are suitable for export, consumption in the general market, or for the local community. This would allow for the best animal production system type to be included in the environmental authorisation application by linking the proposed system to the fitness for use for the given water quality and sustainable water resource yield present at the intended site, in addition to making a statement on the suitability of specific product quality consumption by including potential hazard exposure in both communal crops and vegetable gardens and animal products within the applicable domestic sensitive user groups which predominate in the community.

This would be an example of a link between community health and exposure to the norms for animal watering guidelines relating to animal product quality and the potential varying effects within different consumer groups.

3.5 Norms and Categories Applicable

The reference documentation used for CIRRA was changed over the development projects to include not only more typical animal production systems, but also wildlife production systems and rural communal production systems.

This resulted in additional norms becoming applicable, for example, sacrifice zones as a consequence of providing a preferred water quality provision setting for non-mobile water dependent wildlife, or specific maximum acceptable concentrations within animal products for high-exposure low-dietary dilution settings typical of rural communal production systems.

Based on experience gained in the animal production field relating to water quality problems encountered additional norms were also added to those derived for the 1996 South African Water Quality Guidelines, these being presented in Table 3 in section 2.1.2. It should thus be appreciated that some of the norms are applicable to specific production system types with increased Tier III assessments making use of a multidisciplinary skill set.

As noted in section 2.1.2.1, the norms should be able to cater for new and future concerns which may not yet be fully described and may thus be elaborated upon as new information becomes available, with the DSS capable of capturing information on those norms for which key guidelines are not yet available, in the hope that future assessments may benefit from the data captured.

This is arguably prudent and pertinent to EDC effects, with current guidelines not addressing the effects but potentially being able to do so by a range of different approaches, such as the inclusion of targeted EDC-bioassay results.

It was also noted that, in accordance with the applicability of the envisaged Risk-based guidelines to the relevant Sections of the NWA, the norms should include aspects of the Section 21 activities of the NWA triggered.

The inclusion of norms related to the effects of water quality on biodegradable industrial wastewater generated by confined animal feeding operations would also assist in according with the current National Water Resource Strategy, 2nd Edition (NWRS, 2013-2018) in which it is stated that the reuse of wastewater for irrigation is a key strategy and noted that "considerable potential exists to substantially expand the use of wastewater for irrigation purposes in South Africa."

It is recognised that the risk-based approach adopted should not only address the available types of effects known but also be aligned to primary prevention thereof. The core factors to thus be considered include:

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

The norms may thus be expanded in the CIRRA model (DSS) depending on the user input provided, an example of which is provided in Table 11 below.

Table 11: Norm expansion within the CIRRA model

Norm = Animal Health [within commercial intensive production system]

- Effect = Palatability
    - Inherent Constituents = TDS, SO_4, Cl, Mg, HCO_3^-, Cu, Fe, Mn and Zn.
    - Introduced Constituents = residual chlorine.
    - Description = the occurrence of certain water quality constituents, singularly or in combinations, can affect the palatability of water for livestock. The acceptability of a water source may manifest as a change in water intake. Suboptimal water intake due to adverse palatability can be assessed as poor-quality water for animal production purposes.
    - Effects = Results in an initial reluctance to drink water after which animals either adapt to the water or (if offered no alternative supply be forced via thirst and sodium appetite signals to drink from the available source. The resultant consumption of water is usually suboptimal but may be

excessive after a prolonged period of refusal. Due to the direct positive correlation between water and feed intake, suboptimal water intake can cause production and animal health to decline chronically. In extreme cases where livestock refuse to consume water for an extended period (more than 48 hours), the effects may be acute. Stock which has adapted to highly saline water (often associated with potential palatability problems) tend to increase water intake with increased salinity. This can result in an above-average water intake for an extended period of time, leading to a high intake of other potentially hazardous water quality constituents. Toxic effects can therefore occur from the consumption of water with normally safe concentrations, primarily due to the increased ingestion. A continuous high intake of saline water can also lead to primary hypertension with mainly the heart, brain, eyes and kidneys affected. A long-term effect on renal clearance of some water quality constituents may occur, with the glomerular filtration rate increasing slightly.

- Reversibility = the effects are generally reversible, provided suboptimal water intake has not occurred for an extended period of time (days to weeks) and acceptable alternative water can be offered.
- Mitigation = Livestock can generally adapt to adverse palatability, but this varies markedly between species, palatability constituents involved, comparable palatability of other water sources used and production system specifics. These influence the degree to which adverse effects can be alleviated. Primary factors include forage moisture percentage and energy content of the ration.
- Norms = the norm used to assess palatability is the response of the animal primarily in terms of water intake. Deviation of the water intake from the normal level as dictated by the physiological requirement is an indication of adverse palatability. Additionally, any decline in production, health or feed intake may indicate suboptimal water intake. Changes in animal behaviour may be observed at the drinking trough when confronted by water found to be unpalatable. A reluctance or refusal to drink may be observed, sometimes with longer periods of time spent in the immediate vicinity of the trough without settling down to consume water. This may be a significant problem in intensive confined animal feeding operations where time at the drinker point and dominance behaviour can adversely impact growth and production.
- Site-specific information = In addition to inherent water quality, the following may aid in identifying and alleviating problems associated with palatability:
    - Initial refusal
    - Ratios of certain salts present
    - Water temperature
    - Time taken to drink readily
    - Volume consumed compared to freshwater intake
    - General condition of the animal
    - Type of ration, notably protein and fat intake
    - Mineral content of ration/pasture.

Examples of a first and second level division of Animal Use Categories to which these norms apply within the CIRRA model are provided in Table 12 and Table 13.

This sequenced approach aligns with the increased site-specific detail noted in the Tiered approach. The Animal Feed Manufacturers Industry may still be added as a user. Currently water is used in this industry for all the recognised industrial processes (dilution, waste removal, etc.) but the effects of water quality on the registered user and related norms (e.g. health and wastewater quality) via effects on the final product when included in the manufacturing process are largely ignored.

This is not currently included as it may be considered to reside more appropriately under Industrial Water Uses.

Table 12: First level division of Animal Use Categories considered by the CIRRA model.

	Commercial:
1.1	Intensive Production of products for Human consumption
1.2	Intensive Production of products not destined for Human consumption
1.3	Breeding Systems
1.4	Semi-intensive production systems
1.5	Extensive production systems
	Rural Systems:
2.1	Communal production systems
2.2	Subsistence systems
3	Wildlife:
3.1	National Parks and Trans-frontier Parks
3.2	Commercial systems

Table 13: Second level division of Animal Use Categories considered by the CIRRA model.

1 Commercial
- 1.1 Intensive Production of products for Human Consumption:
  - 1.1.1 Cattle
    - 1.1.1.1 Type = Dairy
      - 1.1.1.1.1 Breed = Friesland

As can be appreciated from Table 12 and Table 23, the Specific-WQGIS has as the central basis a vast host of different WIRRs thus applying to differing nutrient requirements, an example of thereof provided in Table 14.

Table 14: An example of different WIRRDs catered for by the Specific-WQGIS for cattle.

Animal Types:

- **Cattle – beef**
- **Cattle – dairy**
- Goats
- Horses
- Pigs
- Poultry
- Sheep
- Wildlife

Cattle – Beef:

Breed options:

- *Bos indicus*:
  - Afrikaner
  - Nguni
  - Sanga
  - Brahman
- *Bos taurus:*
  - Brown Swiss
  - Charolais
  - Dexter
  - Hereford
  - Limousin
  - Pinzgauer
  - SA Angus
  - Shorthorn
  - Simmentaler
  - South Devon
  - Sussex
- Composites and crosses:
  - Beefmaster, Bonsmara, Bos indicus crosses
  - *Bos indicus x Bos taurus* (greater % *Bos indicus*)
  - *Bos indicus x Bos taurus* (greater % *Bos taurus*)
  - *Bos Taurus* crosses
  - Bovelder, Branus, Drakensberger, Santa Gertrudis
- Other

Livestock Production Systems: Beef Cattle:

- Weaner production
- Production of steers
- Speculative beef production
- Intensive improved pasture feedlots
- Zero-grazing feedlot

Beef Category Options:

- Bulls, maintenance and regaining body condition
- Cow's nursing calves – average milking ability (1^{st} 3-4 months post-partum) 5 kg MP/d
- Cow's nursing calves – superior milking ability (1^{st} 3-4 months post-partum) 10 kg MP/d
- Dry pregnant mature cows – last trimester of pregnancy
- Dry pregnant mature cows – middle trimester of pregnancy
- Growing and finishing cattle – large-frame bull calves and compensating large-frame yearling steers
- Growing and finishing cattle – large-frame heifer calves and compensating medium-frame yearling heifers
- Growing and finishing cattle – large-frame steer calves and compensating medium-frame yearling steers
- Growing and finishing cattle – medium-frame heifer calves
- Growing and finishing cattle – medium-frame steer calves and medium-frame bulls
- Pregnant yearling heifers – last trimester of pregnancy
- Two-year-old heifers nursing calves – 1^{st} 3-4 months post-partum (5 kg MP/d)

Environment Type options:

Humid, sub-humid and sub-tropical
Arid, semi-arid and sub-tropical
Temperate savanna and grasslands

Cattle – Dairy:

Breed options:

Ayrshire
Crossbreeds
Friesland
Guernsey
Jersey

Livestock Production Systems: Dairy Cattle:

Extensive grazing
Forage and concentrate feeding
Group feeding
Individual feeding
Total Mixed Rations
Small farming – individual farmers
Small farming – collectively owned dairies
Small farming – dairy ranching

Dairy Cattle Options:

Cows in mid-and late lactation – FCM 10 L/d
Cows in mid-and late lactation – FCM 15 L/d
Cows in mid-and late lactation – FCM 20 L/d
Cows in mid-and late lactation – FCM 25 L/d
Cows in mid-and late lactation – FCM 30 L/d
Cows in mid-and late lactation – FCM 35 L/d
Cows in mid-and late lactation – FCM 40 L/d
Cows in mid-and late lactation – FCM 45 L/d
Cows in mid-and late lactation – FCM 50 L/d
Cows in mid-and late lactation – FCM 55 L/d
Cows in mid-and late lactation – FCM 60 L/d
Growing large-breed calves fed milk or milk replacer
Growing large-breed calves fed milk plus starter mix
Growing small-breed calves fed milk or milk replacer
Growing small-breed calves fed milk plus starter mix
Growing veal calves fed milk or milk replacer
Large-breed growing females
Small-breed growing females
Large-breed growing males
Small-breed growing males
Maintenance of mature growing bulls
Period – dry
Period – early lactation
Period – mid lactation
Period – late lactation

Environment Type options:

Humid, sub-humid and sub-tropical
Arid, semi-arid and sub-tropical
Temperate savanna and grasslands

3.6 Updates to the Existing Ingestion Rate Risk Assessment Model

3.6.1 Application Level - Generic

The CIRRA model offered the user two guideline application levels, namely a Generic-WQGIS and a Specific-WQGIS. A generic guideline application implies an absence of site-specific information and may be considered to be a first-tier approach to assessing fitness for use, using a mg/L or concentration-based approach.

As noted in section 3.4, the Tiered system also presents with subsets to each Tier and the use of a DSS further facilitates the user moving between the Tiers, even if the actual site-specific detail is not known, by virtue of offering a selection of possible input data fields.

As an example, all that is needed to improve the assessment performed in the Generic-WQGIS Application level is to identify animal production system categories in order to implement an ingestion-based assessment, which permits the use of the central water ingestion rate reference documents.

It is thus possible that a user may create and thus provide a subset to the initial water quality file as a range of alternative assessment outputs which may be presented as potential options, following which a more informed selection may be made by a different party. This would thus provide, even for a Generic-WQGIS Application, an assessment for different animal types, categories and production systems. Those that are not applicable to the actual site may be discarded by the actual site-specific user.

The existing format should be updated to provide a Tiered entry selection option page, with further subsets therein possible as next level choices within each Tier.

As it currently stands the Generic-WQGIS presents with several shortcomings as discussed in section 2.1.2. Despite these shortcomings, a Generic-WQGIS would still be required to be offered in order to align the CIRRA model with the DSS tiered approach as detailed earlier.

The existing Generic-WQGIS can be improved to provide more user-friendly and meaningful assessment outputs.

A tiered approach by implication correlates to user input detail, with progression within tier subsets to across tiers guided by the amount and type of detail available. It should, however, not be presumed that adequate water quality detail is a central common data input. Experience within the water use sector frequently reveals this to be a primarily obstacle to producing an informed assessment.

Typical examples of how the water sample analytical information is compromised include:

- Failure to analyse for the water quality constituents for which guidelines exist.
    - This is typically noted for trace elements with only a selected few presented in the analytical report.

        - An ICP-MS (Inductively coupled plasma mass spectrometry) is the minimum requirement currently and failure to provide this information should result in a "Caution" note being generated by the DSS.
- Failure to determine the concentration of the water quality constituent at a sufficiently sensitive limit of quantification.
    - This is noted with macro and trace elements with some laboratories producing results at limit of detection concentrations which are above the target water quality concentration.
        - In many cases this may be simply due the laboratory performing a standard method suitable for a different water quality data use, with the issue being resolved by indicating upfront the concentration ranges required.
            - This may be addressed by "Caution" notes and by having an appropriate Water Quality Data Capturing Guide being generated by the DSS.
- Failure to sample correctly:
    - This relates to:
        - Failure to correctly collect the sample:
            - This relates to failure to acidify samples for trace element inorganic chemistry and thus obtain insufficient detection levels and misleading results, failure to determine in situ parameters for representative value (e.g. residual chlorine) and other incorrect methodologies.
        - Failure to adequately obtain a representative sample (source as opposed to point of use):
            - This is a key problem with many changes being observed in water quality from storage, potential treatment to final provision.
- Failure to include microbiological indicator organisms or physico-chemical data.
    - In some cases these may be of more relevance to source quality (e.g. physico-chemical results) but the same sampling strategy should be applicable to source and fitness for use assessments in recognition of the link between water quality guidelines and water resource quality objectives.
    - In other cases, targeted testing may be indicated, for example, pesticide screening or EDC bioassays.
        - The need thereof may be noted again by the DSS, but typically this would be to highlight potential water quality issues relating to inputs of suspected clinical problems and thus be more applicable to higher Tier assessments.
- Failure to discern inherent versus introduced chemicals:
    - It is increasingly experienced that inherent chemistry is disregarded with disinfection strategies, leading to the generation of potentially hazardous chemical constituents as disinfection by-products.
        - In some instances the use of various oxidants can introduce trace contaminants into the system.
    - Corrosion of fittings and fixtures can also introduce trace elements into the water provided

- These aspects are also addressed by the DSS reporting on "Verification Aspects", which may relate to background coding, for example, between Total Hardness, Langelier or Rynzar Index results and associated trace element results in the water quality data input.

It thus follows that improving the key data input of water quality, irrespective of the guideline application level, may be prudent.

Subsequent to the development of CIRRA additional tests and constituents are noted as being relevant to water quality used for animal production systems. Key examples include the oestrogenic, anti-androgenic, androgenic and thyroid-function bioassays developed for the WRC EDC programme and the Contaminants of Concern as detailed in the 2015 WRC dialogues thereon.

> The existing Water Quality Input requirements must be structured in such a way as to alert the user to provide the required analytical information for all Guideline Application levels and Tiers.
> The list of water quality constituents and analytical methods must also be updated to include current protocols and new procedures available, notably, EDC bioassays, and Contaminants of Emerging Concern.

The Generic-WQGIS can also be updated to provide concentration statements in addition to the cautionary notes provided in the current concentration-based assessments. The assessment may also be changed to offering the user of choice of selecting a best-fit recommendation in terms of animal production system type, animal type, category and conditions of use for the water quality data provided. Using the water quality constituent Fluoride as an example, the following improvements may be recommended for the Tier I (Generic-WQGIS) Application level (Table 15):

Table 15: Potential changes to the Generic-WQGIS

	User Input
User defined choices >>Tier 1	
>>I do not have site-specific user detail for this water sample	
	Animal Type >>Other
	Animal Production System >>Other
→Application Level	= Tier 1 subcategory 1.1 = Generic-WQGIS
>>water quality detail	Fluoride result >>1 mg/L
→ Result:	PHCC = Fluoride
→ Risk of adverse effects = Marginal	
→ Norms affected: Animal Health - toxicity	
→Types of Adverse effects = Dental and Skeletal fluorosis	
→ Clinical signs displayed =	

difficulty in chewing
periodic feed intake decreases
reluctance to drink cold water
intermittent lameness with abnormal hoof wear (elongated rear leg toes)
general performance reduction

→ Notes:

- Fluoride at this concentration range may be <u>safely tolerated</u> by most animal types if:
    - Exposure is after teeth have already erupted:
        - Sheep:
            - Premolars & Molars: all erupted by 2 years
            - Incisors: all erupted by 4 years with first 3 pairs by 3 years.
        - Cattle:
            - Premolars & Molars: all erupted by 3 years
            - Incisors: all erupted by 4 years with first 3 pairs by 3 years.
    - Exposure is limited to via the drinking water:
        - Thus dietary concentration = range of 2-16 mg F kg^{-1} DM
        - Thus soil concentration = lower range of 30-100 mg F kg^{-1} DM
    - Risk may be reduced by:
        - Ensuring pastures are not overgrazed (limit soil ingestion)
        - Ensuring phosphate supplements are defluorinated
        - Ensuring no airborne contamination is applicable.
        - Ensuring exposure is to a more tolerant animal species:
            - Poultry and Pigs = most tolerant
            - Sheep intermediate
            - Cattle = least tolerant
        - Ensuring exposure is to non-breeding mature animals
        - Ensuring exposure is short-term, for example in a feedlot scenario
        - Ensuring exposure is during cooler months when water intake is lower
        - Ensuring exposure is continuous at a median concentration as opposed to very high for a short period
        - Vigilance for dental fluorosis may assist with early diagnosis using enamel hypoplasia in the erupting incisors (consult a veterinarian in this regard)

- Vigilance for skeletal fluorosis may assist with management using lameness and abnormal bone production assessments (exostosis, subperiosteal hyperostosis) - consult a veterinarian in this regard
- Providing mitigation factors in the diet (e.g. calcium carbonate) – a nutritionist should be consulted in this regard.

  - Obtain the information presented in the Data Capturing Guide in order to arrive at a more accurate assessment.

It may be possible to also provide the user with a spatial representation of the reported incidence of occurrence in the water source used as typically encountered in South African treated water, groundwater and surface water sources, thereby focussing management attention on predominant problematic water quality constituent as opposed to the degree of toxicity attributed inherently to a water quality constituent.

The following terminology is applicable to the Generic-WQGIS and should be updated to include aspects such as contaminants of emerging concern, disinfection by-products, EDC effects and a statement on risk that addresses both deficiency (e.g. risk of deficiency – in the case of fluoride which is recognised as an essential element water F may actually contribute to a beneficial fluoride status) and type of adverse excess risk (e.g. marginal, high, acute risk of chronic or acute fluorosis).

Concentrations recorded for WQCs which exceed the applicable local or international guideline are reported as potentially hazardous constituents (PHC) or potentially hazardous chemical constituents (PHCC). Constituents that recorded values within 10% of a guideline limit or may within normal stochastic variation for the constituent approach within 10% of a guideline limit are reported as constituents of concern (COC).

Relevant terms are defined as:

WQC:	Water quality constituent, e.g. Arsenic.
PHC:	Indicates that exposure to the WQC in question is likely to result in adverse effects.
COC:	Indicates that the WQC in question could conceivably become a PHCC due to concentration variations, such as seasonal fluctuation in the water source or evaporative effects and should therefore be monitored.
TWQR	target water quality range (DWAF, 1996) Concentrations in this range are unlikely to have any adverse effects associated with use.
AV	antagonistic variable (Underwood & Suttle, 1999)

Tox	Toxicity
Pal	Palatability
NPS	non-point source pollution markers indicative of potential impact by wastewater handling practices.

Given the localised prevalence of many geochemical factors which influence water resource quality it is furthermore proposed to include a more localised Incidence of Occurrence set, which will either be derived by local water quality data and may align with Water Quality Planning Limits derived for specific catchments (and possibly in some instances specific Management Units).

Thus, even if the sample location is not known, the user may be directed to a map which could allow the site-specific user to be informed regarding other risk factors, for example, known areas with excessive soil or plant concentrations of the PHCCs identified.

> As a draft example of a more updated general overview the following set of Incidence of Occurrence in water sources is tentatively proposed by water resource type (Table 16), but this should be validated and possibly adjusted where required:

Table 16: Generic-WQGIS application Occurrence of PHCCs in surface and groundwater

Potentially hazardous constituents and parameters based on groundwater occurrence		
High Incidence	Medium Incidence	Low Incidence
Macro-elements Calcium, Chloride Fluoride Magnesium Nitrate and nitrite Sodium; Sulphate; SAR Total Dissolved Solids Total Hardness Trace-elements: Bromide Cobalt Iron Manganese Strontium Zinc	Arsenic Copper Molybdenum Selenium Microbiological Indicator Organisms	Trace elements: Antimony, Aluminium, Ammonia Barium, Boron, Beryllium, Cadmium, chromium, lead, mercury, nickel, pesticides and herbicides, Tin, Titanium, Uranium, Vanadium Pathogens and parasites
Potentially hazardous constituents and parameters based on surface water occurrence		
High Incidence	Medium Incidence	Low Incidence
Pathogens and parasites Microbiological Indicator Organisms Macro-elements Nitrate and nitrite Trace-elements:	Macro-elements Calcium, Chloride Fluoride Magnesium Sodium; Sulphate; SAR Total Dissolved Solids Total Hardness	Antimony, Aluminium, Ammonia Barium, Boron, Beryllium, Cadmium, chromium, Copper, Cobalt Lead, Mercury, Molybdenum Nickel, Strontium

Iron Manganese	Trace-elements Arsenic Bromide Selenium Titanium, Zinc pesticides and herbicides	Tin, Uranium, Vanadium.
Potentially hazardous constituents and parameters based on treated water occurrence		
High Incidence	Medium Incidence	Low Incidence
Chlorine-residual Disinfection by-products*	Total Hardness TDS (below ideal TWQR) Bromide	Most macro and trace elements.
* dependent on inherent chemistry of water treated and treatment method		

In addition to the extensive Help File, the following User warning alerts are provided for the Generic-WQGIS, but these both require updates in terms of new information and adjustments to the alerts to include more risk-based terminology and statements on the tiered approach.

The cautionary note to the shortcomings with a Generic Application level (Tier 1) should be elaborated on, with an example provided below of the information required to appropriately inform the user thereof:

Fitness for use for livestock watering is assessed using local and international guidelines (further detail may be obtained from Water Research Commission WRC Final Reports 644/1/98, 644/2/98, 644/3/98 and 857/1/01, 857/2/01) on a generic guideline application level. This level is **concentration-based**, as opposed to ingestion based, and is therefore **conservative** in risk estimation. A more accurate risk assessment may be performed when intake of a constituent is known from feed, water and other sources, and combined with site-specific risk factors that may increase, or decrease, the concentration at which a constituent in the water source may have an adverse effect. Use of specific information in this manner forms part of an **ingestion-based** specific guideline application level and hence involves site investigations with various data capturing procedures.

Two aspects must be noted:

Firstly, elevated water intakes due to osmo-sodium responses, high ambient temperatures, and palatability responses, significantly increase the risk for toxicity at any given guideline value (most are based on an average temp of 16 degrees Celsius).

Secondly, combinations of hazardous constituents in the same water source can be synergistic, or antagonistic, and as such, end effects may mitigate, or exacerbate, toxicity. Few water quality guidelines comment on recommended levels of water and diet/feed/forage levels simultaneously. Dual incorporation of these factors is at times impractical, for example, high variability between breeds and species makes the incorporation thereof into guidelines difficult.

Finally, a generic level risk assessment is recommended as the first step in determining baseline exposures required for the identification of constituents in the geochemical environment that may contribute to adverse effects on health, productivity, and product quality.

Any potential hazards identified would then require further investigation regarding the water, user, environment and nutrition.

In many cases, due to factors ranging from adverse effects at exceedingly low concentrations (e.g. endocrine disrupting chemicals) to confounding outcomes from multiple-exposures, directed clinical biochemistry investigations may provide site-specific insight into fitness for use and potential mitigation options.

The presentation of the Generic-WQGIS to the user is predominantly in the form of the familiar tabulated guideline system, but additional generic options can still be provided in order to increase the accuracy of the generic-level assessment provided, based on the assumption that the user has some, even if limited, information pertaining to the water sample use detail.

Examples in which the user selects certain livestock specific detail regarding type and diet are provided in the tables that follow and would conceivably correspond to the subsets within Tier 1 and Tier 2 noted earlier.

These tables may be viewed as subsets within the Tier 1 system in which the user may make a varying degree of selections to the production system detail options provided, whilst still not having actual water intake or other relevant site-specific risk factor detail.

As noted earlier a key update required to these tables is to include at the initial "no adverse effects" statement a range of deficiency statements to accurately reflect the essentiality and potential positive effect of the constituent presence in the water source (examples provided from Table 17 to Table 21).

Table 17: Current Generic guideline used in practice*: Livestock – Selenium – small ruminants

Target water quality range Selenium (mg/L)	Comments
0-0.02	Adverse effects due to excess selenium intake unlikely
0.02-0.05	Adverse effects possible but risk factor dependant (intake, speciation, limiting nutrients, physiological stage- sensitive user groups)
0.05-0.7	Adverse effects likely with minimal risk factors present in sensitive user groups
0.7-2.5	Adverse effects likely (chronic selenosis) with minimal to zero risk factors present in all groups
>2.5	Adverse effects probable (chronic to acute selenosis) in all groups.

* This guideline is currently used to prompt clinical biochemical investigations with status determined prior to differential diagnosis procedures.

Table 18: Draft proposed generic guideline: Commercial – Sheep – Type I subset A

Commercial: Intensive production for human consumption: Feedlot: Sheep: South African Mutton Merino breed WQC: Selenium Type 1 = General Information: Diet Subset A = No organic selenium inclusion, adequate Vitamin E status, diet digestibility q = 0.7				
Range (mg Se/L)	**0-0.03**	**0.03-0.06**	**0.06-0.12**	**>0.12**
Comments	High probability of a Positive response on supplementation in high yielding mature animals (late stage – finishing)	Possible benefit of supplementation in all groups.	Possible benefit of supplementation in first stage animals	Supplementation may led to excessive supply
Types of effects	Significant Deficiencies	Deficiencies	Marginal Deficiencies	Deficiencies unlikely
Classification	**Poor**	**Marginal**	**Target range**	**Marginal**

Table 19: Draft proposed generic guideline: Commercial – Sheep – Type I subset B

Type 1 = General Information: Diet Subset B = No organic selenium inclusion, adequate Vitamin E status, diet digestibility q = 0.5				
Range (mg Se/L)	**0-0.09**	**0.09-0.185**	**0.185-0.37**	**>0.37**
Comments	High probability of a Positive response on supplementation in high yielding mature animals (late stage – finishing)	Possible benefit of supplementation in all groups.	Possible benefit of supplementation in first stage animals	Supplementation may led to excessive supply
Types of effects	Significant Deficiencies	Deficiencies	Marginal Deficiencies	Deficiencies unlikely
Classification	**Poor**	**Marginal**	**Target range**	**Marginal**

The change in target range is based on factorial estimates for requirements predominantly based on essential intermediate metabolism pathways.

The specific exposure period applicable to this production system and product quality requirements for human consumption are incorporated in the ranges proposed.

Table 20: Draft proposed generic guideline: Commercial – Sheep – Type 2 subset A

Type 2 = General Information: Diet, performance Subset A = High yield and mature body weight, diet digestibility q = 0.7			
Range (mg Se/L)	**Comments**	**Types of Effects**	**Classification**
< 0.02	No risk of selenosis	Deficiencies possible if no supplementation	Marginal with supplementation Poor with no supplementation
0.02-0.05	Adequate supply - Very Low Risk of selenosis - highly risk factor dependent	Deficiencies possible if no supplementation	Target if organic supplementation occurs at upper band of requirements
0.05-0.1	Adequate supply – low risk of selenosis – risk factor dependent	Marginal excess possible	Target if supplementation probable
0.1-0.24	Adverse chronic selenosis effects possible in sensitive user groups	Marginal chronic toxicities	Marginal
0.24-0.7	Adverse chronic selenosis effects probable in most groups	Chronic toxicities	Poor
0.7-1.8	High risk of chronic selenosis in most groups	Chronic toxicities	High risk
> 1.8	Risk of acute selenosis	Acute toxicities	Unacceptable

Table 21: Draft proposed generic guideline: Commercial – Sheep – Type 2 subset B

Type 2 = General Information: Diet, performance Subset B = Low yield and body weight, diet digestibility q = 0.5			
Range (mg/L)	**Comments**	**Types of Effects**	**Classification**
< 0.01	No risk of selenosis	Deficiencies possible if no supplementation	Marginal with supplementation Poor with no supplementation
0.01-0.02	Adequate supply - Very Low Risk of selenosis - highly risk factor dependent	Deficiencies possible if no supplementation	Target if organic supplementation occurs at upper band of requirements
0.02-0.7	Adequate supply – low risk of selenosis – risk factor dependent	Marginal excess possible	Target if supplementation probable
0.7-1.11	Adverse chronic selenosis effects possible in sensitive user groups	Marginal chronic toxicities	Marginal
1.11-2.22	Adverse chronic selenosis effects probable in most groups	Chronic toxicities	Poor
2.22-5.55	High risk of chronic selenosis in most groups	Chronic toxicities	High risk
>5.55	Risk of acute selenosis	Acute toxicities	Unacceptable

These tables demonstrate the benefit of applying Generic animal production type factors to concentration-based guidelines in that indices for deficiencies, adequacy and toxicities are incorporated dependent on standard system components.

It should be noted that most international guidelines for animal watering stop at a single level recommended maximum limit and few accommodate changing concentrations, (with TDS as an example although still with significant errors). Consequently, the vast majority are overly simplistic and focussed on a "safe" level of exposure.

As noted earlier, the existing Generic-WQGIS developed is now also outdated and the addition of new WQCs and revised constituent concentrations is required. It should also be considered that the adoption of the SANS 241 values should not occur without careful evaluation of the concentration derivation, noting that the source document for these standards emanate from the WHO guidelines which explicitly state that the rationale for the derived concentrations is based on the expected or anticipated occurrence thereof in treated drinking water.

As demonstrated in the WRC projects referred to this occurrence assumption does not hold true for South African groundwater or surface water resources and cannot be thus applied. As is also recognised inference of human drinking water guidelines to animals is not possible due to the significantly different exposure scenarios and fundamental physiological differences.

A key aspect that will need to be considered in the following phases of the project is the viability of producing area-specific Generic Tier I guidelines and Production System Specific Generic Tier I guidelines.

Although these variations are addressed to an extent in the tables provided above, they may need to be adapted for intensive confined animal feeding operations where water intake values are constantly evolving to meet the change in genetic progress, nutrition, housing and management, all of which lead to an intake setting which can be more accurately incorporated even with a generic-concentration based approach.

3.6.2 Application Level - Specific

In order to progress from the Tier I type Generic Application approach outlined above, additional information inputs based on either reference type documents and/or site-specific data would be used and centre on water ingestion rate reference documents that are compiled with corrections for body weight, dry matter intake and water turnover rates, amongst other things. This would serve as inputs to the application of hazard and risk procedures applicable to the specific production system type.

It was noted that the central component is the WIRRD, with an example for sheep expanded as:

Sheep = Breed specific water turnover rate factors; Breed specific production system factors; Breed specific environment type factors; trigger factors for column B in the WIRRD; sheep protein limits by LW and physiological category; Sheep available copper coefficient regression equations; Sheep copper allowance alert; salt and lick composition; DMI% factors for TWI modification; Sheep nutritional limits for the MINRD calculations; Environmental rules for temperature, altitude, soil content and availability; palatability factors; and Geographical location factors and tables.

The risk assessment generated report 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.

3.7 Considerations for selected Water Quality Constituent Updates

An updated list of all water quality constituents is required but is beyond the scope of this project, with updates made for the following selected key water quality constituents:

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

It should be noted at the outset that the increase in sensitivity of analytical detection limits and clinical investigations has fuelled many diverse opinions regarding "safe" exposure concentrations and leads to a vast array of specialist opinions published in peer-reviewed scientific literature. With this as a backdrop it should be appreciated that the "assumptions" cited when formulating guidelines, notably for domestic drinking water, are frequently challenged as being simply incorrect. Challenges to the uncertainty factors, allocation factors, and NOAEL used are the primary areas of debate. It is beyond the scope of this deliverable to address this, but the selected water quality constituents detail listed above is provided in Appendix A, with this section highlighting the overall issues and possible influences thereof to the CIRRA model approach and reference documentation.

It is thus noteworthy that similar changes to these mentioned above are noted for nutrient requirements for animals with advances in both production parameters and corresponding nutritional approaches observed in animal production literature, thus also effectively changing not only the recommended daily intake (or more correctly requirement) but also the contribution from formulated feeds.

A key difference in terms of animal production systems is that not all categories of animals within a production system are sensitive user groups or exposed for long-term periods, with many able to arguably withstand elevated ingestion rates without developing significant adverse effects.

At the other end of the scale, it is also true that the increased production rates expected from high performing animals, notably with the elevated feed and water intake requirements to sustain the high production rates, have yielded some of the categories as very sensitive user groups.

Some relevant examples are highlighted next as they pertain to benefits and changes required and recommended for the Specific-WQGIS Application, with selenium provided as an example constituent.

<u>Selenium</u>

Using domestic drinking water guidelines as illustrative of more recent guideline directions it is noteworthy that the departure in 2011 by the World Health organisation (WHO) (WHO, 2011) health-based drinking water guideline from the 0.01 mg/L limit to 0.04 mg/L has been heavily criticised (Vinceti *et al.,* 2012). Key factors cited include the widely published recognition of adverse effects at both low and high blood serum values and the questionable use of changed reference values in the guideline derivation.

This is pertinent to the animal industry as selenium is viewed as a critical element in the diet (organic form supplemented) but known to have a narrow range between deficiency and toxicity. Given that the inorganic form in water is associated more with adverse effects than the dietary organic forms, the reduction in the recommended guideline has been challenged. Challenges to recent Environmental protection Agency (EPA) statements on selenium limits and environmental impacts have also met with specialist criticism.

The links to adverse effects and inorganic selenium exposure via the drinking water are too vast to present here and will be presented for Deliverable 3, but the guideline derivation aspects are worth noting. The WHO previously supported a No Observed Adverse Effect Level (NOAEL) of 0.004 mg/kg Body weight (BW)/day assuming a 60 kg adult consumes 2 L of water per day and that selenium from this pathway contributes 10% of the total dietary intake (a value used for many other inorganic constituents).

The 2011 version changed this approach to use an upper tolerable intake of 0.4 mg Se/day which was derived from the NAS 2000 data. The same NAS data sheet notes the upper tolerable intake to range from 0.045-0.280 mg Se/day for the ages of 6 months to 13 years respectively.

The rationale for not catering for most sensitive life stage by the WHO in the guideline derivation was not provided, nor was the change in contribution of drinking water selenium to the total selenium exposure.

Additional concerns were raised for other inorganic constituents in the 2011 WHO Guidelines for Drinking-water Quality, including the failure to update the guidelines for (or not establish, or exclude or elevate) aluminium, boron, manganese, mercury, molybdenum, nickel, nitrite, uranium and selenium.
It is insightful to note that the stated reason for the removal of some guideline values were cited as “this health-based value is well above concentrations of manganese normally found in drinking-water, it is not considered necessary to derive a formal guideline value”, whereas this has been criticised as many countries do use drinking water which presents with these values, notably in communal groundwater supplies (also applicable to South Africa).

This aspect was noted in the Inception Report when alluding to the incorrect use of SANS 241 Standards and the failure to recognise the difference between treated water across countries with different source water characteristics and treatment capabilities.

When comparing domestic guidelines, it is insightful to note the differences between countries with many citing similar source reference documentation but differing in which to use and what factor values to apply. The U.S. EPA (2012) cites a Maximum Contaminant Level of 0.05 mg/L, similar to the WHO guideline value of 0.04 mg/L, whereas the California OEHAA (OEHHA, 2010) Public Health Goal is set at 0.03 mg/L, using a NOAEL of 0.015 mg/kg BW. The Australian drinking water guideline is set at a significantly lower 0.01 mg/L (NHMRC and NRMM, 2011). The Canadian drinking water guideline is set at 0.05 mg/L (Health Canada, 2014).

When evaluating the guideline derivation formulae the following is noted:

Upper Limit (mg/d) = NOAEL / Uncertainty Factor (UF)

Where: NOAEL of 0.8 mg/day and UF = 2

Yields UL = 0.4 mg/d

This UL is used in the drinking water guideline derivation as:

Health Based Value (mg/L) = [0.4 mg/d x 0.20]/1.5 L/d = 0.053 mg/L

This health-based value (HBV) is rounded off to 0.05 mg/L. When comparing different guidelines all these inputs are changed between the different countries. The allocation factor of 20% used above of drinking water to selenium exposure is noted as the same for the WHO guideline, whereas a factor of 10% is used in the Australian guidelines. This significantly alters the HBV which would be rounded to 0.02 mg/Las shown below:

Health Based Value (mg/L) = [0.4 mg/d x 0.10]/1.5 L/d = 0.026 mg/L

The Australian guidelines also adopt a different UL of 0.24 mg/d, and also use a higher water intake allocation for an adult of the same body weight (2 L for 70 kg) as shown below:

Health Based Value (mg/L) = [0.24 mg/d x 0.10]/2 L/d = 0.01 mg/L

These levels differ, presumably also as a function of the country of study and background exposure values, even for within country values. The Canadian drinking water technical document highlights the differences in published studies and corresponding recommendations, for example, the Recommended Dietary Intake values for selenium range from 0.015 to 0.055 mg/d, with the minimum intake cited as causing toxicity as 0.910 mg/d and the maximum safe exposure concentration cited as 0.750 mg/d. These studies lead to significantly varying NOAEL values being cited.

It should be noted that the allocation factor must be viewed in context of the typical water quality exposure values cited in the respective country. The Canadian concentration ranges cited are significantly lower than that noted in South African groundwater observations, with 8869 samples yielding 95% < the LOD of 0.001 mg/L and a maximum value cited of 0.011 mg/L. The maximum selenium concentration reported in the Canadian data sets was 0.027 mg/L (n = 14683 samples).

Concentrations noted in associating with studies conducted for the Department of Agriculture in new groundwater source investigations (DoA Reports, 2006-2007) highlight concentration ranges with a median value of 0.036 mg/L and a maximum value of 3.069 mg/L (n = 507).

Given the high water intakes noted earlier in South African conditions, it follows that the allocation factors would need to be altered significantly to arrive at a more accurate country-specific guideline value. The exposure scenario in many rural communities where water resources are linked to specific age groups, for example, schools and single groundwater sources, may validate applying the lower Upper Tolerable Intake level of 0.150 to 0.280 mg/d for the Rural Communal Animal Production Model (as opposed to the 0.4 mg/d used by the WHO and Canada), especially when dietary dilution to animal product reliance and intake is not significant.

Whilst these points highlight the issues for domestic drinking water it can be appreciated that in many cases the values are based on animal exposure studies and the issues noted are in principle applicable to the different dietary and production factors for animal systems. As an example, the nutrient requirements for sheep may range from 0.020-0.055 mg/kg DM depending on live weight, production parameters and diet digestibility.

An additional aspect of selenium to be considered relates to the link between ingested selenium and the potential impact on water resources and the environment through the generation and subsequent handling of biodegradable industrial wastewater.

The Canadian approach highlights that due to the potential for selenium to bio-accumulate in aquatic food chains the water quality concentration recommended for irrigation water (not wastewater) is 0.02 mg/L for continuous use on all soils and 0.05 mg/L for intermittent use on all soils. The corresponding water quality guideline for livestock is greater than the continuous irrigation use value, cited as 0.05 mg/L, obtained from the outdated 1987 CCREM document cited in current water quality summary tables for (CCME, 2018).

As the inclusion of selenium in animal diets at the upper range of the nutrient requirements and the corresponding presence of an elevated selenium concentration in water used for animal production may impact the concentration thereof in the raw, liquid and solids fractions from confined animal feeding operations, it follows that an inclusive approach is required.

The Canadian recommendation for soil quality limits for the protection of human and environmental health cites a soil range in mg/kg dry weight ranging from 1 to 2.9 for residential and commercial/industrial use respectively.

On this topic it should again be noted that Section 21 water use activities should be incorporated noting that water use on the site of a confined animal feeding operation may include washing and flushing water, with the inclusion thus of water quality norms for water distribution systems on site warranted, as it is not only via the diet and drinking water that selenium may impact manure quality and thus water resources and the environment.

This may additionally be included to link to the existing soil background values for selenium within applied areas, noting that this could be correlated to selenium deficient and excessive areas with the allowable biodegradable industrial wastewater limit value thus a function of the receiving environment as opposed to a simple wastewater limit independent of site-specific factors.

It should be noted that currently this is not occurring and General Authorisations, prescribed guidelines and licence conditions do not adequately provide for the site-specificity and may thus at times be both unnecessarily prescriptive and overly conservative for some environments, whilst possibly fail to protect ecosystems in other environments.

As an example of the potential impact of the various water use activities and different diets brought on site, groundwater quality and wastewater quality comparisons for fluoride and selenium have been observed in compliance monitoring for confined animal feeding operations (CAFO) as follows (mg/L):

- Fluoride: [water]-{wastewater}
    - CAFO 1: [0.73]-{0}
    - CAFO 2: [0.45]-{0.74}
    - CAFO 3: [15.26]-{38.71}
    - CAFO 4: [0.5]-{2.92}

- Selenium: [water]-{wastewater}
    - CAFO 1: [<0.001]-{0.098}
    - CAFO 2: [0.006]-{0.032}
    - CAFO 3: [0.016]-{0.062}
    - CAFO 4: [0.013]-{0.249}

Whilst some clear correlations are noted between high water concentrations and wastewater generated, other clear variances are noted. These variances are explained by different diets, source water quality and wastewater handling systems. These ranges do highlight the significantly different effects of both high inherent water quality concentrations and the influence of diets provided on-site, providing rationale for site-specific assessments of both fitness for use and wastewater handling practices.

The updates noted in the preceding sections to the CIRRA model for the new norms and links as described are thus deemed essential in order for the Risk-based guidelines to allow the DWS to perform its mandate of water resource protection.

The last set of updates relate to a fundamentally different approach to the manipulation of the central WIRRD. The current approach relies on the animal category specific WIRRD as a central reference document, with the actual TWI a key method of incorporating site-specific ingestion differences. Risk factors are then applied to the WIR column value yielded as a change to the final Risk index obtained. Although this method does permit site-specific factors for both the source, pathway and receptors to be considered, it may be more accurate to make fundamental changes to the guideline effect column values. This approach allows for additional changes to the applicable column by implementing statements on the scenario setting and trigger factors which are subdivided into source, pathway and receptor aspects.

The trigger values may change per column and may also change per table type, for example, different trigger values may be used for gestation compared to growth. This approach will provide an additional benefit of guiding the user regarding the source, pathway and receptor events applicable.

It is reasonable to opt for this approach as a more conventional manner for introducing Risk-based guidelines by relating the values used to commonly used hazard and risk assessment processes.

Using Selenium as an example, the following may be considered as a draft example to illustrate the approach, noting that the tables are best considered with a complete update for all the production categories within the animal type selected (Table 22):

Table 22: Example of a Specific-WIRRD for Livestock Type = Sheep; Category = Ewes – maintenance; Water Quality Constituent = Selenium; Core WIRRD

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	1	2.87	0.116	[0.013] 0.00151	[0.02] 0.00232	[0.05] 0.0058	[0.7] 0.0812	[2.5] 0.29	>0.29
60	1.1	3.26	0.113	[0.0116] 0.00131	[0.0174] 0.00197	[0.044] 0.00497	[0.616] 0.0696	[2.20] 0.2487	>0.2487
70	1.2	3.642	0.111	[0.0104] 0.0011	[0.0156] 0.00173	[0.0394] 0.00437	[0.5516] 0.0612	[1.980] 0.2186	>0.2186
80	1.3	4.028	0.1108	[0.0094] 0.0010	[0.0141] 0.00157	[0.0346] 0.00394	[0.4987] 0.0552	[1.781] 0.1973	>0.1973
90	1.4	4.414	0.11	[0.0086] 0.0009	[0.0129] 0.00142	[0.0325] 0.00357	[0.455] 0.050	[1.625] 0.1788	>0.1788

*[ ] = values adjusted for column A as per factorially derived selenium nutrient requirements.
^Where columns A to E 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 following Table 23 and Table 24 elaborate on the proposed source, pathway and receptor entry into the WIRRD for the applicable column, noting that this method will be user group specific and user interface dependant.

Table 23: Example of a Specific-WIRRD for Livestock Type = Sheep; Category = Ewes – maintenance; Water Quality Constituent = 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 22		

Table 24: Example of a Specific-WIRRD for Livestock Type = Sheep; Category = Ewes – maintenance; Water Quality Constituent = Selenium; Column C

Site-specific conditions – Column C^^		
Source setting: Column C = - organic dietary selenium supplementation - forage Se 5-15 mg/kg DM - soil concentrations 0.02-3.7 mg/kg DM. - geographical location = seleniferous area	**Pathway setting:** Column C = - temperature 16-22.5 degrees Celsius	**Receptor setting**: Column C = Production parameters = set reference values
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 22		

Table 25: Example of a Specific-WIRRD for Livestock Type = Sheep; Category = Ewes – maintenance; Water Quality Constituent = 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 22		

The series of tables provided for Table 22 may be altered by changing the WIR reference values per column on the basis of site-specific data entered. As previously stated, the most significant change is warranted when the TWI changes based on actual site-specific observations. The influence of a different water intake is significant in the guideline derivation process as noted earlier for selenium in domestic guidelines, and this data input is viewed as the key data input required.

It should be noted that in accordance with the NWA the actual volume of water used in commercial animal production systems should be measured, although in practice the total volume on site remains the most measured volume, consequently requiring the WIRRD and categories to still be utilised to obtain physiological and production specific values. As noted in the Inception Report these can also be derived from established regression equations, frequently involving feed intake. The use of temperature as an input is also established, but less so for all the various breeds, although some breed management guides do have detailed information.

A practical challenge to using on-site or production site volumes relates to the need that is often observed to improve water sparing practices on sites, with water wastage a potentially significant component of the estimated volume consumed. In many cases water lines are separated from wash lines and staff facilities and intensive production sites are generally moving toward more accurate drinker line metering.

The value of this accurate category specific measurement cannot be overstated, noting in the recognised reference publications a significant range is always quoted even for specific categories, for example, the lactation phase for dairy cattle, for ewes and sows is typically cited as 68-114, 4-12 and 18-35 L respectively. Changes in housing, nutrition and genetics are also continually changing production goals (e.g. increase from 12 to 18 born-alive piglets over the past few years).

In the more extensive and less intensive systems the use of a temperature adjustment is nonetheless warranted. A temperature derived set of changes may also be used to change the WIR reference values in the guideline effect concentration range columns, noting that the effect is amplified as the column concentration increases (towards excessive risk values) as provided in Table 26.

Table 26: Example of a Specific-WIRRD for Livestock Type = Sheep; Category = Ewes – maintenance; Water Quality Constituent = Selenium – temperature input adjustment

Temperature adjustment = ↑ of 7ºC from default setting									
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	1	2.87	0.116	[0.011] 0.00128	[0.015] 0.00182	[0.041] 0.0048	[0.586] 0.0679	[2.09] 0.2429	>0.2429
60	1.1	3.26	0.113	[0.0095] 0.00107	[0.0138] 0.00156	[0.036] 0.00416	[0.515] 0.0583	[1.843] 0.2083	>0.2083
70	1.2	3.642	0.111	[0.0087] 0.00096	[0.0124] 0.00137	[0.0329] 0.00366	[0.461] 0.0512	[1.650] 0.1831	>0.1831
80	1.3	4.028	0.1108	[0.00078] 0.00087	[0.0112] 0.00124	[0.0298] 0.00330	[0.417] 0.0462	[1.491] 0.1653	>0.1653
90	1.4	4.414	0.11	[0.0072] 0.000079	[0.0102] 0.00112	[0.0272] 0.00299	[0.381] 0.0419	[1.361] 0.1497	>0.1497

*[ ] = values adjusted for column A as per factorially derived selenium nutrient requirements.

^Where columns A to E 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

Hypo-osmotic Effects

This is a key topic to be addressed with reported guidelines outdated and significantly flawed, both in terms of statements made and are illustrative of a disconnect with current performance and health requirements and incorrect physiological interpretation. Updates to the CIRRA model and redressing the concept of a target Total Dissolved Solids (TDS) guideline are viewed as key to allowing water users and water resource managers to not incorrectly choose low TDS waters as a preferred or target water quality objective.

This section presents background information regarding the mechanism involved in the possible hypo-osmotic related effects due to the inorganic chemistry of the drinking water provided using poultry as a production animal type. The relevant physiological principles are briefly outlined with a proposed mitigation consideration.

Some of the consequences may relate to production parameter problems as communicated by farm managers, consultant veterinarians and nutritionists, when compared to different production sites using similar genetics, nutrition and other production inputs, yet different water sources.

Whilst water quality guidelines typically relate to exposure to high concentrations of elements with subsequent toxic, carcinogenic and/or endocrine disruptive effects, low Total Dissolved Solids (TDS) concentrations can also have adverse consequences.

Water quality results from a layer farm are used to illustrate the relevant issues, but similar concerns are also valid for broilers with reductions in mortalities (late cycle cardiac failure), lowered wet litter and lowered ascites incidence noted on water treatments applied to increase the osmotic activity of the drinking water.

This section is not intended to provide an exhaustive review, but to stimulate further discussion on the relevant issues.

- **Water quality: Osmotic Comparison**

  The Total Dissolved Solids values observed were very low at **8 and 10 mg/L** for point of use exposure concentrations.

  By way of comparison, an intravenous (IV) preparation is mostly isotonic to prevent fluid and acid: base disturbances. Whilst this approach is of specific reference to re-hydration and management of several fluid imbalances, the approach is *illustrative* of the general factors involved.

  A normal saline IV contains 0.9% w/v NaCl. This implies:

  9 g NaCl/L

  Or

  9000 mg NaCl/L

  This effectively implies a TDS value of 9000 mg/L.

  This equates to an osmolarity value of 285 mOsm/L (the same value observed in blood, interstitial fluid and intracellular fluid) as follows:

  NaCl (23)(35.5) = 58.5 g MW = 1 Mole

  9 g NaCl = 0.154 moles

  NaCl dissociates into 2 osmotically active particles (Na+ & Cl-), thus:

  1 mole NaCl =2 osmoles, thus

  0.154 x 2 = 0.308 Osmoles/L

  = 308 mOsm/L

  At an effective osmotic pressure coefficient of 93% this approximates:

  285 mOsm/L

Even when different types of IVs are used, for example, D5 (Dextrose at 5% or 50 g glucose/L) or Hartman's Solution, the total composition presents an osmotically active component of approximately 9000 mg/L.

Thus, by comparison, the 10 mg/L TDS offered to the layers represents comparatively "pure" water for drinking purposes that is best considered as a water replacement and not a fluid requirement. It is noted in some poultry guidelines that the range for TDS should be 300-500 mg/L, however, for domestic use (humans) no significant effects are recorded at 1000 mg/L, with 2400 mg/L considered to present only marginal risk (to sensitive user groups).

TDS values of >2400 mg/L present with a "salty" taste that may result in poor water intakes, although evidence suggests that this is not a renal clearance limit, but an aesthetic value that can be adapted to.

It is important to note that TDS does not equate to NaCl alone. Individual guidelines for these elements also exist and need to be accounted for. Sodium concentrations of 200-400 mg/L may impart a mild salty taste to water, whilst Chloride concentrations of 200 mg/L impart a distinctly salty taste (refer to palatability zones reported in CIRRA related WRC projects).

It is generally reported that the use of high-energy diets greatly increases sodium requirements. Sodium deficiency in laying hens was reported at (0.5 g /kg DM) to also be aggravated by chlorine restriction (at 0.8 g/kg DM) (Underwood & Suttle, 1999). In the first week of the broiler cycle sodium and chloride requirements are much higher than initially thought (5 g Na /kg DM v. 1.3 g Na /kg DM).

Concern for excessive exposure has been reported for the laying hen with sodium concentrations of 600 mg/L resulting in an increased percentage of damaged eggshells, although many studies failed to comprehensively describe the chemistry of the water offered, and many of the studies referenced are not repeated by other workers.

Egg shell quality concerns have been reported from Sodium concentrations of 200 mg/L, although the ratio of the major cations and anions is known to be a significant factor in determining tolerance. The avian renal portal system delivers a higher perfusion to the tubules than the mammalian efferent arteriole supply (peritubular capillary network) and assists in a greater tubular secretion of uric acid. Since this is in a precipitated form (not in solution), it does not contribute to the effective osmotic pressure and do therefore not result in an osmotic diuresis.

Whereas urea plays a crucial role in the conservation of water (ADH response) in the mammalian renal system (hyperosmolality of the medullary interstitium), it does not have any effect in the avian system, with NaCl reabsorption from the ascending Loop of Henle thought to be responsible.

It is also important to note that post-renal modification of ureteral urine is possible in the avian system due to the exposure thereof to the cloaca membranes. Some retrograde flow may also result in effects in the colon and caeca.

Lastly, it is important to consider the effect of laying (oviposition) on water intake. This has been well described and may influence the volume of water consumed in a given time period. This can significantly alter the degree to which the responses detailed later are initiated. Briefly, if a higher intake over a shorter period is considered as a consequence of oviposition then the hypo-osmotic effects are more likely to occur whilst digesta content buffer effects are likely to be lower.

The water may thus be considered as hypo-osmotic and if presented as such will increase the risk for blood sodium to be diluted, specifically during requirements for high water intake typical of high producing animals (and 8-10 hours post oviposition), causing serum osmolality to decline.

This causes several physiological processes to be initiated that do not facilitate the high standard of production required. Although these effects may be transient and asymptomatic, cumulative priming of these homeostatic mechanisms does not assist with cost-effective production. Consequently, factors such as a low FCR and sub-optimal performance may be noted. Physiological consequences may involve primarily cardiac, renal and respiratory systems.

- **Basic Mechanism**

<u>Setting:</u>
The composition of the intracellular and extracellular compartments is predominated by potassium and sodium respectively. Cumulative osmolar contributions result in these compartments having equal values, typically ca. 285 mOsm/L.
This allows the cellular environment to be maintained with the correct fluid composition and subsequent cellular tonicity. The primary method by which these compartments are homeostatically maintained is by the regulation of blood volume and sodium concentration (with potassium reciprocally controlled).

Blood pressure is regulated primarily by: Cardiac Output x Peripheral Vascular Resistance.
Blood volume is directly linked to blood sodium as this is the major dominant osmotically active electrolyte (other blood components may be present in significant concentrations but do not impose an osmotic gradient effect).

A combination of osmo-receptors (actually sodium-osmoreceptors), atrial stretch receptors and baroreceptors initiate neural-endocrine responses to maintain blood pressure and renal function in accordance with the maintenance of blood volume and composition.

Sequence of Events:

The provision of this water for drinking purposes will briefly initiate the following:

- Primarily - Movement of water into the vascular portion of the ECF causing:
    - Dilution of blood Na+
    - Volume expansion (effective circulating fluid volume)
        - Homeostatic mechanisms to rectify this.
            - Elevated blood pressure to cause an increase in Glomerular Filtration Pressure (and thus rate), which causes:
                - Increased renal tubular filtration flow rate
                - Lower renal reabsorption (shift in tubular transport and threshold values)
                - Possibly medullary washout and loss of electrolytes
                - **Pressure Diuresis**
            - Neural-endocrine mechanisms to reabsorb Sodium (renal JG RAS system & Aldosterone effects in late CT & CCD)
            - Initiation of a “Salt” or **Sodium Appetite**.
- Secondary – Movement of water into the interstitial and finally intracellular compartment causing:
    - Hypotonic effects
        - Increased distances for nutrients and waste products resulting in less effective cellular metabolism
    - Decreased neural stimulation to Thirst Centre (lower water intake stimulus)
    - Strong and persistent (possibly delayed) sodium appetite

This sequence of events is also noted in equines where isotonic dehydration has occurred and fresh or pure water is offered. Equines actually dehydrate even further in this instance since the sodium-dilution initiates a pressure diuresis to conserve sodium preferentially as opposed to correcting the water deficit.

It is important to note that the sodium composition of blood is defended at the cost of volume, with only significant fluid deficits (>8% Body Weight loss) taking preference for baroreceptor stimuli to the thirst centre – although when this is initiated it is more powerful dipsogenic response than the initial cellular dehydration (secondary thirst signal is an extracellular vascular hypovolemic stimulus).

Potential Adverse Effects:

The relative water excess is also cleared with a volume-loaded pressure diuresis that causes two key adverse effects.

- Firstly, the high pressure on the nephron may cause several renal perfusion complications if repetitively stimulated. These relate to long-term high pressure in the glomerulus which can inflame the fenestrae causing the filtration barrier to be compromised.
    - If this occurs, the ability to retain blood proteins may result in significant adverse effects linked to a failure to maintain Plasma Colloid Osmotic Pressure, including:
        - Generalized **oedema** (also **ascites** related events).
        - Increased renal loss of nutrients and an **osmotic diuresis** (similar to diabetic patient).
- Secondly, the increased speed of tubular filtrate flow may result in a wash-out of some essential nutrients at plasma concentrations below their transport maximums and thus represent a loss thereof.
- Hypotonic effects may result in less efficient feed utilization due to suboptimal cellular metabolism environment.
- The elevated blood pressure in response to volume expansion may result in an increase in hypertensive disorders and possible increase in related complications.
- Although too complex to present here it should be noted that the renal effects on sodium balance may significantly alter potassium balance (renal tubular H+/bicarbonate regeneration system). This could in turn affect:
    - Respiration response that may increase difficulty in adapting to temperature related control mechanisms
    - Complications for eggshell quality (ionisation effects linked to compensatory acid: base shifts).
    - This may present as a mixed disturbance.
- It should be noted that for poultry, both the unique respiratory system and renal portal system, can potentially exacerbate these responses.

All these effects may be subclinical, but be noted by management as:

- Higher feed intakes to weight gain, or lowered FCR values.
- Erratic water: feed intake profiles
- Higher wet litter problems
- Higher mortalities linked to renal and cardiovascular events.
- Egg shell quality issues

<u>Summary:</u>

The water quality offered can induce a *relative water excess* causing a pressure diuresis and cessation in drinking or thirst signals in an attempt to prevent further volume expansion and sodium dilution.

Stimulation of this mechanism and subsequent scenario being caused to develop repetitively will promote a hypotonic response with hyponatremia observed.

This can result in a persistent sodium appetite with simultaneous problems in feed utilization, with renal tubular washout, hypotonicity and possible ureteral modification effects involved.

The choice of water source for intensive confined animal feeding operations with high production targets should be with the above-mentioned aspects taken into consideration, noting that in many cases blending of high saline and low TDS water to yield a stable exposure value in the 1000-2000 mg/L TDS appears to not only alleviate problems associated with both too high (>3000 mg/L TDS) or too low (<300 mg/L TDS) TDS water sources.

Nitrate

It is noteworthy that the existing guidelines are based on the incidence of methemoglobinaemia which is primarily a nitrite toxicosis and have been primarily of application to ruminant stock due to the rumen reduction of nitrate to nitrite and subsequent increase in risk for nitrite toxicosis.

Changes to the water ingestion rate is required to enable an exposure period for ruminant animals to be included, as continual exposure to a concentration range of 44-90 mg/L of nitrate (as NO_3) can lead to an adaptation in the rumen where the nitrite is further reduced to ammonia, with a significant reduction in the nitrite risk.

Despite the apparent tolerance of monogastric animals increasing field observations of pigs and poultry presenting with methemoglobinaemia outcomes have been noted and gastrointestinal reduction appears thus more prevalent than recognised. It may be in the case of pigs that the risk is a function of dose ingestion as the primary adverse endpoints such as stillbirths, mummified foetuses and lethargy in the pregnant sow are mainly observed in the breeding unit (gestating and farrowing sows). In the case of poultry the concern appears more applicable to breeding farms as well. Both scenarios have on-site haemoglobin tests (supported by some post-mortem aqueous ocular fluid nitrate values) that support the concern for increased methmoglobinaemia, with most responding to either a removal of nitrate exposure (or reduction) and increased iron supplementation.

As is noted in the literature regarding iron deficiency anaemia in pregnant women and the increased need for iron supplementation therapy (intra-venous or intra-muscular and not per os), this correlation should be included in nitrate guidelines.

Additional concerns that are not catered for currently include the failure to account the reported EDC effects and the general disregard for inherent nitrate concentrations and subsequent chlorine-based disinfection strategies and formation of NDMA (observed in some confined animal feeding operations).

Bromide

Bromide elevations have been noted in many South African subterranean sources, with broilers used for the Water Research Commission EDC Programme for sentinel monitoring purposes relating to public health investigations. Results have indicated that thyroid disruption may occur in broilers within a normal 35 day cycle period as evidenced by thyroid histopathology observed and in pigs as evidenced by low thyroxine levels, with both scenarios responding positively to mitigation treatments or removal of high bromide containing drinking water.

Observed bromide concentrations are anomalously elevated due to naturally occurring geochemical anomalies, contaminants from agricultural chemicals (at times introduced via chlorine-based disinfection systems) and pollution from coal-fired power stations (Van Briesen, 2013; Good and van Briesen 2017).

Research conducted in broilers exposed to a range of bromide values where thyroid dysfunction was noted both in blood T4 values and in the histopathological lesions observed in thyroid sections (Meyer *et al* 2014l; Meyer *et al* 2015). It is noteworthy that in the high exposure broiler sites (all Ross 308) poor growth was noted in the last seven days of the cycle, which coincides with the activation of the thyroid in poultry physiology. It is thus suggested that these exposure values may present with hypothyroidism that may be correlated to the high feed intakes noted at some Layer Farms.

It is essential to note that endocrine disruption does not imply dysfunction that is physiologically significant. Research into EDCs is thus complex and best performed on a site-specific basis. Observed exposure values exceeding 0.1 mg/L are thus best considered as trigger values that should warrant further investigation.

The main results are presented in Table 27 below from previous WRC reports showing the significant reductions in thyroxine values (leading to reported poor growth and other production losses), but it should be noted that the results of the bioassays performed on water and sediment should also be used in conjunction with any investigation in addition to clinical biochemistry and histopathology.

Similar disruption effects linked to elevated Br concentrations (0.1-1 mg/L) have been noted other poultry and pig production systems, with an additional concern for essential trace element induced-deficiencies apparently also applicable (as evidenced by clinical biochemical investigations).

It thus remains a strong recommendation that the inorganic chemistry tests utilising an ICP-MS must include bromide, as this is noted in the recent WRC reports as an endocrine disrupting chemical and viewed as a Contaminant of Emerging Concern, in addition to which the USEPA report noted key concerns for bromide discharges from coal-fired power stations, critically for the increase in harmful disinfection by-products (bromate) with treatment of water for domestic use (Van Briesen, 2013; Wang *et al* 2017). As noted with nitrate, the inherent bromide concentration of the drinking water is seldom considered when disinfection strategies are formulated, and this should become a priority given the brominated, chlorinated and mixed brominated/chlorinated disinfection by-products known.

Table 27 : Comparisons between observed data and reference values for plasma Thyroxine (total T4).

Plasma Thyroxine values (Total T_4) in nmol/L at 35 days (median ± SD)					
Observed Sites* (n= 10 per site)			**Reference: Ross**	**Reference: Non-Commercial**	**Reference: Range for 6 commercial broiler breeds**
Site 1	**Site 2**	**Site 3**			
[a]3.14 ± 1.696	[a] 4.945 ± 1.625	[b] 9.855 ± 4.098	10.89 ± 0.849	8.906 ± 1.081	9.715 ± 0.514 10.707 ± 0.489
Plasma Thyroxine values (Total T_4) in nmol/L at 1 day					
Corresponding Br exposure values (mg/L) Site 1: 0.610 Site 2: 0.942 Site 3: 0.017			**Reference: Ross**	**Reference: Non-Commercial**	**Reference: Range for 6 commercial broiler breeds**
			5.933 ± 0.785	5.997 ± 0.123	4.337 ± 0.694 6.151 ± 0.939

*Values without a common superscript differ significantly (P≤0.05)

4. RISK METHODOLOGIES AND CALCULATION PROCEDURES

4.1 Overview

The central component to the risk-based guideline DSS is the use of a water ingestion rate reference document (WIRRD) which is specific to an animal category with corresponding detail. Comparisons are made at the lower tier level between water quality results and standard intake values to these reference documents (Generic Application Level) with minimal modification thereto whilst at the higher tier levels comparisons are made between ingestion rates which are increasingly based on actual site-specific observations as opposed to derived values. Modifications to the WIRRD tables increase as source, pathway and receptor data is entered.

Whilst the updates to the WIRRD tables are included in Appendix A and are not repeated here, in order to present the modelling approach adopted the basics thereof are again highlighted in this section, following which the rules for modifications are then presented. As these tables and modifications generate a significant amount of data only examples are provided to illustrate the methodology. The reader is referred to Appendix A for all the updated tables and the previous sections for the principal motivation and rationale thereto.

The following tables highlight examples of the central reference document calculations using sheep as a livestock type example with several subcategories for comparative purposes to indicate the variety of nutrient requirement and production parameter references used in the derivations. The source reference document uses a combination of live weight specific DMI values or calculated DMI values with the resultant TWI being calculated using the applicable regression formula for the specific livestock type.

The values used are based on the minimum requirements to sustain normal health, production and performance and the WIRRD is thus a conservative estimate inclusive of safety factors inherent in the published nutrient requirement tables. The WIRRD reference documentation is obtained from predominantly three sources:

- Various Authorities and Agencies (e.g. National Research Council for the National Academies and European Food Safety Authority)
- Applicable articles in peer-reviewed literature (e.g. Journal of Animal Science)
- Various country and/or animal breed specific guideline documentation (e.g. Olkowski, 2009).

It is again noted that these estimates provide for a significantly more accurate exposure assessment than a concentration-based approach, but the objective remains to move the assessment to a higher tier level in which case these table inputs are based on actual measured observations in site-specific livestock production systems. On this aspect it is noteworthy that these observations are increasingly performed in commercial animal production systems with significant variations noted during production cycles, these being linked to physiological changes and seasonal effects amongst numerous other variable factors.

The central WIRRD values produced in the Columns provide for guideline effect concentration (GEV) ranges in the corresponding Columns which are specific to the WQC applicable. These Columns thus have variable interpretations depending on the WQC mode of action as illustrated by the different WRC WIRRD tables provided later. These Columns may then be manipulated as follows:

- Altering the GEV to include updates to the field of knowledge per constituent and animal type

- Altering the final WIR derived by inserting the derived value into a risk-assessment index calculation which recognises 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 tables calculate for each livestock type and subcategory water ingestion rate (WIR) specific guidelines on a per WQC basis. The calculation utilises reference table values for live weight, dry matter intake (DMI) and total water intake (TWI). This is the central source code reference basis used in the assessments conducted and the reader is referred to previous deliverables for the physiological and guideline methodology philosophy applicable.

It is relevant to note that the derived ingestion rate is furthermore Live Weight specific and is not by default set on a mg/kg LW/day basis. Expressing this on a metabolic water basis as opposed to a LW basis provides a physiologically more accurate guideline reference value based on the relationship between metabolic rate and water turnover.

The WIRRD for each livestock type is specific to that type and the calculated allowable ingestion rates for a given WQC between livestock types using this method is more accurate, allowing for the derived value to be based on requirements which are in turn based on numerous regression equations, for example, livestock type specific growth curves.

4.1.1 Calculation Methodology

The updated Central WIRRD tables developed as part of the project, is used to elaborate on the calculation methodology: Livestock Type = Sheep; Category = Ewes – maintenance; WQC = Selenium.

Table 28: 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
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.

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 values in Table 28 are 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

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 WQC 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. This is demonstrated for similar live weights but a different physiological stage for the same Livestock Type and WQC in Table 29.

Table 29: Updated Specific-Central WIRRD for Livestock Type = Sheep; Category = Ewes – Mature Breeding; 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	1.029	2.984	0.1037	[0.0058] 0.000702	[0.0138] 0.001653	[0.0569] 0.00826	[0.9716] 0.1157	[3.467] 0.4131	>0.413
61.0	1.171	3.531	0.1079	[0.0056] 0.000688	[0.0117] 0.001422	[0.0586] 0.00711	[0.8211] 0.0996	[2.930] 0.3555	>0.355
71.21	1.329	4.140	0.1252	[0.00548] 0.000687	[0.01] 0.001253	[0.05] 0.00626	[0.7] 0.0877	[2.5] 0.3132	>0.313
81.419	1.453	4.619	0.1252	[0.00537] 0.000673	[0.0089] 0.001123	[0.0448] 0.00561	[0.6276] 0.0786	[2.240] 0.2806	>0.280
91.62	1.592	5.155	0.1268	[0.00527] 0.000670	[0.0080] 0.001019	[0.0401] 0.00509	[0.5624] 0.0713	[2.007] 0.2547	>0.254

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. To illustrate this further the different specific derived values are presented below for Table 29:

- 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 = 0.022711 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 = 0.0414 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 = 0.207 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 = 2.898024 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 = 10.35009 for Selenium)
    - GEV = (SDAEF/TWI)
        - Column E Ingestion Rate Value - IRV (mg WQC/ kg$^{0.82}$/d)
            - GEV * WIR

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 3 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.

Due to the volume of calculations only excerpts of the derived values for Livestock Type Sheep and WQC = Selenium is provided in Table 30 as illustrative of the central WIRRD methodology adopted. Additionally, to demonstrate the differences in these derivations between different WQCs, the key derived values for the remaining constituents are provided thereafter for the WQCs addressed as per the updated WIRRD tables corresponding to Appendix A (Table 31 to Table 36).

Table 30: Updated Specific-Central WIRRD derived values for Livestock Type = Sheep; Category = all; WQC = Selenium

Categories	Derived values*				
	Column A SMNRF	Column B SDRF	Column C SDAF	Column D SDCEF	Column E SDAEF
Ewes – maintenance	0.020628	0.036673	0.1836673	2.56711	9.168252
Ewes – Mature Breeding	0.022711	0.0414	0.207	2.898024	10.35009
Ewes – Mature Early Gestation	0.025501	0.047703	0.238517	3.339242	11.92587
Ewes – Mature Late Gestation	0.31392	0.06101	0.30505	4.270703	15.25151
Ewes – Mature Early Lactation	0.034183	0.067313	0.336566	4.711921	16.82829
Ewes – Mature Mid Lactation	0.03054	0.059084	0.29542	4.135886	14.77102
Ewes – Mature Late Lactation	0.028059	0.053481	0.267407	3.743692	13.37033
Growing Ewe Lambs – yearlings at 40% of mature weight	0.020728	0.03072	0.1536	2.150405	7.680018
Growing Ewe Lambs – Breeding	0.036363	0.6136	0.0306801	4.295215	15.34005
Growing Ewe Lambs – Early Gestation	0.037345	0.063461	0.317306	4.442287	15.86431
Growing Ewe Lambs – Late Gestation	0.041991	0.072391	0.361953	5.067346	18.09767
Growing Ewe Lambs – Early Lactation	0.032164	0.05131	0.265656	3.71918	13.28278
Growing Ewe Lambs – Mid Lactation	0.032341	0.053481	0.267407	3.743092	13.37033
Growing Ewe Lambs – Late Lactation	0.041813	0.07204	0.360202	5.042834	18.01012
Growing Rams – at 40% of mature weight	0.038011	0.063461	0.317306	4.442287	15.86531
Rams – Maintenance	0.041991	0.072391	0.361953	5.067346	18.09767
Rams – Pre-breeding	0.04628	0.080795	0.403974	5.655637	20.1987

Where:
SMNRF = Specific Minimum Nutrient Requirement Factor; SDRF = Specific Derived Requirement Factor; SDAF = Specific Derived Adequacy Factor; SDCEF = Specific Derived Chronic Excess Factor; SDAEF = Specific Derived Acute Excess Factor

*Values primarily adapted from: NRC (2007); Plumlee (2004) & Underwood & Suttle (1999).

Constituent: Fluoride

Table 31: Updated Specific-Central WIRRD for Livestock Type = Sheep; Category = Ewes – maintenance; WQC = Fluoride

User Specific Input			Ingestion*	Water Quality Constituent^					
				mg F/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	[0.1101] 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 32: Updated Specific-Central WIRRD derived values for Livestock Type = Sheep; Category = all; WQC = Fluoride

Categories	Derived values*				
	Column A SMNRF	Column B SDRF	Column C SDAF	Column D SDCEF	Column E SDAEF
Ewes – maintenance	0.371498	2.5621	3.667301	3.34602	22.0038
Ewes – Mature Breeding	0.409207	2.898	4.140035	7.86606	23.8052
Ewes – Mature Early Gestation	0.459485	3.3924	4.77034	9.06365	27.429
Ewes – Mature Late Gestation	0.565627	4.2707	5.79595	11.59191	35.0807
Ewes – Mature Early Lactation	0.615905	4.7119	6.0583	12.7895	37.022
Ewes – Mature Mid Lactation	0.550264	4.13588	5.31756	11.22598	32.496
Ewes – Mature Late Lactation	0.5055264	3.74368	4.81331	10.16145	29.4147
Growing Ewe Lambs – yearlings at 40% of mature weight	0.234013	2.15	2.7648	5.836813	21.325
Growing Ewe Lambs – Breeding	0.56842	4.29521	5.522419	11.65844	32.214
Growing Ewe Lambs – Early Gestation	0.585179	4.44228	5.711512	12.05764	33.317
Growing Ewe Lambs – Late Gestation	0.656407	5.1034	6.5151	13.7511	38.004
Growing Ewe Lambs – Early Lactation	0.56842	4.2952	5.21567	11.658	33.2141
Growing Ewe Lambs – Mid Lactation	0.5055573	3.7436	4.5459	10.1614	28.077
Growing Ewe Lambs – Late Lactation	0.653613	5.04286	6.1234	13.6877	37.821
Growing Rams – at 40% of mature weight	0.585179	4.44228	5.711	12.0567	34.903
Rams – Maintenance	0.65407	5.06734	7.2390665	14.478	43.434
Rams – Pre-breeding	0.723444	5.6556	7.6755	15.7549	46.457

Where:
SMNRF = Specific Minimum Nutrient Requirement Factor; SDRF = Specific Derived Requirement Factor; SDAF = Specific Derived Adequacy Factor; SDCEF = Specific Derived Chronic Excess Factor; SDAEF = Specific Derived Acute Excess Factor

*Values primarily adapted from: NRC (2007); Plumlee (2004) & Underwood & Suttle (1999).

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 (refer to previous deliverable) as the WIR value will differ according to the differing LW, ADI and TWI values.

For some WQCs 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, WQCs such as bromide which may yield other disinfection by-product concerns (thus additional WQC data input requirements) which would prompt methodology in which the disinfection by-product results may be at stricter limits than the initial WQC (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.

Although comparisons between the various categories for the livestock type do highlight the significance of the WIRRD approach compared to a static tabulated concentration-based approach, this is more easily demonstrated in Figures 2.4 to 2.7, in which the comparison between the ranges of values generated by the methodology are presented, firstly for the derived value used in the WIRRD table, and secondly, for the final WIRRD value used in the risk assessment.

Lastly, it is noteworthy that currently, despite the recognition of potential EDC-related adverse effects due to exposure to WQCs including nitrate and fluoride, the derivation of a safe dose or ingestion rate is not at a stage where clear safe limits can be derived. As noted in the endocrine society statements referred to in other WRC publications on the EDC Programme it is argued that due to the mode of action of EDCs it may be possible that no safe dose exists.

The risk is thus managed by a precautionary approach in which conservative Column values are provided to the user and the DSS system which will trigger a User Interface Caution Note wherein the appropriate clinical tests will be described to confirm if a substantive risk is present. Due to the difficulties in predicting or estimating risk from EDCs across multiple WQC exposures and site-specific factors, it is in any event more accurate to assess site-specific contextual risk by obtaining clinical and histopathological evidence.

As noted earlier the ability to use animal data for sentinel monitoring purposes for community health, notably for EDC-related risks, should be viewed as a key DSS asset for reducing uncertainty in other water use guidelines.

Constituent: Nitrate

Table 33: Updated Specific-Central WIRRD for Livestock Type = Sheep; Category = Ewes – maintenance; WQC = Nitrate

User Specific Input			Ingestion*	Water Quality Constituent^					
LW (kg)	DMI (kg/d)	TWI (L/d)	WIR ($L/kg^{0.82}/d$)	mg $NO_3/kg^{0.82}/d$^^					
				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 34: Updated Specific-Central WIRRD derived values for Livestock Type = Sheep; Category = all; WQC = Nitrate

Categories	Derived values*				
	Column A SMNRF	Column B SDRF	Column C SDAF	Column D SDCEF	Column E SDAEF
Ewes – maintenance	31.370	161.361	330.057	550.095	810.473
Ewes – Mature Breeding	34.554	182.161	372.60	621.005	914.947
Ewes – Mature Early Gestation	38.800	209.895	429.33	715.55	1054.24
Ewes – Mature Late Gestation	47.763	268.444	549.690	915.15	1348.32
Ewes – Mature Early Lactation	52.008	296.177	605.898	1009.697	1487.621
Ewes – Mature Mid Lactation	46.465	259.97	531.75	886.261	1305.758
Ewes – Mature Late Lactation	42.692	235.31	481.332	802.219	1181.937
Growing Ewe Lambs – yearlings at 40% of mature weight	27.360	135.168	276.480	460.801	678.913
Growing Ewe Lambs – Breeding	47.999	269.984	552.241	920.403	1356.061
Growing Ewe Lambs – Early Gestation	49.414	279.229	571.151	951.918	1402.494
Growing Ewe Lambs – Late Gestation	55.428	318.518	651.515	1085.86	1599.834
Growing Ewe Lambs – Early Lactation	47.999	269.984	552.241	920.403	1356.061
Growing Ewe Lambs – Mid Lactation	42.692	235.317	481.331	802.219	1181.937
Growing Ewe Lambs – Late Lactation	55.193	316.978	648.364	1080.607	1592.093
Growing Rams – at 40% of mature weight	49.414	279.229	571.151	951.918	1402.494
Rams – Maintenance	55.428	318.518	651.515	1085.86	1599.834
Rams – Pre-breeding	61.089	355.497	727.153	1211.922	1785.565

Where:
SMNRF = Specific Minimum Nutrient Requirement Factor; SDRF = Specific Derived Requirement Factor; SDAF = Specific Derived Adequacy Factor; SDCEF = Specific Derived Chronic Excess Factor; SDAEF = Specific Derived Acute Excess Factor

*Values primarily adapted from: NRC (2007); Plumlee (2004) & Underwood & Suttle (1999).

Constituent: **Bromide**

Table 35: 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
71.21	1.20	3.667	0.1109	[0.01085] 0.001205	[0.09] 0.009988	[0.9] 0.09988	[1.75] 0.19421	[2.5] 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.

Table 36: Updated Specific-Central WIRRD derived values for Livestock Type = Sheep; Category = all; WQC = Bromide

Categories	Derived values*				
	Column A SMNRF	Column B SDRF	Column C SDAF	Column D SDCEF	Column E SDAEF
Ewes – maintenance	0.039816	0.330057	3.300571	6.41777	9.168252
Ewes – Mature Breeding	0.04385	0.37260	3.72603	7.24506	10.35009
Ewes – Mature Early Gestation	0.04924	0.42933	4.29331	8.34710	11.92587
Ewes – Mature Late Gestation	0.06062	0.54909	5.490903	10.6767	15.25251
Ewes – Mature Early Lactation	0.06601	0.60581	6.05818	11.7798	16.8282
Ewes – Mature Mid Lactation	0.05897	0.53174	5.31756	10.33972	14.77102
Ewes – Mature Late Lactation	0.054186	0.48133	4.81331	9.35923	13.37033
Growing Ewe Lambs – yearlings at 40% of mature weight	0.03472	0.27648	2.764806	5.3760	7.68001
Growing Ewe Lambs – Breeding	0.060922	0.55224	5.52241	10.73801	15.34005
Growing Ewe Lambs – Early Gestation	0.06271	0.57115	5.71151	11.10572	15.86531
Growing Ewe Lambs – Late Gestation	0.07352	0.65151	6.51515	12.66837	18.09767
Growing Ewe Lambs – Early Lactation	0.060922	0.55224	5.52241	10.73804	15.34005
Growing Ewe Lambs – Mid Lactation	0.05418	0.48133	4.81331	9.35923	13.37033
Growing Ewe Lambs – Late Lactation	0.07005	0.64364	6.48364	12.60709	18.01012
Growing Rams – at 40% of mature weight	0.06271	0.57115	5.711512	11.10572	15.86531
Rams – Maintenance	0.070352	0.65152	6.51515	12.66837	18.09767
Rams – Pre-breeding	0.077537	0.727153	7.271533	14,13909	20.1987

Where:
SMNRF = Specific Minimum Nutrient Requirement Factor; SDRF = Specific Derived Requirement Factor; SDAF = Specific Derived Adequacy Factor; SDCEF = Specific Derived Chronic Excess Factor; SDAEF = Specific Derived Acute Excess Factor

*Values primarily adapted from: NRC (2007); Plumlee (2004) & Underwood & Suttle (1999).

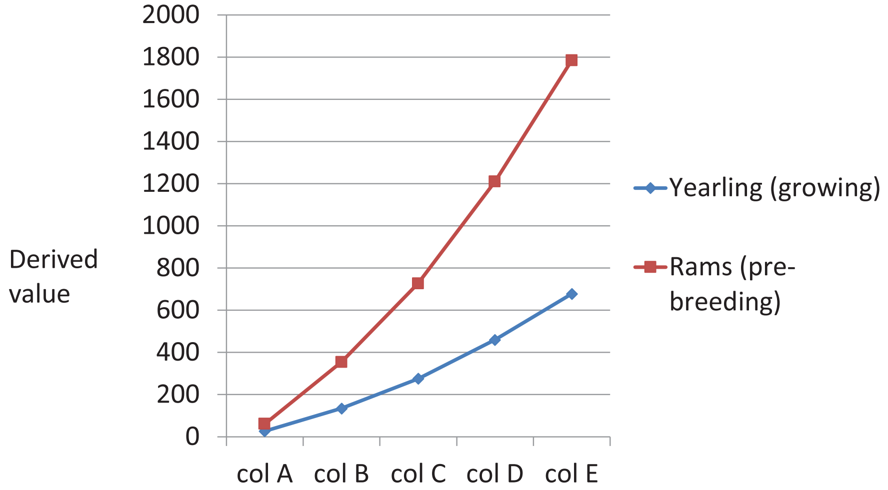

Figure 2.4. WIRRD derived coloumn values for WQC = Nitrate for different Livestock Type = Sheep category ranges.

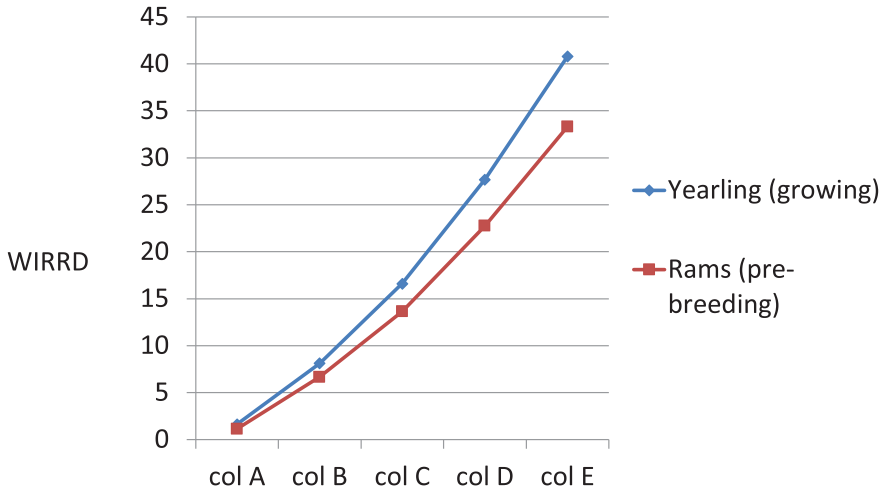

Figure 2.5. WIRRD generated coloumn values for WQC = Nitrate for different Livestock = Sheep category ranges.

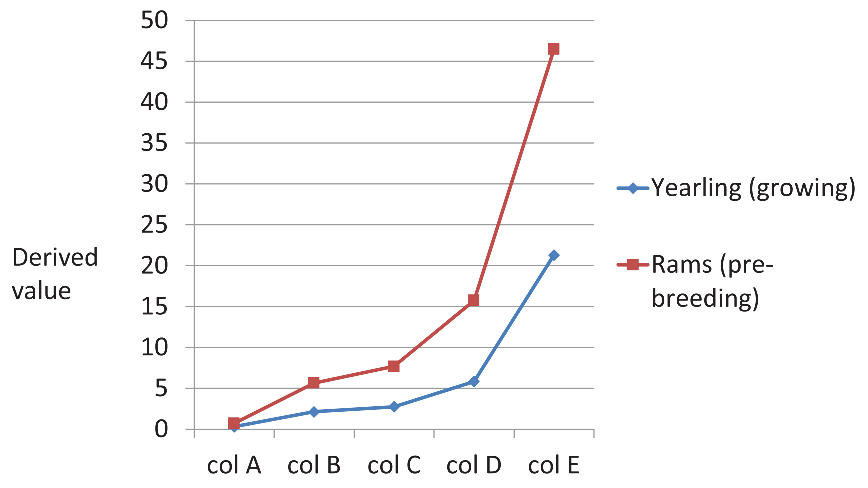

Figure 2.6. WIRRD derived coloumn values for WQC = Fluoride for different Livestock Type = Sheep category ranges.

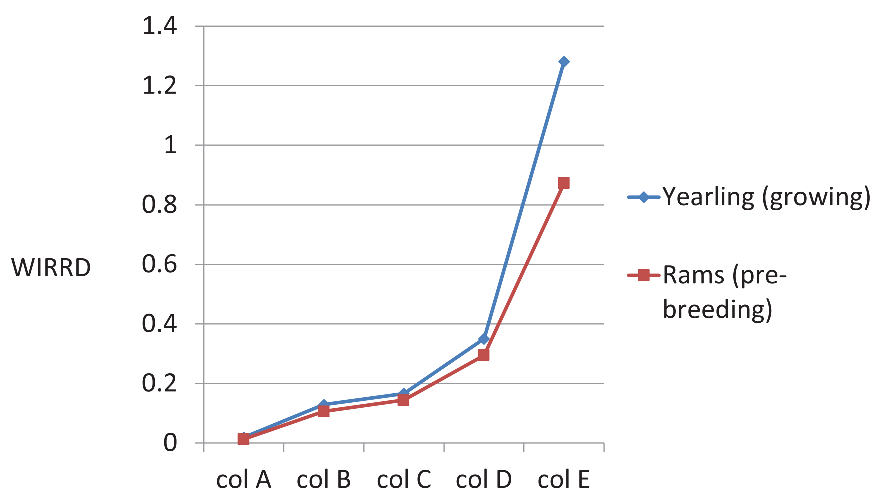

Figure 2.7. WIRRD generated coloumn values for WQC = Fluoride for different Livestock = Sheep category ranges.

4.1.2 Central WIRRD Assessments

As noted previously the data handling generates significant reference documentation. The WIRRD tables provided are only illustrative of the methodology and it is stressed that the source code programming allows for all live weights within the ranges provided for the Livestock Type and specific Category to be calculated for. This implies that results are not rounded off to the nearest live weight row provided in the tables above (50.8-61.0-71.21-81.4 and 91.6 kg), but to the nearest kg within the range of 50-92 kg LW. Correspondingly, this changes the results for the WIR, GEV and IRV on which the assessment if based.

Therein it is noteworthy that the same concentration for the specific WQC can result in a different risk assessment Column being triggered for the same Livestock Type between categories and even within categories. Also, should site-specific variables alter DMI or TWI within a LW row a different Column could be triggered. This is a critical benefit in the methodology adopted in the WIRRD and could not be achieved with a static tabulated concentration-based water quality guideline.

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]

User input examples 2.1 to 2.5 above 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. User input examples 3.1 to 3.3 highlight how the reverse is also true, 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. The input examples use a Selenium range of 0.63, 0.7 and 0.77 mg/L, noting that at standard WIRRD input user input values for input example 3.2 the Column D risk assessment statement would not be triggered and that and that input example 3.3 would not be triggered at a slightly lower water intake value of 5.4 L/d. The examples highlight the effects of both physiological stage and changes in water intake, and whilst not performed here it should be noted that numerous iterations of LW, DMI and TWI across categories and concentration ranges could be also compiled.

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 Basic Assessment 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]

Based on the data flow 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.

This section has focussed on the primary rules for the methodology behind the WIRRD tables and user specified input values relevant to the final reference values generated. The effects of site-specific factors relative to these tables and the subsequent methodology for recognising these adjustments in the assessment process are presented in the following section.

4.2 Methodology for Modifying the WIRRDs

Examples of how the WIR approach provides for a more accurate estimate of exposure risk compared to static concentration-based guidelines were highlighted previously and the rules for simple WIRRD reference derivation and comparison were elaborated on in the preceding chapter. The calculated Ingestion Rate Value may be viewed as a central reference value for each of the Column specific risk statements with subsequent increases or decreases therein increasing or decreasing risk.

Site-specific variables in addition to the production system detail are therefore 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 in this chapter.

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.

In order to reach the Tier 3 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. 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).

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 this section 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.

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.

As noted previously this can be used to align the initial basic assessment process for environmental authorisations when determining which sites are more suited to specific animal production systems wherein water quality (available resource quality) is included in the assessment.

It is worthwhile considering that currently the focus in usually on water volume for the intended production with water quality guidelines typically only receiving attention after authorisation is granted and water use licences being applied for thus at a later stage. It is held that for water resource management to be effective this process should change to an assessment of fitness for use (for all the norms previously described which include potential wastewater impacts) as an initial requirement and part of the background information document compilation.

Thus, whilst some site-specific factors are difficult to change or manipulate, they may be easily compared in terms of risk outcomes for different water resource quality by compiling trial *.wqs files with different input data types. The use of user-defined routines can allow for a specific catchment or management unit type approach to scenario planning with water quality planning limits as the primary focus area. The DSS should thus be able to provide different user "types" or target audiences with the ability to evaluate changes to the water use in question with the focus on their area of interest or expertise. This does not change the methodology described here but some guidance will be required at the user interface to guide the user through the application options and objectives.

4.2.1 Methodology for Set User Selections

The tables thus far used provide in the first four Columns values as described earlier, for a selected Livestock Type and category for the selected water quality constituents selenium, fluoride, nitrate and bromide. Set User Selections furthermore provide for varying links between the Livestock Type and additional detail thereon specific to the production system and environmental setting. This section highlights the methodology for handling:

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

Using Table 30 as a reference to illustrate the methodology adopted it can be furthermore elaborated on that the central reference values relate to:

- Livestock Type = Sheep

On selection of the Livestock Type at the Specific-GAL the user is presented with a list of sheep breeds and corresponding sheep production system types to select from. The Livestock Type = sheep is thus a form of generic sheep used to represent that applicable to commercial sheep production. Some of these breeds are more suited to specific environments than others and some have varying abilities to adapt to water scarce or harsh environments due to differing physiology. This may be related, for example, to specific differences in salt tolerance and renal function.

Other user defined system selections may provide environmental factors which may relate to either synergistic or antagonistic effects which may be fixed or variable. Adjustments to the calculated WIRRD IRV values are thus required to reflect the change to the risk estimated. It should be noted that these can be more varied for some Livestock Types as evidenced in the user breed and production system options offered, notably for Cattle and Dairy Production.

4.2.1.1 *Animal Specific Production System Factors*

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

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%

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):

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

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

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 = 0.004994136<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.

Animal Specific Production Factor 2

- Rule: Breed specific Production System Factor
    - 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. The following example demonstrates the methodology used where multiple risk factors are applicable and where the RF does not equal 1. It is relevant to note that these may vary from having a synergistic to an antagonistic effect and are handled thus as variances as demonstrated below.

It is also noteworthy that outcomes following exposure may vary based on the actual factors applicable and range from supra-additive to infra-additive, with other possible combinations (e.g. potentiation), in the absence of applicable pharmacological evidence the assessments used here focus on simple synergistic and antagonistic effects.

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%

Additional motivation for the use of this variance methodology is provided later for equal risk factor scenarios.

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 examples provided above illustrate the application of the rules for the animal specific production factors and how they effectively cater for increases and decreases to the concentration at which a specific WQC will have a potential effect. Although due to text volume considerations and thus not demonstrated here it should be appreciated that due to the derivation of the WIRRD tables being WQC specific and linked to animal type (e.g. ruminant compared to monogastric) and production system fit (e.g. breeding versus feedlot) these factors will have a different degree of influence on the WIRRD calculations applied. As the final assessment considers multiple site-specific factors the only feasible manner in which such an assessment could be performed is in the DSS described in previous deliverables.

Additional animal specific production factors and site-specific variable factors are described in the sections that follow without examples provided as the fundamental handling methods remain primarily as already described. Where alternative methodology is used it is accordingly noted.

<u>Animal Specific Production Factor 3</u>

- Rule: Breed specific <u>Environment Type Factor</u>
  - If Livestock Type = Sheep and
    - Breed = x and
    - Environment Type = Harsh; Semi-harsh; Temperate, then:
      - Apply the corresponding Risk Factor to the WIR Column.
        - Where:
          - Breed & ETF RF
          - Afrino + Harsh= 1
          - Afrino + Semi-harsh = 1

- Afrino + Temperate = 0.95
- Blackheaded Persian & Harsh = 1
- Blackheaded Persian & Semi- Harsh = 1
- Blackheaded Persian & Temperate = 0.9
- Dohne Merino & Harsh = 1.1
- Dohne Merino & Semi- Harsh = 1
- Dohne Merino & Temperate = 1
- Dormer & Harsh = 1.1
- Dormer & Semi- Harsh = 1
- Dormer & Temperate = 1
- Dorper & Harsh = 1
- Dorper & Semi- Harsh = 1
- Dorper & Temperate = 0.95
- Ille de France & Harsh = 1.2
- Ille de France & Semi- Harsh = 1.1
- Ille de France & Temperate = 1
- Indigenous & Harsh = 1
- Indigenous & Semi- Harsh =1
- Indigenous & Temperate =0.9
- Karakul & Harsh = 1
- Karakul & Semi- Harsh = 1
- Karakul & Temperate = 0.9
- Merino & Harsh = 1.1
- Merino & Semi- Harsh = 1
- Merino & Temperate = 1
- SA Mutton Merino & Harsh = 1.1
- SA Mutton Merino & Semi- Harsh = 1
- SA Mutton Merino & Temperate = 1
- Van Rooy & Harsh = 1
- Van Rooy & Semi- Harsh = 1
- Van Rooy & Temperate = 0.9
- Vandor & Harsh = 1
- Vandor & Semi- Harsh = 1
- Vandor & Temperate = 0.9

The following Animal Specific Production Factor caters for those production system types which involve a least sensitive user group due to the physiological stage during which exposure starts and the duration of exposure. This will also be WQC specific for those which typically follow a chronic cumulative route. An example would be a feedlot scenario where animals are brought into a production system from numerous different environments and backgrounds at an age many developmental challenges would no longer be applicable.

Fluoride and dental fluorosis would be such an example of an applicable WQC as the primary adverse endpoint occurs pre-eruption. Concerns for skeletal fluorosis would be negated due to the short stay (e.g. 100-120 days for beef cattle feedlot) and the general high quality of nutrition provided (specific ration formulation for fast growth). The primary product produced in this system is protein with growth and carcass quality the key parameters, so any potential EDC effect of fluoride on reproductive traits would not be relevant (as the animals are to be slaughtered and not kept for breeding purposes). Although thyroid-related EDC effects from fluoride may possibly be relevant, due to the short exposure time, this would be confined to a higher concentration and risk statement Column.

In this instance animals thus brought into a feedlot scenario could be exposed to a higher fluoride concentration in the drinking water without significant adverse production-related effects being experienced. Another way of stating this would be to observe that a higher fluoride concentration may still be within an *acceptable risk level* for the site-specific production system.

Within the WIRRD functionality this would not change the first two Columns as there is still arguable a nutrient requirement applicable given the high growth rate required. What would change is the IRV for which Column C would be true, thus the “upper limit for safe use” would be increased to be closer to the Column D risk statement of “risk of chronic fluorosis”.

This in effect implies that for an exposure group that is not reproductive or developmental, within an exposure setting (short-stay, zero grazing, feedlot), for a chronic cumulative PHCC, the derivation value for Column C would shift to be closer to the Column D value. Specifically in the case for WQC = Fluoride a shift for the Column D derivation value to be closer to the Column E value is also applicable. This would, however, not be considered valid for selenium due to the narrower range for chronic to acute adverse effects. The Column E values would not change for any WQC as the trigger values imply an acute ingestion scenario which is fundamentally more independent of exposure time. The changes thus effected apply thus to specific production system settings, specific WQCs and thus specific Column risk statements.

The methodology adopted to effect these changes differs from that used above for other animal production system factors in that the calculated IRV does not change, but the comparison to the reference IRV in the WIRRD is changed by altering the central reference value accordingly to the lower risk present. This is effected by a changing the Guideline Effect Value used to arrive at the IRV. It is relevant to note that the WIR value is not adjusted as this may technically not change under the feedlot scenario in terms of a reference value yet changes in that actually observed still need to be catered for in the assessment comparison. The changes are thus effected to the reference value alone as illustrated in the example below.

<u>Animal Specific Production Factor 4</u>

- Rule: Breed specific <u>Livestock Production System Exposure Factor</u>
  - If Livestock Type = Sheep and
    - Category = lambs finishing
    - Production System Type = Zero-grazing; Intensive Improved Pasture Production, then:
      - Calculate the applicable sample IRV without system factor adjustments; and
      - Apply the corresponding Risk Factor to the central reference WIRRD table for Column C & D Guideline Effect Values:
        - Where:
          - WQC + PSE RF
          - (WQC = F) & PSE = Zero grazing + intensive improved pasture production
            - Reference WIRRD Calculate Central Reference Row Col C Guideline Effect Value as:
              - ([GEV Col D – GEV Col C]*0.75 + GEV Col C) * WIR = adjusted IRV
            - Reference WIRRD Calculate Central Reference Row Col D Guideline Effect Value as:
              - ([GEV Col E – GEV Col D]*0.75 + GEV Col D) * WIR = adjusted IRV

To illustrate the effect of this rule to the new central reference IRV used in the comparisons, assume:

WIR = 0.2037
Col C GEV = 0.90
Col C IRV = 0.1833
Col D GEV = 1.9
Col D IRV = 0.38703
Col E GEV = 5.499
Col E IRV = 1.1206
Then;

Rule applied =

New Col C IRV = [(1.9-0.9) *0.75] + 0.9 *{2.037} = 1.65{0.2037} =
Adjusted IRV = 0.336105 (mg WQC/ $kg^{0.82}$/d)
New Col D IRV = [(5.499-1.9) *0.75] + 1.9 *{2.037} = 4.599{0.2037} =
Adjusted IRV = 0.93686 (mg WQC/ $kg^{0.82}$/d)

The net effect is that the initial central reference WIRRD Col C IRV has increased from 0.1833 to 0.336105, and initial central reference WIRRD Col D IRV has increased from 0.38703 to 0.93686. Corresponding calculated sample IRV comparisons would thus require a significantly greater WQC concentration for the WQC specified (fluoride in this case) to trigger the same Column compared to the original unadjusted central reference WIRRD Column risk statements, thereby reflecting the synergistic effect of the combination of the WQC in question and applicable exposure period.

Whilst there are differences in the rule detail between WQCs this Production System Exposure Factor is applicable to the following WQCs:

Al, As, Br, Cd, CO, Cr, F, Ni, Se, V.

Differences would equate to the factor used to adjust the risk statement Column values and to the number and specific Column involved.

4.2.1.2 Environmental System Factors

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

Environmental System Factor 1

- 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:

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

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:

<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) = 0.65

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

<u>Assessment Report</u>:

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:

<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) = 0.65

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:

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) = 0.665

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

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 = 0.11137>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 WQC concentration resulting in a different risk scenario.

- Rule: Temperature 2
    - User defined input for Temperature = no value, and
    - Water Source Input = coordinates
        - If entry field is ≥ to 120 in corresponding Temp 2 reference document, then:
    - If Livestock Type = Sheep and
        - WQC = x
            - Apply the corresponding equation to the WIRRD TWI Column:
                - Where:
                    - Applicable T2 RF = 1.025
                        - (WIR * A1 RF) = WIR*1.025
                            - Recalculate IRV

Temperature 2 Reference Document:

	Long	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33
Lat																			
22																			
23															120	120	120	120	
24														120	90	60	120	120	
25													120	120	60	30	90	120	
26							120			120	120	90	90	90	60	30	90	120	
27							120	120	120	120	90	90	60	60	30	30	60	120	
28							150	120	120	90	90	60	60	30	30	30	60	60	10
29			10	60	150	150	150	120	120	90	90	60	60	30	30	60	30	60	10
30				10	90	120	120	120	120	90	60	60	30	30	10	10	10	10	
31				10	60	60	60	90	90	60	60	300	60	10	10	10	10		
32					10	90	60	60	60	60	30	60		10	10	10			
33					10	10	60	60	10	10	10	10	10	10	10				
34					10	10	10	10	10	10	10	10	10	10					
35					10	10	10	10											

This second temperature rule caters for days wherein the maximum temperature exceeds 30º C based on the sample location and where the user input data for temperature is not populated. This would still generate a cautionary result note alerting the user to the fact that the antagonistic factor is derived from the sample location and that a more accurate assessment will be made if the Temperature 1 rule is applied.

Environmental System Factor 3

- Rule: Soil – Norm = Animal Health
    - User defined input for Soil =
        - Element value (composition mg/kg)
        - pH

        - Condition
        - Moisture %
    - If Livestock Type = Sheep and
        - Soil Element Constituent input > Soil Concentration Reference Limit 1:
            - Al > 80
            - As > 2
            - Be > 0.1
            - B > 2
            - Br > 5
            - Cd > 0.4
            - Cr > 25
            - V > 100
        - And, applicable element not entered into water or feed data input fields;
                - Then:
                    - Result Statement:
                        - "Constituents recommended for Analysis"
                            - "applicable element" in feed and/or water
                            - Reason: "Exceeds normal soil concentration".
        - Soil Element Constituent input > Soil Concentration Reference Limit 2:
            - Al > 300
            - As > 5
            - Be > 40
            - Cd > 1
            - Cr > 80
            - Se > 0.5
            - Tl > 1
            - V > 200
        - And, applicable element not entered into water or feed data input fields;
                - Then:
                    - Result Statement:
                        - "Constituents recommended for Analysis"
                            - "applicable element" in feed and/or water
                            - Reason: "Exceeds High soil concentration".
        - pH
            - Soil Element Constituent input outside Soil Concentration Reference Range 3:
                - B [5-7]
                - Cu [5-6]

        - Fe [4-6]
        - Mn [4-6.5]
        - Mo [7-9]
        - P [6-8]
        - Zn [5-6]
- And, applicable element not entered into water or feed data input fields;
        - Then:
            - Result Statement:
                - "Constituents recommended for Analysis"
                    - "applicable element'
                    - Reason: "Soil pH may increase availability"
- Condition
    - Soil condition input = Wet
        - Then:
            - Result Statement:
                - "Constituents recommended for Analysis"
                    - "Mg'
                - Reason: "Soil condition may decrease Mg availability"
    - Soil condition input = Dry
        - Then:
            - Result Statement:
                - "Constituents recommended for Analysis"
                    - "Plant/pasture NO_3"
                - Reason: "Nitrate may accumulate to a greater extent in plants."

These site-specific factors are taken into account by ensuring that they are determined for the ingestion pathways of feed and water. It is additionally site-specific as some soil content issues may not affect the norm of health as the stock are not exposed thereto either by geophagia or by pastures or feed grown as they may be housed or grazed elsewhere, and the forage produced sold off-site. Since exposure may be relevant, however, it is prudent to ensure that any anomalous soil compositional factor is assessed in the feed and water pathways.

The statements generated are thus linked to the user input fields and generate cautionary notes and/or data capturing guides and also possibly instructions for specialist consideration. It should be noted that many of the trace and macro element excesses and deficiencies in livestock may be subclinical with depletion stages difficult to diagnose. Proactive monitoring to ensure deficiencies or excesses are detected at depletion or accumulation stages is thus required.

Environmental System Factor 4

- Rule: Soil – Norm = wastewater impact
    - User defined input for Soil =
        - Element value (composition mg/kg)
    - If Livestock Type = Sheep and
        - Soil Element Constituent input > Soil Concentration Reference Limit 3:
            - *refer to table below*
                - Then:
                    - Result Statement:
                        - “Constituents recommended for Analysis”
                            - “applicable element’ in water, feed and wastewater and relevant fractions (solid and liquid fractions).
                            - Reason: “Soil value may be suggestive of excessive nutrient loading of the soil which may adversely affect crop production and pose a risk to water resource quality”.

Soil Concentration Reference Limit 3:

Constituent	**SSA Reference values* Median {range} (75%ntile)**	**SA Reference Values^ (AM total)**	**World Ranges* & (US EPA Unrestricted Use)**	**SA TMT#**
P	42 {25-2358} (44)			
K	7902 {291-77898} (16807)			
Cu	13 {0.3-114} (22)	29.5	1.0-250* (270)	120
Zn	20 {0.3-138} (42)	45.2	10-602* (1100)	200
Mn	276 {1.6-6576} (637)		7-9000*	

* Towett et al (2015). Elemental composition of Sub-Saharan African soils.
^Herselman (2007). Concentration of selected trace metals in South African soils.
NWA Section 21 (e) Prescribed WRC TT 262/06 Guidelines: Total Maximum Threshold.

Constituent	**Range**	**Low#**	**High#**	**Excessive#**
Total N (%)	0.1-0.15^ 0.15-0.56*			
P (mg/kg)		<20	40-100	>100
Ca (mg/kg)		<1000	>2000	
Mg (mg/kg)		<60	>300	
K (mg/kg)		<150	250-800	>800
Cu (mg/kg)	>0.6 sufficient	<1		
Mn (mg/kg)	>1.5 sufficient	<40		
Zn (mg/kg)	>1 sufficient	<1.6	3.1-4.0	8.0
B (mg/kg)		<0.5	1-2	>2.0

References:
^http://soils.tfrec.wsu.edu/webnutritiongood/soilprops/soilnutrientvalues.htm
(2004)
*Miles, N (1999) KwaZulu-Natal Department of Agriculture and Environmental Affairs.
#http://extension.oregonstate.edu/sorec/sites/default/files/soil_test_interpretation_ec1478.pdf

In this scenario the concern exists that the soil concentration observed for key marker elements in the Soil Concentration Reference Limit 3 table may be suggestive of an excessive nutrient application rate. This could, however, be due to a high content of the constituent in the source water (and thus in urine and faeces and wash-water) and/or the feed, resulting in a higher wastewater concentration. It could also be the result of an excessive application of the wastewater fractions to the applied areas.

This could imply that either adjustments need to be made to the application rate or the source of the elements addressed (for example by checking the nutrient inclusion rate in feed). This update to the DSS is viewed as an additional option to draw the attention of the user to the required compliance monitoring as this not only assists the competent authorities to manage the resource but also assists the water user to protect a critical asset of the production system, namely the water resources utilised.

These potential linkages to the databases housed within the competent authorities' systems are in the process of being made accessible for the general public to submit monitoring data, with this extending to water, wastewater and environmental samples, including soil. It is envisaged that this will significantly increase the water resource quality information at the disposal of the competent authority in order to assist with water quality planning limits for specific management units within catchments.

The DSS can play an important role in this regard and linking the water sample input data (including the soil nutrient content) to the *.wqs is a relatively simple process utilising the relational data bases. As is the case elsewhere the increased use of biodegradable agricultural wastewater fractions to lower water resource pressure and the use of commercial inorganic fertilisers is viewed as a crucial strategy to secure both water and food in the southern African region which is characterised by water scarcity and soil nutrient deficiencies.

4.3 Methodology for Variable Site Data

As was detailed in section 4.1 the next set of site-specific factors addressed is:

- Variable Site Data:
    - Nutritional Specific Factors
    - Palatability

It is stressed at the outset that 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.

The detail in the Nutrition Specific Factors is too complex and vast to present in its entirety here with the reader referred to previous WRC reports on Water Quality Guideline Index System developed, but some examples are highlighted to demonstrate the methodology, but it should be noted that the nutritional factors are based on published studies with established derivation methods and 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.

The General-GAL also performs adjustments to the acceptable concentration range for a WQC with the corresponding Comments, Types of Effects and Classification being affected.   These adjustments may be triggered by nutritional factors such as the digestibility of the ration within a subset of animal specific category (e.g. high yield or low yield and digestibility quotient). Additional factors are included as provisory requirements for these adjustments as Set Nutrient Factor Requirements, for example the presence or absence of organic forms of the constituent included in the ration and co-nutritional factors relevant to the outcome following exposure to a specific constituent (e.g. Vitamin E status and Selenium).

These allow for a more accurate determination to be made of the types of effects possible to concentration exposures noting that the fundamental approach is similar to that in the Specific-GAL in the sense that the target is not 0 mg/L or 0 IRV, but cognizant of the balance between requirements and excesses as they relate to depletion, deficiency and repletion and toxicity.

4.3.1 Nutritional Specific Factors

The following Nutritional Specific Factors are provided to illustrate the methodology adopted

Nutritional Specific Factor 1

- Rule: Crude Protein specific Nutritional Specific Factor
    - If Livestock Type = Sheep and

- Breed = x and
- General Feed Input = Crude Protein %
  - Source: system data base selection or analytical composition input
    - Where:
      - Value entered/derived >Crude Protein % Ref Doc
    - Then:
      - Applicable CP RF = 1.025
        - (WIR * CP RF) = WIR*1.025
          - Recalculate IRV

As the nutritional reference documents are vast only a few excerpts are provided below.

Example of Crude Protein Reference Document:

(where Livestock Type = Sheep and Live Weight = 50 kg)

Category 1: Ewes-maintenance

Live Weight	CP%
50	9.4

Category 2: Non-lactating (first 15 weeks gestation)

Live Weight	CP%
50	9.2

Category 3: Last 4 weeks gestation (130-150% lambing rate expected)

Live Weight	CP%
50	11

Category 4: Last 4 weeks gestation (180-225% lambing rate expected)

Live Weight	CP%
50	11.5

Category 5: First 6-8 weeks (single lamb) or last 4- 6 weeks (twins)

Live Weight	CP%
50	14.4

Nutritional Specific Factor 2

Rule: Dry Matter % specific Nutritional Specific Factor

- If Livestock Type = Sheep and
  - Breed = x and
  - General Feed Input = Dry Matter %
    - Source: system data base selection or analytical composition input
      - Where:
        - Value entered/derived >DM % Ref Doc
      - Then:
        - Applicable DM RF = z

- (WIR * DM% RF) = WIR*1.025
    - Recalculate IRV

Example of DM% Reference Document:
(where Livestock Type = Sheep)

DM%	DM% RF
<20	0.3
20-50	0.5
50-80	0.8
>80	1

Where;

DM% as per User input entry field, or
If multiple feed types, reference, or user input values as per inclusion rates, and
Category Feed = not pelleted.

Nutritional Specific Factor 3

Rule: Mineral Reference Document specific Nutritional Specific Factor

- If Livestock Type = Sheep and
    - Breed = x and
    - General Feed Input = MINRD
        - Source: system data base selection or analytical composition input
            - Where:
                - TWI * [WQC]water = IW = Ingestion Water (mg/d)
                - DMI *([constituent]feed * % inclusion) = IF = Ingestion Feed (mg/d)
                - IW + IF = TI = Total Ingestion
                - And
                    - TI/LW $kg^{0.82}$
            - Then:
                - Compare to MINRD
                    - If result >MINRD report as PHCC or COC in corresponding Water and Feed Tab

Nutritional Specific Factor 4

Rule: Salt Supplement % specific Nutritional Specific Factor

- If Livestock Type = Sheep and
    - Breed = x and

- General Feed Input = Salt Supplement/Lick Supplement
  - Source: system data base selection or analytical composition input
    - Where:
      - Value entered/derived > Ref Doc
    - Then:
      - Applicable Note:
        - "Supplement levels of x may exceed acceptable levels and result in an increase in total ingestion."
        - "In order to ensure trace contaminants are at acceptable values an ICP-MS should be performed to include bromide."

Example of Salt Supplement Reference Document:

(where Livestock Type = Sheep)

Constituent	Content Limit (%)
Moisture	2.01%
NaCl	96.8%
Si	0.02%
SO_4	0.35%
Ca	0.25%
Mg	0.1%
K	0.05
P	0.2 mg/kg
Zn	0.2 mg/kg
Fe	0.3 mg/kg
Cu	0.1 mg/kg
Mn	1 mg/kg
NO_3	0
Co	0.1 mg/kg
F	17 mg/kg

The nutritional factors are Livestock Type and even Breed specific. To illustrate this the DM% Rule for Dairy Cattle is provided below.

Nutritional Specific Factor 5

Rule: Dry Matter % specific Nutritional Specific Factor

- If Livestock Type = Dairy Cattle and
  - Breed and Fat Corrected Milk Yield (FCM) and LW input
  - Proc as:

Category (LW) (FCM = 15)		DM % of Total Ration	DM% of Silage fed	DMI of silage	TOTAL DMI (kg/d)
1	600	Step 1	step 2	step 3-z	Step 4

Step 1:

DM% Total Ration:

If DM%>50%, then F = 1.00

If DM%<50%, then F = 0.02% Decrease in DMI/100 kg LW per 1% decrease from 50%, by category, by LW:

e.g.: DM% = 41%, for LW 600 kg = 1.08 kg DM decrease

If User Defined Input for WIRRD DMI Column = true, then use input value to calculate WIR

If User Defined Input for WIRRD DMI Column = not true, then user WIRRD Ref DMI (15.6 kg/d)

Recalculate DMI = 15.6-1.08 = 14.52

And

$TWI = 2.51(DMI) + 0.73(FCM) + 12.3$

$WI = TWI/ LW\ kg^{0.82}$

If, no User defined input for Step 2, then:

If DM% of silage fed >50%, then F = 1.00

If DM% of silage fed <50%, then F = DM% 50 – DM% 41 = 9%, and

9*0.02 = 0.18

0.18 *6 (derived from 600 kg LW) = 1.08 kg DM decrease

If, no User defined input for Step 2, then use input = Silage Type selection, where:

Silage type = high moisture content = DM =30%

Silage type = wilted = DM =35%

Silage type = haylage = DM =51%

Recalculation only for Silage Type 1 & 2

Step 3 =

If user defined input (z), then use.

If no user defined input, then calculate as:

Category 1 = silage intake = 1.95 kg DM silage/100 kg LW

All other categories = silage intake = 1.13 DM silage/100 kg LW

Then: 6*1.95 = 11.7 kg DMI (as equivalent Z value for step 3)

And, 11.7 / 15.6 = 75%

And, 0.75 *1.08 = 0.81 decrease for DMI

Recalculate WIRRD with: DMI = 15.6-0.81 = 14.79

As noted previously the nutritional specific factors are numerous and include recognised nutrient interactions that are also Livestock Type specific, notably for Cu, Mo and SO_4 in sheep. Additionally these interactions are also category specific and norm specific. An example of this is veal production in dairy cattle where the iron concentration has an effect on the norm “Product Quality” without necessarily having an adverse effect on animal health as this influences the haemoglobin and consumer acceptable colour requirement of the finished product.

The iron concentration permitted in the drinking water is thus correlated to the iron content of milk replacer used and calculated as a combination of total ingestion and live weight. These are not provided further here with the reader referred to previous applicable WRC publications.

4.3.2 Palatability Factors

Water palatability is a crucial factor as it affects water intake and feed intake and thus production. The typical TDS limits cited are not found to be true in site-specific settings and as described in great detail in previous WRC reports and dealt with in terms of hypo-osmotic concerns in section 3.7, the provision of osmotically active substances in the water at specific ratios enables a higher TDS to be preferred over low TDS water.

This is a crucial aspect relevant to South Africa as many of the natural groundwater TDS and associated major cations and anions exceed cited guidelines, but in many instances production is not adversely affected. The difference in outcome appears related to specific osmo-sodium receptors and to specific acceptable zones of major anions and cations present. Ensuring trace-element palatability factors are also within limits is required (e.g. Fe, Mn, Al.)

The derivation of acceptable zones has led to the previous CIRRA version having a Palatability Solution in which the inherent water quality may be adjusted by the addition of specific salts to move the overall quality into an acceptable palatability zone.

Thus, the water quality is manipulated to obtain the required water intake for fluid and electrolyte balance to be maintained. This has an additional consequence of increasing TWI with the new value used in the recalculations required in the WIRRD documentation. If the Palatability Solutions are not applied then a RF of 1.1 is used to recalculate the increased WQC ingestion rates.

4.4 Source, Pathway and Receptor conditions

As was previously described 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 WQC 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 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 results reporting methods. 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 as:

Table 37: 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

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

It should be noted that the focus in terms of the prototype DSS this project focused on the animal health aspects, the other aspects may be assessed in the DSS using the numerous established methods that exist for many of these. This would, for example, include the use of a Langelier and Ryznar Index for corrosion and scaling effects in water distribution systems in animal production units and the Maximum Acceptable Concentration of potentially hazardous substances in animal products destined for human consumption. These are not repeated here but there inclusion in the Results reporting in the assessment would be presented within the DSS according to the established assessment methods.

Within the WIRRD approach detailed in 4.1 and the preceding sections of this it is 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. As was detailed in Section 3, the following examples for Livestock = Sheep, Category Ewes – maintenance for WQC = Selenium were provided as examples thereof (Table 38, Table 39 and Table 40) as they relate to the example used elsewhere in this section (Table 41 as described in section 4.1.1 – Table 28).

Table 38: 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 41.		

Table 39: 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 - soil concentrations 0.02-3.7 mg/kg DM. - geographical location = seleniferous area	**Pathway setting:** Column C = - temperature 16-22.5 degrees Celsius	**Receptor setting**: Column C = Production parameters = set reference values
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 41.		

Table 40: 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 41.		

Table 41: 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
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.

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

It is thus noteworthy that 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 3 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 sections 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, with an example thereof detailed below and corresponding changes to the central reference row provided in Table 3.6.

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 42: 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 WQCs 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 WQC concentration which would result in an acceptable risk level being reached. An example of these settings for Sheep and the WQC, Copper (Cu) are provided in Table 43, Table 44 and Table 45 to demonstrate the user inputs required.

Table 43: 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 - Diet Cu Herbage <6; Roughage <4 mg/kg DM - Soil Cu <0.3 mg/kg - Soil Mo >0.1 mg/kg	**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
^^ the statements in the Columns relate to the WIRRD guideline effect values provided in the corresponding Cu WIRRD table.		

Table 44: Example of a Specific-WIRRD for Livestock Type = Sheep; Category = Ewes – maintenance; WQC = Copper; Column B

<u>**Site-specific conditions – Column A^**</u>		
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 45: Example of a Specific-WIRRD for Livestock Type = Sheep; Category = Ewes – maintenance; WQC = Copper; Column C

<u>**Site-specific conditions – Column A^**</u>		
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.		

4.5 Precautionary Comparison Methodology

It is 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 use of the variance approach described earlier in the assessment methodology is furthermore advocated as it errs on the conservative side. This implies that the Assessment Result presented will thus 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.

4.6 Sources of Uncertainty

As was described sources of uncertainty are at times directly included in the guideline derivation formula used by the use of an Uncertainty Factor in the equation. The approaches adopted by different countries to the choice of the numeric value assigned to this factor were also shown to vary to an extent that significantly altered the final derived guideline value.

The criticism by Vinceti *et al.* (2012) of the WHO (2011) health-based drinking water guideline which was altered from 0.01 mg/L to 0.04 mg/L was noted previously and related to the context of information on adverse effects at widely ranging blood serum values and the questionable use of changed reference values in the guideline derivation.

The impacts of assumptions in the guideline derivations were also highlighted, these involving both choice of a NOAEL and receptor exposure pathway contributions, with it being stressed that the new guideline value was not accompanied by reasons for the change in reference values used.

This is mentioned to highlight the uncertainty which is inherent in most guideline derivations and it is thus noted that the WIRRD is a significantly more accurate means of assessing the likely effects following exposure as it is able to cater for more accurate requirements which are specific to the Livestock Types and Breeds and physiological categories. This approach is a clear benefit to animal production system guidelines compared to those for domestic use largely as the observations of actual intakes and exposures are measured routinely and in research publications, this being motivated for by the commercial interest and value in these values.

The reduced confounding factors within animal production systems should also be appreciated as a valuable asset to increased accuracy in the linking between exposure and effect, this again being a function of the controlled environment and extent of composition and volume being described, measured and ensured. The challenges with exposure frequency and duration typical of human hazard assessments are thus largely negated.

The point to the above-mentioned aspects is that the WIRRD approach is itself representative of more certainty and that this is applied within a context of application in which less uncertainty exists.

There are, however, uncertainties which are still relevant to the methodology adopted. As described previously for fluoride, the contributions thereof in drinking water to environmental burden was highlighted, as was the lack of inclusion of EDC effects in guideline derivation. This implies that some of the norms triggered in the system may not all be at a sufficiently descriptive stage to model values on. Given the value of wastewater reuse and recognition thereof as a key strategy in the National Water Resource Strategy (2^{nd} Edition), it still remains necessary to ensure such reuse does not result in negative environmental or water resource impacts.

In order to address this the system may be considered to include a link between successive *.wqs files for the same water sample files which would enable a comparison to be performed for water, feed, wastewater and soil data input fields which could itself then provide a comparison towards trend analysis. This may trigger a Data Capturing Guide which would require additional soil samples to be obtained which are reflective of not just the applied areas, but also control (non-applied areas) and other types of applied areas (inorganic commercial fertilisers), in order to evaluate the obtained values within the context of the local geochemistry applicable. This would assist with a source, pathway and receptor analysis of the potential impacts thereof towards environmental and water resource receptors.

Additional uncertainty that still exists in the methodology adopted is common to other recognised source, pathway and receptor assessments, 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 loss. For this reason, as noted in section 4.6, the precautionary approach is thus adopted.

5. PROTOTYPE DECISION SUPPORT SYSTEM DESIGN

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 (CIRRA) model with a new modelling approach developed and presented in the form of a DSS.

The prototype DSS provides an overview of the user interface aspects and is presented as a standalone deliverable in conjunction with the Volume 1 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 Department of Water and Sanitation (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.

5.1. Overview of the DSS

The DSS presents the user with two fundamental water quality guideline index systems (WQGIS), namely a Generic-WQGIS and a Specific-WQGIS with varying levels of site-specific input and is analogous to the Tiered approach adopted in which Tier 1 represents a more basic generic approach whilst Tier 3 represents a specialist-based site-specific risk-based approach.

The previous sections presented the methodology in applying the Tiered approaches from the Generic to the Specific Guideline Application Levels (GALs), focusing on the rules and assessments, central source reference documentation, modifications thereto and new WIRRDs compiled, which is central to the key functionality of the DSS.

A key component to note is that the previous DSS, namely CIRRA, was at the time a fully functional DSS and although now outdated from several aspects still presents the user with insight into how the new DSS is intended to function. Accordingly, some of the data input and results screens are provided as CIRRA still represents a working DSS.

Just as significant modelling changes were required to the previous CIRRA version (detailed in previous sections of this report) due to advances in the fields of science relating to water quality and animal production, advancements in the fields of programming and technology platforms available have also rendered the previous version largely outdated. The new DSS is thus not only an updated version of the previous in numerous aspects pertaining to animal science but also fundamentally different from a software and coding perspective.

5.2. Tiered System

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 DSS provides a structured approach necessary for addressing the main decision contexts for the use of the guidelines. The overall product is to comprise a three-tiered system with increasing data flow noted with higher tiers. A brief description and overview are provided below:

- Tier 1 is equivalent to 1996 generic guidelines and is made available in the DSS. Tier 1 assessment does not involve rigorous calculation methodology. The DSS contains specific literature-based information about constituents under consideration, hazard characterisation, exposure data and relevant supporting datasets. It may require some user defined input.
- Tier 2 is a specific application level with increasing data inputs to the model occurring, as more site-specific detail is provided.
- Tier 3 is reliant on additional specialist input (in addition to the site-specific data) with corresponding adjustments to the guideline values, using referenced modules of the DSS but also inclusion of

subsequent files based on, for example, the obtaining of clinical biochemistry values. Tier 3 requiring significant more expertise.

Table 46: 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).

Whilst the above-mentioned descriptions conveniently demarcate tiers, these are in reality more flexible with increasing variations of site-specific detail use as the user moves from Tier 1 to Tier 3, with a general migration from reference documentation used in the calculations performed to user-defined site-specific input. In computing terms this may be considered as moving from recursive algorithms to dynamic algorithms.

5.3. DSS Functionality

The DSS 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 WIRRD 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 fundamental difference between the two is that the Generic-WQGIS uses default values in the source code whereas the Specific-WQGIS caters for actual on-site measured values as input data, thus effectively enabling the change from a concentration-based reference source to an increasingly site-specific calculated ingestion-based risk assessment. The data flow from the Generic to the Specific GAL may be thought to thus represent an increase in data flow as more data is included in the assessment, either by way of including reference documentation coded within the model or by providing actual site-specific measurements as data inputs.

The figures below (Figure 1 to Figure 3) indicate the key differences between Generic and Specific Application Levels within the system data flow. It is highlighted that even at the Tier 1 application level (Generic) some user defined input does lead to a guideline effect value adjustment in the WIRRD tables.

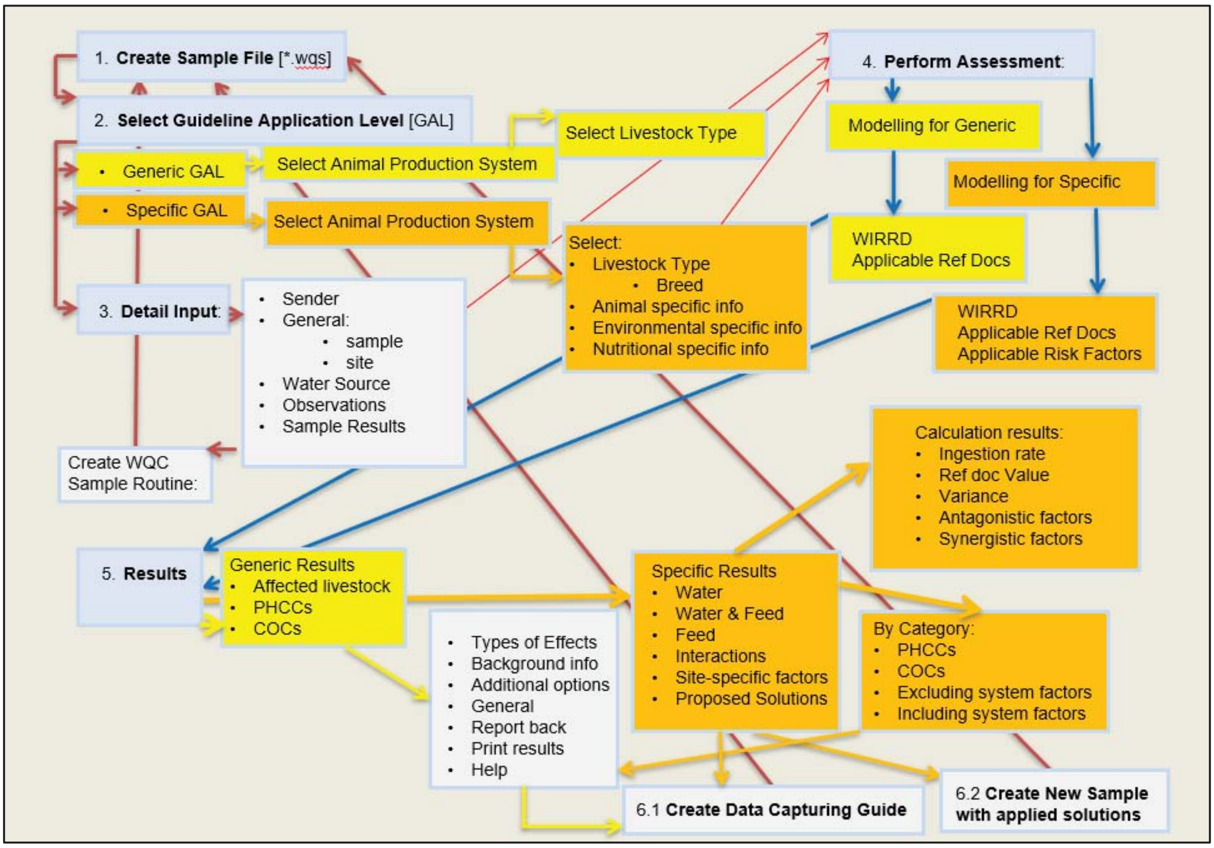

Figure 1: System data flow

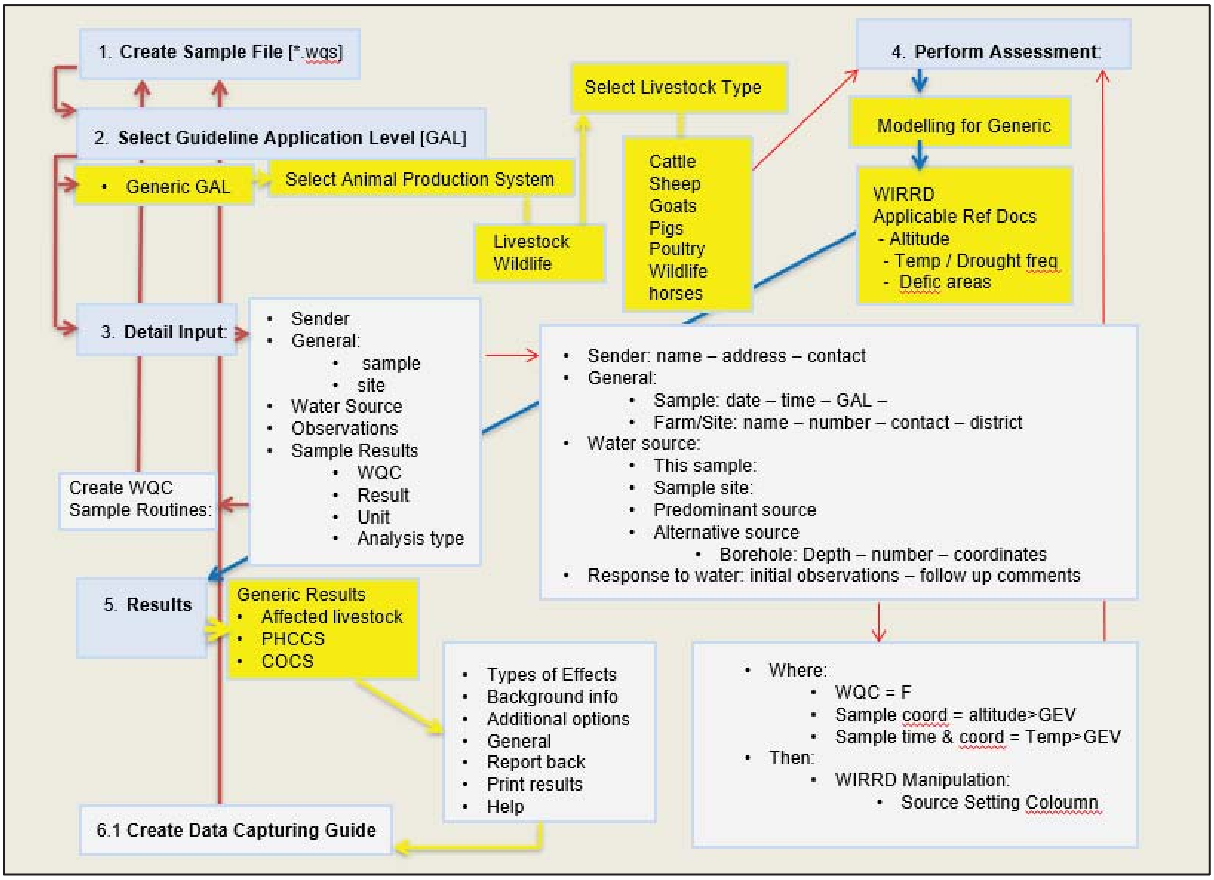

Figure 2: Generic system overview

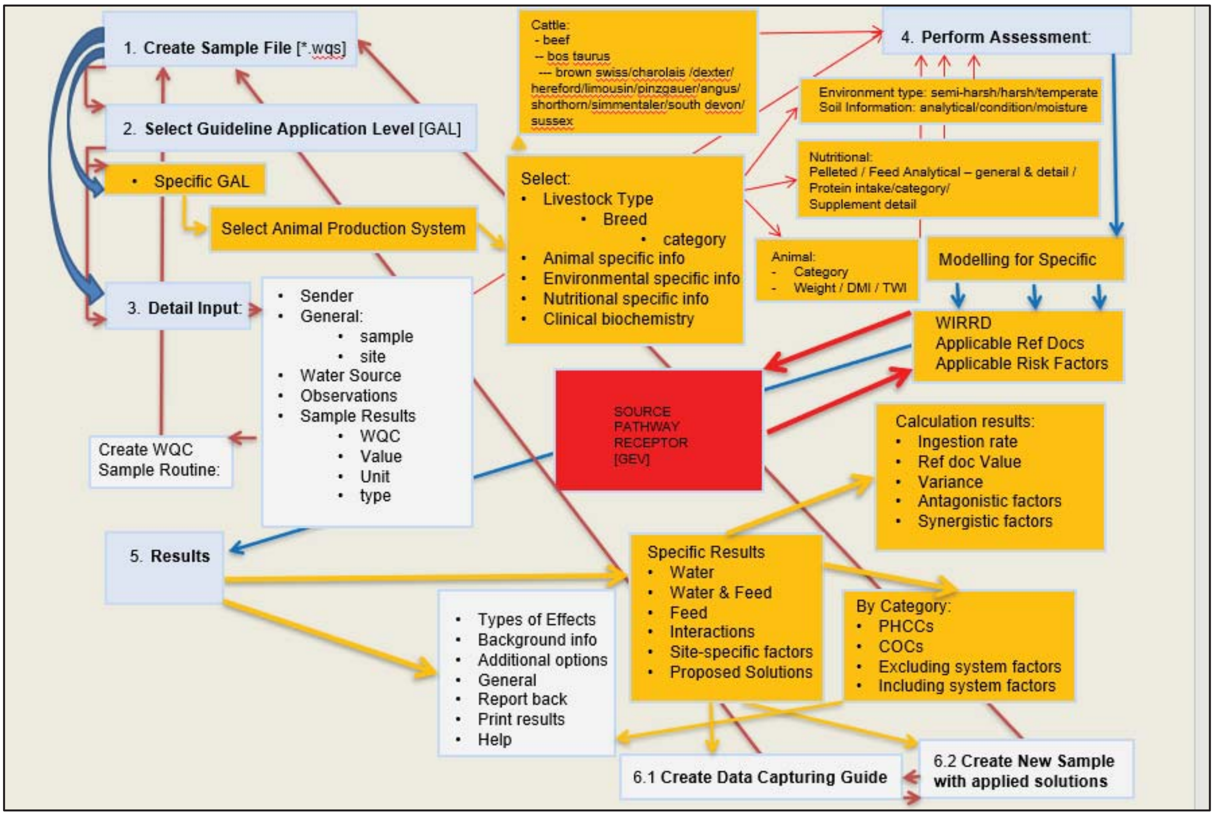

Figure 3: Specific system overview

As such, the transition from a Generic to a Specific GAL corresponds to movement from Tier 1 to Tier 2, with Tier 3 representing a higher degree of user defined input and in reality updates to the assessment as data capturing guides are implemented leading to new risk assessment files being created. This transition aligns with the objective of defining an acceptable risk level as new data captured, for example, clinical biochemistry values, could lead to a significant change in the risk assessment posed under the specific site-conditions applicable.

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 sections presented the CIRRA model per WQC for the Livestock Type: Sheep: 17 WIRRDs. The total WIRRD tables for sheep accommodated by the source code would thus be 17 *(n WQC).

At this juncture it is noteworthy that all single constituent concentration-based guidelines suffer from the inability to accommodate the end effects of concurrent exposure to multiple potentially hazardous constituents from multiple exposure routes. In this regard the final assessment of the outcome clinically may be obtained from targeted clinical investigations which could demonstrate more accurately the risk posed and thus vary from potentially beneficial site factors which lower risk to acceptable levels, or potentially adverse site factors which increase the risk posed.

The main output of the Generic Guideline Application Level (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.

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.

Additional results screen tabs include statements which range from relevant interactions to proposed solutions, noting that the user may create a dummy *.wqs file in which the outcome of manipulated system factors can be evaluated. These may entail changes to the feed (e.g. moisture percentage or mineral composition) and/or production system (e.g. change from breeding exposure to growing exposure) in addition to experimenting with the change in risk outcome by altering water quality concentrations of the PHCCs or COCs listed.

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.

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 indicates 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.

As detailed in previously, 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.

Details on the system data flow, generic and specific GALs and different tiers are provided in Volume 1 of this final report, with only some key data flow aspects highlighted in the following figures, with Figure 4 an indication of the opening selection options, Figure 5 an example of the user detail input/selection and Figure 6 an example of a results screen.

The graphical user interfaces of the DSS prototype for Animal (Livestock) Watering water use is presented as Appendix B.

Although this final 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.

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 the Volume 1 final report. 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 Volume 1 of this final report.

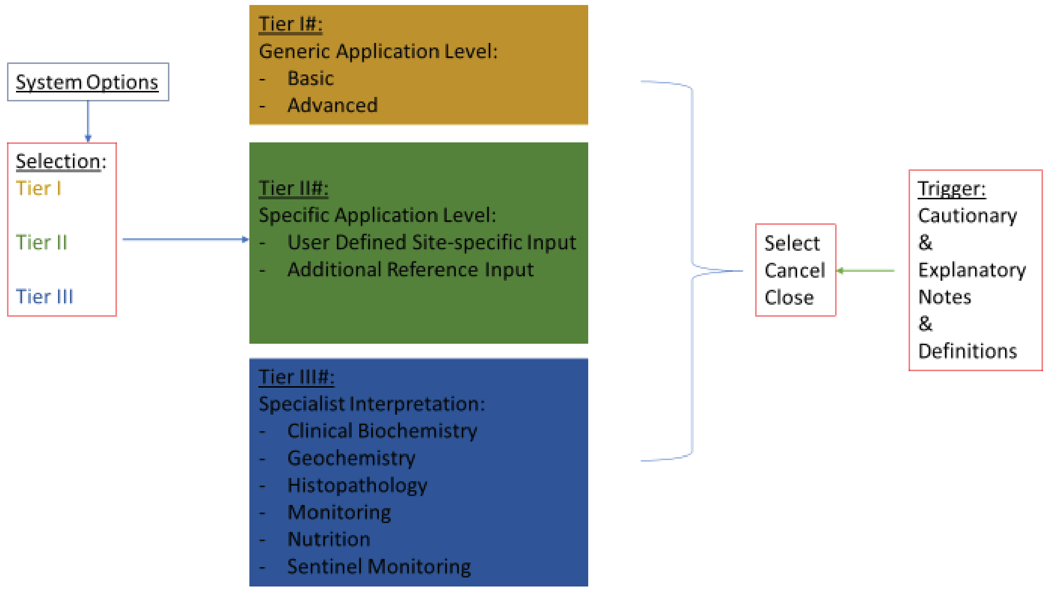

Figure 4: User input additions – Application types

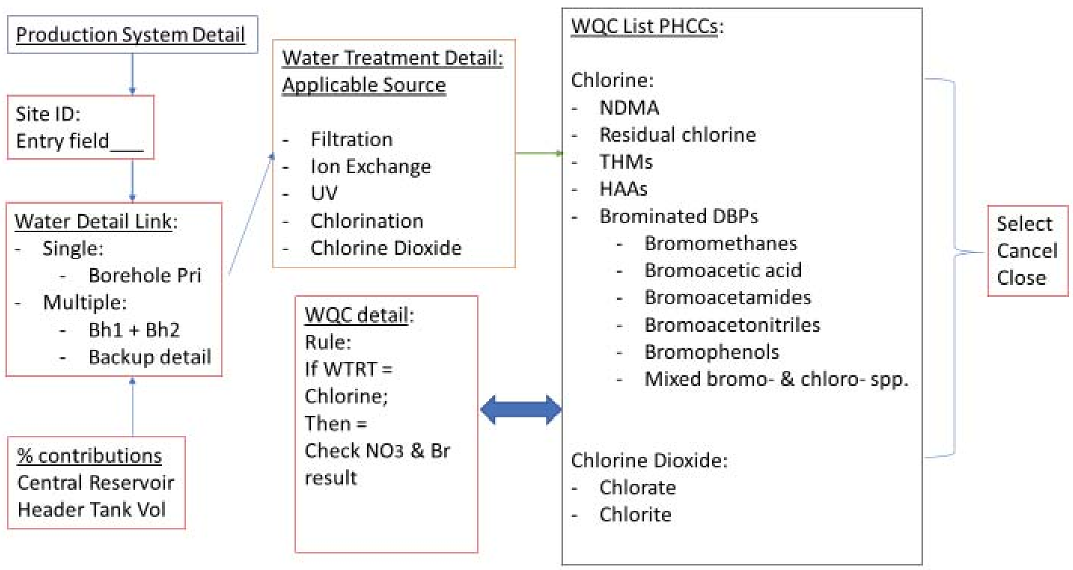

Figure 5: User input additions – Selection = Water Detail - Treatment

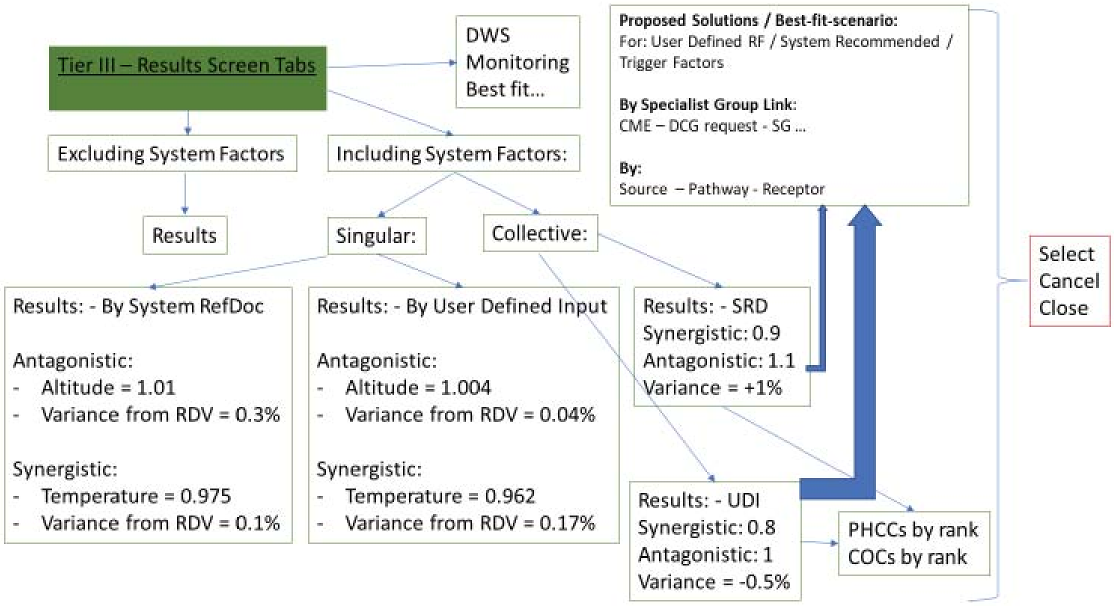

Figure 6: Results screen: Tier III

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Water Research Interim Deliverables as part of this project:

WRC, K5/2817//4 – Deliverable 1: Inception Report: August 2018

WRC, K5/2817//4 – Deliverable 2: Progress Report 1: Risk Approach fundamentals for Animal Watering: January 2019

WRC, K5/2817//4 – Deliverable 3: Progress Report 2: Updated Constituent Hazard Assessment for Risk Approach Guideline for Animal Watering: June 2019

WRC, K5/2817//4 – Deliverable 4: Progress Report 3: Report on Risk Methodologies for Animal Watering. K5/2817//4 January 2020

APPENDIX A: UPDATED CONSTITUENT HAZARD ASSESSMENT DATA

OVERVIEW OF UPDATED CENTRAL WIRRD TABLES

Fundamental perspective

The central component to the CIRRA model is a water ingestion rate reference document (WIRRD). This 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 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 livestock 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 water quality constituent (WQC) for the Livestock Type: Sheep: 16 WIRRDs; Total = 336 WIRRD tables for sheep being accommodated by the source code. The tables presented in section 3 of this report have expanded this to 17 WIRRD tables per constituent.

Examples of the application thereof to alleviate adverse WQC effects in different livestock and livestock production systems were presented in the WRC report 644/2/98 with experimental results, but it should be noted that whilst the data inputs of actual site-specific measurements are preferred, the model does rely on a significant degree of source reference documentation.

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. A variety of recognised reference sources for nutrient requirements and production parameters were used in the derivation of the category list and table content using either live weight specific DMI values or calculated DMI values, the TWI being calculated using the applicable regression formula for the specific livestock type.
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 E) may:

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

- 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 3 assessment the user is required to make subsets of the water sample file in which the identified potentially hazardous chemical constituents (PHCCs) and constituents of concern (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.

Central Format Update

The format of the WIRRD documentation is germane to many constituents and livestock types and categories, however, key differences do occur between and within livestock types and water quality constituents. Whilst it is not possible to address the basic physiology and nutritional principles applicable in this document, some key points are briefly dealt with in this section.

A key constituent to address is selenium due to the widespread supplementation thereof in diets and widely recognised narrow margin between essentiality and toxicity. This setting is further exacerbated by the tendency for inorganic forms thereof which occur in water to follow a predominantly toxic route.
Illustrative of the increasing recognition of the requirement to consider total exposure, the most recent Canadian review for drinking water for humans opted for a maximum acceptable concentration for selenium in source drinking water of 0.01 mg/L, citing concerns for routinely high dietary exposure to selenium from natural feedstuffs and supplementation practices (BCME, 2014). The water quality

guideline was noted as the maximum acceptable concentration to protect against adverse effects in humans from excessive exposure.

Another recent Canadian proposal for the maximum concentration of selected nutrients in animal feeds proposed 1 mg/kg DM for selenium and noted that whilst the current maximum concentration permitted is 0.3 mg/kg DM the current data indicated that 1 mg/kg DM would not result in a transfer thereof to meat, milk or eggs that would be of concern (CFIA, 2018).

The study also noted, however, that selenium in feed formulations is “rarely, if at all” taken into consideration and that the 0.05 mg/kg DM may grossly underestimate total dietary burden. Accordingly, the column B value in the updated WIRRD tables was selected at the conservative 0.01 mg/L reference value.

It is also noteworthy that whilst the Canadian review for selenium in source drinking water was lowered to 0.01 mg/L, lowering of the livestock watering guideline value (0.03 mg/L) was not done as this was not yet updated.

It is again noteworthy that the maximum tolerable level of 5 mg/kg DM is based on animal health and does not address the norm of consumer product safety, with the European Food Safety Authority (EFSA 2016) suggested a maximum of 0.5 mg/kg DM for animal feed.

As is the case in North America, South Africa also has geographical areas which are regarded as low, medium and potentially high selenium areas, with a wide range of nutrient requirements corresponding to these background values.

A risk-based approach requires a total exposure assessment, with this being site-specific, a point thus noted with selenium in which a generic animal feed ration formulated for nutrient requirements, but done so in isolation of the background site-specific exposure setting, may provide selenium at or above the high range of adequacy, with potential excess supply thus possible.

Accordingly, the risk would differ for animals receiving generic rations and those grazing natural pastures, although the inclusion of selenium in vitamin and mineral premixes and other supplementary feeding may further increase the potential for excessive exposure in high naturally occurring seleniferous areas.

In recognition of the observations of selenium in groundwater resources in South Africa to occur at low (<0.01 mg/L) and significantly elevated (>0.05 mg/L) concentrations, a precautionary approach is adopted in selecting the corresponding column values in the WIRRD tables.

The WIRRD reference documentation is obtained from predominantly three sources:

- Various Authorities and Agencies (e.g. National Research Council for the National Academies and European Food Safety Authority)
- Applicable articles in peer-reviewed literature (e.g. Journal of Animal Science)
- Various country and/or animal breed specific guideline documentation (e.g. Olkowski, 2009).

It is not uncommon to have country or regional specific experimentation published which differs from the national recommendations or guidelines, as site-specific factors may lead to differing observations and subsequent recommendations. This is in some respects similar to the US EPA Maximum Contaminant Level and Maximum Contaminant Level Goal approach, in which varying capabilities to arrive at final concentrations are acknowledged.

As this project has focussed on a few key selected water quality constituents, it can be appreciated that new research is continually being presented on specific elements and animal types and is one of the fundamental reasons for ultimately having the WIRRD documents as a source code template reference database which can be updated by inserting new reference values as they become available.

The long delay in the 2007 NRC guidelines for sheep is a case in point, with the last 1985 edition presenting values largely derived from the previous 1975 version. It must be noted that when comparing the WIRRD tables derived initially and the updated tables presented here, that whilst the numeric values may appear similar, small differences in the numeric values equate to significant differences in both practice and in the final trigger values within the WIRRD tables.

Similar adaptations to the reference values are to be noted for fluoride, with increasing scientific criticisms being brought against the US EPA decision to revert back to an elevated Maximum Contaminant Level, with the challenge set forth by Connett and Connett (2003) arguably still valid, noting that the current US EPA MCL and MCLG are set at 4.0 mg/L, whilst the non-enforceable secondary standard is cited in the 2011 US EPA Fact Sheet at 2 mg/L (and thus linked only to cosmetic effects, even for enamel hypoplasia).

The fundamental point raised to the US EPA rests on the fact that the duty of the EPA is to recommend a safe standard based on the best available science and that the applicable Safe Drinking Water Act requires that the EPA establish such standards “which protect against any known or anticipated adverse effects within adequate margins of safety”.

It was comprehensively argued, on the basis of the available scientific information, that the MCLG should be lowered from 4 mg/L to 0.01 mg/L and the MCL to 0.2 mg/L.

It is noteworthy that a precautionary approach was adopted and although animals are not routinely supplemented with fluoride (as with water-fluoridation for domestic water supplies), nor are the aesthetics of dental mottling deemed significant, the requirement for preventing enamel hypoplasia is nonetheless a crucial aspect to ensuring adequate feed intakes and thus performance (due to pain during mastication of feed and consumption of cold drinking water).

It is thus relevant that the WIRRD tables balance the initial requirement recognition with the potential for excessive exposures, and whilst this may be more relevant to commercial intensive production system settings compared to extensive systems, these differences would be catered for most appropriately by selecting the corresponding dietary and soil exposure values (or listed reference feedstuffs).

It is thus noteworthy that whilst the selected WIRRD reference updates are presented here, similar updated feedstuff composition tables would also be required to be included in the CIRRA programming. It should be noted that the initial WIRRD documentation was published as an appendix to the corresponding WRC Report and may be consulted for an indication of the volume of tables subsequently generated by this approach for all the livestock types and categories.

Despite the detail and validity of the WIRRD it must lastly be mentioned that these are trigger values used in the CIRRA modelling, and the provision of a *.wqs file that enables (and encourages) the user to obtain and insert actual site-specific values, is the strongly preferred option.

The initial column reference value is selected based on the nutrient requirement at a median performance level for the respective livestock category at a median digestibility quotient. This would equate to a median production parameter for milk yield or average daily gain, and to a digestibility quotient of 0.6.

This allows for adaptations thereto to be made in the selection of variables across either site-specific performance indices or in the manipulation of identified risk management factors. Thus an alteration in the performance observed (deviation from the breed-norm) and changes to ration digestibility can be included to observe the resulting change in deviation from the WIRRD trigger value.

The following updated WIRRD tables for sheep are addressed:

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

Tables A1 and A2 provide the updates to the initial WIRRD based on the new NRC nutrient requirement guidelines and demonstrate the changes to the WIR values used (NRC, 2007).

A review thereof is not included here, but it should be noted that additional inputs to the values are obtained by various targeted scientific articles and publications which focus on mineral nutrition of livestock. Whilst the estimates in the updated version do not appear to differ much, the numerical values are different and due to the calculations performed do alter the final WIR reference values.
Changes to the updated central reference document table column reference values are also significantly different based on additional work and reviews thereon as noted in the Table series that follow.

Table A1: Example of initial WIRRD for Livestock Type = Sheep; Category = Ewes – maintenance; WQC = Selenium*

User Specific Input			Ingestion	Water Quality Constituent				
Live Weight (kg)	DMI (kg/d)	TWI (L/d)	WIR (L/kg$^{0.82}$/d)	mg Se/kg$^{0.82}$/d^				
				A (0-0.02)	B (0.021-0.05)	C (0.051-0.7)	D (0.71-2.5)	E >2.5
50	1	2.87	0.116	0.00232	0.0058	0.0812	0.29	>0.29
60	1.1	3.26	0.113	0.00226	0.00565	0.0791	0.2825	>0.2825
70	1.2	3.642	0.111	0.00222	0.00555	0.0777	0.2775	>0.2775
80	1.3	4.028	0.1108	0.002216	0.00554	0.007756	0.277	>0.277
90	1.4	4.414	0.11	0.0022	0.0055	0.077	0.275	>0.275

^Where columns A to E relate to target water quality range to possible acute adverse effects as “guideline effect concentration ranges”.
*Adapted from NRC (1985)

Table A2: Updated WIRRD for Livestock Type = Sheep; Category = Ewes – maintenance; WQC = Selenium*

User Specific Input			Ingestion	Water Quality Constituent				
Live Weight (kg)	DMI (kg/d)	TWI (L/d)	WIR (L/kg$^{0.82}$/d)	mg Se/kg$^{0.82}$/d^				
				A (0-0.02)	B (0.021-0.05)	C (0.051-0.7)	D (0.71-2.5)	E >2.5
50.8	0.92	2.599	0.119	0.00238	0.00595	0.0833	0.2975	>0.297
61.0	1.07	3.142	0.103	0.00206	0.0515	0.0721	0.2575	>0.257
71.21	1.20	3.667	0.090	0.0018	0.0045	0.063	0.225	>0.225
81.419	1.32	4.132	0.081	0.00162	0.00405	0.0567	0.2025	>0.202
91.62	1.45	4.612	0.073	0.00146	0.00365	0.0511	0.1825	>0.182

^Where columns A to E relate to target water quality range to possible acute adverse effects as “guideline effect concentration ranges”.

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

Updates to the Water Ingestion Rate Reference Documents – Sheep

The updates presented may be considered two stem from two types of inputs. The first is the input by live weight for the specific category from which derived dry matter intakes (DMI) and Total Water Intakes (TWI) are derived.

The second relates to the changes to the column reference values, note only in the updated constituent specific reference values for each corresponding column, but in the addition of a requirement column, or a potential beneficial response on supplementation statement. This is an essential component of the CIRRA approach in which risk-based objectives are inclusive of the recognition that a zero mg/L concentration is not the quality objective.

In addition to the user being able to select the appropriate category and live weight applicable, these are user specific input options in the CIRRA model to which actual values may be inserted.

The user may thus provide an estimated live weight (or actual), failing which, the calculations will be performed for the central live weight value. Thus, in order to cater for a central tendency approach about the mean of the source data values several row values are derived by taking the median values between upper and lower values in the reference material.

This is a change from the Table A2 version presented in above in which the starting point for the central reference value was the first row live weight (50 kg LW). It should also be noted that in many instances the source reference live weight may not correspond to the median live weight of 71 kg (for sheep), but is adapted from the cited 75 kg live weight reference value (noting that publications may differ in the central representative live weight chosen, with the 2007 NRC values using 71 kg).

The WIR calculation method was previously described in detail and is retained in the updated tables, as is the regression used to calculate the TWI (this regression is still retained in the 2007 NRC edition and thus remains unchanged).

The initial column A presents values for each row within the column around which a central reference value for requirement is based. The primary reason for this is that the requirements subsequently used as reference material are typically provided for a range of performance characteristics with the use of a median value throughout validated by the conversion thereof to a mg X requirement/DM format within a category thus adjusted accordingly as the DMI is adapted to live weight changes.

It may be considered in the programming to allow for a variable within a minimum and maximum live weight entry field (done in the previous CIRRA) to cater for breed differences where different body weights are associated between breeds for the same physiological category.

This central requirement reference value is consistent within physiological modes (e.g. pregnancy) but differ 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, 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 previously, with site-specific recognition of source exposure differences linked to altitude and temperature included in the initial CIRRA model.

Continual discharge of fluoride in effluents remains, however, a general water resource concern with over 23500 tons estimated environmental load per annum to the Canadian environment, of which one of the three primary contributors include fertiliser production.

As noted by Olkowski (2009) widely cited safe dietary and water concentrations for livestock from 1980 NRC tables did not consider differences known due to the form of fluoride (NaF compared to CaF) and downward revision of safe levels were already suggested in 1985.

Current concerns for milk, neonatal blood concentrations and adverse endocrine effects continue to be noted (reproductive and thyroid endpoints) with caution generally cited for setting a safe water limit in the absence of correcting for total dietary intake, temperature (water intake changes), exposure duration (cumulative chronic toxin with clinical signs potentially appearing after several years) and time of exposure (physiological stage).

The guidelines generally cite 1 mg/L as being considered safe even if fluoride is available from the feed, but seldom are actual corresponding dietary references provided other than a wide concentration range. Choubisa (*et al.,* 2011) observed increases in prevalence in clinical signs of dental fluorosis to increase from 12.5% in sheep at exposure concentrations of 1.5 mg F/L to 41.7% at 3.5 mg/L, with 50% observed at the highest exposure concentration of 4.4 mg/L. An increased prevalence for dental lesions were observed for all exposure concentrations for cattle.

Simons (*et al.*, 2014) observed that the rates of dental fluorosis have increased dramatically in the USA, leading to a downward adjustment to water fluoridation to 0.7 mg/L being recommended.

This was supported by the review of water fluoridation and subsequent physiological effects by Peckham and Awofeso (2014) who observed that despite the increasing global need for the prevention of dental caries, in addition to the need to urgently seek an alternative method for the reduction of dental caries that does not involve systemic ingestion of fluoride due to the potential at the fluoridated levels for major adverse human health problems to occur, the discharge of fluoride compounds due to fluoridation into the environment was an issue which further requires a global reconsideration of water fluoridation.

Concerns for a wide range of adverse effects following exposure to claimed “safe” water fluoridation levels are increasingly noted for non-classical chronic fluorosis effects (dental and skeletal), with endocrine, cancer and neurological endpoints cited.

The failure to arrive at a “safe” drinking water fluoridation concentration is illustrative of the fundamental reason why risk-based guidelines need to be adopted that are not concentration based, but ingestion based with modelling that allows for site specific factors to be considered.
These are not solely linked to the obvious key issues of total exposure and temperature affecting water intake, but also to interactions between elements, with it noted that at concentrations of less than 1 mg/L when associated with concurrent low iodine status, intellectual deficits have been observed in children (Peckham and Awofeso, 2014).

It is relevant that when considering human guidelines aesthetic impacts must be accounted for, as even enamel discolouration and mottling in the absence of hypoplasia may have an adverse psychological effect, but for livestock in intensive and extensive production systems, this is not considered relevant.
Caution is thus adopted in the derivation of the Column A reference value as whilst fluoride is typically cited as “an important constituent” of bones and teeth, essentiality is not provided as a requirement for dietary inclusion, suggesting that even low concentrations in feedstuffs are sufficient to cater adequately for any requirement.
Conversely, finishing animals (final stages of a feedlot cycle prior to slaughter) offer an opportunity for high fluoride waters to be safely used, as the time required for adverse effects to present is too short and no consumer concerns are applicable to animal product residues.

Due to concerns for developmental aspects this allocation of high fluoride water to feedlot and/or animals in a final or latter stage of production which are destined for slaughter is not included in the WIRRD tables to a great extent, with adjustments primarily implemented by the user in the CIRRA modelling in which the selection of specific production options (e.g. feedlots) are accordingly adjusted elevated concentration exposures by the use of adjustment factors.

The issue of nitrate has received a great deal of attention of late, on the one hand for increasing recognition of endocrine disruption effects (which have not been catered for in the classic concentration-based approach to guidelines which focus on the incidence of clinical methaemoglobinaemia), and on the other extreme the possible use thereof as an NPN source to lower urea use in an attempt to lower methane production from the animal production industry.

As observed by Lee and Beauchemin (2014) ruminants can adapt to nitrate (via the reduction of ruminal nitrite to ammonia) if exposure is to acceptable values over a long period of time, with the potential to lower urea supplemented.

Whilst further work is needed to standardise the adaptation phase and investigate other potential benefits to nitrate supplementation (e.g. nitric oxide benefits), currently this holds a crucial perspective shift towards addressing nitrate concentrations in water in a manner congruent with the inclusion of column A requirement reference values in the updated WIRRD tables for selenium (and other potentially beneficial elements with demonstrated essentiality).

In the instance of nitrate. It is not the essentiality per se that is applicable, but rather the potential to mitigate against increasing concerns of impacts from intensive animal production systems on the environment.

Given the prevalence of high nitrate groundwater concentrations in South Africa it is also a pertinent potential mitigation consideration for the management of nitrate therein and nitrite induced risk factor mitigation.

It is interesting to note that the inclusion thereof in a water resource management scenario highlights the need to move towards risk-based guidelines as opposed to the critically flawed historic target water quality range approach wherein zero mg/L was viewed as the management goal.

The risk-based ingestion approach is furthermore motivated for by the potential for future increases in the supplementation of nitrate in feedstuffs, with total exposure assessments thus required with water quality guidelines on their own insufficient with which to derive suitable outcomes.

The inclusion of bromide as a key element stems from primarily from the increasing recognition of the risk posed to drinking water supplies by bromide discharges into the environment and potential for hazardous disinfection by-product formation (DPBs), with coal-fired power station a key source identified (Van Briesen, 2013; Good and Van Briesen, 2017).

Additionally, the observations of bromide in drinking waters for confined animal feeding operations have been noted to result in thyroid disruption and an increased requirement for essential trace elements (copper, selenium, manganese, iodine and zinc).

This is viewed as a similar mechanism to molybdenum in ruminants, wherein molybdenum itself is not regarded as highly toxic, but in association with low copper and elevated sulphate exposures, can significantly increase the risk of copper deficiency.

It is thus noteworthy that whilst it may be cited that bromide itself is not considered to pose a toxicological hazard at the concentrations typically observed in human drinking water supplies, it does appear to result in induced deficiencies and thyroid disruption at the exposure levels observed in groundwater in confined animal feeding operations, this being influenced by higher concentrations and intakes associated with intensive production systems.

This induced deficiency pathway has been observed to be response to lowered exposure concentrations or increased supplementation of the key elements involved and offers an important risk factor mitigation option for animal production systems without having to incur the burden of reverse osmosis treatment system or similar concentration reduction technologies.

As a general statement, it may be noted that between different physiological categories, trends between the parameters (LW, DMI and TWI) are not always consistent. This is a function of the physiological stage, for example, mature ewes in early lactation, despite an increase in DMI and TWI with an increase in Live Weight, do not provide a linear WIR, but present rather as a Gaussian distribution.

It is further observed that for similar body weights, despite changing performance parameters, similar column B to F WIR values are derived (the exponent value is similar). In many instances the changes in the WIR result value reflect changes in DMI as a ratio despite increases in requirements, this being a function of the corresponding growth or performance curve.

Different values may thus be noted for some categories, whilst others are retained, for example, compared to mature ewes growing ewes do not revert to a lactation reference value across the same live weight as they are experiencing changing nutrient requirements through the growth phase over lactation and gestation phases.

Whilst document volume constraints do not permit a detailed discussion on all the reference values and reasons for selection of specific numeric values, all are obtained from reference materials as described above. Additionally, the corresponding values are included in the updated WIRRD tables in [parenthesis] and may thus easily be adjusted or altered as new information becomes available.

Lastly, 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 yield 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.

This adjustment is similar in principle to the WHO fluoride concentration-based guideline and ambient temperature for which different environments could yield similar intakes for different user groups (e.g. adolescent could ingest the same TWI in a warmer climate as an adult in a cooler climate).

The application of the WIRRD approach and the relevance of the WIR values in accurately portraying ingestion rates is worthy of mention at this juncture, noting that the cumulative result yielded is compared to a final ingestion rate value (appropriately corrected for on a physiologically defensible basis) in a manner that allows for risk and risk factor mitigation to not only be identified, but also manipulated to arrive at an acceptable risk value.

Updated WIRRD tables for Sheep

The tables that follow provide the updated NRC values as illustrated in the first four columns of Table A2, with additional corresponding updates to the remaining column A to F values as described earlier, for Livestock Type = Sheep, for the selected water quality constituents selenium, fluoride, nitrate and bromide.

Livestock Type: **Sheep**

Constituent: **Selenium**

Table A3: 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
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.

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 A4: Updated Specific-Central WIRRD for Livestock Type = Sheep; Category = Ewes – Mature Breeding; 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	1.029	2.984	0.1037	[0.0058] 0.000702	[0.0138] 0.001653	[0.0569] 0.00826	[0.9716] 0.1157	[3.467] 0.4131	>0.413
61.0	1.171	3.531	0.1079	[0.0056] 0.000688	[0.0117] 0.001422	[0.0586] 0.00711	[0.8211] 0.0996	[2.930] 0.3555	>0.355
71.21	1.329	4.140	0.1252	[0.00548] 0.000687	[0.01] 0.001253	[0.05] 0.00626	[0.7] 0.0877	[2.5] 0.3132	>0.313
81.419	1.453	4.619	0.1252	[0.00537] 0.000673	[0.0089] 0.001123	[0.0448] 0.00561	[0.6276] 0.0786	[2.240] 0.2806	>0.280
91.62	1.592	5.155	0.1268	[0.00527] 0.000670	[0.0080] 0.001019	[0.0401] 0.00509	[0.5624] 0.0713	[2.007] 0.2547	>0.254

*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

Table A5: Updated Specific-Central WIRRD for Livestock Type = Sheep; Category = Ewes – Mature Early Gestation; 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	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

Table A6: Updated Specific-Central WIRRD for Livestock Type = Sheep; Category = Ewes – Mature Late Gestation; 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	1.4787	4.717	0.1883	[0.0053] 0.0010	[0.0129] 0.00243	[0.0646] 0.01217	[0.9052] 0.1704	[3.232] 0.6088	>0.608
61.0	1.6685	5.450	0.1872	[0.0052] 0.00098	[0.0111] 0.00209	[0.0559] 0.01047	[0.7835] 0.1467	[2.798] 0.5239	>0.523
71.21	1.837	6.101	0.1846	[0.0051] 0.00095	[0.01] 0.00184	[0.05] 0.00923	[0.7] 0.1292	[2.5] 0.4615	>0.461
81.419	2.0191	6.804	0.1844	[0.00507] 0.00093	[0.0089] 0.00165	[0.0448] 0.00827	[0.6276] 0.1157	[2.241] 0.4135	>0.413
91.62	2.1953	7.4841	0.1842	[0.00501] 0.00092	[0.0081] 0.00150	[0.0407] 0.00750	[0.5706] 0.1051	[2.037] 0.3753	>0.375

*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

Table A7: Updated Specific-Central WIRRD for Livestock Type = Sheep; Category = Ewes – Mature Early Lactation; 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	1.288	3.982	0.1589	[0.0055] 0.000879	[0.0169] 0.00268	[0.0845] 0.01343	[1.831] 0.18809	[4.225] 0.6717	>0.671
61.0	1.618	5.258	0.1806	[0.00526] 0.00095	[0.0128] 0.00231	[0.0640] 0.01156	[0.896] 0.16187	[3.200] 0.5781	>0.578
71.2	2.000	6.731	0.2037	[0.00507] 0.001034	[0.01] 0.00203	[0.05] 0.01018	[0.7] 0.14259	[2.5] 0.5092	>0.509
81.419	2.174	7.401	0.2006	[0.00501] 0.001007	[0.0090] 0.00182	[0.0454] 0.00912	[0.636] 0.12776	[2.273] 0.4562	>0.456
91.62	2.349	8.079	0.1988	[0.00497] 0.000988	[0.0083] 0.00165	[0.0416] 0.00828	[0.583] 0.11597	[2.082] 0.4141	>0.414

*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

Table A8: Updated Specific-Central WIRRD for Livestock Type = Sheep; Category = Ewes – Mature Mid Lactation; 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	1.422	4.525	0.1806	[0.0053] 0.000975	[0.0130] 0.00235	[0.0652] 0.01179	[0.913] 0.1650	[3.264] 0.5896	>0.589
61.0	1.619	5.626	0.1807	[0.00526] 0.000951	[0.0112] 0.00203	[0.0561] 0.01014	[0.784] 0.1420	[2.807] 0.5074	>0.507
71.21	1.787	5.908	1.1788	[0.00516] 0.000924	[0.01] 0.00178	[0.05] 0.00894	[0.7] 0.1251	[2.5] 0.4470	>0.447
81.419	1.958	6.568	1.1780	[0.00509] 0.000907	[0.0089] 0.00160	[0.0449] 0.00901	[0.629] 0.1121	[2.248] 0.4005	>0.400
91.62	2.113	7.169	1.176	[0.00503] 0.000889	[0.0082] 0.00145	[0.0412] 0.00727	[0.576] 0.1017	[2.060] 0.3635	>0.363

*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

Table A9: Updated Specific-Central WIRRD for Livestock Type = Sheep; Category = Ewes – Mature Late Lactation; 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	1.288	3.982	0.1589	[0.00552] 0.00087	[0.0134] 0.00213	[0.0671] 0.01067	[0.940] 0.14944	[3.357] 0.5337	>0.533
61.0	1.467	4.673	0.1605	[0.00536] 0.00086	[0.0114] 0.00183	[0.0572] 0.00918	[0.801] 0.12861	[2.860] 0.4593	>0.459
71.21	1.642	5.348	0.1618	[0.00524] 0.00084	[0.01] 0.00161	[0.05] 0.00809	[0.7] 0.11329	[2.5] 0.4046	>0.404
81.419	1.795	5.939	0.1610	[0.00516] 0.00083	[0.009] 0.00145	[0.0450] 0.00725	[0.630] 0.10150	[2.250] 0.3625	>0.362
91.62	1.950	6.538	0.1609	[0.00509] 0.00082	[0.0008] 0.00131	[0.0408] 0.00658	[0.572] 0.0921	[2.044] 0.3290	>0.329

*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

Table A10: Updated Specific-Central WIRRD for Livestock Type = Sheep; Category = Growing Ewe Lambs – yearlings at 40% of mature weight; 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]
30.84 (0,55)	0.920	2.564	0.1541	[0.0070] 0.00109	[0.0119] 0.001846	[0.059] 0.00923	[0.838] 0.12924	[2.995] 0.46157	<0.4615
30.84 (0.66)	1.052	3.072	0.1846	[0.0067] 0.00124	[0.01] 0.001846	[0.05] 0.00923	[0.7] 0.12924	[2.5] 0.46157	<0.4615
30.84 (0.88)	1.297	4.017	0.2414	[0.0063] 0.00153	[0.0076] 0.001846	[0.038] 0.00923	[0.535] 0.12924	[1.911] 0.46157	<0.4615

*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:
#(ADG) ##Note final reference values similar for columns B-F due to same exponent result (LW common).
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

Table A11: Updated Specific-Central WIRRD for Livestock Type = Sheep; Category = Growing Ewe Lambs – Breeding; 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]
40.82	1.306	4.052	0.1935	[0.0063] 0.00122	[0.0151] 0.00293	[0.0757] 0.01465	[1.059] 0.20513	[3.785] 0.73262	>0.7326
50.80	1.576	5.094	0.2033	[0.0060] 0.00123	[0.0120] 0.00244	[0.0602] 0.01224	[0.843] 0.17145	[3.011] 0.61235	>0.6123
61.23	1.846	6.136	0.2108	[0.0059] 0.00124	[0.01] 0.00210	[0.05] 0.01054	[0.7] 0.14756	[2.5] 0.52700	>0.5270
71.21	2.240	7.659	0.2317	[0.0057] 0.00133	[0.0080] 0.00185	[0.0400] 0.00928	[0.560] 0.12998	[2.002] 0.46422	>0.4642
81.64	2.635	9.182	0.2489	[0.0056] 0.00140	[0.0066] 0.00166	[0.0334] 0.00831	[0.467] 0.11646	[1.670] 0.41594	>0.4159

*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

Table A12: Updated Specific-Central WIRRD for Livestock Type = Sheep; Category = Growing Ewe Lambs – Early Gestation; 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]
40.82	1.356	4.245	0.2027	[0.00629] 0.001276	[0.0149] 0.00303	[0.0747] 0.01515	[1.0464] 0.21215	[3.737] 0.75771	0.75771
50.80	1.628	5.295	0.2113	[0.00605] 0.00128	[0.0119] 0.00243	[0.0599] 0.01266	[0.8388] 0.17733	[2.995] 0.63332	>0.6333
61.23	1.900	6.346	0.2180	[0.00589] 0.001286	[0.01] 0.00218	[0.05] 0.01090	[0.7] 0.15261	[2.5] 0.54505	>0.5450
71.21	2.159	7.344	0.2222	[0.00579] 0.001287	[0.0086] 0.00192	[0.0432] 0.00960	[0.6048] 0.13443	[2.1602] 0.48012	>0.4801
81.64	2.417	8.342	0.2261	[0.00570] 0.001291	[0.0076] 0.00172	[0.0380] 0.00860	[0.5325] 0.12045	[1.9018] 0.43018	>0.4301

*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

Table A13: Updated Specific-Central WIRRD for Livestock Type = Sheep; Category = Growing Ewe Lambs – Late Gestation; 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]
40.82	1.224	3.737	0.1784	[0.0065] 0.00115	[0.0193] 0.00345	[0.0968] 0.01728	[1.355] 0.24201	[4.842] 0.86432	>0.8643
50.80	1.678	5.488	0.2190	[0.0060] 0.00132	[0.0131] 0.00289	[0.0659] 0.01444	[0.9233] 0.20228	[3.297] 0.72243	>0.7224
61.23	2.131	7.239	0.2486	[0.0058] 0.00144	[0.01] 0.00248	[0.05] 0.01243	[0.7] 0.174088	[2.5] 0.62174	>0.6217
71.21	2.408	8.307	0.2513	[0.0057] 0.001436	[0.0087] 0.00219	[0.0435] 0.01095	[0.610] 0.15334	[2.178] 0.54767	>0.5476
81.64	2.685	9.375	0.2542	[0.0056] 0.001434	[0.0077] 0.00196	[0.0386] 0.00981	[0.5405] 0.1374	[1.930] 0.49071	>0.4907

*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

Table A14: Updated Specific-Central WIRRD for Livestock Type = Sheep; Category = Growing Ewe Lambs – Early Lactation; 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]
40.82	1.419	4.490	0.2144	[0.00622] 0.00133	[0.0118] 0.00253	[0.0591] 0.01268	[0.8282] 0.17762	[2.958] 0.63473	>0.6347
50.80	1.632	5.313	0.2120	[0.00605] 0.00128	[0.01] 0.00212	[0.05] 0.01060	[0.7] 0.14846	[2.5] 0.53023	>0.5302
61.23	1.846	6.136	0.2108	[0.00592] 0.00124	[0.0086] 0.00182	[0.0432] 0.00912	[0.6061] 0.12777	[2.164] 0.45632	>0.4563
71.21	2.029	6.845	0.2071	[0.00584] 0.00121	[0.0077] 0.00168	[0.0388] 0.00803	[0.5433] 0.11255	[1.940] 0.40196	>0.4019
81.64	2.213	7.554	0.2048	[0.00577] 0.00118	[0.0070] 0.00144	[0.0351] 0.00720	[0.4923] 0.10084	[.758] 0.36015	>0.3601

*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

Table A15: Updated Specific-Central WIRRD for Livestock Type = Sheep; Category = Growing Ewe Lambs – Mid Lactation; 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]
40.82	1.247	3.824	0.1826	[0.0064] 0.00117	[0.0139] 0.00255	[0.0699] 0.01277	[0.978] 0.17879	[3.49] 0.63855	>0.6385
50.80	1.444	4.586	0.1830	[0.0062] 0.00113	[0.0116] 0.00213	[0.0583] 0.01067	[0.816] 0.14944	[2.91] 0.53372	>0.5337
61.23	1.642	5.348	0.1837	[0.0060] 0.00111	[0.01] 0.00183	[0.05] 0.00918	[0.7] 0.12861	[2.5] 0.45933	>0.4593
71.21	1.796	5.943	0.1798	[0.0059] 0.00107	[0.0089] 0.00161	[0.0449] 0.00809	[0.629] 0.11329	[2.24] 0.40461	>0.4046
81.64	1.950	6.538	0.1772	[0.0058] 0.00104	[0.0081] 0.00145	[0.0408] 0.00725	[0.572] 0.10150	[2.04] 0.36253	>0.3625

*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

Table A16: Updated Specific-Central WIRRD for Livestock Type = Sheep; Category = Growing Ewe Lambs – Late Lactation; 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]
40.82	1.551	4.997	0.2386	[0.0061] 0.00145	[0.0144] 0.00344	[0.072] 0.01720	[1.0080] 0.24084	[3.603] 0.86014	>0.8601
50.80	1.837	6.101	0.2434	[0.0059] 0.00144	[0.0118] 0.00287	[0.0590] 0.01437	[0.826] 0.20130	[2.951] 0.71893	>0.7189
61.23	2.122	7.204	0.2474	[0.0058] 0.001436	[0.01] 0.00247	[0.05] 0.01237	[0.7] 0.17324	[2.5] 0.61873	>0.6187
71.21	2.399	8.272	0.2503	[0.0057] 0.00143	[0.008] 0.00218	[0.0435] 0.01090	[0.609] 0.15260	[2.177] 0.54502	>0.5450
81.64	2.676	9.340	0.2532	[0.0056] 0.00142	[0.007] 0.00195	[0.0385] 0.00976	[0.539] 0.13673	[1.928] 0.48833	>0.4883

*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

Table A17: Updated Specific-Central WIRRD for Livestock Type = Sheep; Category = Growing Rams – at 40% of mature weight; 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 (0,55)	1.632	5.313	0.2120	[0.0061] 0.00130	[0.0119] 0.00253	[0.059] 0.01266	[0.836] 0.17733	[2.98] 0.63331	<0.6333
50.8 (0.6)	1.900	6.346	0.2533	[0.0059] 0.00151	[0.01] 0.00253	[0.05] 0.01266	[0.7] 0.17733	[2.5] 0.63331	<0.6333
50.8 (1.1)	2.163	7.361	0.2938	[0.00578] 0.00153	[0.0086] 0.00253	[0.043] 0.01266	[0.603] 0.17733	[2.15] 0.63331	<0.6333

*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:

#(ADG) ##Note final reference values similar for columns B-F due to same exponent result (LW common).

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

A18: Updated Specific-Central WIRRD for Livestock Type = Sheep; Category = Rams - 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]
102.0	1.805	5.978	0.1346	[0.0059] 0.00080	[0.0121] 0.00163	[0.060] 0.00815	[0.847] 0.11416	[3.02] 0.40772	>0.4077
114.7	1.968	6.608	0.1352	[0.00586] 0.00079	[0.0109] 0.00148	[0.054] 0.00740	[0.766] 0.10369	[2.73] 0.37033	>0.3703
127.4	2.131	7.239	0.1359	[0.0058] 0.000788	[0.01] 0.00135	[0.05] 0.00679	[0.7] 0.09514	[2.5] 0.33979	>0.3397
140.1	2.290	7.851	0.1363	[0.00574] 0.000784	[0.0092] 0.00126	[0.046] 0.00628	[0.645] 0.08801	[2.30] 0.31433	>0.3143
152.8	2.449	8.464	0.1369	[0.0057] 0.00078	[0.0085] 0.00117	[0.042] 0.00585	[0.598] 0.08197	[2.13] 0.29275	>0.2927

*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

Table A19: Updated Specific-Central WIRRD for Livestock Type = Sheep; Category = Rams – Pre-breeding; 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]
102.0	1.991	6.696	0.1508	[0.0058] 0.00088	[0.012] 0.00182	[0.060] 0.00910	[0.846] 0.12764	[3.01] 0.45505	>0.4550
114.7	2.170	7.37	0.1511	[0.00578] 0.00087	[0.0109] 0.00165	[0.054] 0.00826	[0.766] 0.11593	[2.73] 0.41333	>0.4133
127.4	2.349	8.079	0.1516	[0.00572] 0.000869	[0.01] 0.00151	[0.05] 0.00758	[0.7] 0.10618	[2.5] 0.37924	>0.3792
140.1	2.521	8.744	0.1518	[0.00568] 0.000863	[0.0092] 0.00140	[0.046] 0.00701	[0.647] 0.09840	[2.30] 0.35082	>0.3508
152.8	2.694	9.410	0.1522	[0.00564] 0.00085	[0.0085] 0.00130	[0.042] 0.00653	[0.602] 0.09164	[2.14] 0.32673	>0.3267

*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

Livestock Type: **Sheep**
Constituent: **Fluoride**

Table A20: Updated Specific-Central WIRRD for Livestock Type = Sheep; Category = Ewes – maintenance; WQC = Fluoride

User Specific Input			Ingestion*	Water Quality Constituent^					
				mg F/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	[0.1101] 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 A21: Updated Specific-Central WIRRD for Livestock Type = Sheep; Category = Ewes – Mature Breeding; WQC = Fluoride

User Specific Input			Ingestion*	Water Quality Constituent^					
				mg F/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	1.029	2.984	0.1037	[0.1062] 0.01265	[0.9710] 0.11568	[1.387] 0.16526	[2.635] 0.3140	[7.976] 0.95027	>0.9502
61.0	1.171	3.531	0.1079	[0.1021] 0.01239	[0.8206] 0.09956	[1.172] 0.14223	[2.227] 0.27023	[6.741] 0.81782	>0.8178
71.21	1.329	4.140	0.1252	[0.0988] 0.012384	[0.6986] 0.0877	[1.0] 0.12528	[1.899] 0.23804	[5.75] 0.72039	>0.7203
81.419	1.453	4.619	0.1252	[0.0968] 0.012133	[0.6272] 0.07857	[0.896] 0.11225	[1.702] 0.21328	[5.152] 0.64547	>0.6454
91.62	1.592	5.155	0.1268	[0.0950] 0.012065	[0.5621] 0.07132	[0.803] 0.10189	[1.525] 0.1936	[4.617] 0.58589	>0.5858

*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 A22: Updated Specific-Central WIRRD for Livestock Type = Sheep; Category = Ewes – Mature Early Gestation; WQC = Fluoride

User Specific Input			Ingestion*	Water Quality Constituent^					
				mg F/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	1.183	3.579	0.1428	[0.101] 0.01455	[0.932] 0.13329	[1.332] 0.19042	[2.531] 0.3628	[7.662] 1.09492	>1.0949
61.0	1.345	4.202	0.14437	[0.098] 0.01422	[0.794] 0.11471	[1.135] 0.16388	[2.156] 0.31138	[6.526] 0.94232	>0.9423
71.21	1.492	4.770	0.14436	[0.096] 0.01390	[0.7] 0.10105	[0.999] 0.14436	[1.899] 0.27428	[5.749] 0.83006	>0.8300
81.419	1.644	5.348	0.1452	[0.094] 0.01373	[0.623] 0.09054	[0.890] 0.12934	[1.691] 0.24575	[5.118] 0.74372	>0.7437
91.62	1.787	5.908	0.1454	[0.093] 0.01354	[0.565] 0.08218	[0.807] 0.11740	[1.534] 0.2230	[4.642] 0.67508	>0.6750

*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 A23: Updated Specific-Central WIRRD for Livestock Type = Sheep; Category = Ewes – Mature Late Gestation; WQC = Fluoride

User Specific Input			Ingestion*	Water Quality Constituent^					
				mg F/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	1.4787	4.717	0.1883	[0.096] 0.01817	[0.905] 0.17048	[1,228] 0.23136	[2.457] 0.46273	[7.435] 1.40037	>1.4003
61.0	1.6685	5.450	0.1872	[0.094] 0.01765	[0.783] 0.14671	[1.063] 0.19911	[2.126] 0.39823	[6.436] 1.20519	>1.2051
71.21	1.837	6.101	0.1846	[0.092] 0.01711	[0.7] 0.12924	[0.949] 0.17539	[1.90] 0.35079	[5.749] 1.06162	>1.0616
81.419	2.0191	6.804	0.1844	[0.091] 0.01685	[0.627] 0.11579	[0.851] 0.15715	[1.703] 0.31431	[5.155] 0.95120	>0.9512
91.62	2.1953	7.4841	0.1842	[0.090] 0.01663	[0.570] 0.10511	[0.774] 0.14265	[1.548] 0.28530	[4.687] 0.86340	>0.8634

*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 A24: Updated Specific-Central WIRRD for Livestock Type = Sheep; Category = Ewes – Mature Early Lactation; WQC = Fluoride

User Specific Input			Ingestion*	Water Quality Constituent^					
				mg F/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	1.288	3.982	0.1589	[0.995] 0.01583	[1.183] 0.18809	[1.521] 0.241839	[3.211] 0.51053	[9.296] 1.47786	>1.4778
61.0	1.618	5.258	0.1806	[0.947] 0.011712	[0.896] 0.16187	[1.152] 0.208132	[2.432] 0.43938	[7.040] 1.27188	>1.2718
71.21	2.000	6.731	0.2037	[0.914] 0.01863	[0.699] 0.15259	[0.90] 0.18333	[1.9] 0.38703	[5.499] 1.12036	>1.1203
81.419	2.174	7.401	0.2006	[0.090] 0.01815	[0.63] 0.12776	[0.818] 0.16426	[1.727] 0.34678	[5.001] 1.00348	>1.0034
91.62	2.349	8.079	0.1988	[0.895] 0.01780	[0.581] 0.11597	[0.749] 0.14910	[1.582] 0.31477	[4.582] 0.91118	>0.9111

*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 A25: Updated Specific-Central WIRRD for Livestock Type = Sheep; Category = Ewes – Mature Mid Lactation; WQC = Fluoride

User Specific Input			Ingestion*	Water Quality Constituent^					
				mg F/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	1.422	4.525	0.1806	[0.097] 0.01756	[0.913] 0.16509	[1.15] 0.21226	[2.480] 0.44812	[0.] 1.2971	>1.2971
61.0	1.619	5.626	0.1807	[0.094] 0.01713	[0.785] 0.14208	[1.010] 0.18268	[2.133] 0.3856	[0.] 1.1163	>1.1163
71.21	1.787	5.908	1.1788	[0.093] 0.01665	[0.699] 0.12616	[0.899] 0.16092	[1.90] 0.33972	[0.] 0.98340	>0.9834
81.419	1.958	6.568	1.1780	[0.917] 0.01634	[0.629] 0.11214	[0.809] 0.14418	[1.709] 0.30438	[0.] 0.88111	>0.8811
91.62	2.113	7.169	1.176	[0.090] 0.01601	[0.576] 0.10179	[0.741] 0.13087	[1.565] 0.27629	[0.] 0.79979	>0.7997

*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 A26: Updated Specific-Central WIRRD for Livestock Type = Sheep; Category = Ewes – Mature Late Lactation; WQC = Fluoride

User Specific Input			Ingestion*	Water Quality Constituent^					
				mg F/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	1.288	3.982	0.1589	[0.099] 0.015833	[0.940] 0.14944	[1.208] 0.19214	[2.551] 0.40563	[7,386] 1.17419	>1.1741
61.0	1.467	4.673	0.1605	[0.096] 0.01552	[0.801] 0.12861	[1.299] 0.16536	[2.174] 0.34909	[6.293] 1.01539	>1.0153
71.21	1.642	5.348	0.1618	[0.094] 0.0153	[0.699] 0.11329	[0.899] 0.145661	[1.90] 0.30705	[5.499] 0.89014	>0.8901
81.419	1.795	5.939	0.1610	[0.093] 0.01499	[0.630] 0.10150	[0.810] 0.13051	[1.710] 0.27552	[4.952] 0.79757	>0.7975
91.62	1.950	6.538	0.1609	[0.091] 0.01478	[0.572] 0.09124	[0.736] 0.11846	[1.554] 0.25009	[4.498] 0.72395	>0.7239

*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 A27: Updated Specific-Central WIRRD for Livestock Type = Sheep; Category = Growing Ewe Lambs – yearlings at 40% of mature weight; WQC = Fluoride

User Specific Input			Ingestion*	Water Quality Constituent^					
				mg F/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]
30.84 (0,55)	0.920	2.564	0.1541	[0.110] 0.01703	[0.838] 0.12921	[1.078] 0.16616	[2.276] 0.35079	[8.316] 1.28165	>0.128164
30.84 (0.66)	1.052	3.072	0.1846	[0.105] 0.01947	[0.699] 0.12921	[0.899] 0.16616	[1.9] 0.35079	[6.941] 1.28165	>0.128164
30.84 (0.88)	1.297	4.017	0.2414	[0.099] 0.02400	[0.535] 0.12921	[0.688] 0.16616	[1.452] 0.35079	[5.308] 1.28165	>0.128164

*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 A28: Updated Specific-Central WIRRD for Livestock Type = Sheep; Category = Growing Ewe Lambs – Breeding; WQC = Fluoride

User Specific Input			Ingestion*	Water Quality Constituent^					
				mg F/$kg^{0.82}$/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]
40.82	1.306	4.052	0.1935	[0.099] 0.01921	[1.059] 0.20513	[1.289] 0.24950	[2.876] 0.55679	[7.949] 1.53851	>1.5385
50.80	1.576	5.094	0.2033	[0.095] 0.01937	[0.843] 0.17145	[1.025] 0.20854	[2.288] 0.46538	[6.323] 1.28593	>1.2859
61.23	1.846	6.136	0.2108	[0.092] 0.01952	[0.699] 0.14756	[0.9] 0.18972	[1.90] 0.40052	[5.249] 1.10670	>1.1067
71.21	2.240	7.659	0.2317	[0.090] 0.02087	[0.560] 0.12998	[0.682] 0.15809	[1.522] 0.35281	[4.205] 0.97486	>0.9748
81.64	2.635	9.182	0.2489	[0.088] 0.02200	[0.467] 0.11646	[0.568] 0.14165	[1.269] 0.31611	[3.508] 0.87347	>0.8734

*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 A29: Updated Specific-Central WIRRD for Livestock Type = Sheep; Category = Growing Ewe Lambs – Early Gestation; WQC = Fluoride

User Specific Input			Ingestion*	Water Quality Constituent^					
				mg F/$kg^{0.82}$/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]
40.82	1.356	4.245	0.2027	[0.098] 0.01994	[1.046] 0.21215	[1.345] 0.27277	[2.840] 0.57586	[0.] 1.59118	>1.5911
50.80	1.628	5.295	0.2113	[0.094] 0.02001	[0.838] 0.17733	[1.078] 0.22799	[2.276] 0.48132	[0.] 1.32996	>1.3299
61.23	1.900	6.346	0.2180	[0.092] 0.02010	[0.699] 0.15261	[0.9] 0.19621	[1.9] 0.41423	[0.] 1.44060	>1.4406
71.21	2.159	7.344	0.2222	[0.090] 0.02011	[0.604] 0.13443	[0.777] 0.17284	[1.641] 0.36489	[0.] 1.00824	>1.0082
81.64	2.417	8.342	0.2261	[0.089] 0.02018	[0.532] 0.12045	[0.684] 0.15486	[1.445] 0.32693	[0.] 0.90338	>0.9033

*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 A30: Updated Specific-Central WIRRD for Livestock Type = Sheep; Category = Growing Ewe Lambs – Late Gestation; WQC = Fluoride

User Specific Input			Ingestion*	Water Quality Constituent^					
				mg F/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]
40.82	1.224	3.737	0.1784	[0.100] 0.01994	[1.365] 0.24373	[1.743] 0.31115	[3.680] 0.65687	[7.848] 1.81503	>1.8150
50.80	1.678	5.488	0.2190	[0.094] 0.02001	[0.929] 0.20372	[1.187] 0.26007	[2.506] 0.54904	[6.291] 1.51706	>1.5170
61.23	2.131	7.239	0.2486	[0.090] 0.02010	[0.704] 0.17632	[0.899] 0.22382	[1.899] 0.47241	[5.249] 1.30562	>1.30562
71.21	2.408	8.307	0.2513	[0.089] 0.02011	[0.614] 0.15444	[0.784] 0.19716	[1.655] 0.41627	[4.536] 1.15008	>1.1500
81.64	2.685	9.375	0.2542	[0.088] 0.02018	[0.544] 0.13837	[0.694] 0.17665	[1.467] 0.37293	[3.993] 1.03046	>1.0304

*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 A31: Updated Specific-Central WIRRD for Livestock Type = Sheep; Category = Growing Ewe Lambs – Early Lactation; WQC = Fluoride

User Specific Input			Ingestion*	Water Quality Constituent^					
				mg F/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]
40.82	1.419	4.490	0.2144	[0.097] 0.02087	[0.956] 0.20513	[1.161] 0.24909	[2,596] 0.55677	[7.397] 1.5862	>1.586
50.80	1.632	5.313	0.2120	[0.094] 0.02007	[0.8008] 0.17145	[0.981] 0.20820	[2.194] 0.46537	[6.251] 1.32586	>1.3258
61.23	1.846	6.136	0.2108	[0.092] 0.01952	[0.699] 0.14756	[0.850] 0.17918	[1.899] 0.40050	[5.412] 1.14106	>1.1410
71.21	2.029	6.845	0.2071	[0.091] 0.01891	[0.627] 0.12998	[0.761] 0.15783	[1.703] 0.35279	[4.852] 1.00513	>1.0051
81.64	2.213	7.554	0.2048	[0.090] 0.01848	[0.568] 0.11643	[0.690] 0.14142	[1.543] 0.31610	[4.396] 0.90059	>0.9005

*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 A32: Updated Specific-Central WIRRD for Livestock Type = Sheep; Category = Growing Ewe Lambs – Mid Lactation; WQC = Fluoride

User Specific Input			Ingestion*	Water Quality Constituent^					
				mg F/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]
40.82	1.247	3.824	0.1826	[0.100] 0.01934	[0.978] 0.17879	[1.188] 0.21710	[2.656] 0.48529	[7.340] 1.34093	>1.3409
50.80	1.444	4.586	0.1830	[0.096] 0.01775	[0.816] 0.14943	[0.991] 0.18146	[2.215] 0.40562	[6.121] 1.12079	>1.1207
61.23	1.642	5.348	0.1837	[0.094] 0.01736	[0.699] 0.12861	[0.849] 0.15617	[1.899] 0.34909	[5.249] 0.96458	>0.9645
71.21	1.796	5.943	0.1798	[0.093] 0.01673	[0.629] 0.11329	[0.764] 0.13756	[1.709] 0.30750	[4.724] 0.84967	>0.8496
81.64	1.950	6.538	0.1772	[0.091] 0.01628	[0.572] 0.10150	[0.695] 0.12326	[1.554] 0.27552	[4.293] 0.7613	>0.7613

*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 A33: Updated Specific-Central WIRRD for Livestock Type = Sheep; Category = Growing Ewe Lambs – Late Lactation; WQC = Fluoride

User Specific Input			Ingestion*	Water Quality Constituent^					
				mg F/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]
40.82	1.551	4.997	0.2386	[0.095] 0.02281	[1.008] 0.24084	[1.225] 0.29244	[2.738] 0.65371	[7.567] 1.80629	>1.8062
50.80	1.837	6.101	0.2434	[0.092] 0.02257	[0.826] 0.20130	[1.003] 0.24443	[2.43] 0.54639	[6.199] 1.50976	>1.5097
61.23	2.122	7.204	0.2474	[0.090] 0.02245	[0.700] 0.17324	[0.849] 0.21036	[1.90] 0.47024	[5.249] 1.29933	>1.2993
71.21	2.399	8.272	0.2503	[0.893] 0.02235	[0.609] 0.15260	[0.740] 0.18530	[1.654] 0.41422	[4.572] 1.1445	>1.144
81.64	2.676	9.340	0.2532	[0.088] 0.02234	[0.539] 0.13673	[0.655] 0.16603	[1.465] 0.37113	[4.049] 1.0255	>1.025

*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 A34: Updated Specific-Central WIRRD for Livestock Type = Sheep; Category = Growing Rams – at 40% of mature weight; 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 (0,55)	1.632	5.313	0.2120	[0.094] 0.02007	[0.836] 0.17733	[1.074] 0.22799	[2.269] 0.48128	[6.569] 1.39328	>1.3932
50.8 (0.6)	1.900	6.346	0.2533	[0.092] 0.02336	[0.699] 0.17733	[0.899] 0.22799	[1.899] 0.48128	[5.499] 1.39328	>1.3932
50.8 (1.1)	2.163	7.361	0.2938	[0.090] 0.02659	[0.603] 0.17733	[0.775] 0.22799	[1.637] 0.48128	[4.741] 1.39328	>1.3932

*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 A35: Updated Specific-Central WIRRD for Livestock Type = Sheep; Category = Rams - Maintenance; WQC = Fluoride

User Specific Input			Ingestion*	Water Quality Constituent^					
				mg F/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]
102.0	1.805	5.978	0.1346	[0.092] 0.01252	[0.847] 0.11416	[1.210] 0.16308	[2.421] 0.32617	[7.265] 0.97853	>0.9785
114.7	1.968	6.608	0.1352	[0.091] 0.01240	[0.766] 0.10369	[1.295] 0.14813	[2.190] 0.29626	[6.572] 0.88880	>0.8888
127.4	2.131	7.239	0.1359	[0.090] 0.01232	[0.699] 0.09514	[1.0] 0.13591	[1.999] 0.27183	[5.999] 0.81550	>0.8155
140.1	2.290	7.851	0.1363	[0.0898] 0.01225	[0.645] 0.08801	[0.921] 0.12573	[1.843] 0.25146	[5.531] 0.75439	>0.7543
152.8	2.449	8.464	0.1369	[0.0890] 0.0122	[0.598] 0.08197	[0.855] 0.11710	[1.710] 0.2342	[5.131] 0.79259	>0.7925

*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 A36: Updated Specific-Central WIRRD for Livestock Type = Sheep; Category = Rams – Pre-breeding; 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]
102.0	1.991	6.696	0.1508	[0.091] 0.01381	[0.844] 0.12741	[1.146] 0.17292	[2.352] 0.35494	[6.937] 1.04663	>1.0466
114.7	2.170	7.387	0.1511	[0.090] 0.01367	[0.765] 0.11573	[1.038] 0.15706	[2.132] 0.32239	[6.288] 0.95066	>0.9506
127.4	2.349	8.079	0.1516	[0.089] 0.01358	[0.699] 0.10618	[0.949] 0.14411	[1.949] 0.29580	[5.749] 0.87226	>0.8722
140.1	2.521	8.744	0.1518	[0.088] 0.01348	[0.646] 0.98231	[0.877] 0.13331	[1.801] 0.27364	[5.312] 0.80689	>0.8068
152.8	2.694	9.410	0.1522	[0.088] 0.01342	[0.601] 0.09148	[0.815] 0.12416	[1.674] 0.25485	[4.936] 0.7515	>0.7515

*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

Livestock Type: **Sheep**

Constituent: **Nitrate**

Table A37: Updated Specific-Central WIRRD for Livestock Type = Sheep; Category = Ewes – maintenance; WQC = Nitrate

User Specific Input			Ingestion*	Water Quality Constituent^					
LW (kg)	DMI (kg/d)	TWI (L/d)	WIR ($L/kg^{0.82}/d$)	mg $NO_3/kg^{0.82}/d$^^					
				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 A38: Updated Specific-Central WIRRD for Livestock Type = Sheep; Category = Ewes – Mature Breeding; 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	1.029	2.984	0.1037	[8.97] 1.0686	[61.03] 7.2715	[124.8] 14.8736	[208.0] 24.7894	[306.5] 36.5231	>36.523
61.0	1.171	3.531	0.1079	[8.62] 1.04626	[51.58] 6.2580	[105.1] 12.8006	[175.8] 21.3343	[259.0] 31.4326	>31.432
71.21	1.329	4.140	0.1252	[8.34] 1.0457	[44] 5.5126	[90] 11.2758	[150] 18.7930	[221] 27.6883	>27.688
81.419	1.453	4.619	0.1252	[8.17] 1.0245	[39.42] 4.9392	[80.65] 10.1029	[134.4] 16.8382	[198.0] 24.8083	>24.808
91.62	1.592	5.155	0.1268	[8.02] 1.0188	[35.33] 4.4833	[72.27] 9.1706	[120.4] 15.2841	[177.4] 22.5185	>22.518

*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 A39: Updated Specific-Central WIRRD for Livestock Type = Sheep; Category = Ewes – Mature Early Gestation; 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	1.183	3.579	0.1428	[8.59] 1.2287	[58.6] 8.3785	[119.9] 17.138	[199.8] 28.563	[294.5] 41.083	>41.083
61.0	1.345	4.202	0.14437	[8.32] 1.2015	[49.9] 7.2107	[102.1] 14.749	[170.2] 24.582	[250.8] 36.218	>36.218
71.21	1.492	4.770	0.14436	[8.13] 1.1741	[44] 6.3519	[90] 12.92	[150] 21.654	[221] 31.903	>31.903
81.419	1.644	5.348	0.1452	[7.98] 1.1594	[39.1] 5.6911	[80.1] 11.641	[133.5] 19.401	[196.7] 28.585	>28.585
91.62	1.787	5.908	0.1454	[7.86] 1.1436	[35.5] 5.1658	[72.6] 10.566	[121.1] 17.611	[178.4] 25.947	>25.947

*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 A40: Updated Specific-Central WIRRD for Livestock Type = Sheep; Category = Ewes – Mature Late Gestation; 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	1.4787	4.717	0.1883	[8.149] 1.5347	[56.89] 10.7157	[116.3] 21.9189	[193.9] 36.5315	[285.7] 53.8230	>53.823
61.0	1.6685	5.450	0.1872	[7.959] 1.4903	[49.24] 9.2222	[100.7] 18.8639	[167.9] 31.4398	[247.3] 46.3214	>46.321
71.21	1.837	6.101	0.1846	[7.828] 1.4454	[44] 8.1237	[90] 16.6167	[150] 27.6945	[221] 40.8032	>40.803
81.419	2.0191	6.804	0.1844	[7.715] 1.4234	[39.45] 7.2786	[80.70] 14.8884	[134.5] 24.8140	[198.1] 36.5593	>36.559
91.62	2.1953	7.4841	0.1842	[7.626] 1.4048	[35.86] 6.6068	[73.36] 13.5142	[122.2] 22.5237	[180.1] 33.1849	>33.184

*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 A41: Updated Specific-Central WIRRD for Livestock Type = Sheep; Category = Ewes – Mature Early Lactation; 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	1.288	3.982	0.1589	[8.410] 1.3370	[74.36] 11.8227	[151.1] 24.18310	[253.5] 40.3054	[253.5] 69.3837	>69.383
61.0	1.618	5.258	0.1806	[8.003] 1.4458	[46.32] 10.1748	[115.2] 20.8125	[192.0] 34.6878	[192.0] 51.1070	>51.107
71.21	2.000	6.731	0.2037	[7.726] 1.5739	[44] 8.9630	[90] 18.3334	[150] 20.5557	[150] 45.0187	>45.018
81.419	2.174	7.401	0.2006	[7.636] 1.5326	[40.01] 8.030	[81.84] 16.4263	[136.4] 27.3774	[136.4] 40.3363	>40.336
91.62	2.349	8.079	0.1988	[7.561] 1.5035	[36.65] 7.2893	[74.98] 14.9102	[124.9] 24.8505	[124.9] 36.1344	>36.134

*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 A42: Updated Specific-Central WIRRD for Livestock Type = Sheep; Category = Ewes – Mature Mid Lactation; 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	1.422	4.525	0.1806	[8.209] 1.4829	[57.44] 10.3776	[117.5] 21.2267	[195.8] 35.3782	[288.5] 52.1237	>52.123
61.0	1.619	5.626	0.1807	[8.002] 1.4467	[49.40] 8.93124	[101.0] 18.2682	[168.4] 30.4473	[248.1] 44.8489	>44.848
71.21	1.787	5.908	1.1788	[7.864] 1.4061	[44] 7.8672	[90] 16.0921	[150] 26.8202	[221] 39.5152	>39.515
81.419	1.958	6.568	1.1780	[7.750] 1.3804	[39.579] 7.0490	[80.956] 14.4182	[134.92] 24.0306	[198.7] 35.4050	>35.405
91.62	2.113	7.169	1.176	[7.665] 1.3562	[36.262] 6.3984	[74.173] 13.0874	[123.6] 21.8127	[182.1] 32.1372	>32.137

*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 A43: Updated Specific-Central WIRRD for Livestock Type = Sheep; Category = Ewes – Mature Late Lactation; 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	1.288	3.982	0.1589	[8.410] 1.3370	[59.08] 9.3932	[120.8] 19.2140	[201.4] 32.0231	[296.7] 47.1810	>47.181
61.0	1.467	4.673	0.1605	[8.126] 1.3105	[50.35] 8.0840	[102.9] 16.4360	[171.6] 27.5598	[252.9] 40.6050	>40.605
71.21	1.642	5.348	0.1618	[7.982] 1.2919	[44] 7.1212	[90] 14.5661	[150] 24.2769	[221] 35.7680	>35.768
81.419	1.795	5.939	0.1610	[7.858] 1.2656	[39.61] 6.3803	[81.03] 13.0511	[135.0] 21.7516	[198.9] 32.0476	>32.047
91.62	1.950	6.538	0.1609	[7.755] 1.2481	[35.98] 5.7914	[73.61] 11.8465	[122.6] 19.7440	[180.7] 29.0897	>29.089

*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 A44: Updated Specific-Central WIRRD for Livestock Type = Sheep; Category = Growing Ewe Lambs – yearlings at 40% of mature weight; 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]
30.84 (0,55)	0.920	2.564	0.1541	[9.336] 1.4388	[52.709] 8.1231	[107.82] 16.6165	[179.7] 27.6942	[264.7] 40.8027	>40.802
30.84 (0.66)	1.052	3.072	0.1846	[8.906] 1.6443	[44] 8.1236	[90] 16.6165	[150] 27.6943	[221] 40.8029	>40.802
30.84 (0.88)	1.297	4.017	0.2414	[8.395] 2.0271	[33.643] 8.1231	[68.81] 16.6165	[114.6] 27.6924	[168.9] 40.8027	>40.802

*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 A45: Updated Specific-Central WIRRD for Livestock Type = Sheep; Category = Growing Ewe Lambs – Breeding; 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]
40.82	1.306	4.052	0.1935	[8.381] 1.6221	[66.620] 12.8939	[136.2] 26.3746	[227.1] 43.9574	[334.6] 64.7641	>64.764
50.80	1.576	5.094	0.2033	[8.044] 1.6359	[52.996] 10.7772	[108.4] 22.0448	[180.6] 36.7411	[266.1] 54.1320	>54.132
61.23	1.846	6.136	0.2108	[7.822] 1.6490	[44] 9.2753	[90] 18.9722	[150] 31.6203	[221] 46.5873	>46.587
71.21	2.240	7.659	0.2317	[7.606] 1.7630	[35.24] 8.1702	[72.10] 16.7121	[120.1] 27.8533	[177.0] 41.0374	>41.037
81.64	2.635	9.182	0.2489	[7.461] 1.8578	[29.401] 7.3204	[60.14] 14.9739	[100.2] 24.9563	[147.6] 36.7691	>36.769

*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 A46: Updated Specific-Central WIRRD for Livestock Type = Sheep; Category = Growing Ewe Lambs – Early Gestation; 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]
40.82	1.356	4.245	0.2027	[8.306] 1.6840	[65.77] 13.3352	[134.5] 27.2775	[224.2] 45.4623	[330.3] 66.9815	>66.981
50.80	1.628	5.295	0.2113	[7.994] 1.6900	[52.72] 11.1460	[107.8] 22.7995	[179.7] 37.9989	[264.8] 55.9854	>55.985
61.23	1.900	6.346	0.2180	[7.786] 1.6976	[44] 9.5929	[90] 19.6218	[150] 32.7030	[221] 48.1825	>48.182
71.21	2.159	7.344	0.2222	[7.653] 1.6988	[38.01] 8.4498	[77.7] 17.2842	[129.6] 28.8069	[190.9] 42.4425	>42.442
81.64	2.417	8.342	0.2261	[7.535] 1.7043	[34.47] 7.5709	[68.4] 15.4865	[114.1] 25.8107	[168.1] 38.0281	>38.028

*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 A47: Updated Specific-Central WIRRD for Livestock Type = Sheep; Category = Growing Ewe Lambs – Late Gestation; 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]
40.82	1.224	3.737	0.1784	[8.520] 1.5207	[85.22] 15.2117	[174.3] 31.1154	[290.5] 51.8596	[428.0] 76.4063	>76.406
50.80	1.678	5.488	0.2190	[7.950] 1.7418	[58.04] 12.7144	[118.7] 26.0073	[197.8] 43.3460	[291.5] 63.830	>63.83
61.23	2.131	7.239	0.2486	[7.656] 1.9042	[44] 10.9426	[90] 22.3827	[150] 37.3046	[221] 54.9621	>54.962
71.21	2.408	8.307	0.2513	[7.538] 1.8951	[338.34] 9.6388	[78.42] 19.7161	[130.7] 32.8605	[192.5] 48.4144	>48.414
81.64	2.685	9.375	0.2542	[7.447] 1.8930	[33.97] 8.6363	[69.49] 17.6655	[115.8] 29.4427	[170.6] 43.3789	>43.378

*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 A48: Updated Specific-Central WIRRD for Livestock Type = Sheep; Category = Growing Ewe Lambs – Early Lactation; 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]
40.82	1.419	4.490	0.2144	[8.220] 1.7629	[60.12] 12.8939	[122.98] 26.3744	[294.9] 43.9574	[302.0] 64.7641	>64.764
50.80	1.632	5.313	0.2120	[7.990] 1.6947	[50.8] 10.7772	[103.9] 22.0446	[173.2] 36.7411	[255.2] 54.1320	>54.132
61.23	1.846	6.136	0.2108	[7.822] 1.6490	[44] 9.2753	[90] 18.9722	[150] 31.6203	[221] 46.5873	>46.587
71.21	2.029	6.845	0.2071	[7.709] 1.5971	[39.4] 8.1702	[80.6] 16.7120	[134.4] 27.8533	[198.1] 41.0274	>41.027
81.64	2.213	7.554	0.2048	[7.618] 1.5604	[35.7] 7.3204	[73.1] 14.9738	[121.8] 24.9463	[179.5] 36.7691	>36.769

*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 A49: Updated Specific-Central WIRRD for Livestock Type = Sheep; Category = Growing Ewe Lambs – Mid Lactation; 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]
40.82	1.247	3.824	0.1826	[8.479] 1.5489	[61.52] 11.2381	[125.8] 22.9878	[209.7] 38.3127	[309.0] 56.4478	>56.447
50.80	1.444	4.586	0.1830	[8.189] 1.4994	[51.30] 9.3932	[104.9] 19.2140	[174.9] 32.0231	[]257.6 47.1810	>47.181
61.23	1.642	5.348	0.1837	[7.982] 1.4666	[44] 8.0843	[90] 16.5361	[]150 27.5601	[221] 40.6053	>40.605
71.21	1.796	5.943	0.1798	[7.857] 1.413	[39.59] 7.1210	[80.98] 14.5661	[134.9] 24.276	[198.8] 35.7678	>35.767
81.64	1.950	6.538	0.1772	[7.755] 1.3750	[35.98] 6.3803	[73.61] 13.0511	[122.6] 21.7516	[180.7] 32.0476	>32.047

*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 A50: Updated Specific-Central WIRRD for Livestock Type = Sheep; Category = Growing Ewe Lambs – Late Lactation; 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]
40.82	1.551	4.997	0.2386	[8.0699] 1.9262	[63.41] 15.1381	[129.7] 30.9650	[216.2] 51.6084	[318.5] 76.0366	>76.036
50.80	1.837	6.101	0.2434	[7.8287] 1.9066	[51.95] 12.6530	[106.2] 25.8816	[177.1] 43.1360	[260.9] 63.5540	>63.554
61.23	2.122	7.204	0.2474	[7.6613] 1.8961	[44] 10.8897	[90] 22.2744	[150] 37.1241	[221] 54.6962	>54.696
71.21	2.399	8.272	0.2503	[7.5418] 1.8879	[38.31] 9.5922	[78.37] 19.6208	[130.6] 32.7014	[192.4] 48.1802	>48.180
81.64	2.676	9.340	0.2532	[7.4497] 1.8866	[33.93] 8.5945	[69.41] 17.5800	[115.6] 29.3001	[170.4] 43.1690	>43.169

*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 A51: Updated Specific-Central WIRRD for Livestock Type = Sheep; Category = Growing Rams – at 40% of mature weight; 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 (0,55)	1.632	5.313	0.2120	[7.990] 1.6947	[52.55] 11.1460	[107.4] 22.79952	[179.1] 37.998	[263.9] 55.9854	>55.985
50.8 (0.6)	1.900	6.346	0.2533	[7.786] 1.9725	[44] 11.1464	[90] 22.79957	[150] 37.999	[221] 55.9856	>55.985
50.8 (1.1)	2.163	7.361	0.2938	[7.641] 2.2456	[37.92] 11.1460	[77.5] 22.79952	[129.3] 37.998	[190.5] 55.9854	>55.985

*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 A52: Updated Specific-Central WIRRD for Livestock Type = Sheep; Category = Rams - 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]
102.0	1.805	5.978	0.1346	[7.851] 1.0574	[53.27] 7.1757	[108.9] 14.6779	[181.6] 24.4635	[267.5] 36.0428	>36.042
114.7	1.968	6.608	0.1352	[7.744] 1.04738	[48.19] 6.5177	[98.5] 13.3320	[164.3] 22.2203	[242.0] 32.7379	>32.737
127.4	2.131	7.239	0.1359	[7.656] 1.0407	[44] 5.9804	[90] 12.2326	[150] 20.3877	[221] 30.0379	>30.037
140.1	2.290	7.851	0.1363	[7.585] 1.0344	[40.56] 5.5321	[82.9] 11.3159	[138.2] 18.8600	[203.7] 27.7870	>27.787
152.8	2.449	8.464	0.1369	[7.523] 1.0301	[37.62] 5.1522	[76.9] 10.5389	[128.2] 17.5651	[189.0] 25.8792	>25.879

*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 A53: Updated Specific-Central WIRRD for Livestock Type = Sheep; Category = Rams – Pre-breeding; 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]
102.0	1.991	6.696	0.1508	[7.731] 1.1664	[53.08] 8.0088	[108.5] 16.3820	[180.9] 27.3035	[266.6] 40.2271	<40.227
114.7	2.170	7.387	0.1511	[7.638] 1.1547	[48.11] 7.2745	[98.4] 14.8799	[164.0] 24.7999	[241.6] 36.5385	>36.538
127.4	2.349	8.079	0.1516	[7.561] 1.147	[44] 6.6746	[90] 13.6527	[]150 22.7546	[221] 33.5251	>33.525
140.1	2.521	8.744	0.1518	[7.498] 1.1388	[40.65] 6.1744	[83.15] 12.6296	[138.5] 21.0495	[204.1] 31.0129	>31.012
152.8	2.694	9.410	0.1522	[7.444] 1.1331	[37.77] 5.7504	[77.2] 11.7825	[128.7] 19.6043	[189.7] 28.8836	>28.883

*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

Livestock Type: **Sheep**

Constituent: **Bromide**

Table A54: 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
71.21	1.20	3.667	0.1109	[0.01085] 0.001205	[0.09] 0.009988	[0.9] 0.09988	[1.75] 0.19421	[2.5] 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.

Table A55: Updated Specific-Central WIRRD for Livestock Type = Sheep; Category = Ewes – Mature Breeding; WQC = Bromide

User Specific Input			Ingestion*	Water Quality Constituent^					
LW (kg)	DMI (kg/d)	TWI (L/d)	WIR ($L/kg^{0.82}/d$)	mg $Br/kg^{0.82}/d$^^ A (0-[])	B [A]-[B]	C [B]-[C]	D [C]-[D]	E [D]-[E]	F >[E]
50.8	1.029	2.984	0.1037	[0.01138] 0.001356	[0.1248] 0.01487	[1.248] 0.14873	[2.427] 0.28921	[] 0.41316	>0.4131
61.0	1.171	3.531	0.1079	[0.01094] 0.001328	[0.1055] 0.01280	[1.055] 0.12800	[2.051] 0.24890	[] 0.35557	>0.3555
71.21	1.329	4.140	0.1252	[0.01059] 0.001327	[0.09] 0.01127	[0.9] 0.11275	[1.75] 0.21925	[] 0.31321	>0.3132
81.419	1.453	4.619	0.1252	[0.01038] 0.0013	[0.0806] 0.01010	[0.806] 0.10103	[1.568] 0.19644	[] 0.28064	>0.2806
91.62	1.592	5.155	0.1268	[0.01019] 0.001293	[0.0722] 0.00917	[0.722] 0.09170	[1.405] 0.17831	[] 0.25473	>0.2547

*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.

Table A56: Updated Specific-Central WIRRD for Livestock Type = Sheep; Category = Ewes – Mature Early Gestation; 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	1.183	3.579	0.1428	[0.01091] 0.00156	[0.1199] 0.01713	[1.199] 0.17138	[2.332] 0.33324	[3.331] 0.47606	>0.4760
61.0	1.345	4.202	0.14437	[0.01056] 0.00152	[0.1021] 0.01475	[1.021] 0.14749	[1.986] 0.28679	[2.837] 0.40971	>0.4097
71.21	1.492	4.770	0.14436	[0.01032] 0.00149	[0.09] 0.012993	[0.9] 0.12992	[1.75] 0.25263	[2.5] 0.36090	>0.3609
81.419	1.644	5.348	0.1452	[0.01012] 0.00147	[0.0801] 0.01164	[0.116] 0.11641	[1.557] 0.22635	[2.335] 0.32336	>0.3233
91.62	1.787	5.908	0.1454	[0.00998] 0.00145	[0.0726] 0.01056	[0.105] 0.10566	[1.412] 0.20546	[2.018] 0.29352	>0.2935

*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.

Table A57: Updated Specific-Central WIRRD for Livestock Type = Sheep; Category = Ewes – Mature Late Gestation; 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	1.4787	4.717	0.1883	[0.01034] 0.001948	[0.1163] 0.021919	[1.163] 0.21918	[2.263] 0.42620	[3.232] 0.60885	>0.6088
61.0	1.6685	5.450	0.1872	[0.01010] 0.001892	[0.1007] 0.018864	[1.007] 0.18863	[1.958] 0.36679	[2.798] 0.52399	>0.5239
71.21	1.837	6.101	0.1846	[0.00993] 0.001835	[0.09] 0.016617	[0.9] 0.166167	[1.75] 0.32310	[2.5] 0.46157	>0.4615
81.419	2.0191	6.804	0.1844	[0.00979] 0.001807	[0.0907] 0.014888	[0.807] 0.14888	[1.569] 0.28949	[2.241] 0.41356	>0.4135
91.62	2.1953	7.4841	0.1842	[0.00968] 0.001783	[0.0733] 0.013514	[0.733] 0.13514	[1.426] 0.26277	[2.037] 0.37539	>0.3753

*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.

Table A58: Updated Specific-Central WIRRD for Livestock Type = Sheep; Category = Ewes – Mature Early Lactation; 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	1.288	3.982	0.1589	[0.01067] 0.001697	[0.152] 0.02418	[1.521] 0.24183	[2.957] 0.47023	[4.225] 0.67176	>0.6717
61.0	1.618	5.258	0.1806	[0.01015] 0.001835	[0.115] 0.02081	[1.152] 0.20812	[2.240] 0.40469	[3.200] 0.57813	>0.5781
71.21	2.000	6.731	0.2037	[0.00980] 0.001998	[0.09] 0.01833	[0.9] 0.18333	[1.75] 0.35648	[2.5] 0.50926	>0.5092
81.419	2.174	7.401	0.2006	[0.00969] 0.001945	[0.081] 0.01642	[0.818] 0.16426	[1.591] 0.31940	[2.273] 0.45629	>0.4562
91.62	2.349	8.079	0.1988	[0.00959] 0.001908	[0.074] 0.01491	[0.749] 0.14910	[1.457] 0.28992	[2.082] 0.41417	>0.4141

*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.

Table A59: Updated Specific-Central WIRRD for Livestock Type = Sheep; Category = Ewes – Mature Mid Lactation; 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	1.422	4.525	0.1806	[0.01042] 0.001882	[0.1175] 0.02122	[1.1750] 0.21227	[2.284] 0.41274	[3.264] 0.58963	>0.5896
61.0	1.619	5.626	0.1807	[0.01015] 0.001836	[0.1010] 0.01826	[1.0105] 0.18268	[1.964] 0.35522	[2.807] 0.50745	>0.5074
71.21	1.787	5.908	1.1788	[0.00998] 0.001785	[0.0.09] 0.01609	[0.9] 0.16092	[1.75] 0.31290	[2.5] 0.44700	>0.4470
81.419	1.958	6.568	1.1780	[0.00938] 0.001752	[0.0809] 0.01441	[0.8095] 0.14418	[1.574] 0.28035	[2.288] 0.40051	>0.4005
91.62	2.113	7.169	1.176	[0.00973] 0.001717	[0.0741] 0.01308	[0.7417] 0.13087	[1.442] 0.25448	[2.060] 0.36354	>0.3635

*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.

Table A60: Updated Specific-Central WIRRD for Livestock Type = Sheep; Category = Ewes – Mature Late Lactation; 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	1.288	3.982	0.1589	[0.01067] 0.001697	[0.1208] 0.01921	[1.208] 0.19214	[2.350] 0.37360	[3.357] 0.53372	>0.5337
61.0	1.467	4.673	0.1605	[0.01036] 0.001663	[0.1029] 0.01653	[1.029] 0.16536	[2.002] 0.32153	[2.860] 0.45933	>0.4593
71.21	1.642	5.348	0.1618	[0.01013] 0.00164	[0.09] 0.01456	[0.9] 0.14566	[1.75] 0.28323	[2.5] 0.40461	>0.4046
81.419	1.795	5.939	0.1610	[0.00997] 0.001606	[0.0810] 0.01305	[0.810] 0.13051	[1.575] 0.25377	[2.250] 0.36253	>0.3625
91.62	1.950	6.538	0.1609	[0.00984] 0.001584	[0.0736] 0.01184	[0.736] 0.11846	[1.431] 0.23035	[2.044] 0.32907	>0.3290

*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.

Table A61: Updated Specific-Central WIRRD for Livestock Type = Sheep; Category = Growing Ewe Lambs – yearlings at 40% of mature weight; 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]
30.84 (0,55)	0.920	2.564	0.1541	[0.01185] 0.001826	[0.107] 0.01661	[1.07] 0.16616	[2.096] 0.3231	[2.995] 0.46157	>0.4615
30.84 (0.66)	1.052	3.072	0.1846	[0.01130] 0.002087	[0.09] 0.01661	[0.9] 0.16616	[1.75] 0.3231	[2.5] 0.46157	>0.4615
30.84 (0.88)	1.297	4.017	0.2414	[0.01065] 0.002573	[0.068] 0.01661	[0.688] 0.16616	[1.338] 0.3231	[1.911] 0.46157	>0.4615

*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.

Table A62: Updated Specific-Central WIRRD for Livestock Type = Sheep; Category = Growing Ewe Lambs – Breeding; 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]
40.82	1.306	4.052	0.1935	[0.01063] 0.002059	[0.136] 0.02637	[1.289] 0.24950	[2.649] 0.51283	[3.785] 0.73262	>0.7326
50.80	1.576	5.094	0.2033	[0.01021] 0.002076	[0.108] 0.02204	[1.025] 0.20854	[2.107] 0.42864	[3.011] 0.61235	>0.6123
61.23	1.846	6.136	0.2108	[0.00992] 0.002093	[0.09] 0.01897	[0.9] 0.18972	[1.75] 0.36890	[2.5] 0.52700	>0.5270
71.21	2.240	7.659	0.2317	[0.00965] 0.002238	[0.072] 0.01671	[0.682] 0.15809	[1.401] 0.32495	[2.002] 0.46422	>0.4642
81.64	2.635	9.182	0.2489	[0.00947] 0.002358	[0.060] 0.01497	[0.568] 0.14165	[1.169] 0.29115	[1.670] 0.41594	>0.4159

*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.

Table A63: Updated Specific-Central WIRRD for Livestock Type = Sheep; Category = Growing Ewe Lambs – Early Gestation; 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]
40.82	1.356	4.245	0.2027	[0.01054] 0.002137	[0.134] 0.02727	[1.345] 0.27277	[2.616] 0.53039	[3.737] 0.75771	>0.7577
50.80	1.628	5.295	0.2113	[0.01014] 0.002145	[0.107] 0.0228	[1.078] 0.22799	[2.097] 0.44332	[2.995] 0.63332	>0.6333
61.23	1.900	6.346	0.2180	[0.00988] 0.002155	[0.09] 0.01962	[0.9] 0.19621	[1.75] 0.38153	[2.5] 0.54505	>0.5450
71.21	2.159	7.344	0.2222	[0.0097] 0.002156	[0.077] 0.01728	[0.777] 0.17284	[1.512] 0.33608	[1.210] 0.48012	>0.4801
81.64	2.417	8.342	0.2261	[0.00956] 0.002163	[0.068] 0.01548	[0.684] 0.15486	[1.331] 0.30112	[1.901] 0.43018	>0.4301

*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.

Table A64: Updated Specific-Central WIRRD for Livestock Type = Sheep; Category = Growing Ewe Lambs – Late Gestation; 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]
40.82	1.224	3.737	0.1784	[0.01081] 0.00193	[0.174] 0.03111	[1.743] 0.31157	[3.389] 0.60402	[4.842] 0.86432	>0.8643
50.80	1.678	5.488	0.2190	[0.01009] 0.002211	[0.118] 0.02600	[1.187] 0.26007	[2.308] 0.50570	[3.297] 0.72243	>0.7224
61.23	2.131	7.239	0.2486	[0.00971] 0.002417	[0.09] 0.02238	[0.9] 0.22382	[1.75] 0.43522	[2.5] 0.62174	>0.6217
71.21	2.408	8.307	0.2513	[0.00956] 0.002405	[0.078] 0.01971	[0.784] 0.19716	[1.525] 0.38337	[]2.178 0.54767	>0.5476
81.64	2.685	9.375	0.2542	[0.00945] 0.002403	[0.069] 0.01766	[0.694] 0.17665	[1.351] 0.34349	[1.930] 0.49071	>0.4907

*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.

Table A65: Updated Specific-Central WIRRD for Livestock Type = Sheep; Category = Growing Ewe Lambs – Early Lactation; 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]
40.82	1.419	4.490	0.2144	[0.01043] 0.002238	[0.1228] 0.02637	[1.229] 0.26374	[2.391] 0.51283	[3.416] 0.73262	>0.7326
50.80	1.632	5.313	0.2120	[0.01014] 0.002151	[0.1039] 0.02204	[1.039] 0.22044	[2.021] 0.42864	[2.887] 0.61235	>0.6123
61.23	1.846	6.136	0.2108	[0.00992] 0.002093	[0.09] 0.01897	[0.9] 0.18972	[1.75] 0.36890	[2.5] 0.52700	>0.5270
71.21	2.029	6.845	0.2071	[0.00978] 0.002027	[0.0806] 0.01671	[0.806] 0.16712	[1.568] 0.32495	[2.241] 0.46422	>0.4642
81.64	2.213	7.554	0.2048	[0.00967] 0.001981	[0.0731] 0.01497	[0.731] 0.14973	[1.421] 0.29115	[2.030] 0.41594	>0.4159

*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.

Table A66: Updated Specific-Central WIRRD for Livestock Type = Sheep; Category = Growing Ewe Lambs – Mid Lactation; WQC = Bromide

User Specific Input			Ingestion*	Water Quality Constituent^					
LW (kg)	DMI (kg/d)	TWI (L/d)	WIR ($L/kg^{0.82}/d$)	mg Br/kg$^{0.82}$/d^^					
				A (0-[])	B [A]-[B]	C [B]-[C]	D [C]-[D]	E [D]-[E]	F >[E]
40.82	1.247	3.824	0.1826	[0.01076] 0.001966	[0.1258] 0.02298	[1.258] 0.22987	[2.446] 0.44698	[3.495] 0.63844	>0.6384
50.80	1.444	4.586	0.1830	[0.01039] 0.001903	[0.1049] 0.01921	[1.049] 0.19214	[2.040] 0.37360	[2.915] 0.53372	>0.5337
61.23	1.642	5.348	0.1837	[0.01013] 0.001862	[0.09] 0.01653	[0.9] 0.16536	[1.75] 0.32153	[2.5] 0.45933	>0.4593
71.21	1.796	5.943	0.1798	[0.00997] 0.001794	[0.0809] 0.01456	[0.809] 0.14566	[1.574] 0.28323	[2.249] 0.40461	>0.4046
81.64	1.950	6.538	0.1772	[0.00984] 0.001745	[0.0736] 0.01305	[0.736] 0.13051	[1.431] 0.25377	[2.044] 0.36253	>0.3625

*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.

Table A67: Updated Specific-Central WIRRD for Livestock Type = Sheep; Category = Growing Ewe Lambs – Late Lactation; 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]
40.82	1.551	4.997	0.2386	[0.01024] 0.002445	[0.129] 0.03096	[1.297] 0.30965	[2.522] 0.60210	[3.603] 0.86014	>0.8601
50.80	1.837	6.101	0.2434	[0.00993] 0.00242	[0.106] 0.02588	[1.062] 0.25881	[2.066] 0.50325	[2.951] 0.71893	>0.7189
61.23	2.122	7.204	0.2474	[0.00972] 0.002407	[0.09] 0.02227	[0.9] 0.22274	[1.75] 0.43311	[2.5] 0.61873	>0.6187
71.21	2.399	8.272	0.2503	[0.00958] 0.002396	[0.-78] 0.01962	[0.783] 0.19620	[1.524] 0.38151	[2.177] 0.54502	>0.5450
81.64	2.676	9.340	0.2532	[0.00945] 0.002395	[0.069] 0.01758	[0.694] 0.17580	[1.349] 0.34183	[1.928] 0.48833	>0.4883

*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.

Table A68: Updated Specific-Central WIRRD for Livestock Type = Sheep; Category = Growing Rams – at 40% of mature weight; 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 (0,55)	1.632	5.313	0.2120	[0.01014] 0.002151	[0.1074] 0.0228	[1.074] 0.22799	[2.090] 0.44332	[2.986] 0.63332	>0.6333
50.8 (0.6)	1.900	6.346	0.2533	[0.00988] 0.002504	[0.09] 0.0228	[0.9] 0.22799	[1.75] 0.44332	[]2.5 0.63332	>0.6333
50.8 (1.1)	2.163	7.361	0.2938	[0.0096] 0.00285	[0.0775] 0.0228	[0.775] 0.22799	[1.508] 0.44332	[2.15] 0.63332	>0.6333

*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.

Table A69: Updated Specific-Central WIRRD for Livestock Type = Sheep; Category = Rams - 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]
102.0	1.805	5.978	0.1346	[0.00996] 0.001342	[0.108] 0.01467	[1.089] 0.14678	[2.119] 0.28540	[3.027] 0.40772	>0.4077
114.7	1.968	6.608	0.1352	[0.00983] 0.001329	[0.098] 0.01333	[0.985] 0.13332	[1.916] 0.25923	[2.738] 0.37033	>0.3703
127.4	2.131	7.239	0.1359	[0.00971] 0.001321	[0.09] 0.01223	[0.9] 0.12232	[1.75] 0.23785	[2.5] 0.33979	>0.3397
140.1	2.290	7.851	0.1363	[0.00962] 0.001313	[0.082] 0.01131	[0.829] 0.11316	[1.613] 0.22003	[2.304] 0.32433	>0.3243
152.8	2.449	8.464	0.1369	[0.00954] 0.001308	[0.076] 0.01053	[0.769] 0.10539	[1.496] 0.20492	[2.138] 0.29275	>0.2927

*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.

Table A70: Updated Specific-Central WIRRD for Livestock Type = Sheep; Category = Rams – Pre-breeding; 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]
102.0	1.991	6.696	0.1508	[0.00981] 0.00148	[0.108] 0.01638	[1.085] 0.16382	[2.111] 0.0.31854	[3.016] 0.45505	>0.4550
114.7	2.170	7.387	0.1511	[0.00969] 0.001466	[0.098] 0.01488	[0.984] 0.14880	[1.913] 0.28933	[2.734] 0.41333	>0.4133
127.4	2.349	8.079	0.1516	[0.00959] 0.001456	[0.09] 0.01365	[0.9] 0.136452	[1.75] 0.26547	[2.5] 0.37924	>0.3792
140.1	2.521	8.744	0.1518	[0.00951] 0.001446	[0.083] 0.01263	[0.831] 0.12629	[1.616] 0.24557	[2.309] 0.35082	>0.3508
152.8	2.694	9.410	0.1522	[0.00944] 0.001438	[0.077] 0.01176	[0.772] 0.11762	[1.502] 0.22817	[2.146] 0.32673	>0.3267

*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.

Updates to the Water Ingestion Rate Reference Documents – Other Livestock Types

Overview of Livestock Types

As is demonstrated above, the updated WIRRD tables for sheep for the four selected water quality constituents generated a total of 68 WIRRD tables. The only practical manner in which these reference values can be incorporated into risk assessments is via a DSS.

Furthermore, the value in the WIRRD tables is best appreciated when used in the CIRRA model format as the risk assessment output, when changes thereto in the final index value and risk factors identified are able to be viewed as a deviation from the index value.

The changes to the values are significant when site-specific factors are included in the user input (e.g. temperature, ration moisture percentage, dietary protein etc.) but too numerous to present in the format of a report, noting that each change generates new WIRRD column and row values.

The extent of the WIRRD documentation generated is thus too voluminous and numerically cumbersome to be presented in this report with the required tables just for dairy cattle categories highlighted below:

Animal Types:

Cattle – beef
Cattle – dairy
Goats
Horses
Pigs
Poultry
Sheep
Wildlife

Cattle – Dairy:

Breed options:

Ayrshire
Crossbreeds
Friesland
Guernsey
Jersey

Livestock Production Systems: Dairy Cattle:

Extensive grazing
Forage and concentrate feeding
Group feeding
Individual feeding
Total Mixed Rations
Small farming – individual farmers
Small farming – collectively owned dairies
Small farming – dairy ranching

Dairy Cattle Options:

Cows in mid-and late lactation – FCM 10 L/d
Cows in mid-and late lactation – FCM 15 L/d
Cows in mid-and late lactation – FCM 20 L/d
Cows in mid-and late lactation – FCM 25 L/d
Cows in mid-and late lactation – FCM 30 L/d
Cows in mid-and late lactation – FCM 35 L/d
Cows in mid-and late lactation – FCM 40 L/d
Cows in mid-and late lactation – FCM 45 L/d
Cows in mid-and late lactation – FCM 50 L/d
Cows in mid-and late lactation – FCM 55 L/d
Cows in mid-and late lactation – FCM 60 L/d
Growing large-breed calves fed milk or milk replacer
Growing large-breed calves fed milk plus starter mix
Growing small-breed calves fed milk or milk replacer
Growing small-breed calves fed milk plus starter mix
Growing veal calves fed milk or milk replacer
Large-breed growing females
Small-breed growing females
Large-breed growing males
Small-breed growing males
Maintenance of mature growing bulls
Period – dry
Period – early lactation
Period – mid lactation
Period – late lactation

Accordingly, only key examples to illustrate updated WIRRDs for cattle, swine and poultry are provided here and it should be noted that although different animal specific considerations apply to each livestock type, the fundamental approach is similar to that noted above.

The 2001 NRC requirements for dairy cattle note that since the 1989 version which cited the selenium requirement at 0.3 mg/kg DM there is "no new data available to dispute this requirement". It should, however, be noted that this limit was predominantly an FDA limit to lower the impact of selenium in wastewaters generated on the environment, and as discussed earlier additional concerns have subsequently been raised regarding the maximum limits for nutrients in animal feeds in order to cater for the concerns for excessive intake thereof in humans (NRC, 2001b).

Selenium is a case in point as described earlier in which concerns have been noted regarding additional supplementation routes leading to excessive intakes. The comment in the 2001 NRC requirements noting that increased selenium in the dairy cow may have health benefits for the calf and humans, whilst true in terms of providing a valuable source of the essential element, is potentially at odds with the total dietary exposure concerns noted in humans.

As far as the health norm for the dairy cow is concerned the 0.3 mg/kg DM limit is viewed as sufficiently below the level which is reported to result in chronic toxicity (5-40 mg/kg DM), although these studies seldom provide full exposure assessments from all routes.

As noted in the table above, the biggest influence in lactating dairy cattle is the fat corrected milk yield, with numerous regression formulae available to assess the Total Water Intake. The equation by Murphy (et al.,. 1983) is still regarded as being the most accurate when compared to actual field observations:

FWI = 15.99 +(1.58 x DMI kg/d) + (0.90 x Milk kg/d) + (0.05 x Na intake g/d) + (1.20 x min Temp)

Of relevance to the varied environments in South Africa under which dairy production occurs is the well documented effect of high temperatures on the breeds which are more suited to northern hemisphere (cooler) climates, with a water intake increase of 29 percent noted from temperature increases from 18 to 30 °C (McDowell, 1967).

As far as linking the norms of fitness for use and wastewater quality, whilst health norms are affected by the increased dose ingestion, it is also noteworthy that the faecal water output is correspondingly decreased by 33 percent with urinary output increased by 15 percent, with these effects required to be included in assessments for manure generation and required land area for crop and soil related nutrient replacement rates.

As is usually the case, the dairy nutrient requirements by the NRC do provide a list of water quality guidelines, but these stem from old data sources with numerous assumptions and errors (previously described) and in addition to the failings noted by Olkowski (2009) the 2001 NRC guidelines note “many dietary, physiological, and environmental factors affect these guidelines and make it impossible to determine precisely the concentration at which problems will occur”. It is further noted that water quality problems typically present as non-specific with water quality one aspect of site-specific investigations.

For beef cattle, the NRC requirements in 2000 note that a lower requirement for selenium of 0.1 mg/kg DM with the text focusing more on deficiency concerns and citing the same 5-40 mg/kg DM chronic toxicity range. Water intake equations are also presented, with the equation by Hicks (et al., 1988) widely cited as the most accurate:

TWI = -18.67 + (0.3937 x Max Temp) + (2.432 x DMI) – (3.870 x Precipitation) – (4.437 x Dietary Salt %)

It is noteworthy that no guidelines are offered, other than to refer the reader to the 1974 NRC publication on nutrients and toxic substances in water for livestock (NRC, 1974). No guidelines offer clear exposure period assessments (applicable in this instance to the feedlot system) and as noted in the initial CIRRA project reports the feedlot environment offers an opportunity to utilise groundwater with those water quality constituents posing a chronic, cumulative and/or developmental hazard as the exposure duration is limited to few months following which no reproductive or milk production endpoints are relevant.

The recent Olkowski (2009) guide notes similar concerns with the influence of external factors to water intake and corresponding problems with a concentration-based guideline, with the focus on changing water intakes within the same live weight and production phase due to factors such as temperature and milk yield.

It should thus be again highlighted that the WIRRD tables provide the fundamental reference platform from which site-specific inputs generate adjustments thereto. Some excerpts for the updated tables for beef cattle are provided below.

Livestock Type: **Beef Cattle**

Constituent: **Selenium**

Table A71: Updated Specific-Central WIRRD for Livestock Type = Beef Cattle; Category = Growing Cattle; 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]
182	3.64	20.45	0.2867	[0.0039] 0.001133	[0.0133] 0.00382	[0.066] 0.019101	[0.932] 0.26742	[3.331] 0.95509	>0.9550
277	5.51	27.25	0.2707	[0.0045] 0.00122	[0.01] 0.002707	[0.05] 0.013536	[0.7] 0.18951	[2.5] 0.67682	>0.6768
264	7.28	32.35	0.2569	[0.0049] 0.00128	[0.008] 0.002164	[0.042] 0.010820	[0.589] 0.15148	[2.105] 0.54100	>0.5410

*Adapted from NRC requirement tables (NRC, 2001).

^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

Table A72: Updated Specific-Central WIRRD for Livestock Type = Beef Cattle; Category = Finishing Cattle; 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]
273	5.46	30.45	0.3061	[0.003448] 0.001056	[0.0122] 0.003765	[0.061] 0.018826	[0.860] 0.26357	[3.074] 0.94132	>0.9413
364	7.28	37.45	0.2974	[0.003738] 0.001112	[0.01] 0.002974	[0.05] 0.014870	[0.7] 0.20818	[2.5] 0.74351	>0.7435
454	9.08	44.3	0.2932	[0.003941] 0.001156	[0.0084] 0.002479	[0.042] 0.012394	[0.591] 0.17352	[2.113] 0.61974	>0.6197

*Adapted from NRC requirement tables (NRC, 2001).

^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

Table A73: Updated Specific-Central WIRRD for Livestock Type = Beef Cattle; Category = Pregnant Cows; 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]
409	8.18	34.05	0.2457	[0.00462] 0.001135	[0.00947] 0.002328	[0.0473] 0.011638	[0.6629] 0.16293	[2.367] 0.58191	>0.5819
454.5	9.09	32.25	0.2134	[0.00542] 0.001157	[0.01] 0.002135	[0.05] 0.010673	[0.7] 0.14943	[2.5] 0.53369	>0.5336
500	10.0	30.45	0.1863	[0.00631] 0.001177	[0.0105] 0.001974	[0.0529] 0.00987	[0.7413] 0.13818	[2.647] 0.49353	>0.4935

*Adapted from NRC requirement tables (NRC, 2001).

^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

Table A74: Updated Specific-Central WIRRD for Livestock Type = Beef Cattle; Category = Mature Bulls; 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]
636	12.72	40.9	0.2055	[0.005981] 0.001229	[0.010416] 0.002141	[0.052] 0.0107029	[0.729] 0.14985	[2.603] 0.53519	>0.5351
681.5	13.63	42.6	0.2022	[0.006153] 0.001245	[0.01] 0.002023	[0.05] 0.0101143	[0.7] 0.14160	[2.5] 0.50571	>0.5057
727	14.54	44.3	0.1995	[0.006312] 0.001259	[0.01096] 0.001918	[0.048] 0.00959	[0.673] 0.13429	[2.404] 0.47961	>0.4796

*Adapted from NRC requirement tables (NRC, 2001).

^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

Livestock Type: **Beef Cattle**

Constituent: **Fluoride**

Table A75: Updated Specific-Central WIRRD for Livestock Type = Beef Cattle; Category = Growing Cattle; WQC = Fluoride

User Specific Input			Ingestion*	Water Quality Constituent^					
				mg F/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]
182	3.64	20.45	0.2867	[0.05480] 0.01571	[0.932] 0.26742	[1.332] 0.38203	[2.531] 0.72587	[2.531] 0.72587	>0.7258
277	5.51	27.25	0.2707	[0.06259] 0.01694	[0.7] 0.18951	[1] 0.27072	[1.9] 0.51438	[1.9] 0.51438	>0.5143
264	7.28	32.35	0.2569	[0.06928] 0.01782	[0.589] 0.15148	[0.842] 0.21640	[1.600] 0.41116	[1.600] 0.41116	>0.4111

*Adapted from NRC requirement tables (NRC, 2001).
^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 A76: Updated Specific-Central WIRRD for Livestock Type = Beef Cattle; Category = Finishing Cattle; WQC = Fluoride

User Specific Input			Ingestion*	Water Quality Constituent^					
				mg F/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]
273	5.46	30.45	0.3061	[0.05521] 0.01690	[0.860] 0.26357	[1.229] 0.37652	[2.459] 0.72587	[7.379] 2.2591	>2.2591
364	7.28	37.45	0.2974	[0.05985] 0.01780	[0.7] 0.20818	[1] 0.29740	[2] 0.59481	[6] 1.7844	>1.7844
454	9.08	44.3	0.2932	[0.06310] 0.01850	[0.591] 0.17352	[0.845] 0.24789	[1.690] 0.49579	[5.072] 1.4873	>1.4873

*Adapted from NRC requirement tables (NRC, 2001).
^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 A77: Updated Specific-Central WIRRD for Livestock Type = Beef Cattle; Category = Pregnant Cows; WQC = Fluoride

User Specific Input			Ingestion*	Water Quality Constituent^					
				mg F/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]
409	8.18	34.05	0.2457	[0.0739] 0.01817	[0.662] 0.16293	[0.947] 0.23276	[1.799] 0.44225	[5.44] 1.3383	>1.3383
454.5	9.09	32.25	0.2134	[0.0867] 0.01852	[0.7] 0.14943	[1] 0.21347	[1.9] 0.40560	[5.75] 1.2274	>1.2274
500	10.0	30.45	0.1863	[0.1011] 0.01884	[0.741] 0.13818	[1.059] 0.19741	[2.012] 0.37508	[6.08] 1.1350	>1.1350

*Adapted from NRC requirement tables (NRC, 2001).
^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 A78: Updated Specific-Central WIRRD for Livestock Type = Beef Cattle; Category = Mature Bulls; 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]
636	12.72	40.9	0.2055	[0.09575] 0.01968	[0.729] 0.14985	[1.0415] 0.21407	[2.083] 0.42815	[6.249] 1.2844	>1.2844
681.5	13.63	42.6	0.2022	[0.09851] 0.01992	[0.7] 0.14160	[1] 0.20228	[2] 0.40457	[6] 1.2137	>1.2137
727	14.54	44.3	0.1995	[0.10105] 0.02016	[0.673] 0.13429	[0.9616] 0.19184	[1.923] 0.38369	[5.769] 1.1510	>1.1510

*Adapted from NRC requirement tables (NRC, 2001).
^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

Livestock Type: **Beef Cattle**

Constituent: **Nitrate**

Table A79: Updated Specific-Central WIRRD for Livestock Type = Beef Cattle; Category = Growing Cattle; 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]
182	3.64	20.45	0.2867	[4.627] 1.3268	[58.63] 16.809	[119] 34.3835	[199] 57.305	[294] 84.430	>84.43
277	5.51	27.25	0.2707	[5.285] 1.4310	[44] 11.912	[90] 24.3655	[150] 40.609	[221] 59.830	>59.83
264	7.28	32.35	0.2569	[5.841] 1.5031	[37.06] 9.521	[75.8] 19.476	[126] 32.460	[186] 47.825	>47.82

*Adapted from NRC requirement tables (NRC, 2001).

^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 A80: Updated Specific-Central WIRRD for Livestock Type = Beef Cattle; Category = Finishing Cattle; 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]
273	5.46	30.45	0.3061	[4.662] 1.4272	[54.11] 16.567	[110] 33.887	[184] 56.479	[271] 82.212	>82.212
364	7.28	37.45	0.2974	[5.054] 1.5031	[44] 13.085	[90] 26.766	[150] 44.610	[221] 65.726	.65.726
454	9.08	44.3	0.2932	[5.329] 1.5627	[37.19] 10.907	[76] 22.310	[126] 37.184	[186] 54.785	>54.785

*Adapted from NRC requirement tables (NRC, 2001).

^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 A81: Updated Specific-Central WIRRD for Livestock Type = Beef Cattle; Category = Pregnant Cows; WQC = Nitrate

User Specific Input			Ingestion*	Water Quality Constituent^					
LW (kg)	DMI (kg/d)	TWI (L/d)	WIR ($L/kg^{0.82}/d$)	mg $NO_3/kg^{0.82}/d$^^					
				A (0-[])	B [A]-[B]	C [B]-[C]	D [C]-[D]	E [D]-[E]	F >[E]
409	8.18	34.05	0.2457	[6.246] 1.5350	[41.6] 10.2416	[85] 20.9488	[141] 34.8425	[209] 51.4406	>51.440
454.5	9.09	32.25	0.2134	[7.328] 1.5644	[44] 9.39300	[90] 19.2129	[150] 32.0216	[221] 47.1785	>47.178
500	10.0	30.45	0.1863	[8.538] 1.5915	[46.6] 8.68614	[95] 17.7671	[158] 29.5506	[234] 43.6278	>43.627

*Adapted from NRC requirement tables (NRC, 2001).

^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 A82: Updated Specific-Central WIRRD for Livestock Type = Beef Cattle; Category = Mature Bulls; WQC = Nitrate

User Specific Input			Ingestion*	Water Quality Constituent^					
LW (kg)	DMI (kg/d)	TWI (L/d)	WIR ($L/kg^{0.82}/d$)	mg $NO_3/kg^{0.82}/d$^^					
				A (0-[])	B [A]-[B]	C [B]-[C]	D [C]-[D]	E [D]-[E]	F >[E]
636	12.72	40.9	0.2055	[8.086] 1.6619	[45.8] 9.41949	[93.7] 19.2671	[156] 32.1119	[230] 47.3115	>47.311
681.5	13.63	42.6	0.2022	[8.318] 1.6827	[44] 8.90062	[90] 18.2059	[150] 30.3430	[221] 44.7054	>44.705
727	14.54	44.3	0.1995	[8.533] 1.7024	[42.3] 8.44119	[86.5] 17.2660	[144] 28.7768	[212] 42.3978	>42.397

*Adapted from NRC requirement tables (NRC, 2001).

^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

Livestock Type: **Beef Cattle**

Constituent: **Bromide**

Table A83: Updated Specific-Central WIRRD for Livestock Type = Beef Cattle; Category = Growing Cattle; WQC = Bromide

User Specific Input			Ingestion*	Water Quality Constituent^					
LW (kg)	DMI (kg/d)	TWI (L/d)	WIR ($L/kg^{0.82}/d$)	mg $Br/kg^{0.82}/d$^^					
				A (0-[])	B [A]-[B]	C [B]-[C]	D [C]-[D]	E [D]-[E]	F >[E]
182	3.64	20.45	0.2867	[0.0058] 0.001684	[0.1199] 0.034377	[1.199] 0.34376	[2.331] 0.66846	[3.331] 0.94409	>0.9440
277	5.51	27.25	0.2707	[0.0067] 0.001816	[0.09] 0.024366	[0.9] 0.24365	1.75] 0.47377	[2.5] 0.6768	>0.676
264	7.28	32.35	0.2569	[0.0074] 0.001908	[0.0757] 0.019472	[0.757] 0.19472	[1.473] 0.37864	[2.105] 0.54100	>0.541

*Adapted from NRC requirement tables (NRC, 2001).

^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.

Table A84: Updated Specific-Central WIRRD for Livestock Type = Beef Cattle; Category = Finishing Cattle; 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]
273	5.46	30.45	0.3061	[0.0059] 0.001812	[0.1106] 0.03388	[1.106] 0.33882	[2.152] 0.64885	[3.074] 0.94127	>0.9412
364	7.28	37.45	0.2974	[0.0064] 0.001908	[0.09] 0.02676	[0.9] 0.26766	[1.75] 0.52045	[2.5] 0.74351	>0.7435
454	9.08	44.3	0.2932	[0.0067] 0.001983	[0.076] 0.02230	[0.760] 0.22307	[1.479] 0.43377	[2.113] 0.61971	>0.6197

*Adapted from NRC requirement tables (NRC, 2001).

^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.

Table A85: Updated Specific-Central WIRRD for Livestock Type = Beef Cattle; Category = Pregnant Cows; 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]
409	8.18	34.05	0.2457	[0.0079] 0.001948	[0.0852] 0.02094	[0.852] 0.20945	[1.657] 0.40728	[2.36] 0.58187	>0.5818
454.5	9.09	32.25	0.2134	[0.0093] 0.001986	[0.09] 0.01921	[0.9] 0.19212	[1.75] 0.37358	[2.5] 0.53369	>0.5336
500	10.0	30.45	0.1863	[0.0108] 0.00202	[0.095] 0.01776	[0.953] 0.17764	[1.853] 0.34542	[2.64] 0.4935	>0.493

*Adapted from NRC requirement tables (NRC, 2001).

^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.

Table A86: Updated Specific-Central WIRRD for Livestock Type = Beef Cattle; Category = Mature Bulls; 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]
636	12.72	40.9	0.2055	[0.0102] 0.002109	[0.093] 0.01926	[0.937] 0.19267	[1.822] 0.37463	[2.603] 0.53519	>0.5351
681.5	13.63	42.6	0.2022	[0.0105] 0.002136	[0.09] 0.01820	[0.9] 0.18205	[1.75] 0.35400	[2.5] 0.50571	>0.5057
727	14.54	44.3	0.1995	[0.0108] 0.002161	[0.086] 0.01726	[0.865] 0.17266	[1.682] 0.33572	[2.40] 0.47961	>0.4796

*Adapted from NRC requirement tables (NRC, 2001).

^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.

Similar aspects regarding the influence of temperature, dietary composition, breed and water flow rates provided are noted to significantly alter feed and water intake in swine. Differences are noted in nutrient requirements for the selected water quality constituents, noting that current commercial piggeries provide a different environmental setting compared to dairy cattle and beef cattle production systems with most being housed entirely indoors in environmentally controlled houses.

As with other intensively produced animals, the essentiality of selenium is recognised, with marginal increases in dietary selenium noted to alleviate deficiency signs (e.g. increase from 0.06 to 0.07 mg/kg DM controlled myopathy in growing pigs). An inclusion rate of 0.06 mg/kg DM was noted to be inadequate to achieve optimal fertility in boars.

It should be noted that modern systems have breed-specific guidelines for restricted feeding and recommended intakes with numerous changes in the diets formulated and provided, even within defined production phases, such as starter, grower and finisher rations in the growing phase.

Whilst it may appear correct to utilise actual water intake values for swine over derived water intakes from feed intake values, the measurement of water intake is technically difficult to perform in a production environment, as despite developments in drinker systems wastage due to animal behaviour around the drinking point remains significant.

An example of the growing phase WIRRD tables is presented below and it is noteworthy that the multiple dietary changes alter the WIR values during the growth period (non-linear).

Table A87: Updated Specific-Central WIRRD for Livestock Type = Pigs; Category = Growing and Finishing; 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]
6.4	0.125	1.881	0.4106	[0.0057] 0.222368	[0.1806] 0.07418	[0.301] 0.12363	[4.215] 1.7309	[15.05] 61819	>6181
7.3	0.33	2.146	0.4204	[0.013346] 0.005612	[0.1583] 0.06659	[0.263] 0.11099	[3.695] 1.5539	[13.19] 5.5497	>5.549
11	0.62	3.234	0.4252	[0.01664] 0.007533	[0.1051] 0.04758	[0.175] 0.07930	[2.452] 1.1102	[8.75] 3.9650	>3.965
18	0.87	5.292	0.4946	[0.1427] 0.007059	[0.0642] 0.03177	[0.07] 0.05295	[1.498] 0.7413	[5.32] 2.6476	>2.647
28.5	1.225	8.379	0.5373	[0.01268] 0.006813	[0.0405] 0.02179	[0.067] 0.03632	[0.946] 0.5085	[3.38] 1.8164	>1.816
42.5	1.9	11.33	0.5235	[0.01455] 0.007621	[0.03] 0.01570	[0.05] 0.02617	[0.7] 0.3664	[2.5] 1.3089	>1.308
57.5	2.3	15.32	0.4428	[0.13023] 0.0072	[0.0221] 0.01225	[0.036] 0.02043	[0.517] 0.2860	[1.84] 1.0215	>1.0215
72.5	2.6	19.32	0.5763	[0.01167] 0.00673	[0.0175] 0.01013	[0.029] 0.01689	[0.410] 0.2365	[1.46] 0.8447	>0.844
87.5	2.85	15.48	0.3957	[0.15978] 0.006323	[0.2194] 0.00868	[0.036] 0.01448	[0.512] 0.2027	[1.82] 0.7240	>0.724
100	3	17.69	0.4053	[0.14717] 0.005965	[0.01921] 0.00778	[0.032] 0.01297	[0.448] 0.1816	[1.60] 0.6489	>0.648

*Adapted from NRC requirement tables (NRC, 1998a) and Thacker (2001).
^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

As with swine, the various poultry production systems (e.g. broilers, layers, and parent breeders) have breed specific targets and guidelines for which live weight, dry matter intake, water intake and growth (or an applicable performance parameter) are published.

These are also significantly influenced by the housing environment and dietary composition provided. Table A88 highlights the values obtained for a specific broiler breed (ROSS 308) and it is noteworthy that requirements are significantly influenced for the water quality constituent selenium by the vitamin E status of the diet, with observations on performance targets being maintained cited to vary from 0.01 to 0.6 mg/kg DM dependent thereon.

The limit of selenium is furthermore also recommended to remain at 0.2-0.28 mg/kg DM (NRC, 1994) to cater for the environmental concerns for selenium in poultry manure. It is, however, assumed in the updated WIRRD tables that the diets offered are indeed Vitamin E replete.

It is noteworthy that the Canadian Food Inspection agency (CFIA) (2018) proposal for increasing the maximum nutrient level for selenium to 1 mg/kg DM in sheep feeds was responded to by the Animal Nutrition Association of Canada (ANAC, 2018) in which they noted that the recommendation to monitor dietary selenium levels was impractical.

They further noted that the significant difference in the absorption of dietary selenium between ruminants and monogastric animals must be taken into account (29% compared to 80% respectively) and that feeding higher levels for ruminants which at present are without adverse effects may be limited by the proposal, adding that more concern exists for deficiency than toxicity.

In closing, the ANAC (2018) note that the EFSA (2016) found that feeding selenium to livestock was deemed to have a negligible effect on the environment, a statement which contradicts much of the concerns expressed previously and by the CFIA (2018).

Table A88: Updated Specific-Central WIRRD for Livestock Type = Broilers; Category = Broiler Growth Cycle; 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]
0.162	0.023	0.065	0.2891	[0.1769] 0.00511	[0.084] 0.02428	[0.14] 0.04048	[1.96] 0.56672	[7.0] 2.0240	>2.024
0.422	0.052	0.112	0.2272	[0.0232] 0.00527	[0.048] 0.01108	[0.08] 0.01846	[1.13] 0.25852	[4.06] 0.92329	>0.9232
0.795	0.09	0.182	0.2196	[0.0247] 0.00543	[0.03] 0.00659	[0.05] 0.01098	[0.7] 0.15377	[2.5] 0.54918	>0.5491
1.279	0.131	0.252	0.2059	[0.0259] 0.00535	[0.021] 0.004463	[0.03] 0.00743	[0.505] 0.19412	[1.8] 0.37188	>0.3718
1.826	0.169	0.311	0.1898	[0.0271] 0.00515	[0.017] 0.00333	[0.02] 0.0055	[0.409] 0.07775	[1.4] 0.27771	>0.2777

*Adapted from NRC requirement tables (NRC, 1998b) and Ross 308 reference data (2015).
^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

Adjustments to the WIRRDs

In response to the differences noted regarding maximum nutrient limits contrasted with performance requirements, the WIRRDs adapt the Column A value to accommodate the noted requirement for selenium, and columns B and C retain lower reference values for breeding and long-term exposure, with higher values for animals destined for slaughter (noting that the form of selenium in water is regarded as more potentially toxic and thus a stricter general approach is warranted).

To illustrate this for broilers and how the difference during the same growth period (0-35 days) in the same breed, but for different production purposes (slaughter versus parent breeders), affects the central reference document, parent breeder growth phases are provided below as well for male and female categories.

This highlights the value of the WIRRD approach and how the ability to not have an entrenched tabulated fixed mg/L water quality guideline that will inevitably be conservative in nature enables a more correct assessment of ingestion and thus risk.

Table A89: Updated Specific-Central WIRRD for Livestock Type = Broilers; Category = Broiler Parent Stock In season – Female Growth Cycle; 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]
0.115	0.024	0.058	0.3417	[0.02069] 0.00707	[0.0558] 0.01909	[0.1568] 0.05362	[2.1965] 0.75073	[7.84] 2.68120	>2.6812
0.215	0.028	0.101	0.3562	[0.0138] 0.004938	[0.0320] 0.01142	[0.090] 0.03209	[1.261] 0.44938	[4.50] 1.60493	>1.6049
0.335	0.032	0.162	0.3972	[0.00987] 0.003923	[0.02] 0.0079	[0.05] 0.019862	[0.7] 0.27807	[2.5] 0.99313	>0.9931
0.45	0.035	0.224	0.4311	[0.00781] 0.003369	[0.01446] 0.00623	[0.040] 0.017516	[0.568] 0.24523	[2.03] 0.87585	>0.8758
0.56	0.038	0.278	0.4538	[0.00683] 0.003102	[0.01165] 0.00528	[0.032] 0.014857	[0.458] 0.20796	[1.63] 0.74273	>0.7427

*Adapted from NRC requirement tables (NRC, 1998b) and Ross 308 reference data (2016).

^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

Table A90: Updated Specific-Central WIRRD for Livestock Type = Broilers; Category = Broiler Parent Stock In season – Male Growth Cycle; 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]
0.150	0.035	0.062	0.29383	[0.02826] 0.00829	[0.0558] 0.01715	[0.1467] 0.04312	[2.054] 0.60379	[7.338] 2.1563	2.1563
0.320	0.042	0.112	0.28513	[0.01875] 0.005346	[0.03207] 0.00921	[0.0812] 0.02316	[1.137] 0.32433	[4.065] 1.1583	1.1583
0.525	0.048	0.181	0.30704	[0.01326] 0.004071	[0.02] 0.006141	[0.05] 0.01535	[0.7] 0.21492	[2.5] 0.7676	0.7676
0.735	0.052	0.251	0.32312	[0.01035] 0.00334	[0.01442] 0.00466	[0.036] 0.01171	[0.507] 0.16400	[1.812] 0.58573	0.58573
0.945	0.056	0.224	0.23465	[0.0125] 0.00293	[0.01616] 0.003792	[0.040] 0.0053	[0.568] 0.13345	[2.03] 0.47663	0.47663

*Adapted from NRC requirement tables (NRC, 1998b) and Ross 308 reference data (2016).

^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

Site-specific conditions as detailed in the report are used as inputs to adjust the column values in the WIRRDs, with these being water quality constituent, animal and environmental factor specific.

These inputs are a combination of reference documentation and user defined inputs, with the preference for default values only in the absence of site-specific detail. Again, it should be appreciated that modelling factors included are vast and produce a significant amount of altered WIR reference values.
These inputs were further illustrated to be categorised into Source, Pathway and Receptor settings, with values either presented by user input or potentially recommended as an output in the CIRRA model.

This allocation is a new update to the CIRRA model and initiated in part by the recognition of the need to link water quality guidelines to resource quality objectives, and also by providing inputs that tend to fit interest or field speciality into easier to understand input formats.

By way of illustrating these input changes further, a simple temperature input deviation upwards and downwards for growing and finishing beef cattle is provided in the following tables which can be compared to the standard default setting (17.7 degrees Celsius) provided earlier.

Table A91: Updated Specific-Central WIRRD for Livestock Type = Beef Cattle; Category = Growing Cattle; WQC = Selenium = User Input = Temperature = 10 ºC

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]
182	3.64	16.3	0.2285	[0.0049] 0.001133	[0.0134] 0.00308	[0.067] 0.01542	[0.944] 0.2159	[3.374] 0.77108	>0.7710
277	5.51	22.0	0.2185	[0.0055] 0.00122	[0.01] 0.00218	[0.05] 0.01092	[0.7] 0.14299	[2.5] 0.54642	>0.54642
264	7.28	25.7	0.2040	[0.0062] 0.00128	[0.0085] 0.00174	[0.042] 0.00873	[0.599] 0.12229	[2.140] 0.43677	>0.4367

*Adapted from NRC requirement tables (NRC, 2001).

^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

Table A92: Updated Specific-Central WIRRD for Livestock Type = Beef Cattle; Category = Finishing Cattle; WQC = Selenium = User Input = Temperature = 10 ºC

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]
273	5.46	24.6	0.2473	[0.0042] 0.001133	[0.0134] 0.003084	[0.060] 0.01593	[0.850] 0.21043	[3.038] 0.7515	>0.751
364	7.28	29.9	0.2374	[0.0046] 0.001222	[0.01] 0.002186	[0.05] 0.01187	[0.7] 0.16621	[2.5] 0.5936	>0.493
454	9.08	35.6	0.2356	[0.0049] 0.001283	[0.0085] 0.001747	[0.0419] 0.0098	[0.587] 0.13854	[2.099] 0.4984	>0.498

*Adapted from NRC requirement tables (NRC, 2001).
^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

Table A93: Updated Specific-Central WIRRD for Livestock Type = Beef Cattle; Category = Growing Cattle; WQC = Selenium = User Input = Temperature = 26.6 ºC

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]
182	3.64	25.4	0.3561	[0.0031] 0.001133	[0.0132] 0.00472	[0.066] 0.012362	[0.928] 0.3307	[3.316] 1.18116	>1.1811
277	5.51	33.7	0.3348	[0.0036] 0.00122	[0.01] 0.003348	[0.05] 0.01674	[0.7] 0.23436	[2.5] 0.83702	>0.8370
264	7.28	40.1	0.3184	[0.004] 0.00128	[0.0084] 0.002676	[0.042] 0.01338	[0.588] 0.18733	[2.100] 0.66906	>0.6690

*Adapted from NRC requirement tables (NRC, 2001).

^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

Table A94: Updated Specific-Central WIRRD for Livestock Type = Beef Cattle; Category = Finishing Cattle; WQC = Selenium = User Input = Temperature = 26.6 ºC

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]
				[0.0027]	[0.0122]	[0.061]	[0.928]	[3.073]	
273	5.46	37.9	0.3810	0.00105	0.00468	0.0234	0.33072	1.1713	>1.171
				[0.0030]	[0.01]	[0.05]	[0.7]	[2.5]	
364	7.28	46.6	0.3700	0.00111	0.00370	0.01850	0.23436	0.92517	>0.925
				[0.0031]	[0.0084]	[0.0424]	[0.588]	[2.122]	
454	9.08	54.9	0.3634	0.00115	0.00308	0.01542	0.18733	0.77116	>0.771

*Adapted from NRC requirement tables (NRC, 2001).
^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

Summary

As explained, the series of tables provided in here may be altered by changing the WIR reference values per column on the basis of site-specific data entered. When viewing the nutrient requirement documentation it is increasingly evident that dietary factors affecting feed and water intake are growing in both number and complexity, rendering tabulated format guidelines, estimates or predictions ever more difficult to provide.

The most significant change to the WIRRDs occurs when the TWI changes based on actual site-specific observations are entered. The influence of a different water intake is significant in the guideline derivation process as noted earlier for selenium in domestic guidelines, and this data input is viewed as the key data input required.

Allowing for this input in collaboration with the analytical determination of the actual ration provided will provide a more meaningful risk assessment than the use of mineral reference documentation as a substitute (as is noted in comments and research elucidating variations in the nutrient requirement documentation published).

Again, it should be noted that in accordance with the National Water Act (Act No. 36 of 1998) (NWA) the actual volume of water used in commercial animal production systems should be measured, although in practice the total volume on site remains the most measured volume, consequently requiring the WIRRD and categories to still be utilised to obtain physiological and production specific values. It is envisaged that increased enforcement of water usage for agricultural sectors and on-site recognition of the management value in knowing the actual intake on-site will continue to increase over time.

Lastly, linking the norms of fitness for use and wastewater should lead to compliance with the advocated policies in the NWA and licences issued, in which the exploration and implementation on an on-going basis is required in terms of water conservation and ever-increasing water efficient use. This is already noted in the international strategies in which agricultural water use is increasingly under pressure from increased domestic and industrial needs. The final outcome of this should be increased awareness of both water quality constituent effects and water usage.

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APPENDIX B: GRAPHICAL USER INTERFACES OF THE DSS PROTOTYPE FOR ANIMAL (LIVESTOCK) WATERING WATER USE