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

NH Casey • JA Meyer

WRC Report No 857/1/01

Water Research Commission

AN EXTENSION TO AND FURTHER REFINEMENT OF A WATER QUALITY GUIDELINE INDEX SYSTEM FOR LIVESTOCK WATERING

VOLUME 1

RURAL COMMUNAL LIVESTOCK PRODUCTION SYSTEMS AND WILDLIFE PRODUCTION SYSTEMS

by
NH Casey & JA Meyer

Department of Animal and Wildlife Sciences

University of Pretoria

Volume 1 of a report to the Water Research Commission on the Project:
"An extension to and further refinement of a water quality guideline index system for livestock watering"

Project Leader	:	Prof NH Casey
Principal Researcher	:	Dr JA Meyer
WRC Report No	:	857/1/01
ISBN No	:	1 86845 713 3
ISBN Set No	:	1 86845 715 X

EXECUTIVE SUMMARY

An extension to and further refinement of a water quality guideline index system for livestock watering

by

NH Casey and JA Meyer
Department of Animal and Wildlife Sciences
University of Pretoria

1. BACKGROUND TO THE STUDY

This is the third WRC project addressing water quality guidelines for animals and presents risk assessment modelling for three new user groups, namely, rural communal livestock production systems, wildlife and poultry production systems.

The growth and development of this research field has taken place over a number of years. An initial brief was obtained from the WRC in 1990 with the request to verify criteria for beef cattle utilising subterranean sources along the North and North Western border regions of South Africa. Other livestock types were subsequently included, and in the Final Report: K5/301, the guidelines then in use were shown to be inadequate and result in inaccurate estimates of risk. Through biological toxicological trials using sheep, cattle and poultry, it was shown how single value cut-off limits were poor indicators of risk under the majority of conditions, and often resulted in the limitation of efficient water utilisation. These trials indicated that animals could be exposed to highly toxic water quality constituents (WQC), far in excess of the guideline ranges, for specific production periods (weaning to market weight), without incurring any adverse effects on growth, health or performance. It was also shown how the omission of palatability effects by the guidelines could lead to financial losses for the livestock producer.

A second WRC project, K5/644, through further biological experimentation, extensive region trials, and modelling, delivered a computer software program called CIRRA, an acronym for Constituent Ingestion Rate Risk Assessment. CIRRA conducts site-specific risk assessment based on the modelling of risk factors from water, animal, environmental and nutritional data, to generate both risk assessment and possible solution options. This is based on a constituent ingestion rate, in mg/d/kg BW, corrected for metabolic water. This represents a radical departure from existing static tabulated guidelines which are all independent of production system effects, nutrition, environmental and animal factors, and appear in the form of a mg/L guideline recommendation. CIRRA caters for beef cattle, dairy cattle, goats, sheep, pigs and horses, in the commercial context.

Through the outputs of these two WRC projects, two guideline editions for livestock watering emerged for the Department of Water Affairs and Forestry, one in 1993, and a second in 1996. These are, however, still largely generic guidelines. As they appear in a tabulated format, utilising a target water quality range concept, they fail to accommodate significant site-specific toxicokinetic and toxicodynamic factors, rendering their application to a conservative, at best generic, estimation of risk. It is recommended that the WRC Report No 644/1/98 is read prior to this report, as it contains much of the scientific basis for the models described in this report.

2. PROBLEM STATEMENT AND STUDY OBJECTIVES

2.1 Rural communal livestock production systems (RCPLS)

As described in previous reports (K5/301; K5/644) many local subterranean water supplies exceed local and international guidelines by large margins. By virtue of the mg/L design, current guidelines do little more than alert users to the possibility of adverse effects occurring, at times arguably being overly conservative in estimation, a necessity brought about by safety factors incorporated due to the reliance on mg/L guidelines independent of the environment. The benefit of developing a risk assessment tool capable of a multidisciplinary approach, is that it allows for the incorporation of mutually antagonistic factors which may effectively allow for the safe use of water containing constituents in excess of the guideline limits.

CIRRA, as developed for commercial systems, provides risk assessments and solutions that are specific for livestock type, breed, production-category, and production-environment. A solution may be proposed by CIRRA to reduce both the severity of fluorosis, and adverse palatability effects of saline water, for non-pregnant Dorper ewes, weighing 55 – 60 kg, fed a maintenance ration under semi-extensive conditions. Whilst this approach is necessary for an accurate risk assessment, it is not appropriate for RCLPS, nor does it find application for WPS. Two primary reasons are the utilisation of a single watering point by multiple livestock species, and mixed breeds, and the lack of identifiable production-category detail within a herd/flock as an input variable.

Important complicating factors arise due to the association between the animals and humans. This became apparent whilst investigating the feasibility of applying alleviator treatments, used to reduce fluorosis in beef cattle under extensive conditions at the Delftzyl Agricultural Research Station, under RCLPS in the adjacent communities.

Important observations made in the communal areas were that the water source tended to be shared by both humans and animals, and that products from these animals formed a large part of the human diet.

The research conducted under WRC Project K5/644 formulated, and implemented, under extensive on-farm conditions at the Delftzyl Agricultural Research Station, an alleviator treatment for fluorosis in cattle. The following advantages and disadvantages apply:

Advantages: Easy administration of treatment
No trained technician required
Cheap cost of chemicals and equipment used
No brine to be removed
Can adapt stock incrementally
Can manipulate treatment for seasonal and WQC changes.

Disadvantages: Treatment must be administered continuously.

The shared utilisation of subterranean water sources by animals and humans require that consideration of the health norm for animals alone is not sufficient. It also poses a serious ethical concern and modelling consideration.

The ethical concern is that solutions cannot be recommended for use in communal areas, even if they alleviate the adverse effects of hazardous constituents in livestock, whilst knowledge exists of shared utilisation of the water by humans. This is because the solutions recommended will in most instances render the water even more unfit for use by humans. Note that the water is in many cases already unfit for human consumption, as indicated in this report. The modelling considerations are that a best-fit option is required to cater for alleviator responses in both user groups, and that animal product quality for consumers (specifically rural subsistence users) must receive increasing attention.

A number of uncertainties exist:

1 To what extent does the presence of other WQCs mitigate or exacerbate adverse effects due to a single WQC.
2 To what extent do high WQC concentrations contribute significantly to alleviate existing trace mineral deficiencies in the diet of the communities involved.
3 To what extent do WQCs present in animal products such as milk, meat and organs, add to the dose intake already experienced by humans from the WQC present in water.
4 To what extent can alleviator treatments demonstrated to be effective for livestock be used to mitigate adverse effects in humans.
5 Is it financially viable to design and build the necessary structures to enable a single water source to receive multiple treatments, each specific to a different water user?

These considerations and uncertainties served to motivate for the development of a separate CIRRA model, designed specifically for RCPLS.

2.2 Wildlife production systems (WPS)

Wildlife production systems pose a number of complex challenges to water quality management. The most obvious is the diverse nature of the user groups, ranging from aquatic organisms requiring permanent water of acceptable quality, to desert animals with adaptive mechanisms which significantly reduce their dependence on drinking water. The user groups differ in physiology, water turnover, territory, feeding spectrums, and water provision design requirements. Perhaps not so obvious is the difficulty of predicting where, how much, and when, an animal drinks. The net risk in terms of actual ingestion of a potentially hazardous constituent for certain wildlife species may be acceptable under conditions where multiple watering points form part of a territory.

It follows that some water sources will pose a greater risk to certain wildlife species than to others. Although this makes for complex guideline models, it affords the manager to opportunity to allocate poor quality water to least sensitive species. This is accomplished by matching habitat, territory, water provision design and immediate habitat with species.

The degree to which management can, or wants to, intervene in a WPS, affects the degree to which alleviator treatments may be used, from the feeding of supplements to the application of water treatments. An additional issue requiring a new CIRRA model for WPS is that of the ecological impact of actually providing, designing, placing, and managing, water used for drinking and other purposes by wildlife. The effect of the presence, or absence, of wildlife on sacrifice zones, herbaceous plant communities and ultimately successful wildlife ranching, are but a few of the water quality considerations that needed to be addressed by the new CIRRA model.

2.3 Poultry production systems (PPS)

The poultry industry has become an important component of our agricultural sector. South Africa is the second biggest producer of eggs (total of 4500 million in 1994) in Africa. Concerns regarding the use of poor quality water within the poultry sector were presented in a previous WRC report (K5/644) and based on results of water quality investigations across the whole of South Africa. Narrow profit margins within commercial poultry production (high feed costs) imply that any decline in health, or the efficiency of feed conversion, can reduce profit.

The primary requirement for a poultry model is a combination of a lack on knowledge of the types and concentrations of WQCs present in water used for poultry production, inadequacies and conflicting guidelines used. This leads to a significant area of concern regarding the influence of water quality on the health and production parameters for both broiler and layer production systems, many of which are as yet not quantified. An additional reason for proposing a modelling approach was the lack of existing guidelines for poultry to incorporate information on the important role played by site-specific factors.

2.4 Ostrich production in the Oudtshoorn district

This report also presents data regarding the influence of water quality on the mineral content of various biological tissues in ostriches. Research regarding water quality for ostrich production systems in the Oudtshoorn District was initiated by the State Veterinary Inspector at the Oudtshoorn Abattoir due to observations of carcass defects that appeared to be more prevalent in birds originating from certain areas within the district. Certain producers had also noted significant seasonal fluctuations in growth rates that appeared to be linked to water quality.

3. METHODOLOGY AND REPORT LAYOUT

This report is divided into two volumes. The first addresses the rural and wildlife production system models developed, whilst the second presents the poultry model and research on the effect of water quality on mineral values in selected ostrich tissues.

The general format employed is to present the supporting information prior to the models proposed. An overview of each model is then followed by a detailed description thereof. This is followed by a section presenting water quality investigations appropriate to each user group. The methods used differ dependent on the purpose of the investigation and nature of the area involved, and are dealt with where appropriate.

Technical information is presented in the first volume only. Due to the extensive nature of the modelling methodology employed, for each volume the reader is referred to WRC Report No: 644/1/98 for a more comprehensive description.

4. SUMMARY OF MAJOR RESULTS AND CONCLUSIONS

4.1 Rural Communal Livestock Production Systems

The rural communal livestock production system model presented in this report attempts to cater for the complex requirement of balancing risk and hazard identification in the realm of environmental toxicology, with the significant role of water quality in improving the health of animals and humans. During the rural area investigations the association between animal and man was observed to be a limiting factor to the successful application of solutions generated by CIRRA for problematic water sources. Shared utilisation effectively prohibits the application of treatments to it, due to the potential for adverse effects in humans.
The effect of animal product quality on human health was an additional area of concern. An accumulation of constituents such as lead and cadmium in renal cortex tissue during intensive commercial systems do not

present a significant consumer hazard, as concentrations and dilution within the urban diet, effectively provide for sufficient safety. This does not hold true for the rural production systems.

The production phase is seldom as short, or well defined, as in commercial systems. Exposure periods are therefore longer, with ingestion rates typically greater due to a number of associated risk factors (e.g. temperature, moisture percentage of ration). Secondly, and possibly quantitatively more important, the nature of the diet differs in terms of input origin variability. Potentially hazardous constituents in the water may find their way into the diet of sensitive user groups, such as reproductively active women and children, through a number of routes. These may be direct via the drinking water, indirect via food preparation and irrigation of subsistence crops, and indirectly via the consumption of animal products from animals exposed to the water source.

A number of other routes incorporating bioaccumulation and bioconcentration may also apply, such as the consumption of aquatic organisms, and the practice of providing reverse-osmosis brine to livestock, which may find its way back into the human diet through the consumption of organs, eggs, or milk. This may be at even greater levels than those occurring naturally in water, partly due to the increased concentration of hazardous constituents in the brine, as compared to raw feed water, and the active transport mechanisms that may increase the concentrations thereof in milk. Localised geochemical anomalies may be magnified in semi-arid regions, and there is increasing evidence that the additional effect of geophagia, incidental and deliberate, by both animals and humans, is significant.

In the developing communities this project reports on, both for livestock and humans, dietary deficiencies in terms of quantity and quality are real challenges. The link between livestock production, animal product quality, and human nutrition, when viewed in context of the additional risk factors in rural communal production systems, takes on a more central role to the modelling of water quality guidelines for the user group. The ramifications of retaining the focus of water quality guidelines for livestock on the health of livestock, and failing to account for norm of product quality, would be grossly negligent. There is much evidence of animal products which may contain potentially hazardous concentrations of constituents with clinically accepted toxicity risks for humans, without the animal presenting with any clinical manifestations of a trace element disorder. As such, livestock health may not be a sufficiently accurate measure of the fitness for use of consumption products.

However, livestock products offer abundant and bioavailable forms of micronutrients, and calcium, iron, zinc, vitamins A and B_{12}, *if managed appropriately*. Low birth weight due to fetal malnutrition has been associated with deficient maternal intakes of iron, zinc, iodine and vitamin B_{12}, as have an increased risk for fatal infections, neuorlogic and cognitive impairment. Not only are animal products compact and efficient sources of many of these nutrients, but they are almost the exclusive source of dietary vitamin B_{12}, efficient sources of many of these nutrients, but they are almost the exclusive source of dietary vitamin B_{12}, and a good source of pre-formed vitamin A. The inclusion of health norms for water quality guidelines for livestock is warranted as successful production has been shown to be a valuable means of income generation for rural households.

A high incidence of specific water quality constituents present in the water at potentially hazardous concentrations was found for all communities. Most were typified by a localised, often isolated, association between the environment, water, animals and humans. The communities had a varied spectrum of user groups, but all included sensitive user groups, namely women of reproductive age, infants and children. The valuable, and at time essential role, played by livestock was evident for most communities. Most systems lacked the required infrastructure to allow for separate alleviator treatments formulated for livestock to be administered to the watering system.

Animal data regarding risk of an environmental toxicological nature, may be used to the benefit of identifying similar risks for humans. The localised geochemical factors shared by both animals and humans allow for some valuable information to be gained regarding the types of effects that may occur due, in varying degrees, to water quality.

The drinking water quality guidelines formulated by the WHO, USEPA, and the Department of Water Affairs and Forestry, are primarily based on hazard identification from single constituent exposure toxicological studies. The outcomes of exposure to multiple constituents, as found to occur in the areas investigated, are not described by local and international guidelines. Ameliorating effects may be negligible, partial, or complete. Further research is required in this regard.

With this, and many other areas of uncertainty, animal health studies can provide a valuable means of determining the risk present due to potentially hazardous water quality constituents with the incorporation of significant site-specific factors. Animal health studies can provide valuable guidance to community health based studies. They afford an opportunity to gather tissue samples, not readily available from humans, for histopathological examination, and various assays, which may provide an indication of possible subchronic, subclinical, effects that may occur in humans. The Data Capturing Guides developed aid in the collection of the required site-specific data.

Finally, the investigations indicate that potential problems are not isolated occurrences, but rather localised anomalies, which have an additional problem of creating the lack of a comparative norm, as large number of animals, and humans, tend to be affected.
The order by which the recommended guidelines are exceeded, and the intrinsic high risk of the product system and related environment, suggest that the possible solution option within CIRRA be expanded

further. The identification of points in the ingestion route between water quality and types of health effects where risk is increased, or decreased, is of great value to proposing solutions to reduce risk. In the modelling of the rural communal livestock production system, this aspect was taken into account in the setting up of different data capturing screens, and in the design of the presentation of the evaluation results. Although perhaps too complex at first glance, once familiar, these screens offer a tool for identifying, and testing, outcomes based management decisions.

4.2 Wildlife Production Systems

With the rapid increase in scientific investigations pertaining to game ranching, more game ranches are changing from an initial "untouched wilderness" concept to one that recognises the active-adaptive approach. There is an increased awareness relating to the profit-based business potential in game ranching. The ecological responsibility of providing water to game is also gaining recognition. The increased demand this places on management is accompanied by an increased requirement for specialist knowledge.

The effect of water quality on wildlife has typically received little attention. Most studies do not include chemical information on water quality, and when they do, it is usually inadequate and extended only to a handful of macro-element values. Studies elucidating the role of water quality constituents on issues such as reproductive health and immune responsive disorders are increasing, but the beginning point of such studies requires knowledge of the quality of water, spatial and temporal, as a fundamental basis.

The water quality investigations presented in this report suggest that sufficient variability in water quality constituents exist, in terms of palatability and toxicology, to require management attention. The availability of multiple water sources, and the presence of multiple wildlife species comprising different physiological stages, makes risk assessment a fairly complex task. A software environment not only enables these complexities to be handled, but also guides the user as to the possible types of site-specific information to be obtained. These information types will find application for game ranch management decisions other than those regarding water quality.

4.3 Poultry production systems

Water quality constituents may impact on several norms, ranging from poultry health to equipment failure, all of which affect profitability. Apart from the obvious disadvantages to production from adverse effects on poultry health due to mineral imbalances, pathogens and parasites, knowledge of water quality is also required for managerial and nutritional purposes. For intensive commercial systems a constituent affecting nutrient bioavailability or feed intake negatively, or increasing nutrient requirements for specific production defined parameters, can increase production cost.

For systems operating on large volumes and narrow feed margins, the contribution that water quality makes towards mineral requirements, and significant dietary and drug interactions, must be taken into account for efficient sources of many of these nutrients, but they are almost the exclusive source of dietary vitamin B_{12}, and a good source of pre-formed vitamin A. The inclusion of health norms for water quality guidelines for livestock is warranted as successful production has been shown to be a valuable means of income generation for rural households.

A high incidence of specific water quality constituents present in the water at potentially hazardous concentrations was found for all communities. Most were typified by a localised, often isolated, association between the environment, water, animals and humans. The communities had a varied spectrum of user groups, but all included sensitive user groups, namely women of reproductive age, infants and children. The valuable, and at time essential role, played by livestock was evident for most communities. Most systems lacked the required infrastructure to allow for separate alleviator treatments formulated for livestock to be administered to the watering system.

Animal data regarding risk of an environmental toxicological nature, may be used to the benefit of identifying similar risks for humans. The localised geochemical factors shared by both animals and humans allow for some valuable information to be gained regarding the types of effects that may occur due, in varying degrees, to water quality.

The drinking water quality guidelines formulated by the WHO, USEPA, and the Department of Water Affairs and Forestry, are primarily based on hazard identification from single constituent exposure toxicological studies. The outcomes of exposure to multiple constituents, as found to occur in the areas investigated, are not described by local and international guidelines. Ameliorating effects may be negligible, partial, or complete. Further research is required in this regard.

With this, and many other areas of uncertainty, animal health studies can provide a valuable means of determining the risk present due to potentially hazardous water quality constituents with the incorporation of significant site-specific factors. Animal health studies can provide valuable guidance to community health based studies. They afford an opportunity to gather tissue samples, not readily available from humans, for histopathological examination, and various assays, which may provide an indication of possible subchronic, subclinical, effects that may occur in humans. The Data Capturing Guides developed aid in the collection of the required site-specific data.

Finally, the investigations indicate that potential problems are not isolated occurrences, but rather localised anomalies, which have an additional problem of creating the lack of a comparative norm, as large number of animals, and humans, tend to be affected.
The order by which the recommended guidelines are exceeded, and the intrinsic high risk of the product system and related environment, suggest that the possible solution option within CIRRA be expanded

further. The identification of points in the ingestion route between water quality and types of health effects where risk is increased, or decreased, is of great value to proposing solutions to reduce risk. In the modelling of the rural communal livestock production system, this aspect was taken into account in the setting up of different data capturing screens, and in the design of the presentation of the evaluation results. Although perhaps too complex at first glance, once familiar, these screens offer a tool for identifying, and testing, outcomes based management decisions.

4.2 Wildlife Production Systems

With the rapid increase in scientific investigations pertaining to game ranching, more game ranches are changing from an initial "untouched wilderness" concept to one that recognises the active-adaptive approach. There is an increased awareness relating to the profit-based business potential in game ranching. The ecological responsibility of providing water to game is also gaining recognition. The increased demand this places on management is accompanied by an increased requirement for specialist knowledge.

The effect of water quality on wildlife has typically received little attention. Most studies do not include chemical information on water quality, and when they do, it is usually inadequate and extended only to a handful of macro-element values. Studies elucidating the role of water quality constituents on issues such as reproductive health and immune responsive disorders are increasing, but the beginning point of such studies requires knowledge of the quality of water, spatial and temporal, as a fundamental basis.

The water quality investigations presented in this report suggest that sufficient variability in water quality constituents exist, in terms of palatability and toxicology, to require management attention. The availability of multiple water sources, and the presence of multiple wildlife species comprising different physiological stages, makes risk assessment a fairly complex task. A software environment not only enables these complexities to be handled, but also guides the user as to the possible types of site-specific information to be obtained. These information types will find application for game ranch management decisions other than those regarding water quality.

4.3 Poultry production systems

Water quality constituents may impact on several norms, ranging from poultry health to equipment failure, all of which affect profitability. Apart from the obvious disadvantages to production from adverse effects on poultry health due to mineral imbalances, pathogens and parasites, knowledge of water quality is also required for managerial and nutritional purposes. For intensive commercial systems a constituent affecting nutrient bioavailability or feed intake negatively, or increasing nutrient requirements for specific production defined parameters, can increase production cost.

For systems operating on large volumes and narrow feed margins, the contribution that water quality makes towards mineral requirements, and significant dietary and drug interactions, must be taken into account for feed formulation to be accurate and representative of true requirements. A system incorporating those site-specific factors influencing the adverse effects that may occur due to potentially hazardous constituents, allows for increased measurement and observations of these factors. It is hoped that this will allow for more efficient usage of water, and also prevent the incorrect classification of water sources that pose a "potential" hazard based on rudimentary guidelines, and encourage water users to acknowledge water with a high mineral content as not simply water with poor quality, but rather as a potentially valuable source of minerals.

4.4 Ostrich production in the Oudtshoorn district

The occurrence of significant differences in mineral concentrations found, and the consistency with which these differences occurred within treatment groups, indicates the need to incorporate the role of water chemistry and geochemistry in formulating the dietary requirements on a farm-specific basis. Pre-scribing a ration or nutritional programme for a district runs the risk of under, and over-estimating the mineral requirements of ostriches. As a result, imbalances may precipitate deficiencies, with consequent loss of productivity, and as appears to be the case in at least several of the farms, may even result in skeletal-related slaughter-process problems.

Where initially a concentration viewed only in water will represent a portion of the dietary requirement, when additional sources of ingestion taken and inter-mineral effects (even only within a water source) are taken into account, the same constituent concentration may well increase the final risk that is posed. Although PHCs such as the constituent Se were present in the vast majority of the samples collected, large differences in the concentrations recorded between areas (North versus south of the Groot Swartberge), and the lack of such differences within an area (South of Groot Swartberge and North of Kamannasie Berg), suggest that there is merit in formulating supplementary alleviator feeds that are area (or valley) specific.

5. RECOMMENDATIONS FOR FURTHER RESEARCH

5.1 Rural Communal Livestock Production Systems

Due to the complexities of modelling relevant risk factors and the varied fields of specialisation that are addressed, achieving a guideline and risk assessment system that is manageable by a wide user audience, is best done in a software environment. Main reasons for this are access to large amounts of data, complex modelling performed, and Internet connectivity enabling sample files that represent a site-specific system to be e-mailed to persons from which specialised insight may be requested.

- On the basis of the potential hazardous found in the water sources sampled, it is recommended that research focus on identifying, and testing, outcomes based system manipulations that allow for the continued use of a water source containing potentially hazardous constituents.

- The efficacy of alleviator chemical treatments for livestock administered to the water supply should be tested in the rural communal production system context.
- The effect of using brine for stock watering in the rural communal production system context on animal product quality, and animal health, should be investigated.
- It is proposed that a formal procedure be developed in which the effect of water quality in rural communal production systems be determined through a series of clearly defined steps. Recommended steps in this regard are:
  1. Commencing with a risk assessment for livestock addressing health and product quality norms, that identify specific potentially hazardous water quality constituents and water quality constituents of concern;
  2. Substantiating the potential risk identified in Step 1 by using clinical evaluations of herd health, animal tissue histopathology and assays for relevant constituents, geochemistry, and feed samples;
  3. Formulating possible risk implications for human health on the basis of the results obtained in Step 2, incorporating direct and indirect, site-specific factors;
  4. Preliminary community-based epidemiological studies to assess the risk factors present;
  5. Substantiating the potential risk identified in Step 4 through community health investigations;
  6. Depending on the outcome of Step 5, viable means of reducing risk in both animals and humans should be identified;
  7. It is proposed that these steps form part of a formal procedure in a software program that consists of different components encompassing the fields of knowledge required. It is envisaged that such a program would enable the identification the probability of risk in potential areas to be based on geochemistry-related data, thus in effect guiding animal and veterinary scientists for step 1. The program can also contribute to the building of Provincial and National databases by linking the relevant data capturing screen information to the relevant specialist field. A program can also accommodate frequent updates as new research evidence and procedure become available.

A specialist component-based software program catering for the variable types of databases (animal, geological, hydrological, climatic, epidemiological, etc.) would aid in encouraging collaborative research, with the central theme of improving the quality of life for humans in the rural communal context, by allowing the correct detection, and management, of critical issues pertaining to water quality to be recognised and addressed.

5.2 Wildlife Production Systems

Although water quality aspects for aquatic systems have, and continue to, receive attention, these monitoring programmes do not always lend themselves to conducting risk assessments for wildlife health. Those who are of the opinion that water quality for wildlife has no place in wildlife management not only neglect the impact thereof on wildlife health, but also on the ecological environment. Choosing not to obtain information on water quality effectively prevents the management of those resources, and the wildlife that rely on them. In order to manage, measurement is a pre-requisite.

- It is recommended that a water quality monitoring programme be designed for the National Parks of South Africa, and that management decisions regarding water provision, placement and design thereof, include water quality risk assessments, for wildlife health and ecological impact norms directly influenced by wildlife, as a pre-requisite to the information types on which the decision making process rests.
- It is recommended that research be conducted regarding the use of mineral licks, and supplementary feeding for wildlife, as corrective and/or alleviator treatment for water sources with potentially hazardous water quality constituent concentrations.

Possible contamination of groundwater and the environment by both production systems, although not typically intensive, should also receive attention.

> The recommendations proposed for the rural communal livestock production systems, and wildlife production systems, should be seen in context of the mission of the Department of Water Affairs and Forestry as custodian of South Africa's water resources, part of which is to "*maintain the fitness for use of water on a sustained basis*", with specific reference to two recognised categories of water use, namely, domestic and agricultural purposes.

5.3 Poultry Production Systems

Due to the intensive nature of commercial poultry production systems, it is recommended that the micro-biological water quality criteria not dealt under the targets formulated for this project be incorporated into the model, with the initial phase consisting of the collection of background data relating to the occurrence of pathogens and parasites in the water sources, and watering systems.

Further research is recommended regarding the fitness of poultry products for human consumption in the rural subsistence context, and indigenous breed differences with regard to tolerances to potentially hazardous constituents.

5.4 Ostrich production in the Oudtshoorn district

Recommendations are made regarding which tissue to use as an indicator of mineral status for specific elements, for example renal tissue for Mn, bone for K and liver for Cu. However, in order to place a high or low value in a tissue in perspective, for example bone values for Mg and Ca, levels for liver and kidney may also required.

As a precautionary measure, it is recommended that Ca and P intake be reduced in breeding males for those producers within the relevant tissue treatment groups, as levels satisfactory for eggshell formation in the female may reduce Mn, Zn and Fe absorption in the male, and given the Ca concentrations in water and several of the tissues investigated, excessive exposure is a definite risk. As far as growing birds destined for slaughter are concerned, a farm-specific risk assessment is required as the results indicate the in some cases bone resorption may be occurring, suggestive of a Ca-deficiency.

Given the low Mn values that accompanied many of the high Ca values observed, and the propensity for fast growing chicks to develop porosis of the stifle between two to eight months, Mn supplementation ranges may have to be increased.

Further areas of research that require attention include the incorporation of additional farm-specific geochemistry data to ascertain the total exposure, seasonal variations in water quality, and detailed profiling of minerals in various tissues in ostriches that pose problems during the slaughter process.

ACKNOWLEDGEMENTS

The research and related outputs presented in this report emanated from a project funded by the Water Research Commission entitled:

"An extension to and further refinement of a water quality guideline index system for livestock watering"

The Steering Committee responsible for this project consisted of the following persons:

Mr DS van der Merwe	Water Research Commission (Chairman)
The late Mr AG Reynders	Water Research Commission
Dr H Meissner	Agricultural Research Council
Dr FK Siebrits	Agricultural Research Council
Dr JPJ Joubert	Agricultural Research Council
Prof NH Casey	University of Pretoria
Prof NFG Rethman	University of Pretoria
Dr JA Meyer	University of Pretoria
Mrs CB Coetzee	University of Pretoria
Ms M Hinch	Department of Water Affairs and Forestry
Mr AT van Coller	National Department of Agriculture
Dr CHM de Brouwer	North West Agriculture Development Institute
Dr A Bekker	KKK Abattoir
Dr WP Burger	Klein Karoo Kooperasie
The Director	SA National Parks
Mr AM Mahanjana	South African Agricultural Union
Mr JF Taljaard	Water Research Commission (Secretary)
Mrs CM Smit	Water Research Commission (Committee services)

The following people are thanked for their specialist input:

Mr T Marais from Incasa (Pty) (Ltd) for his invaluable assistance in all software programming aspects.

Dr J Myburgh from the Department of Community and Herd Health, Faculty of Veterinary Science, at the University of Pretoria for his assistance in collecting data from the Jericho District.

The late Mr P du Toit from Delftzyl Agricultural Research Station for his help and assistance in conducting experimentation and research in the Delftzyl and Immerpan Districts.

Prof TS Kellerman from the Department of Toxicology at the Onderstepoort Veterinary Institute, Agricultural Research Council, for his guidance in all matters toxicological.

Prof J DuP Bothma from the Department of Animal and Wildlife Sciences at the University of Pretoria for guidance regarding the wildlife aspects addressed.

Mr G van Dyk of the Pilanesberg National Park for the collection of data.

Ms K Wilson for assistance with the collection of data from the Klaserie Reserve.

Prof JBJ van Ryssen from the Department of Animal and Wildlife Sciences at the University of Pretoria for guidance in matters pertaining to mineral nutrition.

Dr C de Brouwer for guidance in the investigations conducted in the North West Province.

Mr K Ntshangase from the Potchefstroom ADC for assistance in the collection of data from the Barolong Community.

Mr R Moiloa from the Rustenberg ADC for assistance in the collection of data from the Zeerust District.

Mr EB Spreeth from the Department of Animal and Wildlife Sciences at the University of Pretoria for his assistance with laboratory procedures.

Mrs E Snyman from the Department of Animal and Wildlife Sciences at the University of Pretoria for her assistance with laboratory analysis.

Mr R Coertze from the Hatfield Experimental Farm at the University of Pretoria for his advice concerning the statistical analysis of data.

Prof HT Groeneveld from the Department of Statistics at the University of Pretoria for his assistance regarding the statistical analysis of data.

Dr PD Toens from Toens & Associates in geological aspects with reference to groundwater.

Prof B de Villiers from the Department of Community Health at the University of Stellenbosch.

Prof MC Williams from the Department of Pathology, Faculty of Veterinary Sciences, at the University of Pretoria.

The financing of the project by the Water Research Commission and the contribution by the members of the Steering Committee is gratefully acknowledged.

ABBREVIATIONS

AV	Antagonistic variable
Cat C/D/E	Category level C/D/E
CIRRA	Constituent Ingestion Rate Risk Assessment
COC	Constituent of Concern
CL	Crisis level
DWA&F	Department of Water Affairs and Forestry
DMI	Dry Matter Intake
EPA	(United States) Environmental Protection Agency
FI	Feed Intake
HA	Health Advisory
MPL	Maximum Permissible level
MRL	Maximum recommended limit
mg /L	milligrams/liter
RA	Risk Assessment
RefDoc	Reference Document
RCLPS	Rural Communal Livestock Production System
RL	Recommended Level
PHC	Potentially Hazardous Constituent
TWQR	Target Water Quality Range
TDS	Total Dissolved Solids
TOE	Types of Effects
WI	Water Intake
WQC	Water Quality Constituent
WQG	Water Quality Guideline
WRC	Water Research Commission
WPS	Wildlife Production System
WHO	World Health Organisation

CONTENTS

CHAPTER 1
INTRODUCTION 1

1.1 Risk assessment modelling for water quality guidelines for animals 1
1.2 Motivation for developing new CIRRA models 2
1.2.1 Rural communal livestock production systems (RCLPS) 3
1.2.2 Wildlife production systems (WPS) 5

CHAPTER 2
INORGANIC CONSTITUENTS: Beneficial or toxic? 6

2.1 Introduction 6
2.2 Background 7
2.3 Factors increasing and decreasing risk 9
2.3.1 Requirement 9
2.3.2 Livestock species variations 10
2.3.3 Soil factors 10
2.3.4 Animal product quality 12
2.3.5 Placental transfer 13
2.3.6 Detecting adverse effects due to WQC induced imbalances 13
2.3.7 Significance of constituent-constituent interactions 14
2.3.8 Importance of WQC:WQC ratios 16
2.3.9 Irrigation 16
2.4 The use of drinking water for supplementation and alleviator treatments 16
2.5 Water quality as an indicator of environmental toxicological hazards 19
2.6 The role played by geochemistry 19

CHAPTER 3
RURAL COMMUNAL LIVESTOCK PRODUCTION SYSTEM MODEL 21

3.1 Introduction 21
3.2 Dependency on local environment 22
3.3 Modelling 23
3.3.1 Aspects addressed by reference documents for the Domestic User Group 23
3.3.2 Aspects addressed by reference documents for the Livestock User Group 24
3.3.3 Brief overview of the RCLPS model 24
3.3.2.1 Main components 24
3.3.4 Reference documents incorporated for the Domestic User Group 26
3.3.4.1 Introduction to WTTCCIRRDs 27
3.3.4.2 WQC related risk factors for the RCLPS 28
3.3.4.3 Preferential Guideline Ratios 29
3.4 RCLPS – Domestic User Group 29
3.4.1 RefDoc – GG-TOE1 29
3.4.2 RefDoc – SU-TOE2 31
3.4.3 RefDoc – AV 32
3.4.4 RefDoc – FP-TOE3 32
3.4.5 RefDoc – IR-TOE4 33
3.4.6 RefDoc – ARF 36
3.4.7 RefDoc-PGR 37

3.4.8	RefDoc – WTTCCIRRD (water turnover temperature corrected – constituent ingestion rate reference document)	39
3.4.9	RCLPS REFERENCE DOSE (mg/D) Reference Documents	71
3.5	RCLPS – Livestock User Group	74
3.6	User Interface screen for the RCLPS model	75

CHAPTER 4

WATER QUALITY INVESTIGATIONS IN SELECTED RURAL COMMUNAL LIVESTOCK PRODUCTION SYSTEMS **90**

4.1	Introduction	90
4.2	Methods	90
4.2.1	Water sample collection and analyses	90
4.2.2	Guidelines and acronyms used for water quality assessment	91
4.3	Results	95
4.3.1	Barolong Resettlement Area	95
4.3.1.1	Introduction	95
4.3.1.2	Methods	96
4.3.1.3	Results: Sampling phase 1: Barolong Resettlement Area (Feb 1998)	96
4.3.1.4	Results: Sampling phase 2: Barolong Resettlement Area (June 1999)	98
4.3.1.5	Discussion	103
4.3.2	*Zeerust District – Rietgat and Hartebeeslaagte Communities*	104
4.3.2.1	Introduction	104
4.3.2.2	Methods	104
4.3.2.3	Results	104
4.3.2.4	Discussion	107
4.3.3	Jericho District: Summer Phase	108
4.3.3.1	Introduction	108
4.3.3.2	Methods	109
4.3.3.3	Results	109
4.3.3.3.1	Summer phase sampling for Jericho District	109
4.3.3.3.2	Winter phase sampling for Jericho District	121
4.3.3.4	Discussion	127
4.3.4	Delftzyl and Immerpan Districts	128
4.3.4.1	Introduction	128
4.3.4.2	Methods	129
4.3.4.3	Results	129
4.3.4.3.1	Sampling phase 1: Western Section of Immerpan (March 1998)	129
4.3.4.3.2	Sampling phase 2: Western Immerpan (November 1998)	133
4.3.4.3.3	Sampling phase 3: Central Immerpan farms (March 1999)	138
4.3.4.4	Discussion	144
4.4	Water quality results – implications for communities	144
4.4.1	Introduction	144
4.4.2	Main PHCs recorded in the communal areas investigated	145
4.4.3	Possible types of effects	145
4.4.4	High incidence PHCs	146
4.4.4.1	Arsenic	146
4.4.4.2	Beryllium	147
4.4.4.3	Bromide	147
4.4.4.4	Mercury	147
4.4.4.5	Selenium	147
4.4.4.6	Strontium	148
4.4.4.7	Titanium	148
4.4.5	Medium Incidence PHCs	149

4.4.5.1	Fluoride	149
4.4.5.2	Tellurium	149
4.4.5.3	Molybdenum	149
4.4.5.4	Manganese	149
4.4.5.5	Zinc	149
4.4.5.6	Vanadium	149
4.4.6	Isolated Incidence	150
4.4.6.1	Antimony	150
4.4.6.2	Cadmium	150
4.4.6.3	Chromium	150
4.4.6.4	Thallium	150
4.4.6.5	Lead	150
4.5	Conclusion	151

CHAPTER 5
WILDLIFE PRODUCTION SYSTEM MODEL **152**

5.1	Introduction	152
5.2	Main water quality issues for wildlife	153
5.2.1	Water quality constituents	153
5.2.2	Safe water – concentration versus dose	154
5.2.3	Dangerous concentrations?	155
5.2.4	Typical problems that occur	156
5.2.5	Identifying animal health problems	157
5.2.6	Extent of problems in South African water sources	158
5.2.7	What can be done by the manager?	158
5.2.8	Water quality monitoring	158
5.3	WPS model	159
5.3.1	Introduction to WPS model	159
5.3.2	Procedures and relevant reference documents	160
5.3.2.1	Data Capturing Screens for multiple watering points	161
5.3.2.2	Level 1 RA – Generic Application	163
5.3.2.3	Level 2 RA	163
5.3.2.3.1	Water exposure matrix	163
5.3.2.3.2	Reference Documents used for Level 2 RA	165
5.3.2.4	Level 3 RA	171
5.3.2.5	Level 4 RA	171
5.3.2.6	Level 5 – Ecological Risk Assessments	176
5.3.3	Wildlife User Group: Carnivores	178
5.3.3.1	Risk factors relevant for carnivores	180
5.3.4	Reporting of results	182
5.4	User Interface Screens for the WPS model	183
5.5	Conclusion	198

CHAPTER 6
WATER QUALITY INVESTIGATIONS FOR WILDLIFE **200**

6.1	Introduction	200
6.2	Methods	200
6.2.1	Water sample collection	200
6.2.2	Risk assessment formulation	200
6.3	Areas investigated	202
6.3.1	The Pilanesberg National Park (PNP)	202

6.3.1.1	Introduction	202
6.3.1.2	Results	202
6.3.1.3	Discussion	214
6.3.1.4	Recommendations	215
6.3.1.5	Summary of types of effects	218
6.3.2	Selati Game Ranch	219
6.3.2.1	Introduction	219
6.3.2.2	Methods	220
6.3.2.3	Results	220
6.3.2.4	Discussion	225
6.3.3	Klaserie Area	227
6.3.3.1	Introduction	227
6.3.3.2	Methods	227
6.3.3.3	Results	228
6.3.3.4	Discussion	
6.4	Conclusion	235

CHAPTER 7
RELEVANT TECHNICAL INFORMATION REGARDING CIRRA **236**

7.1	Programming CIRRA	236
7.2	Programming language	236
7.3	User interface	237
7.4	Database	237
7.5	Distribution of CIRRA	237
7.6	Updates to CIRRA	238
7.6.1	Updates to reference documents	238
7.6.2	Data Capturing Guide	238
7.6.2.1	Motivation for developing a DCG	238
7.6.2.2	Description	238
7.6.2.3	Example of DCG for Dairy Cattle	239
7.7	Conclusion	242

CHAPTER 8
CONCLUSIONS AND RECOMMENDATIONS **243**

8.1	General Conclusions	243
8.1.1	Rural Communal Livestock Production Systems	243
8.1.2	Wildlife Production Systems	246
8.2	Recommendations	246
8.2.1	Rural Communal Livestock Production Systems	247
8.2.2	Wildlife Production Systems	248

CHAPTER 9
REFERENCES **249**

LIST OF TABLES

Table 3.1	RefDocs that are used in the RCLPS model.	27
Table 3.2	Guideline modifications for Generic RCLPS.	75
Table 4.3.1.1	Summary statistics for the main PHCs and COCs identified from 15 water samples collected in the Barolong Resettlement Area during February 1998.	98
Table 4.3.1.2	Comparison between drinking trough and reservoir results.	98
Table 4.3.1.3	Summary statistics for the main PHCs and COCs identified from 22 water samples collected in the Barolong Resettlement Area during July 1999.	103
Table 4.3.2.1	Summary statistics for the main PHCs and COCs identified from 16 water samples collected in the Rietgat and Hartebeeslaagte communities.	107
Table 4.3.2.2	Comparison between drinking trough and reservoir results.	107
Table 4.3.3.1	Summary statistics for the main PHCs and COCs identified from 41water samples.	120
Table 4.3.3.2	Summary statistics for important ratios influencing fluoride toxicity.	120
Table 4.3.3.3	Summary statistics tor the main PHC's and COC's identified from 33 water samples	127
Table 4.3.3.4	Summary statistics for important ratios influencing fluoride toxicity.	127
Table 4.3.4.1	Summary statistics for the main PHCs and COCs identified from 11 water samples collected from the western section (IP1) of Immerpan District Farms (March 1998).	132
Table 4.3.4.2	Summary statistics for important ratios influencing fluoride toxicity.	132
Table 4.3.4.3	Summary statistics for the main PHCs and COCs identified from 16 water samples collected from the western section (IP2) of Immerpan District Farms (Nov 1998).	137
Table4.3.4.4.	Summary statistics for important ratios influencing fluoride toxicity for F = PHC.	137
Table 4.3.4.5	Summary statistics for the main PHCs and COCs identified from 21 water samples collected from the Central Immerpan District Farms during March 1999.	143
Table 4.3.4.6	Summary statistics for important ratios influencing fluoride toxicity for F = PHC.	143
Table 4.4.1.	Main potentially hazardous constituents recorded in the communal areas.	145
Table 5.1	Potentially hazardous water quality constituents from a borehole on a game ranch in the Phalaborwa district.	154
Table 5.2	Some information required to perform a risk assessment for water quality.	155
Table 5.3.1	Partial example of a Water Exposure Matrix for WPS.	164
Table 6.3.1.	Summary statistics for the main PHCs and COCs identified from 43 water samples collected from the PNP during October 1999.	213
Table 6.3.2.	Summary statistics for important ratios influencing fluoride toxicity.	214
Table 6.3.3	Classification of PHCs and COCS involved in the PNP - Summer.	218
Table 6.3.4.	Summary statistics for the main PHCs and COCs identified from 19 water samples.	224
Table 6.3.5	Impala liver values for Se and Cu from Selati and other Lowveld ranches.	225
Table 6.3.6	Description of water samples taken and species detected within 100m of in the Klaserie Area.	233
Table 6.3.7	Main PHCs and COCs recorded in the Klaserie Area from 25 samples.	233
Table 6.3.8	Estimation of possible ingestion (mg/d) to hazardous constituents within range clusters for some wildlife species in the south-east Klaserie area.	234

LIST OF FIGURES

Figure 3.1	RCLPS model.	25
Figure 5.1	WPS model.	162

CHAPTER 1

INTRODUCTION

1.1 Risk assessment modelling for water quality guidelines for animals

The growth and development of this research field has taken place over a number of years. An initial brief was obtained from the Water Research Commission (WRC) in 1990, with the request to verify criteria for water quality for beef cattle utilising subterranean sources along the North and North Western border regions of South Africa. This first project was expanded to include other livestock types, and in the Final Report: K5/301 (Casey *et al.*, 1996), the design of the guidelines then in use, were shown to be inadequate, resulting in inaccurate estimates of risk. The first report indicated how single value cut-off limits were not only poor indicators of risk under the vast majority of conditions, but more importantly, often resulted in the limitation of efficient water utilisation. This was demonstrated by conducting biological toxicological trials using sheep, cattle and poultry. These trials indicated that the animals could be exposed to concentrations of highly toxic water quality constituents (WQC), far in excess of the guidelines, for specific production periods (weaning to market weight for sheep and cattle), without incurring any adverse effects on growth, health or performance. This project also showed that the guidelines in use were negligent in not taking into account the major effect of palatability, which often resulted in a significant financial loss to the farmer.

A second WRC project, K5/644 (Casey *et al.*, 1998), developed the theme of a water quality guideline index system, formulated for project K5/301, even further. Through further biological experimentation, extensive region trials, and modelling, the project delivered a computer software program called CIRRA, an acronym for Constituent Ingestion Rate Risk Assessment. CIRRA conducts site-specific risk assessment based on the modelling of water, animal, environmental and nutritional data, to generate both risk assessment and possible solution options. The risk assessment generated is based on a water quality constituent ingestion rate, in mg/d/kg BW, corrected for metabolic water, and represents a radical departure from existing static tabulated guidelines (DWAF, 1996; EPA, 1998; WHO; 1993) which are all independent of production system effects, nutrition, environmental and animal factors, and appear in the form of a mg/L guideline recommendation. CIRRA caters for beef cattle, dairy cattle, goats, sheep, pigs and horses, but with the modelling emphasis on the commercial production system context (Meyer, 1998).

The Department of Water Affairs and Forestry (DWA&F) also engaged in reviewing water quality guidelines (WQG) for agricultural use, which included livestock watering. Through the outputs of these two WRC projects, two guideline editions for livestock watering emerged for the DWA&F, one in 1993 (DWA&F, 1993), and a second in 1996 (DWA&F, 1996). These are, however, still largely generic guidelines. As they appear in a tabulated format, utilising the DWA&F target water quality range concept, they fail to accommodate significant site-specific toxicokinetic and toxicodynamic factors, rendering their application to a conservative, at best generic, estimation of risk.

This report is the third WRC project concerning water quality guidelines for animals. The report deals with risk assessment modelling for two new CIRRA models, addressing two separate user groups, namely, rural communal livestock production systems (RCLPS) and wildlife production systems (WPS). The report also touches on refinements made to existing models in the software program CIRRA. It is recommended that the reader familiarize themselves with the final report from WRC project K5/644 (Casey *et al.*,1998) as it contains much of the scientific basis for the models described in this report.

1.2 Motivation for developing new CIRRA models

The primary purpose for developing a system that did not use a mg/L guideline format was to enable a multidisciplinary approach to be followed with regard to risk assessment formulation. This necessitated a guideline tool with the capability for two primary functions. The first function was to allow for all the major routes of ingestion to be incorporated (soil, feed and water) into the risk assessment. The second function was to allow for the application of known significant site-specific factors, beneficial or adverse.

As described in previous reports (Casey *et al.*,1996; Casey *et al.*,1998, Toens *et al.*, 1998), and this report, many local subterranean water supplies exceed local and international guidelines by large margins. By virtue of the mg/L design, current guidelines do little more than to alert the users of these supplies to the possibility of adverse effects occurring, at times arguably being overly conservative in estimation, a necessity brought about by safety factors incorporated due to the reliance on mg/L guidelines independent of the environment (WHO, 1993). The benefit of developing a risk assessment tool capable of a comprehensive, multidisciplinary approach, is that it would allow for the incorporation of mutually antagonistic factors which may effectively allow for the safe use of water containing WQCs in excess of the guideline limits.

The research conducted for the previous two WRC projects on water quality for livestock focused on addressing the needs of commercial livestock producers from a water quality guideline perspective. Two broad aims received attention:

- To identify and develop a guideline system where the significant factors relevant to performing risk assessments for livestock watering are taken into account.
- To guide the user of the guideline system via a diagnostic tool which would enable the application of proposed solutions on potentially hazardous water sources, and in so-doing, optimise the utilisation of available water sources.

During the research conducted solutions were formulated, and successfully tested, for palatability and toxicological water quality problems most frequently encountered in the South African groundwater environment (Casey *et al.*, 1998). These solutions are carried out by CIRRA, and are specific for livestock type, breed, production-category, and production-environment. A solution may therefore be proposed by CIRRA to reduce both the severity of fluorosis and adverse palatability effects of saline water on Dorper ewes being fed a maintenance ration under semi-extensive conditions. Whilst this approach is necessary for an accurate risk assessment to be conducted, it is not appropriate for RCLPS, nor does it find application for WPS. As each of these two production systems offer unique modelling challenges with regard to water quality risk assessment, they will be dealt with separately.

1.2.1 Rural communal livestock production systems (RCLPS)

As RCLPS differ substantially from commercial livestock production systems, the need for a new CIRRA model was identified (Casey *et al.*, 1998). Two main differences were observed to be relevant. Firstly, the water sources used in RCPLS were utilised by multiple livestock types and breeds. Goats, sheep, horses, donkeys and cattle often consume from the same drinking trough, and in the majority of cases for sheep, goats and cattle, mixed breeds were also present. As CIRRA Version 1.03 caters for specific water turnover rates that are breed specific, it does not find application under RCLPS. Secondly, CIRRA Version 1.03 requires production-category detail within a herd/flock as an input variable, the identification of which is seldom possible within RCLPS.

The primary modelling requirement in terms of predicting the outcome of events associated with providing water to animals in a RCLPS must therefore depend on a best-fit approach. If conducted with only the norms of health (toxicology and palatability) considered, livestock may be ranked according to sensitivity and various solution options formulated accordingly (water, feed and watering manipulation). However, in the RCLPS important complicating factors arise due to the association between the animals and humans. The observation of these factors became apparent whilst investigating the feasibility of applying alleviator treatments, used to reduce fluorosis in beef cattle under extensive conditions at the Delftzyl Agricultural Research Station, under RCLPS in the adjacent communities.

Important observations made in the communal areas were that the water source tends to be shared by both humans and animals, and that products from these animals formed a large part of the human diet.

The research conducted under WRC Project K5/644 formulated, and implemented, under extensive on-farm conditions at the Delftzyl Agricultural Research Station, an alleviator treatment for fluorosis in cattle. This was based on a series of experiments conducted at the UP Hatfield Expeirmental Farm (Casey *et al.*, 1996; Casey *et al.*, 1998; Meyer, 1992; Meyer, 1998). The following advantages and disadvantages apply:

Advantages: Easy administration of treatment
No trained technician required
Cheap cost of chemicals and equipment used
No brine to be removed
Can adapt stock incrementally
Can manipulate treatment for seasonal and WQC changes.

Disadvantages: Treatment must be administered continuously.

Other treatments for alleviating adverse palatability effects were developed for sheep, cattle and goats (Meyer, 1998). Communal areas were included in the water quality investigations and extensive region trials conducted. ***The shared utilisation of subterranean water sources by animals and humans require that consideration of the health norm for animals alone is not sufficient. It also poses a serious ethical concern and modelling consideration.***

The ethical concern is that solutions cannot be recommended for use in communal areas, even if they alleviate the adverse effects of hazardous constituents in livestock, whilst knowledge exists of shared utilisation of the water by humans. This is because the solutions recommended will in most instances, and certainly in their current form, render the water even more unfit for use by humans. Note that the water is in many cases, already unfit for human consumption, as indicated in chapters later in this report. The modelling considerations are that a best-fit option is required to cater for alleviator responses in both user groups, and that animal product quality from a consumer perspective (specifically rural subsistence users) must receive increasing attention.

A number of uncertainties exist:

1 To what extent does the presence of other WQCs mitigate or exacerbate adverse effects due to a single WQC.

2 To what extent do high WQC concentrations contribute significantly to alleviate existing trace mineral deficiencies in the diet of the communities involved.

3 To what extent do WQCs present in animal products such as milk, meat and organs, add to the dose intake already experienced by humans from the WQC present in water.

4 To what extent can alleviator treatments demonstrated to be effective for livestock be used to mitigate adverse effects in humans.

5 Is it financially viable to design and build the necessary structures to enable a single water source to receive multiple treatments, each specific to a different water user?

These considerations and uncertainties served to motivate for the development of a separate CIRRA model, designed specifically for RCPLS.

1.2.2 Wildlife production systems (WPS)

Wildlife production systems pose a number of complex challenges to water quality management. The most obvious is the diverse nature of the user groups, ranging from aquatic organisms requiring permanent water of acceptable quality, to desert animals with adaptive mechanisms which significantly reduce their dependence on drinking water. The user groups differ in physiology, water turnover, territory, feeding spectrums, and water provision design requirements. Perhaps not so obvious is the difficulty of predicting where, how much, and when, an animal drinks. As reported in previous WRC reports (Casey *et al*., 1996; Casey *et al*., 1998) during the phase of assessing which WQC in the aquatic environment posed the main hazards to animals, many farms were found to have multiple water sources that were used for animal watering. Furthermore, most of these sources differed significantly with respect to water quality, largely due to varied water sources (surface and subterranean) and fractured aquifers. As such, a borehole in one area of a game ranch may pose an unacceptably high hazard to animal health, but for those species consuming water from that source and other water sources, the net risk in terms of actual ingestion of a potentially hazardous constituent (PHC), may be acceptable.

It follows that some water sources will pose a greater risk to certain wildlife species than to others. Although this makes for complex guideline models, it affords the manager to opportunity to allocate poor quality water to least sensitive species. This is accomplished by matching habitat, territory, water provision design and immediate habitat with species. The degree to which management can, or wants to, intervene in a WPS, affects the degree to which alleviator treatments may be used, from the feeding of supplements to the application of water treatments. An additional issue requiring a new CIRRA model for WPS is that of the ecological impact of actually providing, designing, placing, and managing, water used for drinking and other purposes by wildlife. The effect of the presence, or absence, of wildlife on sacrifice zones, herbaceous plant communities and ultimately successful wildlife ranching, are but a few of the water quality considerations that needed to be addressed by the new CIRRA model.

CHAPTER 2

INORGANIC CONSTITUENTS: Beneficial or toxic?

2.1 Introduction

Previous WRC reports (Casey *et al.*, 1996; Casey *et al.*, 1998) indicated that a number of WQCs occur naturally within the aquatic environment at levels which can be considered, from an environmental toxicology point of view, to be potentially hazardous for animal watering. This report adds a number of additional trace minerals to the list. This report also presents two risk assessment models, one for wildlife, and one for rural systems. These models attempt to provide sufficient information to enable the user to determine the position of the water source being evaluated, in accordance with the usage context, within the complex area that resides between deprivation and toxicity. Failure to do this can result in the incorrect classification of a water source as not fit for use, whilst in reality the water source may provide a valuable source of essential, and beneficial minerals, to the diets of the users, both animal and human. The reverse is also true, with the possibility that a water source may be declared fit for use based on a per WQC guideline, but in reality multiple constituents are consumed from water, feed and the environment, creating the potential for induced deficiencies, imbalances, and toxicities.

The task is made even more complex by evaluating two additional areas of risk assessment. The first deals with multiple species utilisation of a single water source and the inherent tolerance differences which occur as a result of shared exposure, typically found in wildlife and rural systems. The second is concerned with bioconcentration and bioaccumulation risk for humans, directly and indirectly, and is a product of the type of livestock production system frequently found in rural systems. In order to convey the need, and complexities, of the issues dealt with in these models, a brief introduction to some of the relevant topics is necessary.

The following section provides a brief introduction to the important aspects relating to risk assessment formulation for many of the potentially hazardous WQCs found in the water quality investigations conducted and presented within this report. The purpose of this section is not to provide an exhaustive review of toxicodynamic and toxicokinetic issues as they pertain to WQGs. It is rather to provide the reader with an indication of the complexities involved in establishing causal relationships between constituents present in water, and the direct and indirect adverse effects that may occur in users. These complexities are presented under general headings, each of which are addressed to some extent in the rural and wildlife models developed for this project.

2.2 Background

Recognition of the important nutritional role played by minerals has increased due to the availability of methods to identify and measure mineral elements in body tissues and feedstuffs, and to describe responses to pure elements. Previously, mineral nutrition was considered to be of limited importance. Theiler *et al.* (1924) showed that phosphorus supplementation at Armoedsvlakte in the North Western Province increased growth rates and reproductive levels. Salt sick, identified in 1872 in Florida, was involved with deficiencies of Co, Cu and Fe. The acceptance of mineral deficiencies, or imbalances, as one of the most important limitations to grazing livestock production in tropical and subtropical climates, is growing. In the rural communal production systems in southern Africa, low energy and protein levels are often cited as the reason for suboptimal performance. However, numerous investigations have revealed that stock do not always respond favourably when abundant feed supply provides adequate energy and protein. Clinical signs such as wasting, alopecia, depigmentation, non-infectious abortion, diarrhoea, anemia, decreased feed intake, bone abnormalities, tetany, low fertility and pica, are frequently observed in ruminants in these systems, with mineral imbalances due to the ingestion of soil, water and feed, held responsible.

Geochemical anomalies have been recorded throughout the world to have a significant influence on health, with epidemiological studies revealing iodine, Zn, F, Al, As and many other trace minerals to induce either deficiency, imbalance or toxicity. The relationship between animal and human health, and the distribution of chemicals in the environment, was demonstrated by Webb (1964). Hertz (1986) documented deficiencies in livestock due to Co, Cu, Zn, Se and iodine. Darnley *et al.* (1995) showed soil and pasture to contain trace minerals at concentrations lower than requirement levels. Van Ryssen *et al.* (1992) demonstrated similar deficiencies in pastures in Natal with respect to Se. Mineral deficiencies and toxicities have been recorded in most tropical regions, including confirmed geographical areas for both deficient and toxic conditions (McDowell *et al.*, 1997), with F, Se and Mn recognised as prevalent toxic elements.

According to McDowell (1997) the mineral nutrition disorders characterised by vague unthriftiness or unsatisfactory growth and reproduction are of great importance, mainly as they occur over large areas. Consequently, large numbers of animals are affected, but additionally, the adverse effect may escape detection as the poor performance is accepted as an environmental limit. The occurrence of poisonous plants, protein deficiencies, infectious diseases and parasitism, complicate diagnosis. The expression of mineral disorders as poor growth and reproduction, although vague, are significant, as they usually affect large areas and large numbers of animals. Workers such as Denton (1967) and Becker *et al.* (1944) demonstrated that the attitude of cattle toward salt in a mineral supplement is inversely related to the salt present in water. As such, failure to correct ration and/or mineral supplement formulation for the minerals present in water may lead to incorrect assumptions regarding feed and/or supplement intake, and consequently mineral imbalances.

The confinement of animals and humans in a given area increase the incidence of mineral disorders (McDowell, 1997). The increased risk that accompanies geographically localised communities in terms of water quality, has been widely reported (Fuge, 1996). McDowell (1997) concurs with other workers as to the increased incidence and severity of mineral imbalances in animals and humans confined to localised geographical areas. Of the twenty-six elements known to be required by some animal species, Cr, Co, Cu, I, F, Fe, Mn, Mo, Se and Zn, are considered to be essential. The elements Cu, I, Mn, Mo, Se, Al, As, Cd, Pb, Hg and F, are considered to be potential hazards which may limit livestock production due to ingestion of excessive amounts, with excesses of F, Mo and Se extremely detrimental (McDowell, 1997). Trace minerals such as A, B, Pb, Ni, Si, Sn and V have recently been described as "essential" (McDowell, 1992), although practical essentiality has not been found. Fluoride and Mo, both recorded as PHCs in the areas investigated in this report, are examples of PHCs in the geochemical environment with a narrow concentration range (a few orders of ug/g) between essential and toxic levels.

As the water quality investigations presented in this report indicate, both cations and anions may be supplied by water. Late-gestation cows offered negative dietary electrolyte balanced diets (anionic/acidogenic diets) have lowered incidences of milk fever, possibly due to induced metabolic acidosis facilitating bone-Ca resorption, with improved lactational performance and health (Beede, 1992), and water with high concentrations of Cl and SO_4 may aid in preventing milk fever. Water supplying high concentration of Na and K, on the other hand, may induce milk fever.

Thus, WQGs need more of a composite, production-orientated or contextualised approach, if they are to accomplish the task of accurately describing the likely effects associated with use, beneficial and detrimental. That WQGs need to do this at all is not unanimous. The luxury of having guidelines formulated for each WQC separately, focused on the adverse effects that may occur, and presented without incorporating any site-specific risk factors, is only appropriate where the selection of alternative water sources are made possible by an abundance thereof. Few communities and production systems in southern Africa can afford such a luxury. However, currently the consequence of simply relying on guidelines as a means of indicating the possibility for adverse effects creates the misconception that the less constituents that are present in the water, the more suited it will be for ingestion. This misconception effectively results in a decrease in the utilisation of water sources that may in fact be a rich, valuable source of nutrients. As this report will indicate, the composition of groundwater in the areas investigated, according to most available guidelines, should prohibit the use thereof for both animals and humans. In none of the areas investigated was application of the current guidelines of any benefit, predominantly as alternative water sources were not available. Water consumption by domestic and livestock continued irrespective of possible adverse effects. When the role of water quantity, within the context of rural communal production systems, is included in the description of water quality effects, the need for guidelines describing beneficial and detrimental effects, incorporating site-specific risk factors, becomes apparent.

New techniques for geochemical survey, trace mineral identification and speciation in biological tissues, are leading to an increase in data indicating the nature and extent to which inorganic elements in diets or drinking water affect humans and animals. According to Plant *et al.* (1996) potentially hazardous elements tend to have adverse effects at relatively low levels, and include As, Cd, Pb, Hg and the daughter products of U. Sposito (1989) adds Al to the list. Plant *et al.* (1996) also adds that all trace minerals are toxic if ingested at sufficiently high doses for long enough periods of time. This should be seen in light of the fundamental basis of toxicology, relating to dose and exposure, and in context of the environmental and production systems of the areas investigated in this report.

2.3 Factors increasing and decreasing risk

2.3.1 Requirement

One of the fundamental decisions that must be made regarding the fitness for use of a water source requires knowledge of the degree to which the water source fulfils the user's requirement. Although this may appear an easy task, and certainly many guidelines available adopt a simplistic approach, the discrepancy between effects observed in case studies, and predicted effects, would indicate otherwise. One of the root causes rest on the inherent variability of requirement. The mineral requirements for beef cattle, formulated by the NRC (1996), indicate at times a larger variation between ranges for levels of production, than between suggested requirements and toxicities, partly due to buffering by homeostatic mechanisms, but also due to the variable nature of the optimal mineral dose. Variations between livestock types with respect to the bioavailability of specific forms of minerals, requires WQGs to be species specific. For example, elemental Se is largely unavailable to chicks, but effective in protecting against Se deficiency in sheep and cattle (Underwood, 1981). Inadequate protein and energy levels typically found in ruminants in rural production systems during the dry season also lowers the requirement for minerals, possibly placing livestock at greater risk to toxic consequences (Van Niekerk & Jacobs, 1985). Although South Africa has confirmed geographical regions with Se and F toxicities, the extent of affected areas is not generally appreciated (McDowell, 1997).

The presence of inorganic constituents in the water supply may have more of an effect on inducing trace mineral imbalances than those in the feed (organically complexed), as organic forms lack the same degree of interaction with vitamins and other ions as inorganic forms. Inorganic forms are considered to be more toxic, despite many having a lower bioavailability compared to organic forms (McDowell, 1997). The Cu-Mo-S complexing in the digestive tract of the ruminant is a well documented example of this (Nelson, 1976). For some minerals, such as Se, despite the organic forms yielding higher tissue values than inorganic forms (McDowell *et al.*, 1997), inorganic forms have more pronounced systemic effects on GPX activity (Underwood & Suttle, 1999). Feeding mineral supplements can increase the probability for mineral toxicity (McDowell, 1997). Cattle were observed to prefer an acid supplement (pH 3.5) such as dicalcium phosphate as opposed to defluorinated phosphate (pH 8.5) (Coppock *et al.*, 1988). The lower pH level not only contains more F, but the uptake of F is enhanced in an acid environment. Ammerman *et al.* (1973) reported Pb and As levels in Mn-oxide mineral supplements to vary between 660 – 2180 ppm and 119 – 1400 ppm respectively. According to McDowell (1997) zinc-oxide sources could contain 3% Pb, 149 ppm As, and 1290 ppm Cd. Berg (1990) reported a phosphate source to contain 1400 ppm V.

2.3.2 Livestock species variations

Distinct differences are often found in various livestock species with respect to tolerance to imbalances induced by the ingestion of inorganic WQCc. As an example, ruminants are susceptible to a Co induced vitamin B_{12} deficiency, a condition not yet demonstrated in non-ruminants. Horses and other non-ruminant species appear to grow normally in areas where grazing ruminants develop Co deficiency. Copper responsive disorders, although naturally occurring in ruminants, are rare in non-ruminants.

Differences between ruminants also occur with respect to susceptibility to excessive, or deficient, intakes of PHCs. Sheep are more susceptible to Co deficiency than cattle, perhaps due to a higher requirement of S-amino acids for wool growth, with ovine white liver disease a related disorder. In this instance, the demand in a trace-element-dependent function appears to influence the clinical manifestation of a disorder (Underwood & Suttle, 1999). Tolerance to Cu provides another example, with sheep being extremely intolerant of Cu excess, whereas pigs are highly tolerant. Most WQGs do not include iodine, supposedly on the basis of a low inherent toxicity, but equines are especially susceptible to iodine poisoning. Most species are tolerant to levels < 50 mg I/kg DM, whilst the horse has a tolerance level as low as 5 mg I/kg DM. The implication of these variations is that water of a specific quality may be unfit for use by one species, but acceptable by another. In the commercial livestock production system context this is easy to address, but as most wildlife and rural production systems comprise a mixed user group that is exposed to the water supplied, the provider must often find ways to reduce exposure, or the potential hazards, in sensitive user groups.

2.3.3 Soil factors

Soil, plant, pasture and climatic factors all influence the concentrations and biological availability of minerals in plant matter. Most natural occurring trace mineral imbalances due to trace mineral levels in plants are a direct consequence of soil chemistry (Reid *et al.*, 1984), but unfortunately, these factors do not influence all minerals in the same manner. For example, high soil pH can decrease plant levels, and availability, of Fe, Mn, Zn, Cu and Co, but also increase Mo and Se levels and availability (McDowell, 1985).

Geophagia may present a hazard for grazing animals (Barry *et al.*, 1981), and ruminants may inadvertently ingest as much as 20% of DMI as soil (Healy, 1973; 1974). This can significantly increase the intake of toxic elements (Rosa, 1980), with Cu deficiency being induced due to a resultant increased intake of Mo and Zn, which are present in a biologically available form in soil (Suttle *et al.*, 1975). Soil factors can also play a significant role in the outcome of adverse effects due to the presence, or absence, of a constituent in the drinking water, and must therefore be accounted for in a risk assessment. As an example, soil contamination of Co can significantly alleviate Co deficiency by contributing to the total ingestion (Clark *et al.*, 1989). On the other hand, high soil Mn and heavy liming can depress plant Co uptake, effectively increasing the degree to which the presence of Co in the drinking water acts as a beneficial source that fulfils the animals requirement (Minson, 1990).

Involuntary or deliberate ingestion of soil can have pathological implications. On Delftzyl Agricultural Research Station, very high soil fluoride concentrations have been measured, and form a significant portion of the ingested fluoride in livestock, offering a possible explanation for the lower incidence of dental fluorosis in goats, compared to cattle, who tend to graze closer to the ground, less selectively and do not have the benefit of less soil-contaminated browse as a significant portion of their diet. Clays with high cation exchange ratios can release trace minerals under acid digestive conditions, increasing the amount of available copper, iron, manganese, zinc, and a number of macro-elements. Clays have been found to be a causative factor in growth retardation, anemia and delayed puberty in humans in the Middle East (WHO, 1996). High soil Mo levels, and seasonal factors influencing Cu antagonists, such as high herbage Fe levels in spring, can induce hypocuproses (Underwood & Suttle, 1999). Whilst forage Cu levels are not influenced by soil pH, Mo levels are increased on alkaline soils. Liming on granitic soils can raise Mo levels to levels which significantly decrease the Cu:Mo ratio (Whitelaw *et al.*, 1983), effectively predisposing ruminants to Cu related disorders, effectively increasing the allowable concentration of Cu in water. The relationship between soil pH and plant mineral levels may be linear, as is the case with Mo, or inverse, as exists between soil pH and plant Mn uptake (Mitchell, 1957). High soil pH and arid conditions elevate plant Se levels (Arora *et al.*, 1975), a significant relationship is view of the Se concentrations returned from water samples presented in this report.

Although plant species grown on the same soil vary in mineral content, herbs and legumes tend to have higher levels than grasses. Mature plants also tend to have lower levels, with the exception of Ca. Most subtropical forages contain lower mineral concentrations during the dry season, but soil contamination by wind may reduce this effect. The increase in mineral deficiency symptoms observed in livestock during the wet season, is more a factor of increased requirement than reduced plant levels. Iron deprivation is usually of little practical significance as the Fe content of soils is typically many times that of the plants they support, so ingestion is never low enough to produce deprivation. Hence, for grazing animals, Fe present in the water will usually be utilised to attain the daily requirement, but rather provide an excess which will need to be excreted, or which will interfere with the absorption of other essential minerals.

2.3.4 Animal product quality

The relationship that exists between concentrations of PHCs in the drinking water supply and animal products, differs from being positive, non-responsive, to negative. Milk Co, iodine and Se (Meneses *et al.*, 1994) are examples of WQCs whose levels can rise significantly in response to increased ingestion rates. Iron and Mn concentrations on the other hand are very low, and generally unresponsive to increased intake. Differences in these relationships may also occur between various tissues and product, for example, milk is inherently low in Cu, whilst liver meal may contain moderate Cu levels. The relationship can also be influenced by WQC-WQC interaction, as an example the milk from sheep and cattle fed high-Mo, low-S diets, can have Mo levels several-fold above the normal 0.06 mg Mo/L. Species variations also occur, with normal Cu levels in milk reported to vary widely between livestock species, with cow and goat milk being ca. 0.15 mg Cu/L, and sows 0.75 mg Cu/L. With regard to RCLPS, it is noteworthy that milk iodine levels of > 2mg/L in cows confirm iodosis (Hillman & Curtis, 1980). Bovine milk iodine levels may increase to levels which elevate the risk of thyrotoxicosis in humans, whilst still being tolerable to the cow (Phillips *et al.*, 1988). Hence, in the RCLPS context, simply observing the animals for early warning detection signs of the waters fitness for use may overlook risk for humans. Furthermore, assessment of fitness for use must not be confined to animal health effects, but rather include associated risk to humans consuming animal products. In the Jericho, Immerpan and Hartebeeslaagte communities investigated, the majority of people claimed that they milked cattle and goats for household consumption.

Chatterlee *et al.* (1995) notes chronic arsenic poison due to groundwater arsenic levels are documented on five continents, with biological accumulation, and concentration, of geologically derived arsenic often a contributing factor. One of the most relevant aspects requiring attention with respect to groundwater usage by livestock and humans in rural communal systems, such as those found in the areas investigated in this report, relates to the issue of diet quality for humans, and the important contribution that animal products can make. Animal products such as meat, milk and eggs, are a compact an efficient source of micronutrients (Neumann, 1998). It must be noted that benefits are both direct, via consumption, and indirect, via the improvement of human nutrition by the added buying power sourced from the sale of livestock products. Multiple trace element deficiencies continue to be reported in developing communities in Africa (Neumann, 1998). Whilst this report concerns itself with minimising the risk that animal products may hold for human consumption in the rural subsistence context, it must be mentioned that animal products offer these people an almost exclusive source of dietary vitamin B_{12}, pre-formed vitamin A, riboflavin, and a number of trace elements. As a result, the risk assessments conducted, and resultant modelling, are designed to prevent the incorrect classification of a valuable nutritive source for the human diet. However, in order to accomplish this cognisance must be taken of the potential for animal products with elevated concentrations of certain trace elements to induce, or aggravate, any predisposing imbalance and/or deficiencies that may exist.

2.3.5 Placental transfer

Placental transfer may take place in accordance with concentration gradients, actively against concentration gradients, or show no response, to varying levels of PHCs in water. Placental transfer of Co is not marked (Grace *et al.*, 1986), whereas calf liver Mn values can be increased by supplementing the dam (Howes & Dyer, 1971). Placental transfer of Se responds positively to Se supplementation (Langlands *et al.*, 1990). This relates to water management in terms of water allocation in many of the areas investigated. A positive linear relationship for a WQC will result in pregnant animals being classed as a sensitive user group for a water source containing potentially hazardous levels of that WQC, as is the case for Se. The reverse is also true, affording the manager with a means for allocating water with PHCs to non-sensitive groups without the user incurring a health related risk.

2.3.6 Detecting adverse effects due to WQC induced imbalances

With many trace mineral deficiencies subclinical unthriftiness may go undetected, as it is readily confused with symptoms of parasitism and underfeeding. Many trace mineral toxicities do not present with distinctive pathological features. As is true with all cumulative poisonings, it is not the dietary concentration, but rather the total available dietary intake, that determines the risk of chronic disorder (Underwood & Suttle, 1999).

Low energy and protein levels, infectious diseases, parasitism and the occurrence of toxic plants, render the diagnosis of mineral disorders difficult. Some trace minerals, such as Pb, are not phytotoxic, but may occur in elevated concentrations in plant matter and can cause adverse effects in humans and animals, without a clear indication of the primary source of the hazardous ingestion route. According to Mills (1996), the whole system must be evaluated, from geochemistry to biological tissue, in order to diagnose correctly. A common misleading statement made is that many WQCs are of low toxicity to all species, but this is only true if toxicity is assessed as a multiple of a minimum requirement and when there is a 100-fold margin of safety (Underwood & Suttle, 1999). Cobalt is often classed as having a low order of toxicity, but in terms of dietary concentrations, Co is surpassed only by Cu, Se and I as a threat to health, with field cases of Co toxicity in ruminants having been reported (Dickson & Bond, 1974). Excess of one trace mineral can induce a deficiency of another trace mineral. However, some deficiencies do not yield a high correlation between depletion and deficiency phases and changes in concentrations of the trace mineral at accessible sites (Underwood & Suttle, 1999). Thus, the clinical manifestations of deprivation may only appear once dysfunction has already been effected, and when the animal is in a diseased stage. Iodine is a cumulative chronic poison, causing a paradoxical hypothyroidism, further complicating detection.

Selenium deficiency causes impaired reproductive performance in males and females in all animal species (Underwood & Suttle, 1999). One of the most economically important manifestations of Se deficiency is "ill-thrift", but this is subclinical with no distinctive pathological features or microscopic lesions.

Narrow margins between essential and toxic doses are known to exist for some WQCs. Although Se is considered by Underwood and Suttle (1999) as the most toxic of the essential trace minerals, deficiencies present significant limitations to successful livestock production. Maximum recommended levels for Se are difficult to define as tolerance is influenced by a number of variable factors, such as the chemical forms of Se, duration and continuation of intake. Effects may manifest rapidly, as was found in chicks exposed drinking water levels of 4 mg Se/L, in which reductions in growth and appetite occurred within 7 days (Canto *et al.*, 1984). Requirements vary from form of diet and between species, as is indicated by the following estimates for Se requirements by Underwood and Suttle (1999):

sheep (all stages)	=	0.03 mg Se/kg DM (low digestibility diet – DMI of 0.7 kg/d)
		0.05 mg Se/kg DM (highly digestible diet – DMI of 0.4 kg/d)
cattle – beef	=	0.036 mg Se/kg DM
cattle – dairy	=	0.044 mg Se/kg DM (10L milk yield/d)
		0.07 mg Se/kg DM (30L milk yield/d)
non-ruminants	=	0.1 mg Se/kg DM

According to Mills (1996) there are two main groups of potentially hazardous elements in the geochemical environment which can give rise to disorders associated with essential elements, the first order transition elements Fe, Mn, Ni, Cu, V, Mn, Co, Cr, and Mo, Sn, Se, I, F and B.

2.3.7 Significance of constituent-constituent interactions

Interactions between minerals confound risk assessment, but must be considered in order to establish if a hazard exists or not. When assessing the probable adverse effects associated with the ingestion of water containing a potentially hazardous concentration of a WQC, most guidelines assess risk independently of significant WQC-WQC interactions. The beneficial effect of Cu on alleviating Mo induced scouring disease in cattle illustrated the importance of the interaction between these two trace minerals (Ferguson *et al.*, 1938, 1943). Similarly, chronic Cu poisoning of sheep and cattle associated with low Mo intakes have also been demonstrated (Dick & Bull, 1945). Further work showed that inorganic SO_4 was required for this limiting effect on Cu retention (Suttle, 1991), bringing the total WQCs that need to be considered when performing a risk assessment to a minimum of three. High SO_4 levels in groundwater have also been recorded to cause growth retardation in heifers and neonatal mortality (Smart *et al.*, 1986).

These interactions are seldom simplistic. Antagonisms relevant to risk assessments for Cu include Mo X Cu, Mo X S, Cu X Fe, Zn X Cu, and Cd X Cu (Jarvis & Austin, 1983; Suttle, 1996). The nature of the relationship between various WQCs may be reversed for different livestock species. According to Hartmans and van Ryssen (1997) the addition of Se predisposes sheep to Cu poisoning, whereas increasing dietary Se reduced Cu induced chick mortality (Leach *et al.*, 1990). Prevention of Cu poisoning can be effected by exploiting the known antagonists of Cu (Underwood & Suttle, 1999), most notably Mo and Zn. However, Zn does not afford protection against Cu poisoning in the presence of Fe (Rosa *et al.*, 1986) for sheep, although Fe and Zn in similar concentrations can protect pigs and poultry (Suttle & Mills, 1966). The absorbtion of Se in both ruminants and non-ruminants as selenate may be reduced by antagonism from Mo and SO_4 (Abdel-Rahim *et al.*, 1985).

The relative concentrations of various WQCs must therefore be seen in relation to the type of effect, deficiency or toxicity, most likely to occur. According to Underwood and Suttle (1999), due to prominent antagonisms between Fe and essential trace minerals (notably Cu), Fe should never be used in mineral supplements for grazing or mature housed ruminants. With many livestock supplements available, the effect of these on the metabolism of WQCs must be accounted for prior to assessing the fitness of use of a water source. As an example, conditions of high Cu supplementation can induce a secondary Fe deficiency in pigs (Bradley *et al.*, 1983). Although some WQCs are considered to be of importance primarily due to deficiencies, chronic overload can lead to adverse effects. The cytotoxic action of free Fe may cause peroxidative damage to Fe storage sites, such as the liver, under conditions of excessive chronic Fe overload (Kent & Bahu, 1979). Excessive Mn intakes have been observed to reduce growth rate and heart and plasma Fe concentrations, despite high background pasture levels of Fe of up to 2200 mg Fe/kg DM (Grace, 1973). This is thought to be due to a mutual metabolic antagonism at the absorptive site. The anorexic effect from excessive intakes of Mn supplements have been observed by Grace and Lee (1990).

Induction of the mucosal metal-binding protein metallothionein usually limits Zn absorption at high intakes (Cousins, 1996). Copper, Cd, and possibly Se, effectively limit the amount of Zn available for absorption by increasing the mucosal binding of Zn by metallothionein (Bremner, 1993; House & Welch, 1989). Most WQG state that adverse effects due to excess Zn intakes are unlikely. However, in the absence of sufficient Zn, heavy metals such as Hg, can have markedly increased uptakes (Kul'kova *et al.*, 1993), with even marginal Zn deficiencies being a risk factor in areas with high occurring levels of heavy-metals. Some of the difficulties in estimating requirements for Zn, stem from variances in dietary Ca levels and chronic infections of the lower digestive tract. Although livestock appear tolerant of high Zn intakes, this depends on Ca, Cu, Fe and Cd levels (Underwood & Suttle, 1999). Toxic effects on weanling pigs were recorded at 4 g Zn/kg DM (Hsu *et al.*, 1975), but 3 g Zn/kg DM has been found to enhance the growth of weanling pigs in another study (Smith *et al.*, 1997).

Arthur and Beckett (1994) suggested that concurrent selenium and iodine deficiencies were particularly hazardous in the induction of iodine deficiency disorders. High F and As intakes are thought to contribute to the incidence of human goitre, a noteworthy relationship in view of the prevalence of this disease in developing countries worldwide. Despite a wealth of evidence to indicate that interactions between WQCs may impact either positively, or negatively, on the potential for toxicity of a given constituent, WQGs do not take them into account, predominantly as these relationships are complex and many are still being described (Underwood & Suttle, 1999).

2.3.8 Importance of WQC:WQC ratios

Knowledge of the recommended ratios of various constituents, either for absorption, excretion, or systemic effects, not only enables a more accurate assessment of risk to be made, but also for more potential alleviator solutions to be formulated. The section dealing with WQC-WQC relationships refers.

For example, a ratio of Cu:Mo of 4:1 is required to avoid swayback in sheep (Alloway, 1973). Unfortunately, the ratio level does not reflect Cu stores, or the influence of S and Fe. As a result, flexible ratio interpretation is required, taking Cu:Mo <1 (or Fe:Cu >100) to indicate high risk, and ratios of Cu:Mo of 1-3 (Fe:Cu of 50 – 100) to be marginal. Since Fe and Mo do not act additively, the effects cannot simply be combined. According to Underwood and Suttle (1999), Cu:Mo:S ratios can be deterministic in the occurrence of Cu and Mo related disorders. Although S is usually sufficient to allow for the expression of both antagonisms, S intake from drinking water must be allowed for (Smart *et al.*, 1986). Information regarding WQC:WQC ratios is used predominantly in the RCLPS models.

2.3.9 Irrigation

In New Zealand, diarrhoea was observed to occur in sheep grazing pastures irrigated with high groundwater levels of Fe, but this was associated with Cu depletion. The depletion of liver Cu and induced diarrhoea in cattle exposed to pastures irrigated with Fe-rich groundwater has been recorded (Campbell *et al.*, 1974).

Communities utilising a single, or a few, groundwater sources, and which have a food supply restricted to locally grown food sources are at greater risk of trace mineral related effects on health due to trace minerals in the drinking water. Often, relationships between drinking water, irrigation and solar evaporation are insufficiently characterised to be of value in predicting risk of disease in specific areas (Mills, 1996), and site-specific data must be collected.

2.4 The use of drinking water for supplementation and alleviator treatments

The use of mineral-containing fertilizers is mostly economically prohibitive (McDowell, 1997), with variable plant uptake, complex soil-plant-mineral interrelationships, and animal selection, frequently providing unsatisfactory and highly variable results. The most efficient method for supplementation is in combination with concentrates, predominantly as intake is usually adequate. Unfortunately, this method is not appropriate for rural systems where the animals rely on grazing for nutrition. According to McDowell (1997) the direct administration of minerals to water, licks, drenches, injections and rumen preparations is the most economical. The use of water as a vehicle for mineral supplementation is favoured when only one source is available, or when the watering system allows for a continuous infusion. Major benefits to this system include knowledge of the dosage (concentration x intake), and for drinking water as compared to drenches or oral dosing, the lowered labour costs and reduced handling stress on the animals.

The presence of naturally occurring inorganic WQCs in the drinking water source contributes to the user's requirement of that constituent. For some constituents, the form of the constituent typically found in water is more available than those found in feed, for others the reverse is true. Differences in post-absorptive metabolism of organic and inorganic Se sources are significant, with some inorganic forms more available for the synthesis of selenoproteins than selenomethionine, the most common organic form (Davidson & Kennedy, 1993; Henry & Ammerman, 1995). The ruminant also appears to absorb inorganic Se from concentrates far more than organic Se from forages (Koenig *et al.*, 1997). In terms of reducing the adverse effects associated with trace element excesses, prevention is required as poisoning is incurable, Se being an example of this. Increasing concentrations of mitigating WQCs provides a form of prevention. For some minerals there is indication that absorption is increased when accompanied by water ingestion, as opposed to feed ingestion, due to the different digestive tract conditions that arise. Gradient differences in pH, often saliva-flow influenced, play a major role. According to McDowell (1997) it may be more economical, and as nutritionally sound, to supply minerals, which are only 50% available at twice the level as it is to supply a mineral that is 100% available.

In addition, the direct addition of chemicals to the drinking water, either to supplement a deficiency, or ameliorate adverse effects, has a number of associated benefits. Administering Co via the drinking water is means of direct supplementation (Underwood & Suttle, 1999). Prevention of Cu poisoning can be effected by exploiting the known antagonists of Cu (Underwood & Suttle, 1999), most notably Mo and Zn. Inorganic sources of Mn maintain a high absorbability in the presence of phytate, being in the range of 10.3% (Wedekind *et al.*, 1991). This accords with values obtained for humans, and may well apply to non-ruminant species (Johnson *et al.*, 1991). There does not appear to be any advantage in ruminants fed organic forms of Zn as opposed to inorganic forms (Baker & Ammerman, 1995).

A number of elements can alleviate adverse effects due to excessive Se intakes, namely As, Hg, Au, Cu and Cd (Underwood & Suttle, 1999). Supplementation of Na_2SO_4 was recorded to alleviate growth inhibition effects in rats due to exposure to high levels of inorganic Se (Halverson & Monty, 1960). Problems with the use of these elements in mitigating adverse effects have often been attributed to irregular intakes, a reflection of the variation achieved by the methods used. In the case of Se, the use of As containing licks, administration of various soil and dietary treatments, all offer varying degrees of success. Supplementation of the drinking water offers a viable, effective, alternative. This is predominantly due to better control over the concentrations offered to animals, and a less variable daily intake. Aside from the benefits of supplementing directly in terms of less variance in intake, both daily and weekly, one of the major benefits with water supplementation lies in the accuracy of treatment concentrations. This does not rely on estimating lick intakes by stock, something which not only varies for zero to far in excess of the estimated intake within a group of animals, but which may also need to be regulated by salt percentage inclusion, at times an unsuccessful method. McDowell (1997) recommends supplementation of the water supply as a direct treatment of Ca and P deficiencies. However, if ground rock phosphate is used as the source, poor palatability and excess F, may pose a risk. In some instances, defluorinated phosphates are used in conjunction with fertilizer phosphates (McDowell, 1985).

The use of rumen pellets in correcting mineral imbalances has found but often lack the flexibility of drinking water administration to adjust the dosage in accordance with seasonal variations in pasture levels. Free-choice mineral supplementation is often used on the basis of the animal demonstrating "nutritional wisdom", but as has been shown by many workers, ruminants have no particular desire for minerals other than common salt. The major difficulty with the "free-choice" system is high individual variation in intake.

According to McDowell (1992) the following factors contribute to a highly variable free-choice mineral intake by grazing livestock:

soil fertility and forage type
season (higher intake in winter)
availability of energy-protein supplements
individual requirements
salt content of drinking water
palatability of mineral mixture
availability of fresh mineral supplies
physical form of minerals.

Whilst water intake is variable between animals, and over time, generally it is less variable than free-choice intake due to less of the above-mentioned factors playing a role. Between animal variation with regard to mineral supplement intake is also highly variable. Ullrey *et al.* (1978) observed ewes to vary in salt consumption from 2 – 14 g/day, despite the widely accepted intake figure of 15 g/day (McDowell, 1996). White *et al.* (1992) observed an average consumption of 29g/day for sheep, whilst it is often reported that a proportion of animals in a flock make little or no use of free-choice mixtures. If access to water is granted, water intake does not suffer from this degree of variation, with all animals consuming water on a daily basis. Poorly designed mineral feeders may also suffer from caking, moulding and trace mineral loss due to wind.

2.5 Water quality as an indicator of environmental toxicological hazards

According to Underwood and Suttle (1999) drinking water iodine levels are inversely correlated to the incidence of endemic goitre in humans in many parts of the world. This is primarily attributed to the water concentration reflecting the iodine content of soils and hence forages. As such WQC concentrations offer additional guidance as too what other geochemical hazards may exist. The wildlife and rural models developed also rely on known WQC-WQC relationships to suggest additional constituents which should be analysed in water, feed, and/or soil, by the user.

Geochemical and hydrogeochemical data provide a valuable means with which the impact of trace minerals on health can be assessed, as diagnostically specific signs of excessive or deficient element supply are infrequent. Water quality guideline based predictions are often insufficient in their recognition of the significant antagonistic interactions due to inorganic imbalances to allow for accurate, or meaningful, aetiological studies of disorders (Mills, 1996). According to Plant *et al.* (1988) and Darnley *et al.* (1995), geochemistry, and in particular, trace mineral distribution, can be difficult to predict from geological maps alone. Furthermore, the geochemistry of many elements is not fully, or even well-understood, for example selenium, and predictions can be misleading. It is for this reason that water sample analysis is one of the most valuable items in assessing the actual ingestion related exposure, and hence risk, associated with the geochemical environment. Some relevant issues relating to geochemistry are presented next.

2.6 The role played by geochemistry

Relationships identified recently include pathogenesis of skeletal lesions associated with excessive F in India, low Se concentrations in soil and animals inducing cardiomyopathy of Keshan disease in children, high soil Se and selenosis in Chinese, and many iodine-responsive diseases, for which an estimated one thousand million people are at risk (Hetzel & Welby, 1997).

Most advances made in applied investigations in mineral related deficiencies, toxicities or imbalances, have utilised purified diets, and the recognition of the importance of site-specific geochemical factors in altering the level at which adverse effects appear, and the nature of those effects, although fairly recent, is growing (Mills, 1996; WHO, 1996). Concern for mineral toxicities is increasing (Appleton, 1992). A number of the trace minerals identified to be present at potentially hazardous concentrations include those identified as newer essential elements by Underwood and Suttle (1999), namely, B, Cr, Ni, Mo, Sn and V. According to

Plant *et al*., (1996) PHCs tend to have adverse effects at relatively low levels, and all trace minerals are toxic if ingested at sufficient doses for sufficient periods of time, incorporating contextual toxicology.

Site-specific soil and geochemical factors influence trace minerals in food (plant and animal) and drinking water, and consequently affect the pathological consequences to animals and humans. Some examples include the geochemical composition of rocks from which soils are derived which can results in regional crop deficiencies of Cr, Cu, iodine, Fe, Se, Zn, and excesses of As, Cd, F, Pb and Se. The variable uptake of trace minerals by plants can be influenced by soil moisture, acidity and/or alkalinity. Alkaline groundwater can increase Se and Mo uptake, whereas iron-rich groundwater can restrict plant-selenium uptake. The former is vital information when conducting a WQG based risk assessment, and of particular relevance to the high incidence of the PHC's fluoride and selenium observed in the areas investigated. Implications are referred to in the respective discussions, but briefly, the risk for both human and livestock user groups is increased in these areas due to the effects of geochemistry and the toxicological interaction between Mo and F. A critical factor aiding risk assessment for animals and people, not only the rock type and resultant soil composition, but the main food crop used. In general, cereal grains are more stable and have lower trace mineral values over varying geochemical factors than legumes, pulses or cruciferous crops (Silinpaa, 1982). That establishing the predominant plant species utilised, crop and soil management factors, and the composition thereof, remains and important step in risk assessment, is brought out by work conducted by Aggett and Mills (1996) who found Cu to vary four times, B twenty-one times, and Mo forty-six times, due to these factors.

Although the above-mentioned correlations have been studied, and are being used increasingly (Parr *et al*., 1992), less is known about the relationships between inroganic soil composition, diet and causes of deficiencies of Cu, iodine, Se, Zn and possibly B, Cr, F and toxicity of F, Fe, Mo and Se (Mills, 1996). This has lead to crop failures, decreased animal productivity, and trace mineral disorders in humans.

Mobile elements include alkalis, alkaline earth, halogens (mobile in high pH) such as B, Se, Mo, V and U, and tend to accumulate in arid environments. Both the Jericho and Immerpan regions are classed by Acocks (1975) as arid to semi-arid environments. Chemical elements are separated more in tropical environments than in temperate regions (Trescases, 1992), and tend to have a greater potential for deficiency and/or toxic conditions. Incidentally, he bulk of the data used by the WHO and EPA in formulating drinking water quality guidelines, much of which formed the platform for the DWA&F guidelines, was from the temperate regions.

CHAPTER 3
RURAL COMMUNAL LIVESTOCK PRODUCTION SYSTEM MODEL

3.1 Introduction

Water quality guidelines for domestic and animal drinking purposes provide a generic level of risk assessment, and as such are static, tabulated values, using a mg/L format, and independent of the environment to which they are applied, a developmental factor which necessitates their conservative nature. Other developmental factors contribute to their conservative nature, for example, the uncertainty factor method applied by the World Health Organization (WHO, 1993) for intra- and inter-species extrapolation. However, despite this seemingly conservative approach, fundamental assumptions applied to the derivation of guideline values can result in regional factors leading to adverse effects occurring at concentrations close to, or even below, recommended guideline values. The WHO (1993) guidelines state that local governments and regional departments must take into account those factors that may alter the concentration at which adverse effects may occur. In practice, however, the guideline values are usually applied as is. One of the best examples of the widespread application of guideline values developed in temperate climates, yet adopted by tropic or sub-tropic regions, is the recommended upper limit of water fluoridation. This was implemented in Hong Kong. The values developed were based on a study by Dean (1958) relating to the prevalence of dental caries and water fluoride levels where a range of 0.5 - 1.5 mg F/L was recommended. Recommendations were made with respect to the lowering of fluoridation levels in order to compensate for high temperatures and increased water intakes, but despite this, unacceptably high incidences of dental fluorosis were observed in children at even 0.3 mg F/L. Subsequently the recommendation was made to cap the upper limit of fluoridation at 0.8 mg F/L, substantially lower than the 1.5 mg F/L level. Similar examples exist and are usually a function of higher water intakes and site-specific interactions. Duration and extent of exposure can have an overriding modification of pathological consequences (Mills, 1996; Ottoboni, 1988). Some of the more important modifying effects of interactive variables applicable to PHCs in rural groundwater supplies were dealt with in Chapter 2.

The purpose of the RCLPS model is to allow for the correct description of the possible ramifications of allowing livestock and humans access to water sources, within the rural production system context, and to also provide sufficient indication of the major sources of risk to livestock and human health so as to enable a management plan to be formulated that will offer the best method of allocating, and utilising, the water source to the most tolerant categories within the user groups. To achieve this, it provides a risk assessment for both livestock and domestic users. Two separate risk assessments are thus conducted, but not independently of one another. It is the very nature of the association between the two user groups that influences not only the risk assessment, but also the formulation of solution options. In terms of animal health, there are two focus areas. The first deals with animal health, and the second with animal product quality and resultant consumer health hazards. For the domestic user group, the aim is to generate a risk assessment within the context of potential hazards that may exist in a localised geographical system.

3.2 Dependency on local environment

As mentioned previously, the potential risk present in rural subsistence production systems found in the rural communities that form part of the areas investigated, are not attenuated by food and water obtained from multiple sources. The adverse effects manifested in humans and animals due to environmental geochemistry, either natural or anthropogenic in origin, are exacerbated in developing rural communities, not just due to a larger incidence of malnutrition, but also as a result of the localised nature of food and water sources. Both the Barolong, Immerpan and Jericho areas, both human and animal user groups tend to reside near water, with large tracts of unused land observed between water sources which were more than ca. 10 km apart. Dependency on a single water source was common, which exacerbates any risk present, with previous nomadic habits which used to protect, or limit, adverse effects, no longer applicable (Meyer *et al.*, 2000). Drought also occurs in these areas, a further restriction on food supply and selection, and amplify local anomalies in soil, plant and water composition.

Plant *et al.* (1996) observed that developing countries with communities living on subsistence agriculture are at greater risk of adverse effects due to trace mineral deficiency and/or toxicity, and that studies investigating geochemistry and health are more likely to be of immediate value to these developing communities. According to McMichael (1993) developing countries are at a high risk of potentially harmful waste accumulation due to the use of marginal farmlands and soil erosion from cash cropping. The conversion of soil to inept mineral dust can result from overgrazing, over-cropping, the addition of toxic chemicals, salination (due to irrigation of highly saline waters), all leading to a depletion of essential nutrients. Pollution of air, water and soil may result in increased incidence of heavy metal poisoning related childhood diseases (WHO, 1988; US Geological Survey, 1984). Food and water consumed by both humans and animals is less likely to have a diverse geographical origin, especially in rural subsistence production systems found in the rural communities that form part of the areas investigated during this project. As a result, health risks for humans due to the consumption of animal products increase in these production systems. The risk related to a specific WQC may increase significantly when assessed for the system as a whole, due to multiple pathways of exposure, from water, household crops and animal products. Chemical elements are separated more in tropical environments than in temperate regions (Trescases, 1992), and have a greater potential for deficiency and/or toxic conditions. Incidentally, the bulk of the data used by the WHO and EPA in formulating drinking water quality guidelines, much of which formed the platform for the DWA&F guidelines, was from the temperate regions.

3.3 Modelling

The CIRRA model for RCLPS operates in a similar manner as the models for commercial livestock production systems that are described in detail in WRC Report K5/644 (Casey *et al*., 1998). The reader is referred to that report for information relating to the software programming, programming language description, and core structure of the modelling application.

3.3.1 Aspects addressed by reference documents for the Domestic User Group

The purpose of incorporating human health issues into a guideline system for rural communal livestock production systems has been dealt with in previously. A reference document method is employed to enable a meaningful incorporation of the relevant issues. This involves two distinct phases. Firstly, the relationships between the various types of data that may be collected, derived, or accessed, must be identified and described. This must be done in a manner allowing information to provide insight that is capable of either reducing the variability (and thus potential error) associated with assessing risk due to exposure, or allowing for the risk assessment to incorporate significant beneficial and/or harmful factors. Secondly, the resultant data gathered must be compared to a reference point. Without a reference point, a measurement obtained does not hold much value for a manager, or a user, of a water source. Water quality guidelines, albeit static tabulated guidelines, offer a form of reference.

Both of the above-mentioned phases are critical in arriving at an informed, accurate, site-specific contextual risk assessment for a water source. The reference documents (RefDocs) also trigger additional reference documents to provide the user with background information that may aid in assessing the fitness for use of a water source. Usually these take the form of 'Types of Effects" (TOE) documents, made available to the user by the activation of these buttons on the "Results Screen". The derivation, and examples, of the reference documents used for the RCLPS model, are presented later. Included in the RCLPS model are reference documents for water used for food preparation and irrigation. The reason for this is that many rural communities use the same water source for drinking water for livestock and humans, for food preparation, and for irrigation of household subsistence crops. As a result knowledge of a potential route for hazardous effects, either via the ingestion of milk of animal origin, food crops from household crops, or constituent concentration due to food preparation process, is required for a complete risk assessment.

3.3.2 Aspects addressed by reference documents for the Livestock User Group

The reader is referred to the WRC Final Report K5/644 for a detailed description of the reference documentation used in the livestock models. The RefDocs rely on a water ingestion rate reference document (WIRRD), which corrects for metabolic water, live weight, dry matter intake, and maintenance and production requirements. Additional animal, environmental, nutritional and water-related RefDocs are utilised. These form a substantial amount of reference material, all of which is used in the RCLPS model.

3.3.3 Brief overview of the RCLPS model

3.3.2.1 Main components

The RCLPS model performs two risk assessments, one for livestock and one for humans. A schematic of the information components, inputs and outputs, is presented in figure 3.1. The risk assessments for livestock are conducted as described in WRC Final Report K5/644, with the addition of some revised reference values and manipulations. These are dealt with later, and the reader is referred to the final report for an in-depth description of the modelling. The risk assessment model for humans consists of three basic parts. A data capture phase, an evaluation phase, and a reporting phase. A fourth component deals with solution-driven options. The data capture phase is self-explanatory and the user is guided through the software program screens for the relevant detail, namely, Water Source, Water Chemistry, System Description, Animal Detail, Human User Group Detail, Environmental Detail and Nutritional Detail. The various modelling components utilised reside within the evaluation phase and solution component. These are presented under the RefDocs later in this chapter. A brief outline of the main events handled follows.

The RCLPS model reports the results of the RefDoc-GG as a default. The reason for this is that the user may not enter sufficient site-specific data for the other RefDocs to be utilised, and even if sufficient data is entered, additional data concerning risk factors present may be omitted which could conceivably cause a WQC to precipitate adverse effects, despite the entered data indicating otherwise. Thus, the user is informed of any WQC guideline that is exceeded. This is the first level or risk assessment and is a direct application of the available local and international guidelines. As indicated previously, a number of guidelines are used as single sets from local and international authorities do not provide limits for many of the WQCs found to be present in local water groundwater supplies at potentially hazardous concentrations. The central core of the RCLPS model is the water turnover temperature corrected constituent ingestion rate RefDoc (WTTCCIRRD), presented in detail later in this chapter. It provides a risk assessment as to the types of adverse effects that may be expected based on the predicted ingestion of the constituent within the user defined site-specific factors, such as user groups present and ambient temperatures. In order to remain within the brief and scope of this project, whereas previous CIRRA versions for livestock include synergistic and antagonistic factors as system effects with numeric values which allow for a comparison between the RefDoc ingestion rates, the RCLPS generates a number of WQC and site-specific factor evaluations on the relevant risk factors in addition to the WTTCCIRRD calculated ingestion.

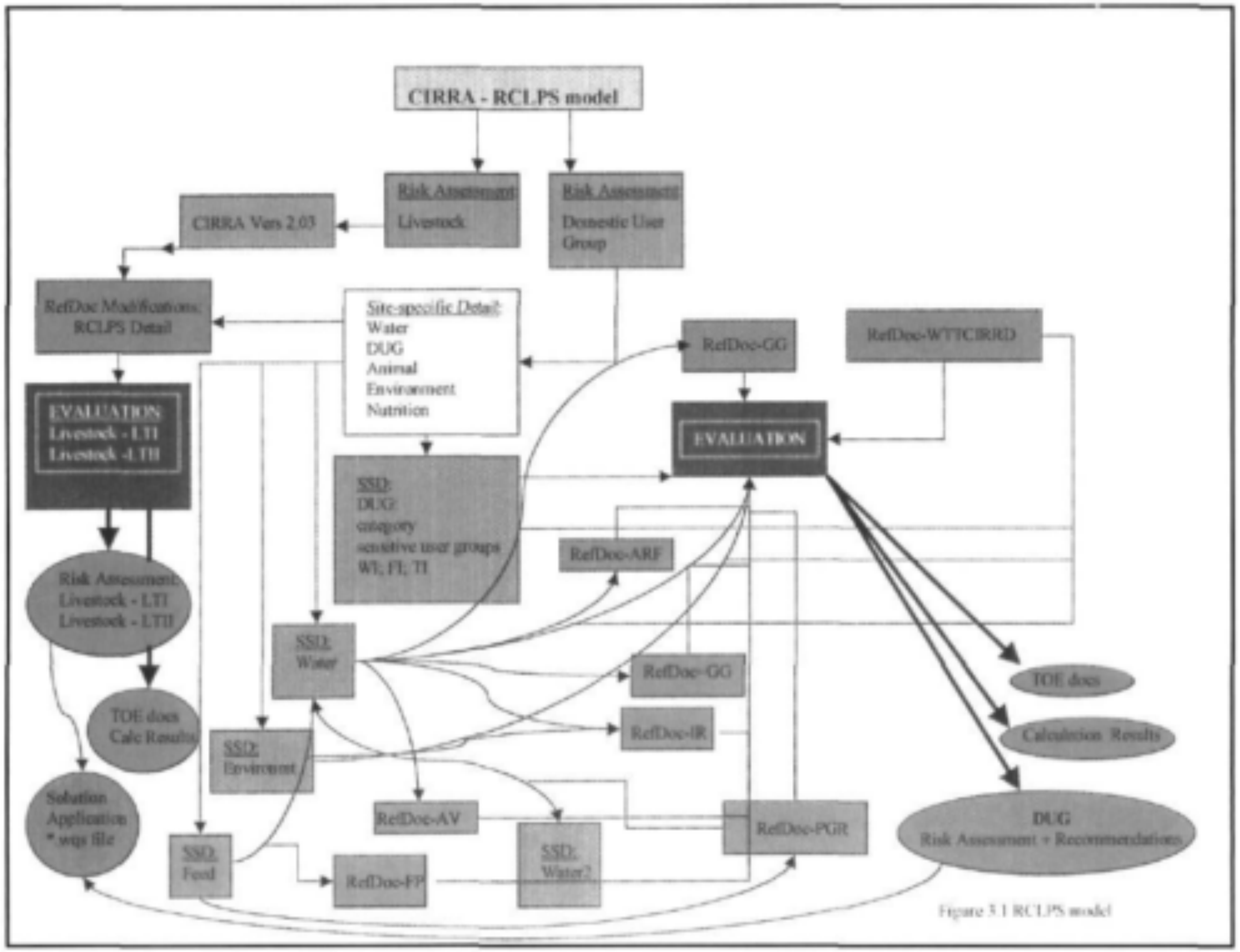


Figure 3.1 RCLPS model

If the user provides detailed site-specific information, for example, actual WI and FI, and chemical composition, the model uses the data in the calculation of total ingestion figures for relevant PHCs and COCs. Should the user group be defined and a BW value provided, the model generates a risk assessment based on a comparison between calculated exposure time and available reference dose information. This is of particular relevance in the rural context, with some individuals exposed to high risk sources intermittently, ranging from only during a portion of the day (herdsman for example) to only on weekends (individuals commuting weekly to work in towns). Failure to account for this exposure time variation effectively overestimates the risk present due to high concentrations of *certain* WQCs. For those WQCs that may present significant risk based primarily on the concentration in water, and effectively resulting in single ingestion exposures (once on a weekend for example) posing sufficient risk, a separate RefDoc is used, RefDoc-ARF1 and RefDoc-ARF2, presented later.

Other site-specific information is dealt with as described in the RefDocs presented later. This comprises a number of different 'relationships' between different types of factors. Some are simplistic, for example, risk due to V is reported as being increased if [F] > 0.7 mg/L and water pH < 7. Others are more complex, for example, the calculation of the preferential guideline ratios between F:B:TDS:Ca:SO_4:Mo.

The RCLPS model caters in the 'Solution' option presented on the 'Results Screen' for various alleviator treatments for livestock. These are based on previous input data, and are flexible based on the ability to provide individual, or group, treatments, either via the feed, the water, or the water and feed. This is one of the most complex areas relating to the RCLPS risk assessment, as it relates to various tolerance levels within the various livestock types present.

3.3.4 Reference documents incorporated for the Domestic User Group

A number of RefDocs are used for the RCLPS, and the method for inclusion in the risk assessment is described in each RefDoc. Rules are developed to indicate which RefDoc is applicable, for example, if temperature is given in the Environmental Tab Detail, then a reference document dealing with temperate linked water ingestion rates, RefDoc - TCG "**Temperature Corrected Guidelines**" is used. Table 3.1 provides a brief description of the RefDocs used in the RCLPS model.

Table 3.1 RefDocs that are used in the RCLPS model.

RefDoc	Components	Basic description
RefDoc-MLW	WQC, limit (mg/L), TOEA	Modified generic guidelines for livestock watering
RefDoc-GG-TOE1	WQC, limit (mg/L), TOE1	Basic generic guidelines – domestic user group
RefDoc-SU-TOE2	WQC, sensitive user groups, range, TOE2	Specific ranges for sensitive user groups
RefDoc-AV	WQC, AV limit, text	Antagonistic variable incorporation
RefDoc-FP-TOE3	WQC, limit range, TOE3, text	Food preparation guidelines
RefDoc-IR-TOE4	WQC, TOE4	Rules based Irrigation of household crops
RefDoc-WTTCCIRRD	21 WQC, Types A-B-C, temp, predicted WI, allowable [WQC], Effective upper limit, Catergory Ingestion (mg/d)	An ingestion based temperature, body weight, corrected guideline, by category, by user group.
RefDoc-ARF1 + ARF2	WQC, WQG, Notes	Aesthetic and other direct and indirect WQC related risk factors
RefDoc-PGR	WQC, rules, procedures	Risk assessment and Solution driven preferential guideline ratios
RefDoc-RD1	WQC, categ, twqr, mg/d	Recommended daily doses for broad categories based on TWQR and adverse effect ranges
RefDoc – DR	WQC, ADD, PTWI, RfD	Allowable daily doses in mg/kg Body weight, tolerable weekly doses

3.3.4.1 Introduction to WTTCCIRRDs

The base reference documents for domestic drinking water are formulated to provide water quality guidelines on an ingestion rate basis, as opposed to a mg/L basis. In-depth discussion of the physiological principles involved in formulating an ingestion rate derived WQG is dealt with in WRC Report K5/644, and the reader is referred to that report for detailed modelling aspects. In brief, the primary objective for this method is two-fold, namely to incorporate toxicodynamic and toxicokinetic principles associated with the ingestion of PHCs, and to correct for different water turnover rates across body weight variations. The latter is incorporated in the derivation of most WQGs to a lesser extent (WHO, 1993; DWA&F, 1993; 1996), usually by applying a safety factor to cater for higher water turnover rates. But due to the static nature of a mg/L basis guideline, this tends to increase the probability of system error in terms of the variations that occur between cause and effect relationships due to inherent biological randomness, and furthermore, it tends to enforce the acceptance of overly conservative guidelines. The reader is referred to other works relating to the derivation of WQGs for more comprehensive information.

The WTTCCIRRD attempts to take into account the actual ingestion rates should they be available, and also to predict the probable ingestion rates based on physiological evidence of the significant factors influencing them. Three types of WTTCCIRRDs are used for each WQC, named Type A, Type B and Type C, dealing with adults, children and infants respectively. WTTCCIRRD Type A is used as the default should the user group not be specified. Should no temperature be specified, 16 degrees Celcius is used as the default temperature. This accords with most WQGs currently in use (WHO, 1993; DWA&F, 1993; 1996).
The "Predicted WI (mg/L)" column, together with the defined category ranges for each WQC in the WTTCCIRRDs provide the derivation basis for the calculations conducted. The former is predominantly

adapted from values used in the WHO (1993) section on guideline formulation, and the DWA&F (1993) and (1996) Guidelines for Domestic Use. The latter are adapted from the DWA&F (1996) and Quality of Domestic Water Supplies (QDWS, 1998) guidelines. It is noteworthy that the values used in the derivation of the WTTCCIRRDs may be considered conservative in the estimation of WI and corresponding types of effects for temperatures exceeding 16 deg C. As an example, the WHO has reported "unacceptably high" incidences of dental fluorosis in children in hot environments such as those found in Hong Kong, and commented that "a realistic upper limit for F in non-temperate climates should be less than 0.8 mg/L), far less than the temperature corrected adaptations applied by many international guideline sources. The upper limit for the temperature range was set at 44 degrees Celcius, not because temperatures higher than this are not experienced in many of the rural communities reliant on groundwater in southern Africa, but rather due to the fact that higher temperatures than this are unlikely to persist for more than two weeks at a time. The calculation of the input temperature value on the Environmental Detail Tab indicates the method employed requires two-week period average. This is mainly to avoid unnecessary repetitions in evaluating a water sample due to naturally high daily variations in temperature.

A WQC will return a different Category status within a user group for different temperatures, and between user groups at the same temperature. This is to cater for the significant effect of temperature on WI and for the significant effects of WTR on WQC dose-response ingestion rates. WTTCCIRRD Type A for F indicates the different temperature corrected values returned from an input of 2 mg/L in *italics*. It is also interesting to note the resultant variation in the mg/L concentration calculated for the TWQR. For a WQC such as F, which has beneficial and/or essential functions at low concentrations, the departure from a fixed value as a TWQR allows the effect of one of the many significant factors which alter WI, and hence dose ingested, to be incorporated into therapeutic dose formulations.

3.3.4.2 WQC related risk factors for the RCLPS

Due to different aesthetic factors, certain PHCs pose less inherent risk than others. Examples of this exist for those WQCs where the ingestion of a significant amount of water containing a potentially hazardous concentration of a certain PHC may be prohibited due to an astringent or repulsive taste, odour and/or appearance. Other PHCs may induce vomiting should a large enough amount of water containing a potentially hazardous concentration of a PHC be ingested. The reverse is also true, and those PHCs which impart no colour, odour or taste to the water, are inherently more hazardous as the user is unaware of the potential danger. Furthermore, some WQCs are cumulative in nature and not readily removed from biological tissues. As a result, a single ingestion event of a large amount of these WQCs may result in significant adverse effects. Other WQCs that are more readily removed from biological tissues, may have adverse effects reversed on cessation of exposure. These factors are addressed by the RefDoc-ARF.

3.3.4.3 Preferential Guideline Ratios

Despite the significant nature of mineral-mineral interactions, the extent to which they are catered by guidelines is usually limited to the incorporation of safety factors, or uncertainty factors, assigned during guideline limit derivation. Some guidelines draw the users attention to one or two main interactions (DWA&F, 1996; QDWS, 1998), or to the likelihood of significant feed-water interactions between minerals (WHO, 1993). However, within a single water source, significant interactions can lead to induced imbalances, ranging from deficiencies to toxicities. As described in earlier chapters, this in effect creates the dual possibility of a single WQC concentration being capable of providing a valuable source of an essential trace mineral on the one hand, and precipitating a deficiency of another trace mineral on the other. Such interactions have been shown to be sufficiently limiting to warrant their inclusion in ration formulation for livestock feeds, and are usually referred to as "optimal ratios" for the constituents concerned. Well documented ratios include those for Ca:P and Cu: Mo:SO_4 (Underwood & Suttle, 1999).

The RefDoc-PGR deals with those ratios that are known to have ameliorating effects on the toxicity of specific WQCs, and indicates both the ratios, and recommended upper limits, for the constituents involved. The beneficial effects may vary from precipitating effects, reduced digestive tract uptake, to systemic effects. The RefDoc-IR alerts the user to increased risk due to exposure to WQC as a result of the influence of site-specific factors, such as soil pH, on the tendency for plants to accumulate the constituent in edible plant parts.

3.4 RCLPS – Domestic User Group

The following section provides all the relevant reference documents (RefDocs) applicable for domestic drinking water within the rural communal context. Many of these RefDocs are linked to "Types of effects" documents, termed TOE documents. Rules are developed to indicate which RefDocs are applicable, and the application thereof is also presented. It must be noted that the actual rules-based source code programming is far more complex than presented here, but to incorporate it would effectively increase the volume of this report by a factor of at least ten.

3.4.1 RefDoc – GG-TOE1

The first of these RefDocs provide the most basic of guidelines, namely generic guidelines, referred to as RefDoc – GG-TOE1. Generic guideline values used for the WQCs addressed for domestic drinking water purposes. The generic guideline values consist of local and international guidelines for reasons already dealt with, and form a base reference document, termed RefDoc - GG, on which a series of modifications, and the generation of other reference documents, are catered for.

Rule Number 1:

The following values (all in mg/L) are used in the same manner as Generic application (as a trigger value). Should entered value exceed the recommended limit, the WQC is reported as a **PHC**, and linked to the TOE reference document dealing with the types of effects for the WQC in question. Reporting is done in the same manner as for RefDoc -GG. The 10% **COC** rule applies (if reported value is within 90% of the PHC cut-off, then it is reported as a COC).

RefDoc – GG-TOE1 for the RCLPS model.

WQC	Limit (mg/L)	Types of Effects 1 – General
Al	0.15	Brain lesions.
Sb	0.006	Increase in blood cholesterol, decrease in blood glucose. Cancer.
As	0.01	Skin damage, circulatory problems, increased risk of cancer.
Ba	0.7	Increase in blood pressure. Circulatory system effects.
B	1	Testicular atrophy.
Be	0.004	Intestinal lesions. Bone and lung damage.
Cd	0.003	Renal damage.
Ca	150	Hypercalcaemia. Induced deficiency of other minerals.
Cl	100	Hypertension, oedema.
Cr	0.05	Allergic dermatitis. Liver, renal and circulatory disorders.
Cu	1.3 (action level)	Short-term effects are gastrointestinal stress. Long-term effects include liver and kidney damage.
F	1	Bone diseases and mottled teeth.
Fe	0.5	Cytotoxic. Reduced liver concentrations of Vitamin E.
I	0.5	Hypothyroidism.
Li	5	Depression, diarrhoea, ataxia.
Pb	0.01	Decreased mental development in infants and children. Kidney and blood pressure problems in adults.
Hg	0.001	Renal and nervous system damage.
Mg	100	Diarrhoea.
Mn	0.5	Neurotoxic effects.
Mo	0.04	Testicular damage.
NO_3 (N)	26	Methaemaglobinaemia
NO_2 (N)	1	Methaemaglobinaemia
Ni	0.02	Heart and liver damage.
PH	6.5-8.5	Interference with mineral absorption.
K	25	
Silver	0.1	Argyria.
SO_4	250	Diarrhoea.
Se	0.02	Circulatory problems, liver damage and hair loss.
TDS	450	Salt overload, dehydration, disturbance of salt and water balance. Laxative effects
Te	0.005	Teratogenic effects.
Ti	0.1	
Sn	0.002	Gastric irritation. Anaemia.
Th	0.002	Hair loss, adverse effects in blood, kidney, liver and intestine.
U	0.02	Renal damage.
V	0.1	Growth suppression and respiratory symptoms.
Zn	5	Gastrointestinal irritation, nausea, vomiting.

3.4.2 RefDoc – SU-TOE2

Rule number 1:

If the user selects the "Sensitive Group" option, and/or the reported WQC value is within the "Sensitive Group Range" defined therein, then this is reported under a BOX entitled "Sensitive User Groups at Risk", and a list *"Sensitive User Group Definition"* with the appropriate text to Types of Effects, termed RefDoc – SU-TOE2 is generated.

RefDoc – SU-TOE2 for the RCLPS model.

WQC	Sensitive User Groups	Range	Types of Effects – 2
As	*Infants less than 2 years old* *Users with kidney disease* *Users with high water intakes*	0.01-0.05 0.05-0.2 0.2-2 >2	Possible health effects - sensitive groups Increasing effects – sensitive groups Risk of chronic health effects - all users Risk of acute health effects - all users
Cd	*Users with sub-optimal Zinc intakes and malnutrition* *Heavy smokers* *Users with high water intakes.*	0.003-0.005 0.005-0.02 0.02-0.05 >0.05	Possible health effects – sensitive groups Increasing effects – sensitive groups Risk of chronic health effects- sensitive users Risk of acute health effects - all users
Ca	*Users with kidney or gall-bladder stones* *Users with high water intakes*	80-150 150-300 >300	Possible health effects Increasing effects – sensitive groups Risk of chronic health effects - sensitive users
Cl	*Infants less than 1 year old* *Users with congestive heart failure or hypertension* *Users on a salt-restricted diet*	100-200 200-600 600-1200 >1200	Possible health effects Increasing effects – sensitive groups Possible long-term health effects Dehydration in infants, nausea and vomiting
Cu	*Users suffering from Wilson's disease* *Users with high water intakes*	1-1.3 1.3-2 2-15 >15	Possible health effects Increasing effects – sensitive groups Risk of chronic health effects - sensitive users Acute effects in all users, nausea and vomiting
F	*Children up to 3 years old* *Users with HIV infection* *Users with suboptimal dietary calcium & zinc* *Users with liver or kidney disease* *Malnourished users* *Users on renal dialysis* *Users with high water intakes*	0.7-1 1-1.5 1.5-3.5 >3.5	Possible health effects - sensitive users Increased effects – sensitive users, tooth staining Increased effects -all users, marked tooth staining Increase risk of effects-all users, severe tooth staining
Fe	*Infants under 4 years of age* *Users with a hypersensitivity to iron*	0.5-1 1-5 5-10 >10	Possible health effects - sensitive users Increased effects – sensitive users Chronic health effects - all users Risk of Fe poisoning - sensitive users
Total Hard - $CaCO_3$	*Users with kidney and/or gall-bladder stones* *Infants under 1 year of age*	200-300 300-600 >600	Possible health effects - sensitive users Possible chronic effects - sensitive users Increased chronic effects - sensitive users
Mg	*Infants under 1 year of age* *Users with high water intakes*	70-100 100-200 200-400 >400	Possible health effects - sensitive users Increased effects – sensitive users Potential diarrhoea – all users Diarrhoea - all users
Mn	*Infants under 2 years of age* *Users with kidney disease* *Users with high water intakes*	0.1-0.4 0.4-4 4-10 >10	Possible health effects - sensitive users Increased health effects - sensitive users Possible health effects - all users Increased health risk – all users
NO_3 (as NO_3)	*Infants under 1 year* *Infants with iron, vitamin C deficiency, anaemia* *Malnourished infants*	26-44 44-89 89-177 >177	Possible health effects - sensitive users Increased health effects - sensitive users Chronic risk – infants Increasing acute health risk – infants
K	*Infants under 2 years of age* *Users with kidney disease*	25-50 50-100 100-500 >500	Possible health effects - sensitive users Increased health effects - sensitive users Possible health risk – all users Definite health risk – all users

Na	*Infants under 2 years of age* *Users with kidney disease* *Users with congestive heart failure or hypertension* *Users on a salt-restricted diet.* *Users with high water intakes*	100-200 200-400 400-1000 >1000	Possible health effects - sensitive users Increased health effects - sensitive users Increased health risk – sensitive users Definite health risk – all users
SO_4	*Infants under 2 years of age* *Users not adapted to high SO_4 water.* *Users with high water intakes*	200-400 400-600 600-1000 >1000	Possible health effects - sensitive users Initial diarrhoea – sensitive users Increased risk of diarrhoea. Poor adaptation Probable diarrhoea. Adaptation does not occur
TDS	*Infants less than 1 year old.* *Users with congestive heart failure or hypertension* *Users with kidney disease.* *Users on a salt-restricted diet.* *Users with chronic diarrhoea.* *Users with high water intakes*	450-1000 1000-2400 2400-3400 >3400	Possible health effects in sensitive users Possibility of salt overload in sensitive users Possible health risk – all individuals Increased risk of dehydration
Zn	*Infants under 2 years of age* *Users receiving chemotherapy* *Users with high water intakes* *Users exposed to deficient/toxic trace mineral levels*	>20	Possible health effects - sensitive users

3.4.3 RefDoc - AV

Rule number 1:

If a reported WQC exceeds an *"AV limit"*, then it is reported as an *"Antagonistic Variable"*, with the accompanying text *"Constituent may induce trace mineral toxicity, deficiency and/or imbalance, specifically with pre-disposing dietary conditions"*. The AV limits listed in the RefDoc –AV apply.

RefDoc – AV. Examples for RCLPS model.

WQC	AV limit (mg/L)
Sr	0.1
Zn	0.1

3.4.4 RefDoc – FP-TOE3

The following section provides the guidelines for water used for food preparation, which is adapted from the DWA&F (1996) guidelines.

Rule number 1:

If a reported WQC is within the limit range, the appropriate reference document is generated, termed RefDoc –FP-TOE3, and reported to the user in the "Results Screen" with the text: *"If water is used for food preparation, TOE3".*

RefDoc – FP-TOE3 for the RCLPS model.

WQC	Limit Range (mg/L)	Types of Effects – 3
TDS	450-2400 2400-3400 >3400	Possible adverse health effects may occur in sensitive users Possible adverse health effects may occur in all users Increased risk of adverse health effects in all users
As	0.01-0.2 0.2-2 >2	Possible adverse health effects may occur in sensitive users Risk of chronic health effects for all users Risk of acute health effects for all users
Cd	0.003-0.02 0.02-0.05 >0.05	Possible adverse health effects may occur in sensitive users Risk of chronic health effects for sensitive users Risk of acute health effects for all users
Ca	>150	Possible adverse health effects may occur in sensitive users
Cl	100-600 600-1200 >1200	Possible adverse health effects may occur in sensitive users Possible long-term health effects in all users Dehydration in infants, nausea and vomiting
Cu	0.5-2 2-15 >15	Noticeable taste Very objectionable taste Repulsive taste
F	0.7-1.5 1.5-3.5 >3.5	Possible adverse health effects may occur in sensitive users Possible health effects in all users Increased health risk in all users
Fe	0.5-5 5-10 >10	Possible adverse health effects may occur in sensitive users Chronic health effects for all users Risk of iron poisoning, specifically in sensitive users
Total Hardness $CaCO_3$	100-300 >300	Scaling of kettles Severe scaling of heated elements
Mg	70-200 200-400 >400	Risk of diarrhoea in sensitive users Potential for diarrhoea in all users Diarrhoea and very bitter taste
Mn	0.1-4 4-10 >10	Possible adverse health effects may occur in sensitive users Possible health effects in all users Increased health risk in all users
NO_3	26-89 89-177 >177	Chronic risk to infants Increased chronic risk to infants Possible acute effects to infants
K	25-100 100-500 >500	Possible adverse health effects may occur in sensitive users Possible health effects in all users Definite health risk to all users
Na	100-400 400-1000 >1000	Possible adverse health effects may occur in sensitive users Increased health risk, specifically in sensitive users Definite health risk to all users
SO_4	200-600 600-1000 >1000	Initial diarrhoea, possible adaptation Diarrhoea with poor adaptation High risk of diarrhoea with no adaptation
Zn	3-10 10-20 >20	Noticeable taste Astringent taste Repulsive taste

3.4.5 RefDoc – IR-TOE4

The following section provides the guidelines for water used for the irrigation of sustainable household crop production, and is adapted from the DWA&F (1996) guidelines to inform the user of a series of adverse effects that may arise. Some of these effects reduce crop yield, whilst others are of importance due to the possibility of certain WQCs increasing in the edible portion of the crop, thereby leading to a significant route of increased ingestion of the relevant WQC.

Rule Number 1:

Reporting is done per WQC according to the rules provided in the "**RefDoc Irrigation Rules**" under the "Results Screen" heading of "Potential Hazards". The rules applicable draw from data input screens throughout the software program, but predominantly from the Environmental and Water Detail Tabs, and are invariably of the "If – Then do" type, although in some instances the user is simply referred to relevant "Notes". Relevant types of effects are reported in the usual manner.

RefDoc –IR-TOE4 for the RCLPS model.

WQC	Irrigation Rules*
Al – 1. Al – 2.	• If soil pH <5.5, and Al >5 mg/L, then: Crop yield may decrease and soil concentration may increase. • If soil pH >7, and Al> 5 mg/L, then: Precipitated Al may reduce available P to plants.
As – 1. As – 2.	• If As > 0.1 mg/L, then: Root crops (potatoes and radishes) may concentrate As to levels that are dangerous to consumers. • If As >0.5mg/L, then: Crop yield may decrease.
Be – 1. Be – 2. Be – 3.	• If soil pH<7, and Be >0.1 mg/L, then: Crop yield may decrease. • If soil pH>7, and Be >0.5 mg/L, then: Crop yield may decrease • If soil pH< 7, and Be >0.5 mg/l, then: Crop may concentrate Be to levels that are dangerous to consumers, especially if soil Be concentrations are above normal.
B – 1. B – 2. B – 3.	• If B>0.5, then: Crop yield may decrease in plants sensitive to B (fruits, wheat, sunflower, beans, potato, carrot, radish, cucumber, lettuce). • If B>6 mg/L, then: Crop yield may decrease in plants tolerant to B (Cabbage, Maize, squash, cauliflower, lucerne, tomato, sorghum). • Note: It may take several seasons for adverse crop effects due to B to manifest
Cd – 1. Cd – 2.	• If Cd >0.01, then: Crops may concentrate Cd to levels that are dangerous to consumers. • Risk factors include: Soil pH<7, Cl > 100 mg/L
Cl – 1. Cl – 2.	• If Cl>100 mg/L, then: Application of water to soil surface and wetting of crop foliage may reduce crop yield. • If Cl>350 mg/L, then: Increased risk of crop yield decrease with wetting of crop foliage and application of water to soil surface.
Cr(VI) –1. Cr(VI) – 2.	• If soil ph<7, and Cr >0.1 mg/L, then: Crop yield may decrease • If Cr>1 mg/L, then: Crop yield may decrease, Crop may concentrate Cr to levels that are dangerous to consumers, especially if soil Cr concentrations are above normal.
Co – 1. Co – 2.	• If soil ph<7, and Co >0.5 mg/L, then: Crop yield may decrease. N fertilizers may increase herbage Co levels. • If Co>5 mg/L, then: Crop yield may decrease. Crop may concentrate Co to levels that are dangerous to consumers, especially if soil Co concentrations are above normal.

E.coli counts/100ml E.coli counts/100ml	• If E.coli is in the range of 1 – 1000 counts/100ml, then: Crops consumed raw, and milk from cows grazing pastures will result in transmission of human pathogens. • If E.coli is > 1000 counts/100ml, then: No contact with crop and humans should occur.
Cu – 1. Cu – 2.	• If soil pH <7, and Cu > 0.2 mg/L then: Crop yield may decrease. Root crops (potatoes and radishes) may concentrate Cu to levels that are dangerous to consumers. • If Cu>5 mg/L, then: Crop yield may decrease. Root crops (potatoes and radishes) may concentrate Cu to levels that are dangerous to consumers.
F – 1. F – 2.	• If soil pH<7, and F>1 mg/L, then: Crop yield may decrease. Crop may concentrate F to levels that are dangerous to consumers. • If F>15 mg/L, then: Crop yield may decrease. Crop may concentrate F to levels that are dangerous to consumers, especially if soil F concentrations are above normal.
Fe – 1. Fe – 2.	• If soil pH<7, and Fe>5 mg/L, then: Crop yield may decrease • If Fe>20 mg/L, then: Crop yield may decrease.
Pb – 1. Pb – 2.	• If soil pH<7, and Pb>0.2 mg/L, then: Crop yield may decrease. Crop may concentrate Pb to levels that are dangerous to consumers, especially in potatoes, lettuce and hay. • If Pb>2 mg/L, then: Crop yield may decrease. Crop may concentrate Pb to levels that are dangerous to consumers, especially if soil Pb concentrations are above normal.
Li – 1.	• If Li>2.5, mg/L, then: Crop yield may decrease.
Mn – 1. Mn – 2.	• If soil pH<7, and Mn > 0.02 mg/L, then: Crop yield may decrease. • If Mn > 10 mg/L, then: Crop yield may decrease.
Mo – 1. Mo – 2.	• If pH>7, and Mo>0.01 mg/L, then: Crop may accumulate Mo to levels that are dangerous to animals. • If Mo>0.05 mg/L, then: Crop may accumulate Mo to levels that are dangerous to animals.
Ni – 1. Ni – 2.	• If soil pH<7, and Ni > 0.2 mg/L, then: Crop yield may decrease. Crop may concentrate Ni to levels that are dangerous to consumers. • If Ni> 2 mg/L, then: Crop may concentrate Ni to levels that are dangerous to consumers, especially if soil Ni concentrations are above normal.
pH	• If pH<6.5 or >8.4, then: Crop yield may decrease.
Se – 1.	• If Se > 0.02 mg/L, then: Crop may concentrate Se to levels that are dangerous to consumers.
Na – 1.	• If Na>70 mg/L, then: Crop yield may decrease.
TDS – 1. TDS – 2.	• If TDS > 40 mg/L, then: Crop yield may decrease. • If TDS > 540 mg/L, then: Likelihood of sustainable irrigation decreases rapidly.
U – 1. U – 2.	• If pH<7, and U>0.01 mg/L, then: Crop yield may decrease. • If U>0.1 mg/L, then: Crop yield may decrease.
V – 1. V – 2.	• If pH<7, and V>0.1 mg/L, then: Crop yield may decrease. • If V>1 mg/L, then: Crop yield may decrease

Zn – 1.	• If pH<7, and Zn>1 mg/L, then: Crop yield may decrease.
Zn – 2.	• If Zn>5 mg/L, then: Crop yield may decrease.

* concentrations are in water, in mg/L, unless otherwise stated

3.4.6 RefDoc – ARF

This RefDoc deals with differences in inherent risk attributed directly to the attributes of a WQC, and also with water quality risk factors indirectly associated to a WQC. The following table presents those WQCs with low, moderate, and high inherent risk. Those with low inherent risk have aesthetic factors that provide for a degree of protection at concentrations lower than the recommended guideline level. Those with protective effects at concentrations similar to the recommended guideline level are classed as moderate, whilst those with no protective aesthetic attribute are classed as high.

RefDoc-ARF1 for the RCLPS model.

WQC (WQG)	Relevant Level (mg/L)	NOTES
		WQC WITH HIGH INHERENT RISK
As (0.01)	0.01	No taste, odour, or colour. Single day exposure may result in serious adverse effects.
Cd (0.005)	0.005	No taste, odour, or colour. Single day exposure may result in serious adverse effects.
Cr(VI)	0.05	Single day exposure may result in serious adverse effects.
F (1)	1	No taste, odour, or colour.
Pb	0.01	Single day exposure may result in serious adverse effects. Bioaccumulation.
Hg	0.001	Single day exposure may result in serious adverse effects. Bioaccumulation.
No_3 (10) + NO_2 (1)	10 + 1 (as N)	No taste, odour, or colour.
Se	0.02	Single day exposure may result in serious adverse effects.
V	0.1	Single day exposure may result in serious adverse effects.

		WQC WITH LOW INHERENT RISK
Cu (1.3)	1.3 >2	noticeable taste very objectionable taste
Fe (1)	0.2 >2	noticeable taste objectionable
Mg (100)	70 >100 >200	slightly bitter bitter very bitter
Mn (0.4)	0.1 >0.4 1.0	noticeable taste increasingly noticeable objectionable
Zn (20)	4 10 20	taste threshold astringent repulsive
		WQC WITH MODERATE INHERENT RISK
K (50)	50	bitter
Na (200)	200	salty
SO_4 (400)	400	bitter

RefDoc-ARF2 for the RCLPS model.

WQC (WQG)	Relevant Level (mg/L)	Description
Al	0.15	Risk due to ingestion of Al may increase if: water pH = neutral and F > 1 mg/L (solubility increase)
Cd	0.005	Risk due to ingestion of Cd may increase if: water pH = acidic (solubility increase)
Cr(VI)	0.05	Risk due to ingestion of Cr(VI) may increase if: Fe < 0.1 and oxidisable organic matter not present (Ratio of Cr(VI):Cr(II + III) increases)
Cu	1.3	Risk due to ingestion of Cu may increase if: water pH = acidic (solubility increase)
Pb	0.01	Risk due to ingestion of Pb may increase if: Ca<80 (less mitigation)
V	0.1	Risk due to ingestion of V may increase if: water pH = acidic and F<0.7 (solubility increase)
Zn	20	Risk due to ingestion of Zn may increase if: water pH = acidic (solubility increase)

3.4.7 RefDoc-PGR

The following table presents those ratios dealt with in the RCLPS model. The model reports on potentially hazardous ratios in two ways. Firstly, the relevant WQCs involved are reported to the user as: "***Ratio between WQC X and WQC Y is not optimal***". Background information is also made available on the likely effects. Secondly, the model solves for the optimum ratio, as much as is attainable, whilst maintaining upper limit recommendations for the ameliorating WQC. The ratio between Cd and Zn is used as an example:

Rule 1: Report in Results Screen: "Ratio between WQC X and WQC Y is not optimal".

Rule 2: If WQC X is > TWQR, then solve for set ratio by increasing WQC Y to recommended PGR.

Example: Cd and Zn

Background information:

PHC = Cd. Ameliorating WQC = Zn.

WQG = 0.005 mg Cd/L (EPA, 1998; DWA&F, 1996)

0.003 mg Cd/L (QDWS, 1998; WHO, 1993)

3 mg Zn/L (DWA&F, 1996; WHO, 1993)

5 mg Zn/L (secondary maximum contaminant level – EPA, 1998)

20 mg Zn/L (QDWS, 1998)

PGR = Cd: Zn = 1:300 (DWA&F, 1996)

The level at which Zn becomes unacceptable to the user in terms of taste occurs between 5 – 10 mg Zn/L (QDWS, 1998). The WHO (1993) reports the taste threshold as being 4 mg Zn/L. Thus, the maximum limit at which zinc may be added to water containing Cd values in excess of the TWQR, is 10 mg/L. Note that this is well within the 20 mg Zn/L health based guideline.

If Cd = 0.0167 mg/L, and Zn = 0.296 mg/L, then:

PGR for Cd and Zn (1:300) at TWQR for Cadmium =

[Cd = 0.005mg/L]:[Zn = 1.5. mg/L]

Required Zn addition to maintain preferred ratio =

(0.0167 *300) – (0.296) = 4.715 mg/L

RefDoc-PGR for the RCLPS model.

Main PHC	Rules
As:	0.01 – 0.2 = Tolerable (DWAF), 0.01-0.05 = Tolerable (QDWS) Ck – Se, I, Hg Se = 0.02 – 0.05 increase OK Hg = NO increase I = CK
Cd	If Zn is suboptimal, then limit = 0.005 Can increase Cd limit to 0.01 if Zn optimal: Usually Zn:Cd of 300:1 Zn = Increase to 20 mg/L if pH >9.5 Zn = increase to 10 mg/L if pH<9.5 Se also protects, therefore: Se = 0.02 – 0.05 increase OK
Ca	Increase to 80 (hot) to 150 (cold) OK
Cl	Increase to 200 = OK, 600 = tolerable
Cr(VI)	
Cu	Increase 1-1.3 = OK; 1.3 – 30 = tolerable If pH<7.5 = more Cu available
F	**WQC Limit Ratio Result** B 3 0.7: >4.28 Ca 150 0.7: >214.28 TDS 450 0.7: >642 Sr 0.1 0.7: <0.142 Mo 0.07 0.7: <0.1 pH 7.5 0.7: >10.71
Fe	Increase 0.1 – 1 = OK for children Increase 0.1 – 10 = OK for adults If Al + Mn present, may reduce ability to coprecipitate As, Cu, Cd and Pb If As, Cu, Cd or Pb = PHC/COC: then: Fe: Increase to 1 children / 10 for adults
Pb	0.01 limit: Fe: Increase to 1 mg/L for children / 10 mg/L for for adults Ca: Increase to 80 (hot) to 150 (cold) OK
Mn	0.05-50 = OK (DWAF) 0.1-0.4 = OK (QDWS) Ca: Increase to 80 (hot) to 150 (cold) OK
Hg	
Se	0.02 – 0.05 = tolerable CK: S, Fe, As + Cu Cd Hg Cu: Increase to 1.3 (or 3 if Se ingestion = 0.7 mg/d) Fe: Increase to 1 children / 10 for adults S: Increase to 400
V	0.1 limit: Fe: Increase to 1 children / 10 for adults
Zn	3 – 10 OK May interfere with Cu and Cd

RefDoc-GN (general notes)

This RefDoc consists of a number of relevant notes which are brought to the users attention in the Results Screen. Examples are:

Al: If pH = 6.7 – 7.6, and Al>0.15 mg/L, but <0.5 mg/L, then:

"Health risk is less due to the probable formation and precipitation of insoluble Al-salts."

V: If pH = 8.5 – 11.5, and V>0.1 mg/L then:

"Health risk is less due to the probable formation and precipitation of insoluble V-salts."

3.4.8 RefDoc – WTTCCIRRD (water turnover temperature corrected constituent ingestion rate reference document)

The following set of tables present the WTTCCIRRD type A, B and C, documents use for risk assessment in the RCLPS model. Although the basis for conducting the calculations is common to all (WHO, 1993) the guideline values are adopted from a number of different sources, as indicated for each table.

Rule number 1:

If calculated result exceeds Category C status, or worse (DWA&F, 1996; Drinking Water for Domestic Supplies, 1998), the relevant WQC is reported as a PHC and the appropriate supporting text is generated. The usual COC rule applies.

Example:

If user definition = adult, WQC input = F = 2mg/L, Temp input = 14 deg C, then:

Result returned = Category D status for F.

Reason = 1.63<2>3.83 for 14 deg C reference line.

WTTCCIRRD I Type A: Domestic user group = Adult (60 kg BW) for WQC = F.

		Allowable WQC concentration in mg/L[a]				
		TWQR	**Cat B**	**Cat C**	**Cat D**	**Cat E**
		0-0.7	**0.7-1**	**1-1.5**	**1.5-3.5**	**>3.5**
		Effective Upper Limit value used (mg/L)				
		0.69	**0.99**	**1.49**	**3.49**	**3.5**
		Category ingestion (mg/d)				
Temp-C	**Predic. WI (L/d)[b]**	**1.38**	**1.98**	**2.98**	**6.98**	**7**
8	1.1764	1.19007	1.6831	*2.53315*	5.93336	5.95036
10	1.3333	1.05003	1.48504	*2.23506*	5.23513	5.25013
12	1.5384	0.91004	1.28705	1.93708	*4.53718*	4.55018
14	1.8181	0.77003	1.08905	1.63907	*3.83917*	3.85017
16[c]	**2**	**0.7**	**0.99**	**1.49**	*3.49*	**3.5**
18	2.1052	0.66502	0.94053	1.41554	*3.3156*	3.3251
20	2.2222	0.63001	0.89101	1.34101	*3.14103*	3.15003
22	2.3529	0.59501	0.84151	1.26652	*2.96655*	2.97505
24	2.5	0.56	0.792	1.192	*2.792*	2.8
26	2.8571	0.49001	0.69301	1.04302	*2.44304*	2.45004
28	2.8571	0.49001	0.69301	1.04302	*2.44304*	2.45004
30	2.9852	0.46898	0.66327	0.99826	*2.3382*	2.3449
32	3.176	0.44081	0.62343	0.93829	*2.19773*	2.20403
34	3.3333	0.42	0.59401	0.89401	*2.09402*	2.10002
36	3.5087	0.39901	0.56431	0.84932	1.98934	*1.99504*
38	3.7735	0.37101	0.52471	0.78972	1.84974	*1.85504*
40	4	0.35	0.495	0.745	1.745	*1.75*
42	4.2553	0.329	0.4653	0.7003	1.64031	*1.64501*
44	4.6511	0.301	0.42571	0.64071	1.50072	*1.50502*

[a] Adapted from DWA&F (1993; 1996) and Quality of Domestic Water Supplies (1998)

[b] Adapted from DWA&F (1996) and WHO (1993); [c] Default temperature

WTTCCIRRD I Type B: Domestic user group = Children (10 kg BW) for WQC = F.

		Allowable WQC concentration in mg/L[a]				
		TWQR	**Cat B**	**Cat C**	**Cat D**	**Cat E**
		0-0.7	**0.7-1**	**1-1.5**	**1.5-3.5**	**>3.5**
		Effective Upper Limit value used (mg/L)				
		0.79	**0.99**	**1.49**	**3.49**	**3.5**
		Category ingestion (mg/d)				
Temp-C	**Predic. WI (L/d)[b]**	**0.79**	**0.99**	**1.49**	**3.49**	**3.5**
8	0.5882	1.34308	1.6831	2.53315	5.93336	5.95036
10	0.6666	1.18512	1.48515	2.23522	5.23552	5.25053
12	0.7692	1.02704	1.28705	1.93708	4.53718	4.55018
14	0.909	0.86909	1.08911	1.63916	3.83938	3.85039
16[c]	**1**	**0.79**	**0.99**	**1.49**	**3.49**	**3.5**
18	1.052	0.75095	0.94106	1.41635	3.31749	3.327
20	1.1111	0.71101	0.89101	1.34101	3.14103	3.15003
22	1.1764	0.67154	0.84155	1.26658	2.96668	2.97518
24	1.25	0.632	0.792	1.192	2.792	2.8
26	1.4285	0.55303	0.69303	1.04305	2.44312	2.45012
28	1.4285	0.55303	0.69303	1.04305	2.44312	2.45012
30	1.4925	0.52931	0.66332	0.99832	2.33836	2.34506
32	1.5873	0.4977	0.6237	0.9387	2.1987	2.205
34	1.6666	0.47402	0.59402	0.89404	2.09408	2.10008
36	1.7543	0.45032	0.56433	0.84934	1.9894	1.9951
38	1.8867	0.41872	0.52473	0.78974	1.84979	1.85509
40	2	0.395	0.495	0.745	1.745	1.75
42	2.1276	0.37131	0.46531	0.70032	1.64035	1.64505
44	2.3255	0.33971	0.42571	0.64072	1.50075	1.50505

[a] Adapted from DWA&F (1993; 1996) and Quality of Domestic Water Supplies (1998)

[b] Adapted from DWA&F (1996) and WHO (1993); [c] Default temperature

WTTCCIRRD 1 Type C: Domestic user group = Infants (5 kg BW) for WQC = F.

		Allowable WQC concentration in mg/L[a]				
		TWQR	**Cat B**	**Cat C**	**Cat D**	**Cat E**
		0-0.7	**0.7-1**	**1-1.5**	**1.5-3.5**	**>3.5**
		Effective Upper Limit value used (mg/L)				
		0.69	**0.99**	**1.49**	**3.49**	**3.5**
		Category ingestion (mg/d)				
Temp-C	**Predic. WI (L/d)[b]**	**0.5175**	**0.7425**	**1.1175**	**2.6175**	**2.625**
8	0.4411	1.1732	1.68329	*2.53344*	5.93403	5.95103
10	0.5	1.035	1.485	*2.235*	5.235	5.25
12	0.5769	0.89704	1.28705	*1.93708*	4.53718	4.55018
14	0.6818	0.75902	1.08903	*1.63904*	3.8391	3.8501
16[c]	**0.75**	**0.69**	**0.99**	***1.49***	**3.49**	**3.5**
18	0.7894	0.65556	0.94059	*1.41563*	3.31581	3.32531
20	0.8333	0.62102	0.89104	*1.34105*	3.14113	3.15013
22	0.8823	0.58654	0.84155	*1.26658*	2.96668	2.97518
24	0.9375	0.552	0.792	*1.192*	2.792	2.8
26	1.0714	0.48301	0.69302	*1.04303*	2.44307	2.45007
28	1.0714	0.48301	0.69302	*1.04303*	2.44307	2.45007
30	1.1194	0.4623	0.6633	*0.9983*	2.33831	2.34501
32	1.1904	0.43473	0.62374	*0.93876*	2.19884	2.20514
34	1.25	0.414	0.594	*0.894*	2.094	2.1
36	1.3157	0.39333	0.56434	*0.84936*	1.98944	1.99514
38	1.415	0.36572	0.52473	*0.78975*	1.84982	1.85512
40	1.5	0.345	0.495	*0.745*	1.745	1.75
42	1.5957	0.32431	0.46531	*0.70032*	1.64035	1.64505
44	1.7441	0.29671	0.42572	*0.64073*	1.50077	1.50507

[a] Adapted from DWA&F (1993; 1996) and Quality of Domestic Water Supplies (1998)

[b] Adapted from DWA&F (1996) and WHO (1993); [c] Default temperature

WTTCCIRRD 2 Type A: Domestic user group = Adult (60 kg BW) for WQC = As.

		Allowable WQC concentration in mg/L[a]				
		TWQR	**Cat B**	**Cat C**	**Cat D**	**Cat E**
		0.009	**0.01-0.049**	**0.05-0.19**	**0.2-1.99**	**>2**
		Effective Upper Limit value used (mg/L)				
		0.009	**0.049**	**0.19**	**1.99**	**2**
		Category ingestion (mg/d)				
Temp-C	**Predic. WI (L/d)[b]**	**0.018**	**0.098**	**0.38**	**3.98**	**4**
8	1.1764	0.0153	0.0833	0.32302	3.3832	3.4002
10	1.3333	0.0135	0.0735	0.28501	2.98507	3.00008
12	1.5384	0.0117	0.0637	0.24701	2.5871	2.6001
14	1.8181	0.0099	0.0539	0.20901	2.1891	2.2001
16[d]	2	0.009	0.049	0.19	1.99	2
18	2.1052	0.00855	0.04655	0.18051	1.89056	1.90006
20	2.2222	0.0081	0.0441	0.171	1.79102	1.80002
22	2.3529	0.00765	0.04165	0.1615	1.69153	1.70003
24	2.5	0.0072	0.0392	0.152	1.592	1.6
26	2.8571	0.0063	0.0343	0.133	1.39302	1.40002
28	2.8571	0.0063	0.0343	0.133	1.39302	1.40002
30	2.9852	0.00603	0.03283	0.12729	1.33324	1.33994
32	3.176	0.00567	0.03086	0.11965	1.25315	1.25945
34	3.3333	0.0054	0.0294	0.114	1.19401	1.20001
36	3.5087	0.00513	0.02793	0.1083	1.13432	1.14002
38	3.7735	0.00477	0.02597	0.1007	1.05472	1.06002
40	4	0.0045	0.0245	0.095	0.995	1
42	4.2553	0.00423	0.02303	0.0893	0.9353	0.94
44	4.6511	0.00387	0.02107	0.0817	0.85571	0.86001

[a] Adapted from DWA&F (1993; 1996) and Quality of Domestic Water Supplies (1998)

[b] Adapted from DWA&F (1996) and WHO (1993); [c] Default temperature

WTTCCIRRD 2 Type B: Domestic user group = Children (10 kg BW) for WQC = As.

		Allowable WQC concentration in mg/L[a]				
		TWQR	**Cat B**	**Cat C**	**Cat D**	**Cat E**
		0.099	**0.01-0.049**	**0.05-0.19**	**0.2-1.99**	**>2**
		Effective Upper Limit value used (mg/L)				
		0.009	**0.049**	**0.19**	**1.99**	**2**
		Category ingestion (mg/d)				
Temp-C	**Predic. WI (L/d)[b]**	**0.009**	**0.049**	**0.19**	**1.99**	**2**
8	0.5882	0.0153	0.0833	0.32302	3.3832	3.4002
10	0.6666	0.0135	0.07351	0.28503	2.9853	3.0003
12	0.7692	0.0117	0.0637	0.24701	2.5871	2.6001
14	0.909	0.0099	0.05391	0.20902	2.18922	2.20022
16[c]	1	0.009	0.049	0.19	1.99	2
18	1.052	0.00856	0.04658	0.18061	1.89163	1.90114
20	1.1111	0.0081	0.0441	0.171	1.79102	1.80002
22	1.1764	0.00765	0.04165	0.16151	1.6916	1.7001
24	1.25	0.0072	0.0392	0.152	1.592	1.6
26	1.4285	0.0063	0.0343	0.13301	1.39307	1.40007
28	1.4285	0.0063	0.0343	0.13301	1.39307	1.40007
30	1.4925	0.00603	0.03283	0.1273	1.33333	1.34003
32	1.5873	0.00567	0.03087	0.1197	1.2537	1.26
34	1.6666	0.0054	0.0294	0.114	1.19405	1.20005
36	1.7543	0.00513	0.02793	0.10831	1.13436	1.14006
38	1.8867	0.00477	0.02597	0.1007	1.05475	1.06005
40	2	0.0045	0.0245	0.095	0.995	1
42	2.1276	0.00423	0.02303	0.0893	0.93533	0.94003
44	2.3255	0.00387	0.02107	0.0817	0.85573	0.86003

[a] Adapted from DWA&F (1993; 1996) and Quality of Domestic Water Supplies (1998)

[b] Adapted from DWA&F (1996) and WHO (1993); [c] Default temperature

WTTCCIRRD 2 Type C: Domestic user group = Infants (5 kg BW) for WQC = As.

		Allowable WQC concentration in mg/L[a]				
		TWQR	**Cat B**	**Cat C**	**Cat D**	**Cat E**
		0.009	**0.01-0.049**	**0.05-0.19**	**0.2-1.99**	**>2**
		Effective Upper Limit value used (mg/L)				
		0.009	**0.049**	**0.19**	**1.99**	**2**
		Category ingestion (mg/d)				
Temp-C	**Predic. WI (L/d)[b]**	**0.00675**	**0.03675**	**0.1425**	**1.4925**	**1.5**
8	0.4411	0.01519	0.0832	0.32306	3.38359	3.40059
10	0.5	0.0134	0.0734	0.285	2.985	3
12	0.5769	0.01161	0.06362	0.24701	2.5871	2.6001
14	0.6818	0.00983	0.05383	0.20901	2.18906	2.20006
16[c]	0.75	0.00893	0.04893	0.19	1.99	2
18	0.7894	0.00849	0.04649	0.18052	1.89068	1.90018
20	0.8333	0.00804	0.04404	0.17101	1.79107	1.80007
22	0.8823	0.00759	0.0416	0.16151	1.6916	1.7001
24	0.9375	0.00715	0.03915	0.152	1.592	1.6
26	1.0714	0.00625	0.03425	0.133	1.39304	1.40004
28	1.0714	0.00625	0.03425	0.133	1.39304	1.40004
30	1.1194	0.00599	0.03279	0.1273	1.3333	1.34
32	1.1904	0.00563	0.03083	0.11971	1.25378	1.26008
34	1.25	0.00536	0.02936	0.114	1.194	1.2
36	1.3157	0.00509	0.02789	0.10831	1.13438	1.14008
38	1.415	0.00473	0.02594	0.10071	1.05477	1.06007
40	1.5	0.00447	0.02447	0.095	0.995	1
42	1.5957	0.0042	0.023	0.0893	0.93533	0.94003
44	1.7441	0.00384	0.02104	0.0817	0.85574	0.86004

[a] Adapted from DWA&F (1993; 1996) and Quality of Domestic Water Supplies (1998)

[b] Adapted from DWA&F (1996) and WHO (1993); [c] Default temperature

WTTCCIRRD 3 Type A: Domestic user group = Adult (60 kg BW) for WQC = Cd.

		Allowable WQC concentration in mg/L[a]				
		TWQR	**Cat B**	**Cat C**	**Cat D**	**Cat E**
		0.0029	**0.003-0.0049**	**0.005-0.019**	**0.02-0.049**	**>0.05**
		Effective Upper Limit value used (mg/L)				
		0.0029	**0.0049**	**0.019**	**0.049**	**0.05**
		Category ingestion (mg/d)				
Temp-C	**Predic. WI (L/d)[b]**	**0.0058**	**0.0098**	**0.038**	**0.098**	**0.1**
8	1.1764	0.00493	0.00833	0.0323	0.0833	0.08501
10	1.3333	0.00435	0.00735	0.0285	0.0735	0.075
12	1.5384	0.00377	0.00637	0.0247	0.0637	0.065
14	1.8181	0.00319	0.00539	0.0209	0.0539	0.055
16[c]	2	0.0029	0.0049	0.019	0.049	0.05
18	2.1052	0.00276	0.00466	0.01805	0.04655	0.0475
20	2.2222	0.00261	0.00441	0.0171	0.0441	0.045
22	2.3529	0.00247	0.00417	0.01615	0.04165	0.0425
24	2.5	0.00232	0.00392	0.0152	0.0392	0.04
26	2.8571	0.00203	0.00343	0.0133	0.0343	0.035
28	2.8571	0.00203	0.00343	0.0133	0.0343	0.035
30	2.9852	0.00194	0.00328	0.01273	0.03283	0.0335
32	3.176	0.00183	0.00309	0.01196	0.03086	0.03149
34	3.3333	0.00174	0.00294	0.0114	0.0294	0.03
36	3.5087	0.00165	0.00279	0.01083	0.02793	0.0285
38	3.7735	0.00154	0.0026	0.01007	0.02597	0.0265
40	4	0.00145	0.00245	0.0095	0.0245	0.025
42	4.2553	0.00136	0.0023	0.00893	0.02303	0.0235
44	4.6511	0.00125	0.00211	0.00817	0.02107	0.0215

[a] Adapted from DWA&F (1993; 1996) and Quality of Domestic Water Supplies (1998)

[b] Adapted from DWA&F (1996) and WHO (1993); [c] Default temperature

WTTCCIRRD 3 Type B: Domestic user group = Children (10 kg BW) for WQC = Cd.

		Allowable WQC concentration in mg/L[a]				
		TWQR	**Cat B**	**Cat C**	**Cat D**	**Cat E**
		0.0029	**0.003-0.0049**	**0.005-0.019**	**0.02-0.049**	**>0.05**
		Effective Upper Limit value used (mg/L)				
		0.0029	**0.0049**	**0.019**	**0.049**	**0.05**
		Category ingestion (mg/d)				
Temp-C	**Predic. WI (L/d)[b]**	**0.0029**	**0.0049**	**0.019**	**0.049**	**0.05**
8	0.5882	0.00493	0.00833	0.0323	0.0833	0.08501
10	0.6666	0.00435	0.00735	0.0285	0.07351	0.07501
12	0.7692	0.00377	0.00637	0.0247	0.0637	0.065
14	0.909	0.00319	0.00539	0.0209	0.05391	0.05501
16[c]	1	0.0029	0.0049	0.019	0.049	0.05
18	1.052	0.00276	0.00466	0.01806	0.04658	0.04753
20	1.1111	0.00261	0.00441	0.0171	0.0441	0.045
22	1.1764	0.00247	0.00417	0.01615	0.04165	0.0425
24	1.25	0.00232	0.00392	0.0152	0.0392	0.04
26	1.4285	0.00203	0.00343	0.0133	0.0343	0.035
28	1.4285	0.00203	0.00343	0.0133	0.0343	0.035
30	1.4925	0.00194	0.00328	0.01273	0.03283	0.0335
32	1.5873	0.00183	0.00309	0.01197	0.03087	0.0315
34	1.6666	0.00174	0.00294	0.0114	0.0294	0.03
36	1.7543	0.00165	0.00279	0.01083	0.02793	0.0285
38	1.8867	0.00154	0.0026	0.01007	0.02597	0.0265
40	2	0.00145	0.00245	0.0095	0.0245	0.025
42	2.1276	0.00136	0.0023	0.00893	0.02303	0.0235
44	2.3255	0.00125	0.00211	0.00817	0.02107	0.0215

[a] Adapted from DWA&F (1993; 1996) and Quality of Domestic Water Supplies (1998)

[b] Adapted from DWA&F (1996) and WHO (1993); [c] Default temperature

WTTCCIRRD 3 Type C: Domestic user group = Infants (5 kg BW) for WQC = Cd.

		Allowable WQC concentration in mg/L[a]				
		TWQR	**Cat B**	**Cat C**	**Cat D**	**Cat E**
		0.0029	**0.003-0.0049**	**0.005-0.019**	**0.02-0.049**	**>0.05**
		Effective Upper Limit value used (mg/L)				
		0.0029	**0.0049**	**0.019**	**0.049**	**0.05**
		Category ingestion (mg/d)				
Temp-C	**Predic. WI (L/d)[b]**	**0.00218**	**0.00368**	**0.01425**	**0.03675**	**0.0375**
8	0.4411	0.00494	0.00834	0.03219	0.0832	0.08501
10	0.5	0.00436	0.00736	0.0284	0.0734	0.075
12	0.5769	0.00378	0.00638	0.02461	0.06362	0.065
14	0.6818	0.0032	0.0054	0.02083	0.05383	0.055
16[c]	**0.75**	**0.00291**	**0.00491**	**0.01893**	**0.04893**	**0.05**
18	0.7894	0.00276	0.00466	0.01799	0.04649	0.0475
20	0.8333	0.00262	0.00442	0.01704	0.04404	0.045
22	0.8823	0.00247	0.00417	0.01609	0.0416	0.0425
24	0.9375	0.00233	0.00393	0.01515	0.03915	0.04
26	1.0714	0.00203	0.00343	0.01325	0.03425	0.035
28	1.0714	0.00203	0.00343	0.01325	0.03425	0.035
30	1.1194	0.00195	0.00329	0.01269	0.03279	0.0335
32	1.1904	0.00183	0.00309	0.01193	0.03083	0.0315
34	1.25	0.00174	0.00294	0.01136	0.02936	0.03
36	1.3157	0.00166	0.0028	0.01079	0.02789	0.0285
38	1.415	0.00154	0.0026	0.01004	0.02594	0.0265
40	1.5	0.00145	0.00245	0.00947	0.02447	0.025
42	1.5957	0.00137	0.00231	0.0089	0.023	0.0235
44	1.7441	0.00125	0.00211	0.00814	0.02104	0.0215

[a] Adapted from DWA&F (1993; 1996) and Quality of Domestic Water Supplies (1998)

[b] Adapted from DWA&F (1996) and WHO (1993); [c] Default temperature

WTTCCIRRD 4 Type A: Domestic user group = Adult (60 kg BW) for WQC = Ca.

		Allowable WQC concentration in mg/L[a]				
		TWQR	**Cat B**	**Cat C**	**Cat D**	**Cat E[d]**
		79	**80-149**	**150-299**	**>300**	
		Effective Upper Limit value used (mg/L)				
		79	**149**	**299**	**300**	
		Category ingestion (mg/d)				
Temp (deg Cel)	**Predicted WI (L/d)[b]**	**158**	**298**	**598**	**600**	
8	1.1764	134.308	253.315	508.33	510.031	
10	1.3333	118.503	223.506	448.511	450.011	
12	1.5384	102.704	193.708	388.716	390.016	
14	1.8181	86.9039	163.907	328.915	330.015	
16[c]	2	79	149	299	300	
18	2.1052	75.0523	141.554	284.059	285.009	
20	2.2222	71.1007	134.101	269.103	270.003	
22	2.3529	67.1512	126.652	254.154	255.004	
24	2.5	63.2	119.2	239.2	240	
26	2.8571	55.3008	104.302	209.303	210.003	
28	2.8571	55.3008	104.302	209.303	210.003	
30	2.9852	52.9278	99.8258	200.322	200.992	
32	3.176	49.7481	93.8287	188.287	188.917	
34	3.3333	47.4005	89.4009	179.402	180.002	
36	3.5087	45.0309	84.9317	170.433	171.004	
38	3.7735	41.8709	78.9718	158.474	159.004	
40	4	39.5	74.5	149.5	150	
42	4.2553	37.1302	70.0303	140.531	141.001	
44	4.6511	33.9705	64.0709	128.572	129.002	

[a] Adapted from DWA&F (1993; 1996) and Quality of Domestic Water Supplies (1998)

[b] Adapted from DWA&F (1996) and WHO (1993); [c] Default temperature

[d] Not applicable to WQC = Ca

WTTCCIRRD 4 Type B: Domestic user group = Children (10 kg BW) for WQC = Ca.

		Allowable WQC concentration in mg/L[a]				
		TWQR	Cat B	Cat C	Cat D	Cat E[d]
		79	80-149	150-299	>300	
		Effective Upper Limit value used (mg/L)				
		79	149	299	300	
		Category ingestion (mg/d)				
Temp (deg Cel)	**Predicted WI (L/d)[b]**	**79**	**149**	**299**	**300**	
8	0.5882	134.308	253.315	508.33	510.031	
10	0.6666	118.512	223.522	448.545	450.045	
12	0.7692	102.704	193.708	388.716	390.016	
14	0.909	86.9087	163.916	328.933	330.033	
16[c]	1	79	149	299	300	
18	1.052	75.0951	141.635	284.221	285.171	
20	1.1111	71.1007	134.101	269.103	270.003	
22	1.1764	67.154	126.658	254.165	255.015	
24	1.25	63.2	119.2	239.2	240	
26	1.4285	55.3028	104.305	209.31	210.011	
28	1.4285	55.3028	104.305	209.31	210.011	
30	1.4925	52.9313	99.8325	200.335	201.005	
32	1.5873	49.77	93.8701	188.37	189	
34	1.6666	47.4019	89.4036	179.407	180.007	
36	1.7543	45.0322	84.9342	170.438	171.008	
38	1.8867	41.8721	78.9739	158.478	159.008	
40	2	39.5	74.5	149.5	150	
42	2.1276	37.131	70.032	140.534	141.004	
44	2.3255	33.9712	64.0722	128.575	129.005	

[a] Adapted from DWA&F (1993; 1996) and Quality of Domestic Water Supplies (1998)
[b] Adapted from DWA&F (1996) and WHO (1993); [c] Default temperature
[d] Not applicable to WQC = Ca

WTTCCIRRD 4 Type C: Domestic user group = Infants (5 kg BW) for WQC = Ca

		Allowable WQC concentration in mg/L[a]				
		TWQR	Cat B	Cat C	Cat D	Cat E[d]
		79	80-149	150-299	>300	
		Effective Upper Limit value used (mg/L)				
		79	149	299	300	
		Category ingestion (mg/d)				
Temp-C	**Predic. WI (L/d)[b]**	**59.25**	**111.75**	**224.25**	**225**	
8	0.4411	134.323	253.344	508.388	510.088	
10	0.5	118.5	223.5	448.5	450	
12	0.5769	102.704	193.708	388.716	390.016	
14	0.6818	86.9023	163.904	328.909	330.009	
16[c]	0.75	79	149	299	300	
18	0.7894	75.057	141.563	284.077	285.027	
20	0.8333	71.1028	134.105	269.111	270.011	
22	0.8823	67.154	126.658	254.165	255.015	
24	0.9375	63.2	119.2	239.2	240	
26	1.0714	55.3015	104.303	209.306	210.006	
28	1.0714	55.3015	104.303	209.306	210.006	
30	1.1194	52.9301	99.8303	200.331	201.001	
32	1.1904	49.7732	93.876	188.382	189.012	
34	1.25	47.4	89.4	179.4	180	
36	1.3157	45.0331	84.9358	170.442	171.012	
38	1.415	41.8728	78.9753	158.481	159.011	
40	1.5	39.5	74.5	149.5	150	
42	1.5957	37.131	70.032	140.534	141.004	
44	1.7441	33.9717	64.0732	128.576	129.006	

[a] Adapted from DWA&F (1993; 1996) and Quality of Domestic Water Supplies (1998)
[b] Adapted from DWA&F (1996) and WHO (1993); [c] Default temperature
[d] Not applicable to WQC = Ca

WTTCCIRRD 5 Type A: Domestic user group = Adult (60 kg BW) for WQC = Cl.

		Allowable WQC concentration in mg/L[a]				
		TWQR	**Cat B**	**Cat C**	**Cat D**	**Cat E**
		99	**100-199**	**200-599**	**600-1199**	**>1200**
		Effective Upper Limit value used (mg/L)				
		99	**199**	**599**	**1199**	**1200**
		Category ingestion (mg/d)				
Temp-C	**Predic. WI (L/d)[b]**	**198**	**398**	**1198**	**2398**	**2400**
8	1.1764	168.31	338.32	1018.36	2038.42	2040.12
10	1.3333	148.504	298.507	898.522	1798.54	1800.05
12	1.5384	128.705	258.71	778.731	1558.76	1560.06
14	1.8181	108.905	218.91	658.93	1318.96	1320.06
16[c]	2	99	199	599	1199	1200
18	2.1052	94.0528	189.056	569.067	1139.08	1140.03
20	2.2222	89.1009	179.102	539.105	1079.11	1080.01
22	2.3529	84.1515	169.153	509.159	1019.17	1020.02
24	2.5	79.2	159.2	479.2	959.2	960
26	2.8571	69.301	139.302	419.306	839.313	840.013
28	2.8571	69.301	139.302	419.306	839.313	840.013
30	2.9852	66.3272	133.324	401.313	803.296	803.966
32	3.176	62.3426	125.315	377.204	755.038	755.668
34	3.3333	59.4006	119.401	359.404	719.407	720.007
36	3.5087	56.4312	113.432	341.437	683.444	684.014
38	3.7735	52.4712	105.472	317.477	635.484	636.014
40	4	49.5	99.5	299.5	599.5	600
42	4.2553	46.5302	93.5304	281.531	563.533	564.003
44	4.6511	42.5706	85.5712	257.573	515.577	516.007

[a] Adapted from DWA&F (1993; 1996) and Quality of Domestic Water Supplies (1998)

[b] Adapted from DWA&F (1996) and WHO (1993); [c] Default temperature

WTTCCIRRD 5 Type B: Domestic user group = Children (10 kg BW) for WQC = Cl.

		Allowable WQC concentration in mg/L[a]				
		TWQR	**Cat B**	**Cat C**	**Cat D**	**Cat E**
		99	**100-199**	**200-599**	**600-1199**	**>1200**
		Effective Upper Limit value used (mg/L)				
		99	**199**	**599**	**1199**	**1200**
		Category ingestion (mg/d)				
Temp-C	**Predic. WI (L/d)[b]**	**99**	**199**	**599**	**1199**	**1200**
8	0.5882	168.31	338.32	1018.36	2038.42	2040.12
10	0.6666	148.515	298.53	898.59	1798.68	1800.18
12	0.7692	128.705	258.71	778.731	1558.76	1560.06
14	0.909	108.911	218.922	658.966	1319.03	1320.13
16[c]	1	99	199	599	1199	1200
18	1.052	94.1065	189.163	569.392	1139.73	1140.68
20	1.1111	89.1009	179.102	539.105	1079.11	1080.01
22	1.1764	84.155	169.16	509.181	1019.21	1020.06
24	1.25	79.2	159.2	479.2	959.2	960
26	1.4285	69.3035	139.307	419.321	839.342	840.042
28	1.4285	69.3035	139.307	419.321	839.342	840.042
30	1.4925	66.3317	133.333	401.34	803.35	804.02
32	1.5873	62.3701	125.37	377.37	755.371	756.001
34	1.6666	59.4024	119.405	359.414	719.429	720.029
36	1.7543	56.4328	113.436	341.447	683.463	684.034
38	1.8867	52.4726	105.475	317.486	635.501	636.031
40	2	49.5	99.5	299.5	599.5	600
42	2.1276	46.5313	93.5326	281.538	563.546	564.016
44	2.3255	42.5715	85.573	257.579	515.588	516.018

[a] Adapted from DWA&F (1993; 1996) and Quality of Domestic Water Supplies (1998)

[b] Adapted from DWA&F (1996) and WHO (1993); [c] Default temperature

WTTCCIRRD 5 Type C: Domestic user group = Infants (5 kg BW) for WQC = Cl.

		Allowable WQC concentration in mg/L[a]				
		TWQR	**Cat B**	**Cat C**	**Cat D**	**Cat E**
		99	**100-199**	**200-599**	**600-1199**	**>1200**
		Effective Upper Limit value used (mg/L)				
		99	**199**	**599**	**1199**	**1200**
		Category ingestion (mg/d)				
Temp-C	**Predic. WI (L/d)[b]**	**74.25**	**149.25**	**449.25**	**899.25**	**900**
8	0.4411	168.329	338.359	1018.48	2038.65	2040.35
10	0.5	148.5	298.5	898.5	1798.5	1800
12	0.5769	128.705	258.71	778.731	1558.76	1560.06
14	0.6818	108.903	218.906	658.918	1318.94	1320.04
16[c]	0.75	99	199	599	1199	1200
18	0.7894	94.0588	189.068	569.103	1139.16	1140.11
20	0.8333	89.1036	179.107	539.122	1079.14	1080.04
22	0.8823	84.155	169.16	509.181	1019.21	1020.06
24	0.9375	79.2	159.2	479.2	959.2	960
26	1.0714	69.3018	139.304	419.311	839.322	840.022
28	1.0714	69.3018	139.304	419.311	839.322	840.022
30	1.1194	66.3302	133.33	401.331	803.332	804.002
32	1.1904	62.374	125.378	377.394	755.418	756.048
34	1.25	59.4	119.4	359.4	719.4	720
36	1.3157	56.4338	113.438	341.453	683.476	684.047
38	1.415	52.4735	105.477	317.491	635.512	636.042
40	1.5	49.5	99.5	299.5	599.5	600
42	1.5957	46.5313	93.5326	281.538	563.546	564.016
44	1.7441	42.5721	85.5742	257.583	515.595	516.025

[a] Adapted from DWA&F (1993; 1996) and Quality of Domestic Water Supplies (1998)

[b] Adapted from DWA&F (1996) and WHO (1993); [c] Default temperature

WTTCCIRRD 6 Type A: Domestic user group = Adult (60 kg BW) for WQC = Cu.

		Allowable WQC concentration in mg/L[a]				
		TWQR	**Cat B**	**Cat C**	**Cat D**	**Cat E**
		0.99	**1-1.29**	**1.3-1.99**	**2-14.9**	**>15**
		Effective Upper Limit value used (mg/L)				
		0.99	**1.29**	**1.99**	**14.9**	**15**
		Category ingestion (mg/d)				
Temp-C	**Predic. WI (L/d)[b]**	**1.98**	**2.58**	**3.98**	**29.8**	**30**
8	1.1764	1.6831	2.19313	3.3832	25.3315	25.5015
10	1.3333	1.48504	1.93505	2.98507	22.3506	22.5006
12	1.5384	1.28705	1.67707	2.5871	19.3708	19.5008
14	1.8181	1.08905	1.41906	2.1891	16.3907	16.5007
16[c]	2	0.99	1.29	1.99	14.9	15
18	2.1052	0.94053	1.22554	1.89056	14.1554	14.2504
20	2.2222	0.89101	1.16101	1.79102	13.4101	13.5001
22	2.3529	0.84151	1.09652	1.69153	12.6652	12.7502
24	2.5	0.792	1.032	1.592	11.92	12
26	2.8571	0.69301	0.90301	1.39302	10.4302	10.5002
28	2.8571	0.69301	0.90301	1.39302	10.4302	10.5002
30	2.9852	0.66327	0.86426	1.33324	9.98258	10.0496
32	3.176	0.62343	0.81234	1.25315	9.38287	9.44584
34	3.3333	0.59401	0.77401	1.19401	8.94009	9.00009
36	3.5087	0.56431	0.73532	1.13432	8.49317	8.55018
38	3.7735	0.52471	0.68372	1.05472	7.89718	7.95018
40	4	0.495	0.645	0.995	7.45	7.5
42	4.2553	0.4653	0.6063	0.9353	7.00303	7.05003
44	4.6511	0.42571	0.55471	0.85571	6.40709	6.45009

[a] Adapted from DWA&F (1993; 1996) and Quality of Domestic Water Supplies (1998)

[b] Adapted from DWA&F (1996) and WHO (1993); [c] Default temperature

WTTCCIRRD 6 Type B: Domestic user group = Children (10 kg BW) for WQC = Cu

		Allowable WQC concentration in mg/L[a]				
		TWQR	**Cat B**	**Cat C**	**Cat D**	**Cat E**
		0.99	**1-1.29**	**1.3-1.99**	**2-14.9**	**>15**
		Effective Upper Limit value used (mg/L)				
		0.99	**1.29**	**1.99**	**14.9**	**15**
		Category ingestion (mg/d)				
Temp-C	**Predic. WI (L/d)[b]**	**0.99**	**1.29**	**1.99**	**14.9**	**15**
8	0.5882	1.6831	2.19313	3.3832	25.3315	25.5015
10	0.6666	1.48515	1.93519	2.9853	22.3522	22.5023
12	0.7692	1.28705	1.67707	2.5871	19.3708	19.5008
14	0.909	1.08911	1.41914	2.18922	16.3916	16.5017
16[c]	1	0.99	1.29	1.99	14.9	15
18	1.052	0.94106	1.22624	1.89163	14.1635	14.2586
20	1.1111	0.89101	1.16101	1.79102	13.4101	13.5001
22	1.1764	0.84155	1.09657	1.6916	12.6658	12.7508
24	1.25	0.792	1.032	1.592	11.92	12
26	1.4285	0.69303	0.90305	1.39307	10.4305	10.5005
28	1.4285	0.69303	0.90305	1.39307	10.4305	10.5005
30	1.4925	0.66332	0.86432	1.33333	9.98325	10.0503
32	1.5873	0.6237	0.8127	1.2537	9.38701	9.45001
34	1.6666	0.59402	0.77403	1.19405	8.94036	9.00036
36	1.7543	0.56433	0.73534	1.13436	8.49342	8.55042
38	1.8867	0.52473	0.68373	1.05475	7.89739	7.95039
40	2	0.495	0.645	0.995	7.45	7.5
42	2.1276	0.46531	0.60632	0.93533	7.0032	7.0502
44	2.3255	0.42571	0.55472	0.85573	6.40722	6.45023

[a] Adapted from DWA&F (1993; 1996) and Quality of Domestic Water Supplies (1998)
[b] Adapted from DWA&F (1996) and WHO (1993); [c] Default temperature

WTTCCIRRD 6 Type C: Domestic user group = Infants (5 kg BW) for WQC = Cu

		Allowable WQC concentration in mg/L[a]				
		TWQR	**Cat B**	**Cat C**	**Cat D**	**Cat E**
		0.99	**1-1.29**	**1.3-1.99**	**2-14.9**	**>15**
		Effective Upper Limit value used (mg/L)				
		0.99	**1.29**	**1.99**	**14.9**	**15**
		Category ingestion (mg/d)				
Temp-C	**Predic. WI (L/d)[b]**	**0.7425**	**0.9675**	**1.4925**	**11.175**	**11.25**
8	0.4411	1.68216	2.19225	3.38245	25.3344	25.5044
10	0.5	1.484	1.934	2.984	22.35	22.5
12	0.5769	1.28618	1.6762	2.58624	19.3708	19.5008
14	0.6818	1.0883	1.4183	2.18833	16.3904	16.5004
16[c]	0.75	0.98933	1.28933	1.98933	14.9	15
18	0.7894	0.93995	1.22498	1.89004	14.1563	14.2513
20	0.8333	0.89044	1.16045	1.79047	13.4105	13.5005
22	0.8823	0.84098	1.096	1.69103	12.6658	12.7508
24	0.9375	0.79147	1.03147	1.59147	11.92	12
26	1.0714	0.69255	0.90256	1.39257	10.4303	10.5003
28	1.0714	0.69255	0.90256	1.39257	10.4303	10.5003
30	1.1194	0.66286	0.86386	1.33286	9.98303	10.05
32	1.1904	0.62332	0.81233	1.25336	9.3876	9.4506
34	1.25	0.5936	0.7736	1.1936	8.94	9
36	1.3157	0.56396	0.73497	1.134	8.49358	8.55058
38	1.415	0.52438	0.68339	1.05442	7.89753	7.95053
40	1.5	0.49467	0.64467	0.99467	7.45	7.5
42	1.5957	0.465	0.606	0.93501	7.0032	7.0502
44	1.7441	0.42543	0.55444	0.85546	6.40732	6.45032

[a] Adapted from DWA&F (1993; 1996) and Quality of Domestic Water Supplies (1998)
[b] Adapted from DWA&F (1996) and WHO (1993); [c] Default temperature

WTTCCIRRD 7 Type A: Domestic user group = Adult (60 kg BW) for WQC = Fe

		Allowable WQC concentration in mg/L[a]				
		TWQR	Cat B	Cat C	Cat D	Cat E[d]
		0.49	0.5-0.99	1-4.99	5-9.9	>10
		Effective Upper Limit value used (mg/L)				
		0.49	0.99	4.99	9.9	10
		Category ingestion (mg/d)				
Temp-C	**Predic. WI (L/d)[b]**	**0.98**	**1.98**	**9.98**	**19.8**	**20**
8	1.1764	0.83305	1.6831	8.48351	16.831	17.001
10	1.3333	0.73502	1.48504	7.48519	14.8504	15.0004
12	1.5384	0.63703	1.28705	6.48726	12.8705	13.0005
14	1.8181	0.53902	1.08905	5.48925	10.8905	11.0005
16[c]	2	0.49	0.99	4.99	9.9	10
18	2.1052	0.46551	0.94053	4.74064	9.40528	9.50029
20	2.2222	0.441	0.89101	4.49104	8.91009	9.00009
22	2.3529	0.41651	0.84151	4.24157	8.41515	8.50015
24	2.5	0.392	0.792	3.992	7.92	8
26	2.8571	0.34301	0.69301	3.49305	6.9301	7.00011
28	2.8571	0.34301	0.69301	3.49305	6.9301	7.00011
30	2.9852	0.32829	0.66327	3.34316	6.63272	6.69972
32	3.176	0.30856	0.62343	3.14232	6.23426	6.29723
34	3.3333	0.294	0.59401	2.99403	5.94006	6.00006
36	3.5087	0.27931	0.56431	2.84436	5.64312	5.70012
38	3.7735	0.25971	0.52471	2.64476	5.24712	5.30012
40	4	0.245	0.495	2.495	4.95	5
42	4.2553	0.2303	0.4653	2.34531	4.65302	4.70002
44	4.6511	0.2107	0.42571	2.14573	4.25706	4.30006

[a] Adapted from DWA&F (1993; 1996) and Quality of Domestic Water Supplies (1998)
[b] Adapted from DWA&F (1996) and WHO (1993); [c] Default temperature

WTTCCIRRD 7 Type B: Domestic user group = Children (10 kg BW) for WQC = Fe.

		Allowable WQC concentration in mg/L[a]				
		TWQR	Cat B	Cat C	Cat D	Cat E
		0.49	0.5-0.99	1-4.99	5-9.9	>10
		Effective Upper Limit value used (mg/L)				
		0.49	0.99	4.99	9.9	10
		Category ingestion (mg/d)				
Temp-C	**Predic. WI (L/d)[b]**	**0.49**	**0.99**	**4.99**	**9.9**	**10**
8	0.5882	0.83305	1.6831	8.48351	16.831	17.001
10	0.6666	0.73507	1.48515	7.48575	14.8515	15.0015
12	0.7692	0.63703	1.28705	6.48726	12.8705	13.0005
14	0.909	0.53905	1.08911	5.48955	10.8911	11.0011
16[c]	1	0.49	0.99	4.99	9.9	10
18	1.052	0.46578	0.94106	4.74335	9.41065	9.5057
20	1.1111	0.441	0.89101	4.49104	8.91009	9.00009
22	1.1764	0.41652	0.84155	4.24175	8.4155	8.50051
24	1.25	0.392	0.792	3.992	7.92	8
26	1.4285	0.34302	0.69303	3.49317	6.93035	7.00035
28	1.4285	0.34302	0.69303	3.49317	6.93035	7.00035
30	1.4925	0.32831	0.66332	3.34338	6.63317	6.70017
32	1.5873	0.3087	0.6237	3.1437	6.23701	6.30001
34	1.6666	0.29401	0.59402	2.99412	5.94024	6.00024
36	1.7543	0.27931	0.56433	2.84444	5.64328	5.70028
38	1.8867	0.25971	0.52473	2.64483	5.24726	5.30026
40	2	0.245	0.495	2.495	4.95	5
42	2.1276	0.23031	0.46531	2.34537	4.65313	4.70013
44	2.3255	0.21071	0.42571	2.14578	4.25715	4.30015

[a] Adapted from DWA&F (1993; 1996) and Quality of Domestic Water Supplies (1998)
[b] Adapted from DWA&F (1996) and WHO (1993); [c] Default temperature

WTTCCIRRD 7 Type C: Domestic user group = Infants (5 kg BW) for WQC = Fe.

		Allowable WQC concentration in mg/L[a]				
		TWQR	**Cat B**	**Cat C**	**Cat D**	**Cat E**
		0.49	**0.5-0.99**	**1-4.99**	**5-9.9**	**>10**
		Effective Upper Limit value used (mg/L)				
		0.49	**0.99**	**4.99**	**9.9**	**10**
		Category ingestion (mg/d)				
Temp-C	**Predic. WI (L/d)[b]**	**0.3675**	**0.7425**	**3.7425**	**7.425**	**7.5**
8	0.4411	0.83314	1.68329	8.48447	16.8329	17.0029
10	0.5	0.735	1.485	7.485	14.85	15
12	0.5769	0.63703	1.28705	6.48726	12.8705	13.0005
14	0.6818	0.53901	1.08903	5.48915	10.8903	11.0003
16[c]	0.75	0.49	0.99	4.99	9.9	10
18	0.7894	0.46554	0.94059	4.74094	9.40588	9.50089
20	0.8333	0.44102	0.89104	4.49118	8.91036	9.00036
22	0.8823	0.41652	0.84155	4.24175	8.4155	8.50051
24	0.9375	0.392	0.792	3.992	7.92	8
26	1.0714	0.34301	0.69302	3.49309	6.93018	7.00019
28	1.0714	0.34301	0.69302	3.49309	6.93018	7.00019
30	1.1194	0.3283	0.6633	3.34331	6.63302	6.70002
32	1.1904	0.30872	0.62374	3.1439	6.2374	6.3004
34	1.25	0.294	0.594	2.994	5.94	6
36	1.3157	0.27932	0.56434	2.84449	5.64338	5.70039
38	1.415	0.25972	0.52473	2.64488	5.24735	5.30035
40	1.5	0.245	0.495	2.495	4.95	5
42	1.5957	0.23031	0.46531	2.34537	4.65313	4.70013
44	1.7441	0.21071	0.42572	2.14581	4.25721	4.30021

[a] Adapted from DWA&F (1993; 1996) and Quality of Domestic Water Supplies (1998)

[b] Adapted from DWA&F (1996) and WHO (1993); [c] Default temperature

WTTCCIRRD 8 Type A: Domestic user group = Adult (60 kg BW) for WQC = Mg.

		Allowable WQC concentration in mg/L[a]				
		TWQR	**Cat B**	**Cat C**	**Cat D**	**Cat E**
		69	**70-99**	**100-199**	**200-399**	**>400**
		Effective Upper Limit value used (mg/L)				
		69	**99**	**199**	**399**	**400**
		Category ingestion (mg/d)				
Temp-C	**Predic. WI (L/d)[b]**	**138**	**198**	**398**	**798**	**800**
8	1.1764	117.307	168.31	338.32	678.341	680.041
10	1.3333	103.503	148.504	298.507	598.515	600.015
12	1.5384	89.7036	128.705	258.71	518.721	520.021
14	1.8181	75.9034	108.905	218.91	438.92	440.02
16[c]	2	69	99	199	399	400
18	2.1052	65.552	94.0528	189.056	379.061	380.011
20	2.2222	62.1006	89.1009	179.102	359.104	360.004
22	2.3529	58.651	84.1515	169.153	339.156	340.006
24	2.5	55.2	79.2	159.2	319.2	320
26	2.8571	48.3007	69.301	139.302	279.304	280.004
28	2.8571	48.3007	69.301	139.302	279.304	280.004
30	2.9852	46.2281	66.3272	133.324	267.319	267.989
32	3.176	43.4509	62.3426	125.315	251.259	251.889
34	3.3333	41.4004	59.4006	119.401	239.402	240.002
36	3.5087	39.3308	56.4312	113.432	227.435	228.005
38	3.7735	36.5708	52.4712	105.472	211.475	212.005
40	4	34.5	49.5	99.5	199.5	200
42	4.2553	32.4301	46.5302	93.5304	187.531	188.001
44	4.6511	29.6704	42.5706	85.5712	171.572	172.002

[a] Adapted from DWA&F (1993; 1996) and Quality of Domestic Water Supplies (1998)

[b] Adapted from DWA&F (1996) and WHO (1993); [c] Default temperature

WTTCCIRRD 8 Type B: Domestic user group = Children (10 kg BW) for WQC = Mg

		Allowable WQC concentration in mg/L[a]				
		TWQR	**Cat B**	**Cat C**	**Cat D**	**Cat E**
		69	**70-99**	**100-199**	**200-399**	**>400**
		Effective Upper Limit value used (mg/L)				
		69	**99**	**199**	**399**	**400**
		Category ingestion (mg/d)				
Temp-C	**Predic. WI (L/d)[b]**	**69**	**99**	**199**	**399**	**400**
8	0.5882	117.307	168.31	338.32	678.341	680.041
10	0.6666	103.51	148.515	298.53	598.56	600.06
12	0.7692	89.7036	128.705	258.71	518.721	520.021
14	0.909	75.9076	108.911	218.922	438.944	440.044
16[c]	1	69	99	199	399	400
18	1.052	65.5894	94.1065	189.163	379.278	380.228
20	1.1111	62.1006	89.1009	179.102	359.104	360.004
22	1.1764	58.6535	84.155	169.16	339.17	340.02
24	1.25	55.2	79.2	159.2	319.2	320
26	1.4285	48.3024	69.3035	139.307	279.314	280.014
28	1.4285	48.3024	69.3035	139.307	279.314	280.014
30	1.4925	46.2312	66.3317	133.333	267.337	268.007
32	1.5873	43.47	62.3701	125.37	251.37	252
34	1.6666	41.4017	59.4024	119.405	239.41	240.01
36	1.7543	39.3319	56.4328	113.436	227.441	228.011
38	1.8867	36.5718	52.4726	105.475	211.48	212.01
40	2	34.5	49.5	99.5	199.5	200
42	2.1276	32.4309	46.5313	93.5326	187.535	188.005
44	2.3255	29.671	42.5715	85.573	171.576	172.006

[a] Adapted from DWA&F (1993; 1996) and Quality of Domestic Water Supplies (1998)

[b] Adapted from DWA&F (1996) and WHO (1993); [c] Default temperature

WTTCCIRRD 8 Type C: Domestic user group = Infants (5 kg BW) for WQC = Mg

		Allowable WQC concentration in mg/L[a]				
		TWQR	**Cat B**	**Cat C**	**Cat D**	**Cat E**
		69	**70-99**	**100-199**	**200-399**	**>400**
		Effective Upper Limit value used (mg/L)				
		69	**99**	**199**	**399**	**400**
		Category ingestion (mg/d)				
Temp-C	**Predic. WI (L/d)[b]**	**51.75**	**74.25**	**149.25**	**299.25**	**300**
8	0.4411	117.32	168.329	338.359	678.418	680.118
10	0.5	103.5	148.5	298.5	598.5	600
12	0.5769	89.7036	128.705	258.71	518.721	520.021
14	0.6818	75.902	108.903	218.906	438.912	440.012
16[c]	0.75	69	99	199	399	400
18	0.7894	65.5561	94.0588	189.068	379.085	380.035
20	0.8333	62.1025	89.1036	179.107	359.114	360.014
22	0.8823	58.6535	84.155	169.16	339.17	340.02
24	0.9375	55.2	79.2	159.2	319.2	320
26	1.0714	48.3013	69.3018	139.304	279.307	280.007
28	1.0714	48.3013	69.3018	139.304	279.307	280.007
30	1.1194	46.2301	66.3302	133.33	267.331	268.001
32	1.1904	43.4728	62.374	125.378	251.386	252.016
34	1.25	41.4	59.4	119.4	239.4	240
36	1.3157	39.3327	56.4338	113.438	227.445	228.016
38	1.415	36.5724	52.4735	105.477	211.484	212.014
40	1.5	34.5	49.5	99.5	199.5	200
42	1.5957	32.4309	46.5313	93.5326	187.535	188.005
44	1.7441	29.6715	42.5721	85.5742	171.578	172.008

[a] Adapted from DWA&F (1993; 1996) and Quality of Domestic Water Supplies (1998)

[b] Adapted from DWA&F (1996) and WHO (1993); [c] Default temperature

WTTCCIRRD 9 Type A: Domestic user group = Adult (60 kg BW) for WQC = Mn.

		Allowable WQC concentration in mg/L[a]				
		TWQR	**Cat B**	**Cat C**	**Cat D**	**Cat E**
		0.09	**0.1-0.39**	**0.4-3.99**	**4-9.9**	**>10**
		Effective Upper Limit value used (mg/L)				
		0.09	**0.39**	**3.99**	**9.9**	**10**
		Category ingestion (mg/d)				
Temp-C	**Predic. WI (L/d)[b]**	**0.18**	**0.78**	**7.98**	**19.8**	**20**
8	1.1764	0.15301	0.66304	6.78341	16.831	17.001
10	1.3333	0.135	0.58501	5.98515	14.8504	15.0004
12	1.5384	0.117	0.50702	5.18721	12.8705	13.0005
14	1.8181	0.099	0.42902	4.3892	10.8905	11.0005
16[c]	2	0.09	0.39	3.99	9.9	10
18	2.1052	0.0855	0.37051	3.79061	9.40528	9.50029
20	2.2222	0.081	0.351	3.59104	8.91009	9.00009
22	2.3529	0.0765	0.33151	3.39156	8.41515	8.50015
24	2.5	0.072	0.312	3.192	7.92	8
26	2.8571	0.063	0.273	2.79304	6.9301	7.00011
28	2.8571	0.063	0.273	2.79304	6.9301	7.00011
30	2.9852	0.0603	0.26129	2.67319	6.63272	6.69972
32	3.176	0.05668	0.24559	2.51259	6.23426	6.29723
34	3.3333	0.054	0.234	2.39402	5.94006	6.00006
36	3.5087	0.0513	0.2223	2.27435	5.64312	5.70012
38	3.7735	0.0477	0.2067	2.11475	5.24712	5.30012
40	4	0.045	0.195	1.995	4.95	5
42	4.2553	0.0423	0.1833	1.87531	4.65302	4.70002
44	4.6511	0.0387	0.1677	1.71572	4.25706	4.30006

[a] Adapted from DWA&F (1993; 1996) and Quality of Domestic Water Supplies (1998)

[b] Adapted from DWA&F (1996) and WHO (1993); [c] Default temperature

WTTCCIRRD 9 Type B: Domestic user group = Children (10 kg BW) for WQC = Mn.

		Allowable WQC concentration in mg/L[a]				
		TWQR	**Cat B**	**Cat C**	**Cat D**	**Cat E**
		0.09	**0.1-0.39**	**0.4-3.99**	**4-9.9**	**>10**
		Effective Upper Limit value used (mg/L)				
		0.09	**0.39**	**3.99**	**9.9**	**10**
		Category ingestion (mg/d)				
Temp-C	**Predic. WI (L/d)[b]**	**0.09**	**0.39**	**3.99**	**9.9**	**10**
8	0.5882	0.15301	0.66304	6.78341	16.831	17.001
10	0.6666	0.13501	0.58506	5.9856	14.8515	15.0015
12	0.7692	0.117	0.50702	5.18721	12.8705	13.0005
14	0.909	0.09901	0.42904	4.38944	10.8911	11.0011
16[c]	1	0.09	0.39	3.99	9.9	10
18	1.052	0.08555	0.37072	3.79278	9.41065	9.5057
20	1.1111	0.081	0.351	3.59104	8.91009	9.00009
22	1.1764	0.0765	0.33152	3.3917	8.4155	8.50051
24	1.25	0.072	0.312	3.192	7.92	8
26	1.4285	0.063	0.27301	2.79314	6.93035	7.00035
28	1.4285	0.063	0.27301	2.79314	6.93035	7.00035
30	1.4925	0.0603	0.26131	2.67337	6.63317	6.70017
32	1.5873	0.0567	0.2457	2.5137	6.23701	6.30001
34	1.6666	0.054	0.23401	2.3941	5.94024	6.00024
36	1.7543	0.0513	0.22231	2.27441	5.64328	5.70028
38	1.8867	0.0477	0.20671	2.1148	5.24726	5.30026
40	2	0.045	0.195	1.995	4.95	5
42	2.1276	0.0423	0.18331	1.87535	4.65313	4.70013
44	2.3255	0.0387	0.16771	1.71576	4.25715	4.30015

[a] Adapted from DWA&F (1993; 1996) and Quality of Domestic Water Supplies (1998)

[b] Adapted from DWA&F (1996) and WHO (1993); [c] Default temperature

WTTCCIRRD 9 Type C: Domestic user group = Infants (5 kg BW) for WQC = Mn.

		Allowable WQC concentration in mg/L[a]				
		TWQR	**Cat B**	**Cat C**	**Cat D**	**Cat E**
		0.09	**0.1-0.39**	**0.4-3.99**	**4-9.9**	**>10**
		Effective Upper Limit value used (mg/L)				
		0.09	**0.39**	**3.99**	**9.9**	**10**
		Category ingestion (mg/d)				
Temp-C	**Predic. WI (L/d)[b]**	**0.0675**	**0.2925**	**2.9925**	**7.425**	**7.5**
8	0.4411	0.15303	0.66311	6.78418	16.8329	17.0029
10	0.5	0.135	0.585	5.985	14.85	15
12	0.5769	0.117	0.50702	5.18721	12.8705	13.0005
14	0.6818	0.099	0.42901	4.38912	10.8903	11.0003
16[c]	0.75	0.09	0.39	3.99	9.9	10
18	0.7894	0.08551	0.37053	3.79085	9.40588	9.50089
20	0.8333	0.081	0.35101	3.59114	8.91036	9.00036
22	0.8823	0.0765	0.33152	3.3917	8.4155	8.50051
24	0.9375	0.072	0.312	3.192	7.92	8
26	1.0714	0.063	0.27301	2.79307	6.93018	7.00019
28	1.0714	0.063	0.27301	2.79307	6.93018	7.00019
30	1.1194	0.0603	0.2613	2.67331	6.63302	6.70002
32	1.1904	0.0567	0.24572	2.51386	6.2374	6.3004
34	1.25	0.054	0.234	2.394	5.94	6
36	1.3157	0.0513	0.22232	2.27445	5.64338	5.70039
38	1.415	0.0477	0.20671	2.11484	5.24735	5.30035
40	1.5	0.045	0.195	1.995	4.95	5
42	1.5957	0.0423	0.18331	1.87535	4.65313	4.70013
44	1.7441	0.0387	0.16771	1.71578	4.25721	4.30021

[a] Adapted from DWA&F (1993; 1996) and Quality of Domestic Water Supplies (1998)

[b] Adapted from DWA&F (1996) and WHO (1993); [c] Default temperature

WTTCCIRRD 10 Type A: Domestic user group = Adult (60 kg BW) for WQC = K.

		Allowable WQC concentration in mg/L[a]				
		TWQR	**Cat B**	**Cat C**	**Cat D**	**Cat E**
		24	**25-49**	**50-99**	**100-499**	**>500**
		Effective Upper Limit value used (mg/L)				
		24	**49**	**99**	**499**	**500**
		Category ingestion (mg/d)				
Temp-C	**Predic. WI (L/d)[b]**	**48**	**98**	**198**	**998**	**1000**
8	1.1764	40.8024	83.305	168.31	848.351	850.051
10	1.3333	36.0009	73.5018	148.504	748.519	750.019
12	1.5384	31.2012	63.7025	128.705	648.726	650.026
14	1.8181	26.4012	53.9024	108.905	548.925	550.025
16[c]	2	24	49	99	499	500
18	2.1052	22.8007	46.5514	94.0528	474.064	475.014
20	2.2222	21.6002	44.1004	89.1009	449.104	450.005
22	2.3529	20.4004	41.6507	84.1515	424.157	425.007
24	2.5	19.2	39.2	79.2	399.2	400
26	2.8571	16.8003	34.3005	69.301	349.305	350.005
28	2.8571	16.8003	34.3005	69.301	349.305	350.005
30	2.9852	16.0793	32.8286	66.3272	334.316	334.986
32	3.176	15.1134	30.8564	62.3426	314.232	314.861
34	3.3333	14.4001	29.4003	59.4006	299.403	300.003
36	3.5087	13.6803	27.9306	56.4312	284.436	285.006
38	3.7735	12.7203	25.9706	52.4712	264.476	265.006
40	4	12	24.5	49.5	249.5	250
42	4.2553	11.2801	23.0301	46.5302	234.531	235.001
44	4.6511	10.3201	21.0703	42.5706	214.573	215.003

[a] Adapted from DWA&F (1993; 1996) and Quality of Domestic Water Supplies (1998)

[b] Adapted from DWA&F (1996) and WHO (1993); [c] Default temperature

WTTCCIRRD 10 Type B: Domestic user group = Children (10 kg BW) for WQC = K.

		Allowable WQC concentration in mg/L[a]				
		TWQR	**Cat B**	**Cat C**	**Cat D**	**Cat E**
		24	**25-49**	**50-99**	**100-499**	**>500**
		Effective Upper Limit value used (mg/L)				
		24	**49**	**99**	**499**	**500**
		Category ingestion (mg/d)				
Temp-C	**Predic. WI (L/d)[b]**	**24**	**49**	**99**	**499**	**500**
8	0.5882	40.8024	83.305	168.31	848.351	850.051
10	0.6666	36.0036	73.5074	148.515	748.575	750.075
12	0.7692	31.2012	63.7025	128.705	648.726	650.026
14	0.909	26.4026	53.9054	108.911	548.955	550.055
16[c]	1	24	49	99	499	500
18	1.052	22.8137	46.5779	94.1065	474.335	475.285
20	1.1111	21.6002	44.1004	89.1009	449.104	450.005
22	1.1764	20.4012	41.6525	84.155	424.175	425.026
24	1.25	19.2	39.2	79.2	399.2	400
26	1.4285	16.8008	34.3017	69.3035	349.317	350.018
28	1.4285	16.8008	34.3017	69.3035	349.317	350.018
30	1.4925	16.0804	32.8308	66.3317	334.338	335.008
32	1.5873	15.12	30.87	62.3701	314.37	315
34	1.6666	14.4006	29.4012	59.4024	299.412	300.012
36	1.7543	13.6807	27.9314	56.4328	284.444	285.014
38	1.8867	12.7206	25.9713	52.4726	264.483	265.013
40	2	12	24.5	49.5	249.5	250
42	2.1276	11.2803	23.0306	46.5313	234.537	235.007
44	2.3255	10.3204	21.0707	42.5715	214.578	215.008

[a] Adapted from DWA&F (1993; 1996) and Quality of Domestic Water Supplies (1998)

[b] Adapted from DWA&F (1996) and WHO (1993); [c] Default temperature

WTTCCIRRD 10 Type C: Domestic user group = Infants (5 kg BW) for WQC = K.

		Allowable WQC concentration in mg/L[a]				
		TWQR	**Cat B**	**Cat C**	**Cat D**	**Cat E**
		24	**25-49**	**50-99**	**100-499**	**>500**
		Effective Upper Limit value used (mg/L)				
		24	**49**	**99**	**499**	**500**
		Category ingestion (mg/d)				
Temp-C	**Predic. WI (L/d)[b]**	**18**	**36.75**	**74.25**	**374.25**	**375**
8	0.4411	40.8071	83.3144	168.329	848.447	850.147
10	0.5	36	73.5	148.5	748.5	750
12	0.5769	31.2012	63.7025	128.705	648.726	650.026
14	0.6818	26.4007	53.9014	108.903	548.915	550.015
16[c]	0.75	24	49	99	499	500
18	0.7894	22.8021	46.5543	94.0588	474.094	475.044
20	0.8333	21.6009	44.1018	89.1036	449.118	450.018
22	0.8823	20.4012	41.6525	84.155	424.175	425.026
24	0.9375	19.2	39.2	79.2	399.2	400
26	1.0714	16.8004	34.3009	69.3018	349.309	350.009
28	1.0714	16.8004	34.3009	69.3018	349.309	350.009
30	1.1194	16.08	32.8301	66.3302	334.331	335.001
32	1.1904	15.121	30.872	62.374	314.39	315.02
34	1.25	14.4	29.4	59.4	299.4	300
36	1.3157	13.6809	27.9319	56.4338	284.449	285.019
38	1.415	12.7208	25.9717	52.4735	264.488	265.018
40	1.5	12	24.5	49.5	249.5	250
42	1.5957	11.2803	23.0306	46.5313	234.537	235.007
44	1.7441	10.3205	21.071	42.5721	214.581	215.011

[a] Adapted from DWA&F (1993; 1996) and Quality of Domestic Water Supplies (1998)

[b] Adapted from DWA&F (1996) and WHO (1993); [c] Default temperature

WTTCCIRRD 11 Type A: Domestic user group = Adult (60 kg BW) for WQC = Na.

		Allowable WQC concentration in mg/L[a]				
		TWQR	**Cat B**	**Cat C**	**Cat D**	**Cat E**
		99	**100-199**	**200-399**	**400-999**	**>1000**
		Effective Upper Limit value used (mg/L)				
		99	**199**	**399**	**999**	**1000**
		Category ingestion (mg/d)				
Temp-C	**Predic. WI (L/d)[b]**	**198**	**398**	**798**	**1998**	**2000**
8	1.1764	168.31	338.32	678.341	1698.4	1700.1
10	1.3333	148.504	298.507	598.515	1498.54	1500.04
12	1.5384	128.705	258.71	518.721	1298.75	1300.05
14	1.8181	108.905	218.91	438.92	1098.95	1100.05
16[c]	2	99	199	399	999	1000
18	2.1052	94.0528	189.056	379.061	949.078	950.029
20	2.2222	89.1009	179.102	359.104	899.109	900.009
22	2.3529	84.1515	169.153	339.156	849.165	850.015
24	2.5	79.2	159.2	319.2	799.2	800
26	2.8571	69.301	139.302	279.304	699.31	700.011
28	2.8571	69.301	139.302	279.304	699.31	700.011
30	2.9852	66.3272	133.324	267.319	669.302	669.972
32	3.176	62.3426	125.315	251.259	629.093	629.723
34	3.3333	59.4006	119.401	239.402	599.406	600.006
36	3.5087	56.4312	113.432	227.435	569.442	570.012
38	3.7735	52.4712	105.472	211.475	529.482	530.012
40	4	49.5	99.5	199.5	499.5	500
42	4.2553	46.5302	93.5304	187.531	469.532	470.002
44	4.6511	42.5706	85.5712	171.572	429.576	430.006

[a] Adapted from DWA&F (1993; 1996) and Quality of Domestic Water Supplies (1998)

[b] Adapted from DWA&F (1996) and WHO (1993); [c] Default temperature

WTTCCIRRD 11 Type B: Domestic user group = Children (10 kg BW) for WQC = Na.

		Allowable WQC concentration in mg/L[a]				
		TWQR	**Cat B**	**Cat C**	**Cat D**	**Cat E**
		99	**100-199**	**200-399**	**400-999**	**>1000**
		Effective Upper Limit value used (mg/L)				
		99	**199**	**399**	**999**	**1000**
		Category ingestion (mg/d)				
Temp-C	**Predic. WI (L/d)[b]**	**99**	**199**	**399**	**999**	**1000**
8	0.5882	168.31	338.32	678.341	1698.4	1700.1
10	0.6666	148.515	298.53	598.56	1498.65	1500.15
12	0.7692	128.705	258.71	518.721	1298.75	1300.05
14	0.909	108.911	218.922	438.944	1099.01	1100.11
16[c]	1	99	199	399	999	1000
18	1.052	94.1065	189.163	379.278	949.62	950.57
20	1.1111	89.1009	179.102	359.104	899.109	900.009
22	1.1764	84.155	169.16	339.17	849.201	850.051
24	1.25	79.2	159.2	319.2	799.2	800
26	1.4285	69.3035	139.307	279.314	699.335	700.035
28	1.4285	69.3035	139.307	279.314	699.335	700.035
30	1.4925	66.3317	133.333	267.337	669.347	670.017
32	1.5873	62.3701	125.37	251.37	629.371	630.001
34	1.6666	59.4024	119.405	239.41	599.424	600.024
36	1.7543	56.4328	113.436	227.441	569.458	570.028
38	1.8867	52.4726	105.475	211.48	529.496	530.026
40	2	49.5	99.5	199.5	499.5	500
42	2.1276	46.5313	93.5326	187.535	469.543	470.013
44	2.3255	42.5715	85.573	171.576	429.585	430.015

[a] Adapted from DWA&F (1993; 1996) and Quality of Domestic Water Supplies (1998)

[b] Adapted from DWA&F (1996) and WHO (1993); [c] Default temperature

WTTCCIRRD 11 Type C: Domestic user group = Infants (5 kg BW) for WQC = Na.

		Allowable WQC concentration in mg/L[a]				
		TWQR	**Cat B**	**Cat C**	**Cat D**	**Cat E**
		99	**100-199**	**200-399**	**400-999**	**>1000**
		Effective Upper Limit value used (mg/L)				
		99	**199**	**399**	**999**	**1000**
		Category ingestion (mg/d)				
Temp-C	**Predic. WI (L/d)[b]**	**74.25**	**149.25**	**299.25**	**749.25**	**750**
8	0.4411	168.329	338.359	678.418	1698.59	1700.29
10	0.5	148.5	298.5	598.5	1498.5	1500
12	0.5769	128.705	258.71	518.721	1298.75	1300.05
14	0.6818	108.903	218.906	438.912	1098.93	1100.03
16[c]	0.75	99	199	399	999	1000
18	0.7894	94.0588	189.068	379.085	949.139	950.089
20	0.8333	89.1036	179.107	359.114	899.136	900.036
22	0.8823	84.155	169.16	339.17	849.201	850.051
24	0.9375	79.2	159.2	319.2	799.2	800
26	1.0714	69.3018	139.304	279.307	699.319	700.019
28	1.0714	69.3018	139.304	279.307	699.319	700.019
30	1.1194	66.3302	133.33	267.331	669.332	670.002
32	1.1904	62.374	125.378	251.386	629.41	630.04
34	1.25	59.4	119.4	239.4	599.4	600
36	1.3157	56.4338	113.438	227.445	569.469	570.039
38	1.415	52.4735	105.477	211.484	529.505	530.035
40	1.5	49.5	99.5	199.5	499.5	500
42	1.5957	46.5313	93.5326	187.535	469.543	470.013
44	1.7441	42.5721	85.5742	171.578	429.591	430.021

[a] Adapted from DWA&F (1993; 1996) and Quality of Domestic Water Supplies (1998)

[b] Adapted from DWA&F (1996) and WHO (1993); [c] Default temperature

WTTCCIRRD 12 Type A: Domestic user group = Adult (60 kg BW) for WQC = SO_4.

		Allowable WQC concentration in mg/L[a]				
		TWQR	**Cat B**	**Cat C**	**Cat D**	**Cat E**
		199	**200-399**	**400-599**	**600-999**	**>1000**
		Effective Upper Limit value used (mg/L)				
		199	**399**	**599**	**999**	**1000**
		Category ingestion (mg/d)				
Temp-C	**Predic. WI (L/d)[b]**	**398**	**798**	**1198**	**1998**	**2000**
8	1.1764	338.32	678.341	1018.36	1698.4	1700.1
10	1.3333	298.507	598.515	898.522	1498.54	1500.04
12	1.5384	258.71	518.721	778.731	1298.75	1300.05
14	1.8181	218.91	438.92	658.93	1098.95	1100.05
16[c]	2	199	399	599	999	1000
18	2.1052	189.056	379.061	569.067	949.078	950.029
20	2.2222	179.102	359.104	539.105	899.109	900.009
22	2.3529	169.153	339.156	509.159	849.165	850.015
24	2.5	159.2	319.2	479.2	799.2	800
26	2.8571	139.302	279.304	419.306	699.31	700.011
28	2.8571	139.302	279.304	419.306	699.31	700.011
30	2.9852	133.324	267.319	401.313	669.302	669.972
32	3.176	125.315	251.259	377.204	629.093	629.723
34	3.3333	119.401	239.402	359.404	599.406	600.006
36	3.5087	113.432	227.435	341.437	569.442	570.012
38	3.7735	105.472	211.475	317.477	529.482	530.012
40	4	99.5	199.5	299.5	499.5	500
42	4.2553	93.5304	187.531	281.531	469.532	470.002
44	4.6511	85.5712	171.572	257.573	429.576	430.006

[a] Adapted from DWA&F (1993; 1996) and Quality of Domestic Water Supplies (1998)

[b] Adapted from DWA&F (1996) and WHO (1993); [c] Default temperature

WTTCCIRRD 12 Type B: Domestic user group = Children (10 kg BW) for WQC = SO_4

		Allowable WQC concentration in mg/L[a]				
		TWQR	**Cat B**	**Cat C**	**Cat D**	**Cat E**
		199	**200-399**	**400-599**	**600-999**	**>1000**
		Effective Upper Limit value used (mg/L)				
		199	**399**	**599**	**999**	**1000**
		Category ingestion (mg/d)				
Temp-C	**Predic. WI (L/d)[b]**	**199**	**399**	**599**	**999**	**1000**
8	0.5882	338.32	678.341	1018.36	1698.4	1700.1
10	0.6666	298.53	598.56	898.59	1498.65	1500.15
12	0.7692	258.71	518.721	778.731	1298.75	1300.05
14	0.909	218.922	438.944	658.966	1099.01	1100.11
16[c]	1	199	399	599	999	1000
18	1.052	189.163	379.278	569.392	949.62	950.57
20	1.1111	179.102	359.104	539.105	899.109	900.009
22	1.1764	169.16	339.17	509.181	849.201	850.051
24	1.25	159.2	319.2	479.2	799.2	800
26	1.4285	139.307	279.314	419.321	699.335	700.035
28	1.4285	139.307	279.314	419.321	699.335	700.035
30	1.4925	133.333	267.337	401.34	669.347	670.017
32	1.5873	125.37	251.37	377.37	629.371	630.001
34	1.6666	119.405	239.41	359.414	599.424	600.024
36	1.7543	113.436	227.441	341.447	569.458	570.028
38	1.8867	105.475	211.48	317.486	529.496	530.026
40	2	99.5	199.5	299.5	499.5	500
42	2.1276	93.5326	187.535	281.538	469.543	470.013
44	2.3255	85.573	171.576	257.579	429.585	430.015

[a] Adapted from DWA&F (1993; 1996) and Quality of Domestic Water Supplies (1998)

[b] Adapted from DWA&F (1996) and WHO (1993); [c] Default temperature

WTTCCIRRD 12 Type C: Domestic user group = Infants (5 kg BW) for WQC = SO_4

		Allowable WQC concentration in mg/L[a]				
		TWQR	**Cat B**	**Cat C**	**Cat D**	**Cat E**
		199	**200-399**	**400-599**	**600-999**	**>1000**
		Effective Upper Limit value used (mg/L)				
		199	**399**	**599**	**999**	**1000**
		Category ingestion (mg/d)				
Temp-C	**Predic. WI (L/d)[b]**	**149.25**	**299.25**	**449.25**	**749.25**	**750**
8	0.4411	338.359	678.418	1018.48	1698.59	1700.29
10	0.5	298.5	598.5	898.5	1498.5	1500
12	0.5769	258.71	518.721	778.731	1298.75	1300.05
14	0.6818	218.906	438.912	658.918	1098.93	1100.03
16[c]	0.75	199	399	599	999	1000
18	0.7894	189.068	379.085	569.103	949.139	950.089
20	0.8333	179.107	359.114	539.122	899.136	900.036
22	0.8823	169.16	339.17	509.181	849.201	850.051
24	0.9375	159.2	319.2	479.2	799.2	800
26	1.0714	139.304	279.307	419.311	699.319	700.019
28	1.0714	139.304	279.307	419.311	699.319	700.019
30	1.1194	133.33	267.331	401.331	669.332	670.002
32	1.1904	125.378	251.386	377.394	629.41	630.04
34	1.25	119.4	239.4	359.4	599.4	600
36	1.3157	113.438	227.445	341.453	569.469	570.039
38	1.415	105.477	211.484	317.491	529.505	530.035
40	1.5	99.5	199.5	299.5	499.5	500
42	1.5957	93.5326	187.535	281.538	469.543	470.013
44	1.7441	85.5742	171.578	257.583	429.591	430.021

[a] Adapted from DWA&F (1993; 1996) and Quality of Domestic Water Supplies (1998)

[b] Adapted from DWA&F (1996) and WHO (1993); [c] Default temperature

WTTCCIRRD 13 Type A: Domestic user group = Adult (60 kg BW) for WQC = TDS.

		Allowable WQC concentration in mg/L[a]				
		TWQR	**Cat B**	**Cat C**	**Cat D**	**Cat E**
		449	**449-999**	**1000-2399**	**2400-3399**	**>3400**
		Effective Upper Limit value used (mg/L)				
		449	**999**	**2399**	**3399**	**3400**
		Category ingestion (mg/d)				
Temp-C	**Predic. WI (L/d)[b]**	**898**	**1998**	**4798**	**6798**	**6800**
8	1.1764	763.346	1698.4	4078.54	5778.65	5780.35
10	1.3333	673.517	1498.54	3598.59	5098.63	5100.13
12	1.5384	583.723	1298.75	3118.82	4418.88	4420.18
14	1.8181	493.922	1098.95	2639.02	3739.07	3740.17
16[c]	2	449	999	2399	3399	3400
18	2.1052	426.563	949.078	2279.12	3229.15	3230.1
20	2.2222	404.104	899.109	2159.12	3059.13	3060.03
22	2.3529	381.657	849.165	2039.19	2889.2	2890.05
24	2.5	359.2	799.2	1919.2	2719.2	2720
26	2.8571	314.305	699.31	1679.33	2379.34	2380.04
28	2.8571	314.305	699.31	1679.33	2379.34	2380.04
30	2.9852	300.817	669.302	1607.26	2277.23	2277.9
32	3.176	282.746	629.093	1510.71	2140.43	2141.06
34	3.3333	269.403	599.406	1439.41	2039.42	2040.02
36	3.5087	255.935	569.442	1367.46	1937.47	1938.04
38	3.7735	237.975	529.482	1271.5	1801.51	1802.04
40	4	224.5	499.5	1199.5	1699.5	1700
42	4.2553	211.031	469.532	1127.54	1597.54	1598.01
44	4.6511	193.073	429.576	1031.58	1461.59	1462.02

[a] Adapted from DWA&F (1993; 1996) and Quality of Domestic Water Supplies (1998)

[b] Adapted from DWA&F (1996) and WHO (1993); [c] Default temperature

WTTCCIRRD 13 Type B: Domestic user group = Children (10 kgBW) for WQC = TDS.

		Allowable WQC concentration in mg/L[a]				
		TWQR	**Cat B**	**Cat C**	**Cat D**	**Cat E**
		449	**449-999**	**1000-2399**	**2400-3399**	**>3400**
		Effective Upper Limit value used (mg/L)				
		449	**999**	**2399**	**3399**	**3400**
		Category ingestion (mg/d)				
Temp-C	**Predic. WI (L/d)[b]**	**449**	**999**	**2399**	**3399**	**3400**
8	0.5882	763.346	1698.4	4078.54	5778.65	5780.35
10	0.6666	673.567	1498.65	3598.86	5099.01	5100.51
12	0.7692	583.723	1298.75	3118.82	4418.88	4420.18
14	0.909	493.949	1099.01	2639.16	3739.27	3740.37
16[c]	1	449	999	2399	3399	3400
18	1.052	426.806	949.62	2280.42	3230.99	3231.94
20	1.1111	404.104	899.109	2159.12	3059.13	3060.03
22	1.1764	381.673	849.201	2039.27	2889.32	2890.17
24	1.25	359.2	799.2	1919.2	2719.2	2720
26	1.4285	314.316	699.335	1679.38	2379.42	2380.12
28	1.4285	314.316	699.335	1679.38	2379.42	2380.12
30	1.4925	300.838	669.347	1607.37	2277.39	2278.06
32	1.5873	282.87	629.371	1511.37	2141.37	2142
34	1.6666	269.411	599.424	1439.46	2039.48	2040.08
36	1.7543	255.943	569.458	1367.5	1937.52	1938.09
38	1.8867	237.982	529.496	1271.53	1801.56	1802.09
40	2	224.5	499.5	1199.5	1699.5	1700
42	2.1276	211.036	469.543	1127.56	1597.57	1598.04
44	2.3255	193.077	429.585	1031.61	1461.62	1462.05

[a] Adapted from DWA&F (1993; 1996) and Quality of Domestic Water Supplies (1998)

[b] Adapted from DWA&F (1996) and WHO (1993); [c] Default temperature

WTTCCIRRD 13 Type C: Domestic user group = Infants (5 kg BW) for WQC = TDS.

		Allowable WQC concentration in mg/L[a]				
		TWQR	**Cat B**	**Cat C**	**Cat D**	**Cat E**
		449	**449-999**	**1000-2399**	**2400-3399**	**>3400**
		Effective Upper Limit value used (mg/L)				
		449	**999**	**2399**	**3399**	**3400**
		Category ingestion (mg/d)				
Temp-C	**Predic. WI (L/d)[b]**	**336.75**	**749.25**	**1799.25**	**2549.25**	**2550**
8	0.4411	763.432	1698.59	4079.01	5779.3	5781
10	0.5	673.5	1498.5	3598.5	5098.5	5100
12	0.5769	583.723	1298.75	3118.82	4418.88	4420.18
14	0.6818	493.913	1098.93	2638.97	3739	3740.1
16[c]	0.75	449	999	2399	3399	3400
18	0.7894	426.59	949.139	2279.26	3229.35	3230.3
20	0.8333	404.116	899.136	2159.19	3059.22	3060.12
22	0.8823	381.673	849.201	2039.27	2889.32	2890.17
24	0.9375	359.2	799.2	1919.2	2719.2	2720
26	1.0714	314.308	699.319	1679.34	2379.36	2380.06
28	1.0714	314.308	699.319	1679.34	2379.36	2380.06
30	1.1194	300.831	669.332	1607.33	2277.34	2278.01
32	1.1904	282.888	629.41	1511.47	2141.51	2142.14
34	1.25	269.4	599.4	1439.4	2039.4	2040
36	1.3157	255.947	569.469	1367.52	1937.56	1938.13
38	1.415	237.986	529.505	1271.55	1801.59	1802.12
40	1.5	224.5	499.5	1199.5	1699.5	1700
42	1.5957	211.036	469.543	1127.56	1597.57	1598.04
44	1.7441	193.08	429.591	1031.62	1461.64	1462.07

[a] Adapted from DWA&F (1993; 1996) and Quality of Domestic Water Supplies (1998)

[b] Adapted from DWA&F (1996) and WHO (1993); [c] Default temperature

WTTCCIRRD 14 Type A: Domestic user group = Adult (60 kg BW) for WQC = Zn.

		Allowable WQC concentration in mg/L[a]				
		TWQR	**Cat B**	**Cat C[d]**	**Cat D[d]**	**Cat E[d]**
		19	**20**			
		Effective Upper Limit value used (mg/L)				
		19	**20**			
		Category ingestion (mg/d)				
Temp-C	**Predic. WI (L/d)[b]**	**38**	**40**			
8	1.1764	32.3019	34.002			
10	1.3333	28.5007	30.0008			
12	1.5384	24.701	26.001			
14	1.8181	20.9009	22.001			
16[c]	2	19	20			
18	2.1052	18.0505	19.0006			
20	2.2222	17.1002	18.0002			
22	2.3529	16.1503	17.0003			
24	2.5	15.2	16			
26	2.8571	13.3002	14.0002			
28	2.8571	13.3002	14.0002			
30	2.9852	12.7295	13.3994			
32	3.176	11.9647	12.5945			
34	3.3333	11.4001	12.0001			
36	3.5087	10.8302	11.4002			
38	3.7735	10.0702	10.6002			
40	4	9.5	10			
42	4.2553	8.93004	9.40004			
44	4.6511	8.17011	8.60012			

[a] Adapted from DWA&F (1993; 1996) and Quality of Domestic Water Supplies (1998)

[b] Adapted from DWA&F (1996) and WHO (1993); [c] Default temperature

[d] Not applicable

WTTCCIRRD 14 Type B: Domestic user group = Children (10 kg BW) for WQC = Zn.

		Allowable WQC concentration in mg/L[a]				
		TWQR	Cat B	Cat C[d]	Cat D[d]	Cat E[d]
		19	20			
		Effective Upper Limit value used (mg/L)				
		19	20			
		Category ingestion (mg/d)				
Temp-C	Predic. WI (L/d)[b]	19	20			
8	0.5882	32.3019	34.002			
10	0.6666	28.5029	30.003			
12	0.7692	24.701	26.001			
14	0.909	20.9021	22.0022			
16[c]	1	19	20			
18	1.052	18.0608	19.0114			
20	1.1111	17.1002	18.0002			
22	1.1764	16.151	17.001			
24	1.25	15.2	16			
26	1.4285	13.3007	14.0007			
28	1.4285	13.3007	14.0007			
30	1.4925	12.7303	13.4003			
32	1.5873	11.97	12.6			
34	1.6666	11.4005	12.0005			
36	1.7543	10.8305	11.4006			
38	1.8867	10.0705	10.6005			
40	2	9.5	10			
42	2.1276	8.93025	9.40026			
44	2.3255	8.17029	8.6003			

[a] Adapted from DWA&F (1993; 1996) and Quality of Domestic Water Supplies (1998)

[b] Adapted from DWA&F (1996) and WHO (1993); [c] Default temperature

[d] Not applicable

WTTCCIRRD 14 Type C: Domestic user group = Infants (5 kg BW) for WQC = Zn.

		Allowable WQC concentration in mg/L[a]				
		TWQR	Cat B	Cat C[d]	Cat D[d]	Cat E[d]
		19	20			
		Effective Upper Limit value used (mg/L)				
		19	20			
		Category ingestion (mg/d)				
Temp-C	Predic. WI (L/d)[b]	14.25	15			
8	0.4411	32.3056	34.0059			
10	0.5	28.5	30			
12	0.5769	24.701	26.001			
14	0.6818	20.9006	22.0006			
16[c]	0.75	19	20			
18	0.7894	18.0517	19.0018			
20	0.8333	17.1007	18.0007			
22	0.8823	16.151	17.001			
24	0.9375	15.2	16			
26	1.0714	13.3004	14.0004			
28	1.0714	13.3004	14.0004			
30	1.1194	12.73	13.4			
32	1.1904	11.9708	12.6008			
34	1.25	11.4	12			
36	1.3157	10.8307	11.4008			
38	1.415	10.0707	10.6007			
40	1.5	9.5	10			
42	1.5957	8.93025	9.40026			
44	1.7441	8.1704	8.60042			

[a] Adapted from DWA&F (1993; 1996) and Quality of Domestic Water Supplies (1998)

[b] Adapted from DWA&F (1996) and WHO (1993); [c] Default temperature

[d] Not applicable

WTTCCIRRD 15 Type A: Domestic user group = Adult (60 kg BW) for WQC = Al.

		Allowable WQC concentration in mg/L[a]				
		TWQR	**Cat B**	**Cat C**	**Cat D[d]**	**Cat E[d]**
		0.15	**0.15-0.5**	**>0.5**		
		Effective Upper Limit value used (mg/L)				
		0.149	**0.49**	**0.5**		
		Category ingestion (mg/d)				
Temp-C	**Predic. WI (L/d)[b]**	**0.298**	**0.98**	**1**		
8	1.1764	0.25332	0.83305	0.08501		
10	1.3333	0.22351	0.73502	0.075		
12	1.5384	0.19371	0.63703	0.065		
14	1.8181	0.16391	0.53902	0.055		
16[c]	2	0.149	0.49	0.05		
18	2.1052	0.14155	0.46551	0.0475		
20	2.2222	0.1341	0.441	0.045		
22	2.3529	0.12665	0.41651	0.0425		
24	2.5	0.1192	0.392	0.04		
26	2.8571	0.1043	0.34301	0.035		
28	2.8571	0.1043	0.34301	0.035		
30	2.9852	0.09983	0.32829	0.0335		
32	3.176	0.09383	0.30856	0.03149		
34	3.3333	0.0894	0.294	0.03		
36	3.5087	0.08493	0.27931	0.0285		
38	3.7735	0.07897	0.25971	0.0265		
40	4	0.0745	0.245	0.025		
42	4.2553	0.07003	0.2303	0.0235		
44	4.6511	0.06407	0.2107	0.0215		

[a] Adapted from DWA&F (1993; 1996) and Quality of Domestic Water Supplies (1998)
[b] Adapted from DWA&F (1996) and WHO (1993); [c] Default temperature
[d] Not applicable

WTTCCIRRD 15 Type B: Domestic user group = Children (10 kg BW) for WQC = Al.

		Allowable WQC concentration in mg/L[a]				
		TWQR	**Cat B**	**Cat C[d]**	**Cat D[d]**	**Cat E[d]**
		0.15	**0.15-0.5**	**>0.5**		
		Effective Upper Limit value used (mg/L)				
		0.149	**0.49**	**0.5**		
		Category ingestion (mg/d)				
Temp-C	**Predic. WI (L/d)[b]**	**0.149**	**0.49**	**0.5**		
8	0.5882	0.25332	0.83305	0.85005		
10	0.6666	0.22352	0.73507	0.75008		
12	0.7692	0.19371	0.63703	0.65003		
14	0.909	0.16392	0.53905	0.55006		
16[c]	1	0.149	0.49	0.5		
18	1.052	0.14163	0.46578	0.47529		
20	1.1111	0.1341	0.441	0.45		
22	1.1764	0.12666	0.41652	0.42503		
24	1.25	0.1192	0.392	0.4		
26	1.4285	0.10431	0.34302	0.35002		
28	1.4285	0.10431	0.34302	0.35002		
30	1.4925	0.09983	0.32831	0.33501		
32	1.5873	0.09387	0.3087	0.315		
34	1.6666	0.0894	0.29401	0.30001		
36	1.7543	0.08493	0.27931	0.28501		
38	1.8867	0.07897	0.25971	0.26501		
40	2	0.0745	0.245	0.25		
42	2.1276	0.07003	0.23031	0.23501		
44	2.3255	0.06407	0.21071	0.21501		

[a] Adapted from DWA&F (1993; 1996) and Quality of Domestic Water Supplies (1998)
[b] Adapted from DWA&F (1996) and WHO (1993); [c] Default temperature
[d] Not applicable

WTTCCIRRD 15 Type C: Domestic user group = Infants (5 kg BW) for WQC = Al.

		Allowable WQC concentration in mg/L[a]				
		TWQR	**Cat B**	**Cat C[d]**	**Cat D[d]**	**Cat E[d]**
		0.15	**0.15-0.5**	**>0.5**		
		Effective Upper Limit value used (mg/L)				
		0.149	**0.49**	**0.5**		
		Category ingestion (mg/d)				
Temp-C	**Predic. WI (L/d)[b]**	**0.11175**	**0.3675**	**0.375**		
8	0.4411	0.00494	0.00834	0.03219		
10	0.5	0.00436	0.00736	0.0284		
12	0.5769	0.00378	0.00638	0.02461		
14	0.6818	0.0032	0.0054	0.02083		
16[c]	0.75	0.00291	0.00491	0.01893		
18	0.7894	0.00276	0.00466	0.01799		
20	0.8333	0.00262	0.00442	0.01704		
22	0.8823	0.00247	0.00417	0.01609		
24	0.9375	0.00233	0.00393	0.01515		
26	1.0714	0.00203	0.00343	0.01325		
28	1.0714	0.00203	0.00343	0.01325		
30	1.1194	0.00195	0.00329	0.01269		
32	1.1904	0.00183	0.00309	0.01193		
34	1.25	0.00174	0.00294	0.01136		
36	1.3157	0.00166	0.0028	0.01079		
38	1.415	0.00154	0.0026	0.01004		
40	1.5	0.00145	0.00245	0.00947		
42	1.5957	0.00137	0.00231	0.0089		
44	1.7441	0.00125	0.00211	0.00814		

[a] Adapted from DWA&F (1993; 1996) and Quality of Domestic Water Supplies (1998)
[b] Adapted from DWA&F (1996) and WHO (1993); [c] Default temperature
[d] Not applicable

WTTCCIRRD 16 Type A: Domestic user group = Adult (60 kg BW) for WQC = Cr(VI).

		Allowable WQC concentration in mg/L[a]				
		TWQR	**Cat B**	**Cat C**	**Cat D**	**Cat E**
		0.05	**0.05**	**0.05-1**	**1.00-5**	**>5**
		Effective Upper Limit value used (mg/L)				
		0.049	**0.049**	**0.99**	**4.99**	**5**
		Category ingestion (mg/d)				
Temp-C	**Predic. WI (L/d)[b]**	**0.098**	**0.098**	**1.98**	**9.98**	**10**
8	1.1764	0.0833	0.0833	1.6831	8.48351	8.50051
10	1.3333	0.0735	0.0735	1.48504	7.48519	7.50019
12	1.5384	0.0637	0.0637	1.28705	6.48726	6.50026
14	1.8181	0.0539	0.0539	1.08905	5.48925	5.50025
16[c]	2	0.049	0.049	0.99	4.99	5
18	2.1052	0.04655	0.04655	0.94053	4.74064	4.75014
20	2.2222	0.0441	0.0441	0.89101	4.49104	4.50005
22	2.3529	0.04165	0.04165	0.84151	4.24157	4.25007
24	2.5	0.0392	0.0392	0.792	3.992	4
26	2.8571	0.0343	0.0343	0.69301	3.49305	3.50005
28	2.8571	0.0343	0.0343	0.69301	3.49305	3.50005
30	2.9852	0.03283	0.03283	0.66327	3.34316	3.34986
32	3.176	0.03086	0.03086	0.62343	3.14232	3.14861
34	3.3333	0.0294	0.0294	0.59401	2.99403	3.00003
36	3.5087	0.02793	0.02793	0.56431	2.84436	2.85006
38	3.7735	0.02597	0.02597	0.52471	2.64476	2.65006
40	4	0.0245	0.0245	0.495	2.495	2.5
42	4.2553	0.02303	0.02303	0.4653	2.34531	2.35001
44	4.6511	0.02107	0.02107	0.42571	2.14573	2.15003

[a] Adapted from DWA&F (1993; 1996) and Quality of Domestic Water Supplies (1998)
[b] Adapted from DWA&F (1996) and WHO (1993); [c] Default temperature

WTTCCIRRD 16 Type B: Domestic user group = Children (10 kg BW) WQC = Cr(VI).

		Allowable WQC concentration in mg/L[a]				
		TWQR	**Cat B**	**Cat C**	**Cat D**	**Cat E**
		0.05	**0.05**	**0.05-1**	**1.00-5**	**>5**
		Effective Upper Limit value used (mg/L)				
		0.049	**0.049**	**0.99**	**4.99**	**5**
		Category ingestion (mg/d)				
Temp-C	**Predic. WI (L/d)[b]**	**0.049**	**0.049**	**0.99**	**4.99**	**5**
8	0.5882	0.0833	0.0833	1.6831	8.48351	8.50051
10	0.6666	0.07351	0.07351	1.48515	7.48575	7.50075
12	0.7692	0.0637	0.0637	1.28705	6.48726	6.50026
14	0.909	0.05391	0.05391	1.08911	5.48955	5.50055
16[c]	1	0.049	0.049	0.99	4.99	5
18	1.052	0.04658	0.04658	0.94106	4.74335	4.75285
20	1.1111	0.0441	0.0441	0.89101	4.49104	4.50005
22	1.1764	0.04165	0.04165	0.84155	4.24175	4.25026
24	1.25	0.0392	0.0392	0.792	3.992	4
26	1.4285	0.0343	0.0343	0.69303	3.49317	3.50018
28	1.4285	0.0343	0.0343	0.69303	3.49317	3.50018
30	1.4925	0.03283	0.03283	0.66332	3.34338	3.35008
32	1.5873	0.03087	0.03087	0.6237	3.1437	3.15
34	1.6666	0.0294	0.0294	0.59402	2.99412	3.00012
36	1.7543	0.02793	0.02793	0.56433	2.84444	2.85014
38	1.8867	0.02597	0.02597	0.52473	2.64483	2.65013
40	2	0.0245	0.0245	0.495	2.495	2.5
42	2.1276	0.02303	0.02303	0.46531	2.34537	2.35007
44	2.3255	0.02107	0.02107	0.42571	2.14578	2.15008

[a] Adapted from DWA&F (1993; 1996) and Quality of Domestic Water Supplies (1998)

[b] Adapted from DWA&F (1996) and WHO (1993); [c] Default temperature

WTTCCIRRD 16 Type C: Domestic user group = Infants (5 kg BW) for WQC = Cr(VI).

		Allowable WQC concentration in mg/L[a]				
		TWQR	**Cat B**	**Cat C**	**Cat D**	**Cat E**
		0.05	**0.05**	**0.05-1**	**1.00-5**	**>5**
		Effective Upper Limit value used (mg/L)				
		0.049	**0.049**	**0.99**	**4.99**	**5**
		Category ingestion (mg/d)				
Temp-C	**Predic. WI (L/d)[b]**	**0.03675**	**0.03675**	**0.7425**	**3.7425**	**3.75**
8	0.4411	0.0832	0.08343	1.68216	8.48334	8.50147
10	0.5	0.0734	0.0736	1.484	7.484	7.5
12	0.5769	0.06362	0.06379	1.28618	6.48639	6.50026
14	0.6818	0.05383	0.05397	1.0883	5.48841	5.50015
16[c]	0.75	0.04893	0.04907	0.98933	4.98933	5
18	0.7894	0.04649	0.04662	0.93995	4.74031	4.75044
20	0.8333	0.04404	0.04416	0.89044	4.49058	4.50018
22	0.8823	0.0416	0.04171	0.84098	4.24119	4.25026
24	0.9375	0.03915	0.03925	0.79147	3.99147	4
26	1.0714	0.03425	0.03435	0.69255	3.49263	3.50009
28	1.0714	0.03425	0.03435	0.69255	3.49263	3.50009
30	1.1194	0.03279	0.03287	0.66286	3.34286	3.35001
32	1.1904	0.03083	0.03091	0.62332	3.14348	3.1502
34	1.25	0.02936	0.02944	0.5936	2.9936	3
36	1.3157	0.02789	0.02797	0.56396	2.84411	2.85019
38	1.415	0.02594	0.02601	0.52438	2.64452	2.65018
40	1.5	0.02447	0.02453	0.49467	2.49467	2.5
42	1.5957	0.023	0.02306	0.465	2.34505	2.35007
44	1.7441	0.02104	0.0211	0.42543	2.14552	2.15011

[a] Adapted from DWA&F (1993; 1996) and Quality of Domestic Water Supplies (1998)

[b] Adapted from DWA&F (1996) and WHO (1993); [c] Default temperature

WTTCCIRRD 17 Type A: Domestic user group = Adult (60 kg BW) for WQC = Pb.

		Allowable WQC concentration in mg/L[a]				
		TWQR	**Cat B**	**Cat C**	**Cat D**	**Cat E**
		0.01	**0.01**	**0.01-0.05**	**0.05-0.3**	**>0.3**
		Effective Upper Limit value used (mg/L)				
		0.0099	**0.0099**	**0.049**	**0.299**	**0.3**
		Category ingestion (mg/d)				
Temp-C	**Predic. WI (L/d)[b]**	**0.0198**	**0.0198**	**0.098**	**0.598**	**0.6**
8	1.1764	0.01683	0.01683	0.0833	0.50833	0.51003
10	1.3333	0.01485	0.01485	0.0735	0.44851	0.45001
12	1.5384	0.01287	0.01287	0.0637	0.38872	0.39002
14	1.8181	0.01089	0.01089	0.0539	0.32891	0.33001
16[c]	2	0.0099	0.0099	0.049	0.299	0.3
18	2.1052	0.00941	0.00941	0.04655	0.28406	0.28501
20	2.2222	0.00891	0.00891	0.0441	0.2691	0.27
22	2.3529	0.00842	0.00842	0.04165	0.25415	0.255
24	2.5	0.00792	0.00792	0.0392	0.2392	0.24
26	2.8571	0.00693	0.00693	0.0343	0.2093	0.21
28	2.8571	0.00693	0.00693	0.0343	0.2093	0.21
30	2.9852	0.00663	0.00663	0.03283	0.20032	0.20099
32	3.176	0.00623	0.00623	0.03086	0.18829	0.18892
34	3.3333	0.00594	0.00594	0.0294	0.1794	0.18
36	3.5087	0.00564	0.00564	0.02793	0.17043	0.171
38	3.7735	0.00525	0.00525	0.02597	0.15847	0.159
40	4	0.00495	0.00495	0.0245	0.1495	0.15
42	4.2553	0.00465	0.00465	0.02303	0.14053	0.141
44	4.6511	0.00426	0.00426	0.02107	0.12857	0.129

[a] Adapted from DWA&F (1993; 1996) and *Quality of Domestic Water Supplies* (1998)
[b] Adapted from DWA&F (1996) and WHO (1993); [c] Default temperature

WTTCCIRRD 17 Type B: Domestic user group = Children (10 kg BW) for WQC = Pb.

		Allowable WQC concentration in mg/L[a]				
		TWQR	**Cat B**	**Cat C**	**Cat D**	**Cat E**
		0.01	**0.01**	**0.01-0.05**	**0.05-0.3**	**>0.3**
		Effective Upper Limit value used (mg/L)				
		0.0099	**0.0099**	**0.049**	**0.299**	**0.3**
		Category ingestion (mg/d)				
Temp-C	**Predic. WI (L/d)[b]**	**0.0099**	**0.0099**	**0.049**	**0.299**	**0.3**
8	0.5882	0.01683	0.01683	0.0833	0.50833	0.51003
10	0.6666	0.01485	0.01485	0.07351	0.44854	0.45005
12	0.7692	0.01287	0.01287	0.0637	0.38872	0.39002
14	0.909	0.01089	0.01089	0.05391	0.32893	0.33003
16[c]	1	0.0099	0.0099	0.049	0.299	0.3
18	1.052	0.00941	0.00941	0.04658	0.28422	0.28517
20	1.1111	0.00891	0.00891	0.0441	0.2691	0.27
22	1.1764	0.00842	0.00842	0.04165	0.25417	0.25502
24	1.25	0.00792	0.00792	0.0392	0.2392	0.24
26	1.4285	0.00693	0.00693	0.0343	0.20931	0.21001
28	1.4285	0.00693	0.00693	0.0343	0.20931	0.21001
30	1.4925	0.00663	0.00663	0.03283	0.20034	0.20101
32	1.5873	0.00624	0.00624	0.03087	0.18837	0.189
34	1.6666	0.00594	0.00594	0.0294	0.17941	0.18001
36	1.7543	0.00564	0.00564	0.02793	0.17044	0.17101
38	1.8867	0.00525	0.00525	0.02597	0.15848	0.15901
40	2	0.00495	0.00495	0.0245	0.1495	0.15
42	2.1276	0.00465	0.00465	0.02303	0.14053	0.141
44	2.3255	0.00426	0.00426	0.02107	0.12857	0.129

[a] Adapted from DWA&F (1993; 1996) and Quality of Domestic Water Supplies (1998)
[b] Adapted from DWA&F (1996) and WHO (1993); [c] Default temperature

WTTCCIRRD 17 Type C: Domestic user group = Infants (5 kg BW) for WQC = Pb

		Allowable WQC concentration in mg/L[a]				
		TWQR	**Cat B**	**Cat C**	**Cat D**	**Cat E**
		0.01	**0.01**	**0.01-0.05**	**0.05-0.3**	**>0.3**
		Effective Upper Limit value used (mg/L)				
		0.0099	**0.0099**	**0.049**	**0.299**	**0.3**
		Category ingestion (mg/d)				
Temp-C	**Predic. WI (L/d)[b]**	**0.00743**	**0.00743**	**0.03675**	**0.22425**	**0.225**
8	0.4411	0.01678	0.01678	0.0832	0.50827	0.51009
10	0.5	0.0148	0.0148	0.0734	0.4484	0.45
12	0.5769	0.01283	0.01283	0.06362	0.38863	0.39002
14	0.6818	0.01085	0.01085	0.05383	0.32884	0.33001
16[c]	0.75	0.00987	0.00987	0.04893	0.29893	0.3
18	0.7894	0.00937	0.00937	0.04649	0.28401	0.28503
20	0.8333	0.00888	0.00888	0.04404	0.26905	0.27001
22	0.8823	0.00839	0.00839	0.0416	0.25411	0.25502
24	0.9375	0.00789	0.00789	0.03915	0.23915	0.24
26	1.0714	0.00691	0.00691	0.03425	0.20926	0.21001
28	1.0714	0.00691	0.00691	0.03425	0.20926	0.21001
30	1.1194	0.00661	0.00661	0.03279	0.20029	0.201
32	1.1904	0.00622	0.00622	0.03083	0.18834	0.18901
34	1.25	0.00592	0.00592	0.02936	0.17936	0.18
36	1.3157	0.00562	0.00562	0.02789	0.1704	0.17101
38	1.415	0.00523	0.00523	0.02594	0.15845	0.15901
40	1.5	0.00493	0.00493	0.02447	0.14947	0.15
42	1.5957	0.00464	0.00464	0.023	0.1405	0.141
44	1.7441	0.00424	0.00424	0.02104	0.12855	0.12901

[a] Adapted from DWA&F (1993; 1996) and Quality of Domestic Water Supplies (1998)

[b] Adapted from DWA&F (1996) and WHO (1993); [c] Default temperature

WTTCCIRRD 18 Type A: Domestic user group = Adult (60 kg BW) for WQC = Hg

		Allowable WQC concentration in mg/L[a]				
		TWQR	**Cat B**	**Cat C**	**Cat D**	**Cat E**
		0.001	**0.001**	**0.001-0.05**	**0.05-1**	**>1**
		Effective Upper Limit value used (mg/L)				
		0.0009	**0.0009**	**0.049**	**0.99**	**1**
		Category ingestion (mg/d)				
Temp-C	**Predic. WI (L/d)[b]**	**0.0018**	**0.0018**	**0.098**	**1.98**	**2**
8	1.1764	0.00153	0.00153	0.0833	1.6831	1.7001
10	1.3333	0.00135	0.00135	0.0735	1.48504	1.50004
12	1.5384	0.00117	0.00117	0.0637	1.28705	1.30005
14	1.8181	0.00099	0.00099	0.0539	1.08905	1.10005
16[c]	2	0.0009	0.0009	0.049	0.99	1
18	2.1052	0.00086	0.00086	0.04655	0.94053	0.95003
20	2.2222	0.00081	0.00081	0.0441	0.89101	0.90001
22	2.3529	0.00077	0.00077	0.04165	0.84151	0.85001
24	2.5	0.00072	0.00072	0.0392	0.792	0.8
26	2.8571	0.00063	0.00063	0.0343	0.69301	0.70001
28	2.8571	0.00063	0.00063	0.0343	0.69301	0.70001
30	2.9852	0.0006	0.0006	0.03283	0.66327	0.66997
32	3.176	0.00057	0.00057	0.03086	0.62343	0.62972
34	3.3333	0.00054	0.00054	0.0294	0.59401	0.60001
36	3.5087	0.00051	0.00051	0.02793	0.56431	0.57001
38	3.7735	0.00048	0.00048	0.02597	0.52471	0.53001
40	4	0.00045	0.00045	0.0245	0.495	0.5
42	4.2553	0.00042	0.00042	0.02303	0.4653	0.47
44	4.6511	0.00039	0.00039	0.02107	0.42571	0.43001

[a] Adapted from DWA&F (1993; 1996) and Quality of Domestic Water Supplies (1998)

[b] Adapted from DWA&F (1996) and WHO (1993); [c] Default temperature

WTTCCIRRD 18 Type B: Domestic user group = Children (10 kg BW) for WQC = Hg

		Allowable WQC concentration in mg/L[a]				
		TWQR	**Cat B**	**Cat C**	**Cat D**	**Cat E**
		0.001	**0.001**	**0.001-0.05**	**0.05-1**	**>1**
		Effective Upper Limit value used (mg/L)				
		0.0009	**0.0009**	**0.049**	**0.99**	**1**
		Category ingestion (mg/d)				
Temp-C	**Predic. WI (L/d)[b]**	**0.0009**	**0.0009**	**0.049**	**0.99**	**1**
8	0.5882	0.00153	0.00153	0.0833	1.6831	1.7001
10	0.6666	0.00135	0.00135	0.07351	1.48515	1.50015
12	0.7692	0.00117	0.00117	0.0637	1.28705	1.30005
14	0.909	0.00099	0.00099	0.05391	1.08911	1.10011
16[c]	1	0.0009	0.0009	0.049	0.99	1
18	1.052	0.00086	0.00086	0.04658	0.94106	0.95057
20	1.1111	0.00081	0.00081	0.0441	0.89101	0.90001
22	1.1764	0.00077	0.00077	0.04165	0.84155	0.85005
24	1.25	0.00072	0.00072	0.0392	0.792	0.8
26	1.4285	0.00063	0.00063	0.0343	0.69303	0.70004
28	1.4285	0.00063	0.00063	0.0343	0.69303	0.70004
30	1.4925	0.0006	0.0006	0.03283	0.66332	0.67002
32	1.5873	0.00057	0.00057	0.03087	0.6237	0.63
34	1.6666	0.00054	0.00054	0.0294	0.59402	0.60002
36	1.7543	0.00051	0.00051	0.02793	0.56433	0.57003
38	1.8867	0.00048	0.00048	0.02597	0.52473	0.53003
40	2	0.00045	0.00045	0.0245	0.495	0.5
42	2.1276	0.00042	0.00042	0.02303	0.46531	0.47001
44	2.3255	0.00039	0.00039	0.02107	0.42571	0.43002

[a] Adapted from DWA&F (1993; 1996) and Quality of Domestic Water Supplies (1998)
[b] Adapted from DWA&F (1996) and WHO (1993); [c] Default temperature

WTTCCIRRD 18 Type C: Domestic user group = Infants (5 kg BW) for WQC = Hg

		Allowable WQC concentration in mg/L[a]				
		TWQR	**Cat B**	**Cat C**	**Cat D**	**Cat E**
		0.001	**0.001**	**0.001-0.05**	**0.05-1**	**>1**
		Effective Upper Limit value used (mg/L)				
		0.0009	**0.0009**	**0.049**	**0.99**	**1**
		Category ingestion (mg/d)				
Temp-C	**Predic. WI (L/d)[b]**	**0.00068**	**0.00068**	**0.03675**	**0.7425**	**0.75**
8	0.4411	0.00154	0.00154	0.0832	1.68216	1.70029
10	0.5	0.00136	0.00136	0.0734	1.484	1.5
12	0.5769	0.00118	0.00118	0.06362	1.28618	1.30005
14	0.6818	0.001	0.001	0.05383	1.0883	1.10003
16[c]	0.75	0.00091	0.00091	0.04893	0.98933	1
18	0.7894	0.00086	0.00086	0.04649	0.93995	0.95009
20	0.8333	0.00082	0.00082	0.04404	0.89044	0.90004
22	0.8823	0.00077	0.00077	0.0416	0.84098	0.85005
24	0.9375	0.00073	0.00073	0.03915	0.79147	0.8
26	1.0714	0.00063	0.00063	0.03425	0.69255	0.70002
28	1.0714	0.00063	0.00063	0.03425	0.69255	0.70002
30	1.1194	0.00061	0.00061	0.03279	0.66286	0.67
32	1.1904	0.00057	0.00057	0.03083	0.62332	0.63004
34	1.25	0.00054	0.00054	0.02936	0.5936	0.6
36	1.3157	0.00052	0.00052	0.02789	0.56396	0.57004
38	1.415	0.00048	0.00048	0.02594	0.52438	0.53004
40	1.5	0.00045	0.00045	0.02447	0.49467	0.5
42	1.5957	0.00043	0.00043	0.023	0.465	0.47001
44	1.7441	0.00039	0.00039	0.02104	0.42543	0.43002

[a] Adapted from DWA&F (1993; 1996) and Quality of Domestic Supplies (1998)
[b] Adapted from DWA&F (1996) and WHO (1993); [c] Default temperature

WTTCCIRRD 19 Type A: Domestic user group = Adult (60 kg BW) for WQC = U.

		Allowable WQC concentration in mg/L[a]				
		TWQR	**Cat B**	**Cat C**	**Cat D**	**Cat E[d]**
		0.07	**0.284**	**0.284-1.42**	**>1.42**	
		Effective Upper Limit value used (mg/L)				
		0.069	**0.283**	**1.41**	**1.42**	
		Category ingestion (mg/d)				
Temp-C	**Predic. WI (L/d)[b]**	**0.138**	**0.566**	**2.82**	**2.84**	
8	1.1764	0.11731	0.48113	2.39714	2.41414	
10	1.3333	0.1035	0.42451	2.11505	2.13005	
12	1.5384	0.0897	0.36791	1.83307	1.84607	
14	1.8181	0.0759	0.31131	1.55107	1.56207	
16[c]	2	0.069	0.283	1.41	1.42	
18	2.1052	0.06555	0.26886	1.33954	1.34904	
20	2.2222	0.0621	0.2547	1.26901	1.27801	
22	2.3529	0.05865	0.24055	1.19852	1.20702	
24	2.5	0.0552	0.2264	1.128	1.136	
26	2.8571	0.0483	0.1981	0.98701	0.99401	
28	2.8571	0.0483	0.1981	0.98701	0.99401	
30	2.9852	0.04623	0.1896	0.94466	0.95136	
32	3.176	0.04345	0.17821	0.88791	0.89421	
34	3.3333	0.0414	0.1698	0.84601	0.85201	
36	3.5087	0.03933	0.16131	0.80372	0.80942	
38	3.7735	0.03657	0.14999	0.74732	0.75262	
40	4	0.0345	0.1415	0.705	0.71	
42	4.2553	0.03243	0.13301	0.6627	0.6674	
44	4.6511	0.02967	0.12169	0.60631	0.61061	

[a] Adapted from DWA&F (1993; 1996) and Quality of Domestic Water Supplies (1998)
[b] Adapted from DWA&F (1996) and WHO (1993); [c] Default temperature
[d] Not applicable

WTTCCIRRD 19 Type B: Domestic user group = Children (10 kg BW) for WQC = U.

		Allowable WQC concentration in mg/L[a]				
		TWQR	**Cat B**	**Cat C**	**Cat D**	**Cat E[d]**
		0.07	**0.284**	**0.284-1.42**	**>1.42**	
		Effective Upper Limit value used (mg/L)				
		0.069	**0.283**	**1.41**	**1.42**	
		Category ingestion (mg/d)				
Temp-C	**Predic. WI (L/d)[b]**	**0.069**	**0.283**	**1.41**	**1.42**	
8	0.5882	0.11731	0.48113	2.39714	2.41414	
10	0.6666	0.10351	0.42454	2.11521	2.13021	
12	0.7692	0.0897	0.36791	1.83307	1.84607	
14	0.909	0.07591	0.31133	1.55116	1.56216	
16[c]	1	0.069	0.283	1.41	1.42	
18	1.052	0.06559	0.26901	1.3403	1.34981	
20	1.1111	0.0621	0.2547	1.26901	1.27801	
22	1.1764	0.05865	0.24056	1.19857	1.20707	
24	1.25	0.0552	0.2264	1.128	1.136	
26	1.4285	0.0483	0.19811	0.98705	0.99405	
28	1.4285	0.0483	0.19811	0.98705	0.99405	
30	1.4925	0.04623	0.18961	0.94472	0.95142	
32	1.5873	0.04347	0.17829	0.8883	0.8946	
34	1.6666	0.0414	0.16981	0.84603	0.85203	
36	1.7543	0.03933	0.16132	0.80374	0.80944	
38	1.8867	0.03657	0.15	0.74734	0.75264	
40	2	0.0345	0.1415	0.705	0.71	
42	2.1276	0.03243	0.13301	0.66272	0.66742	
44	2.3255	0.02967	0.12169	0.60632	0.61062	

[a] Adapted from DWA&F (1993; 1996) and Quality of Domestic Water Supplies (1998)
[b] Adapted from DWA&F (1996) and WHO (1993); [c] Default temperature
[d] Not applicable

WTTCCIRRD 19 Type C: Domestic user group = Infants (5 kg BW) for WQC = U.

		Allowable WQC concentration in mg/L[a]				
		TWQR	**Cat B**	**Cat C**	**Cat D**	**Cat E[d]**
		0.07	**0.284**	**0.284-1.42**	**>1.42**	
		Effective Upper Limit value used (mg/L)				
		0.069	**0.283**	**1.41**	**1.42**	
		Category ingestion (mg/d)				
Temp-C	**Predic. WI (L/d)[b]**	**0.05175**	**0.21225**	**1.0575**	**1.065**	
8	0.4411	0.11721	0.48062	2.39628	2.41442	
10	0.5	0.1034	0.424	2.114	2.13	
12	0.5769	0.08962	0.36748	1.83221	1.84607	
14	0.6818	0.07583	0.31094	1.55031	1.56204	
16[c]	0.75	0.06893	0.28267	1.40933	1.42	
18	0.7894	0.06549	0.26856	1.33899	1.34913	
20	0.8333	0.06204	0.25441	1.26845	1.27805	
22	0.8823	0.0586	0.24028	1.19801	1.20707	
24	0.9375	0.05515	0.22613	1.12747	1.136	
26	1.0714	0.04825	0.19787	0.98656	0.99403	
28	1.0714	0.04825	0.19787	0.98656	0.99403	
30	1.1194	0.04619	0.18939	0.94426	0.9514	
32	1.1904	0.04343	0.17809	0.88794	0.89466	
34	1.25	0.04136	0.1696	0.8456	0.852	
36	1.3157	0.03929	0.16113	0.80337	0.80946	
38	1.415	0.03654	0.14982	0.747	0.75265	
40	1.5	0.03447	0.14133	0.70467	0.71	
42	1.5957	0.0324	0.13286	0.66241	0.66742	
44	1.7441	0.02964	0.12155	0.60604	0.61063	

[a] Adapted from DWA&F (1993; 1996) and Quality of Domestic Water Supplies (1998)
[b] Adapted from DWA&F (1996) and WHO (1993); [c] Default temperature
[d] Not applicable to

WTTCCIRRD 20 Type A: Domestic user group = Adult (60 kg BW) for WQC = Se.

		Allowable WQC concentration in mg/L[a]				
		TWQR	**Cat B**	**Cat C**	**Cat D**	**Cat E**
		0.02	**0.02**	**0.02-0.05**	**0.05-1**	**>1**
		Effective Upper Limit value used (mg/L)				
		0.019	**0.019**	**0.049**	**0.99**	**1**
		Category ingestion (mg/d)				
Temp-C	***Predic. WI (L/d)[b]***	***0.038***	***0.038***	***0.098***	***1.98***	***2***
8	1.1764	0.0323	0.0323	0.0833	1.6831	1.7001
10	1.3333	0.0285	0.0285	0.0735	1.48504	1.50004
12	1.5384	0.0247	0.0247	0.0637	1.28705	1.30005
14	1.8181	0.0209	0.0209	0.0539	1.08905	1.10005
16[c]	2	0.019	0.019	0.049	0.99	1
18	2.1052	0.01805	0.01805	0.04655	0.94053	0.95003
20	2.2222	0.0171	0.0171	0.0441	0.89101	0.90001
22	2.3529	0.01615	0.01615	0.04165	0.84151	0.85001
24	2.5	0.0152	0.0152	0.0392	0.792	0.8
26	2.8571	0.0133	0.0133	0.0343	0.69301	0.70001
28	2.8571	0.0133	0.0133	0.0343	0.69301	0.70001
30	2.9852	0.01273	0.01273	0.03283	0.66327	0.66997
32	3.176	0.01196	0.01196	0.03086	0.62343	0.62972
34	3.3333	0.0114	0.0114	0.0294	0.59401	0.60001
36	3.5087	0.01083	0.01083	0.02793	0.56431	0.57001
38	3.7735	0.01007	0.01007	0.02597	0.52471	0.53001
40	4	0.0095	0.0095	0.0245	0.495	0.5
42	4.2553	0.00893	0.00893	0.02303	0.4653	0.47
44	4.6511	0.00817	0.00817	0.02107	0.42571	0.43001

[a] Adapted from DWA&F (1993; 1996) and Quality of Domestic Water Supplies (1998)
[b] Adapted from DWA&F (1996) and WHO (1993); [c] Default temperature

WTTCCIRRD 20 Type B: Domestic user group = Children (10 kg BW) for WQC = Se.

		Allowable WQC concentration in mg/L[a]				
		TWQR	**Cat B**	**Cat C**	**Cat D**	**Cat E**
		0.02	**0.02**	**0.02-0.05**	**0.05-1**	**>1**
		Effective Upper Limit value used (mg/L)				
		0.019	**0.019**	**0.049**	**0.99**	**1**
		Category ingestion (mg/d)				
Temp-C	**Predic. WI (L/d)[b]**	**0.019**	**0.019**	**0.049**	**0.99**	**1**
8	0.5882	0.0323	0.0323	0.0833	1.6831	1.7001
10	0.6666	0.0285	0.0285	0.07351	1.48515	1.50015
12	0.7692	0.0247	0.0247	0.0637	1.28705	1.30005
14	0.909	0.0209	0.0209	0.05391	1.08911	1.10011
16[c]	1	0.019	0.019	0.049	0.99	1
18	1.052	0.01806	0.01806	0.04658	0.94106	0.95057
20	1.1111	0.0171	0.0171	0.0441	0.89101	0.90001
22	1.1764	0.01615	0.01615	0.04165	0.84155	0.85005
24	1.25	0.0152	0.0152	0.0392	0.792	0.8
26	1.4285	0.0133	0.0133	0.0343	0.69303	0.70004
28	1.4285	0.0133	0.0133	0.0343	0.69303	0.70004
30	1.4925	0.01273	0.01273	0.03283	0.66332	0.67002
32	1.5873	0.01197	0.01197	0.03087	0.6237	0.63
34	1.6666	0.0114	0.0114	0.0294	0.59402	0.60002
36	1.7543	0.01083	0.01083	0.02793	0.56433	0.57003
38	1.8867	0.01007	0.01007	0.02597	0.52473	0.53003
40	2	0.0095	0.0095	0.0245	0.495	0.5
42	2.1276	0.00893	0.00893	0.02303	0.46531	0.47001
44	2.3255	0.00817	0.00817	0.02107	0.42571	0.43002

[a] Adapted from DWA&F (1993; 1996) and Quality of Domestic Water Supplies (1998)

[b] Adapted from DWA&F (1996) and WHO (1993); [c] Default temperature

WTTCCIRRD 20 Type C: Domestic user group = Infants (5 kg BW) for WQC = Se

		Allowable WQC concentration in mg/L[a]				
		TWQR	**Cat B**	**Cat C**	**Cat D**	**Cat E**
		0.02	**0.02**	**0.02-0.05**	**0.05-1**	**>1**
		Effective Upper Limit value used (mg/L)				
		0.019	**0.019**	**0.049**	**0.99**	**1**
		Category ingestion (mg/d)				
Temp-C	**Predic. WI (L/d)[b]**	**0.01425**	**0.01425**	**0.03675**	**0.7425**	**0.75**
8	0.4411	0.03219	0.03219	0.0832	1.68216	0.17003
10	0.5	0.0284	0.0284	0.0734	1.484	0.15
12	0.5769	0.02461	0.02461	0.06362	1.28618	0.13001
14	0.6818	0.02083	0.02083	0.05383	1.0883	0.11
16[c]	0.75	0.01893	0.01893	0.04893	0.98933	0.1
18	0.7894	0.01799	0.01799	0.04649	0.93995	0.09501
20	0.8333	0.01704	0.01704	0.04404	0.89044	0.09
22	0.8823	0.01609	0.01609	0.0416	0.84098	0.08501
24	0.9375	0.01515	0.01515	0.03915	0.79147	0.08
26	1.0714	0.01325	0.01325	0.03425	0.69255	0.07
28	1.0714	0.01325	0.01325	0.03425	0.69255	0.07
30	1.1194	0.01269	0.01269	0.03279	0.66286	0.067
32	1.1904	0.01193	0.01193	0.03083	0.62332	0.063
34	1.25	0.01136	0.01136	0.02936	0.5936	0.06
36	1.3157	0.01079	0.01079	0.02789	0.56396	0.057
38	1.415	0.01004	0.01004	0.02594	0.52438	0.053
40	1.5	0.00947	0.00947	0.02447	0.49467	0.05
42	1.5957	0.0089	0.0089	0.023	0.465	0.047
44	1.7441	0.00814	0.00814	0.02104	0.42543	0.043

[a] Adapted from DWA&F (1993; 1996) and Quality of Domestic Water Supplies (1998)

[b] Adapted from DWA&F (1996) and WHO (1993); [c] Default temperature

WTTCCIRRD 21 Type A: Domestic user group = Adult (60 kg BW) for WQC = V.

		Allowable WQC concentration in mg/L [a]				
		TWQR	**Cat B**	**Cat C**	**Cat D**	**Cat E[d]**
		0.01	**0.01**	**0.01-1**	**>1**	
		Effective Upper Limit value used (mg/L)				
		0.009	**0.009**	**0.99**	**1**	
		Category ingestion (mg/d)				
Temp-C	**Predic. WI (L/d)[b]**	**0.018**	**0.018**	**1.98**	**2**	
8	1.1764	0.0153	0.0153	1.6831	1.7001	
10	1.3333	0.0135	0.0135	1.48504	1.50004	
12	1.5384	0.0117	0.0117	1.28705	1.30005	
14	1.8181	0.0099	0.0099	1.08905	1.10005	
16[c]	2	0.009	0.009	0.99	1	
18	2.1052	0.00855	0.00855	0.94053	0.95003	
20	2.2222	0.0081	0.0081	0.89101	0.90001	
22	2.3529	0.00765	0.00765	0.84151	0.85001	
24	2.5	0.0072	0.0072	0.792	0.8	
26	2.8571	0.0063	0.0063	0.69301	0.70001	
28	2.8571	0.0063	0.0063	0.69301	0.70001	
30	2.9852	0.00603	0.00603	0.66327	0.66997	
32	3.176	0.00567	0.00567	0.62343	0.62972	
34	3.3333	0.0054	0.0054	0.59401	0.60001	
36	3.5087	0.00513	0.00513	0.56431	0.57001	
38	3.7735	0.00477	0.00477	0.52471	0.53001	
40	4	0.0045	0.0045	0.495	0.5	
42	4.2553	0.00423	0.00423	0.4653	0.47	
44	4.6511	0.00387	0.00387	0.42571	0.43001	

[a] Adapted from DWA&F (1993; 1996) and Quality of Domestic Water Supplies (1998)

[b] Adapted from DWA&F (1996) and WHO (1993); [c] Default temperature

[d] Not applicable

WTTCCIRRD 21 Type B: Domestic user group = Children (10 kg BW) for WQC = V.

		Allowable WQC concentration in mg/L [a]				
		TWQR	**Cat B**	**Cat C**	**Cat D**	**Cat E[d]**
		0.01	**0.01**	**0.01-1**	**>1**	
		Effective Upper Limit value used (mg/L)				
		0.009	**0.009**	**0.99**	**1**	
		Category ingestion (mg/d)				
Temp-C	**Predic. WI (L/d)[b]**	**0.009**	**0.009**	**0.99**	**1**	
8	0.5882	0.0153	0.0153	1.6831	1.7001	
10	0.6666	0.0135	0.0135	1.48515	1.50015	
12	0.7692	0.0117	0.0117	1.28705	1.30005	
14	0.909	0.0099	0.0099	1.08911	1.10011	
16[c]	1	0.009	0.009	0.99	1	
18	1.052	0.00856	0.00856	0.94106	0.95057	
20	1.1111	0.0081	0.0081	0.89101	0.90001	
22	1.1764	0.00765	0.00765	0.84155	0.85005	
24	1.25	0.0072	0.0072	0.792	0.8	
26	1.4285	0.0063	0.0063	0.69303	0.70004	
28	1.4285	0.0063	0.0063	0.69303	0.70004	
30	1.4925	0.00603	0.00603	0.66332	0.67002	
32	1.5873	0.00567	0.00567	0.6237	0.63	
34	1.6666	0.0054	0.0054	0.59402	0.60002	
36	1.7543	0.00513	0.00513	0.56433	0.57003	
38	1.8867	0.00477	0.00477	0.52473	0.53003	
40	2	0.0045	0.0045	0.495	0.5	
42	2.1276	0.00423	0.00423	0.46531	0.47001	
44	2.3255	0.00387	0.00387	0.42571	0.43002	

[a] Adapted from DWA&F (1993; 1996) and Quality of Domestic Water Supplies (1998)

[b] Adapted from DWA&F (1996) and WHO (1993); [c] Default temperature

[d] Not applicable

WTTCCIRRD 21 Type C: Domestic user group = Infants (5 kg BW) for WQC = V

		Allowable WQC concentration in mg/L[a]				
		TWQR	Cat B	Cat C	Cat D	Cat E[d]
		0.01	0.01	0.01-1	>1	
		Effective Upper Limit value used (mg/L)				
		0.009	0.009	0.99	1	
		Category ingestion (mg/d)				
Temp-C	**Predic. WI (L/d)[b]**	**0.00675**	**0.00675**	**0.7425**	**0.75**	
8	0.4411	0.01519	0.01519	1.68216	1.70029	
10	0.5	0.0134	0.0134	1.484	1.5	
12	0.5769	0.01161	0.01161	1.28618	1.30005	
14	0.6818	0.00983	0.00983	1.0883	1.10003	
16[c]	0.75	0.00893	0.00893	0.98933	1	
18	0.7894	0.00849	0.00849	0.93995	0.95009	
20	0.8333	0.00804	0.00804	0.89044	0.90004	
22	0.8823	0.00759	0.00759	0.84098	0.85005	
24	0.9375	0.00715	0.00715	0.79147	0.8	
26	1.0714	0.00625	0.00625	0.69255	0.70002	
28	1.0714	0.00625	0.00625	0.69255	0.70002	
30	1.1194	0.00599	0.00599	0.66286	0.67	
32	1.1904	0.00563	0.00563	0.62332	0.63004	
34	1.25	0.00536	0.00536	0.5936	0.6	
36	1.3157	0.00509	0.00509	0.56396	0.57004	
38	1.415	0.00473	0.00473	0.52438	0.53004	
40	1.5	0.00447	0.00447	0.49467	0.5	
42	1.5957	0.0042	0.0042	0.465	0.47001	
44	1.7441	0.00384	0.00384	0.42543	0.43002	

[a] Adapted from DWA&F (1993; 1996) and Quality of Domestic Water Supplies (1998)
[b] Adapted from DWA&F (1996) and WHO (1993); [c] Default temperature
[d] Not applicable

3.4.9 RCLPS REFERENCE DOSE (mg/D) Reference Documents

The following RefDocs provide additional methods of estimating risk due to the ingestion of PHCs. These allow the user to enter information relating to the actual ingestion of a PHC in a number of different ways. They also allow for an estimate of weekly intakes to be compared to RefDocs. This is a meaningful method of assessment as in RCLPS many individuals will only ingest water (and related sources such as milk, vegetables, etc.) on weekends. Others may ingest a specific source only during the weekdays, for example, school children in a weekly hostel. As a result, the RefDocs allow for an allowable ingestion, a maximum tolerable daily ingestion, and so forth. The results are thus provided to the user as an indication of where the predicted ingestion resides, from recommended daily allowances or requirements, to low observed adverse effect levels. The RefDod – RD1 provides values for broad body weight user categories, namely, adult, child and infant, to cater to some extent for different water turnover rates.

RefDoc – RD1

The following table presents the upper limits for ingestion in mg/d for selected WQC. The corresponding types of effects are provided in a separate TOE document linked to the category status. The RD1 values are derived from default WI estimates used in guideline derivation by the WHO (1993). Exceeding these values for the respective user group (adult, child, or infant) will be reported as PHCs under the "Reference Dose" tab in the results screens.

RefDoc – RD1 for the RCLPS model.

WQC	Upper category limits in mg/d				
	TWQR	Cat B	Cat C	Cat D	Cat E
F-ad	1.38	1.98	2.98	6.98	7
F-ch	0.79	0.99	1.49	3.49	3.5
F-inf	0.5175	0.7425	1.1175	2.6175	2.625
As-ad	0.018	0.098	0.38	3.98	4
As-ch	0.009	0.00044	8.4E-05	0.00017	0.00033
As-inf	0.00675	0.03675	0.1425	1.4925	1.5
Cd-ad	0.0058	0.0098	0.038	0.098	0.1
Cd-ch	0.0029	0.0049	0.019	0.049	0.05
Cd-inf	0.00218	0.00368	0.01425	0.03675	0.0375
Ca-ad	158	298	598	600	na
Ca-ch	79	149	299	300	na
Ca-inf	59.25	111.75	224.25	225	na
Cl-ad	198	398	1198	2398	2400
Cl-ch	99	199	599	1199	1200
Cl-inf	74.25	149.25	449.25	899.25	900
Cu- ad	1.98	2.58	3.98	29.8	30
Cu- ch	0.99	1.29	1.99	14.9	15
Cu- inf	0.7425	0.9675	1.4925	11.175	11.25
Fe- ad	0.98	1.98	9.98	19.8	20
Fe- ch	0.49	0.99	4.99	9.9	10
Fe- inf	0.3675	0.7425	3.7425	7.425	7.5
Mg- ad	138	198	398	798	800
Mg- ch	69	99	199	399	400
Mg- inf	51.75	74.25	149.25	299.25	300
Mn- ad	0.18	0.78	7.98	19.8	20
Mn- ch	0.09	0.39	3.99	9.9	10
Mn- inf	0.0675	0.2925	2.9925	7.425	7.5
K- ad	48	98	198	998	1000
K- ch	24	49	99	499	500
K- inf	18	36.75	74.25	374.25	375
Na- ad	198	398	798	1998	2000
Na- ch	99	199	399	999	1000
Na- inf	74.25	149.25	299.25	749.25	750
SO4- ad	398	798	1198	1998	2000
SO4- ch	199	399	599	999	1000
SO4- inf	149.25	299.25	449.25	749.25	750
TDS- ad	898	1998	4798	6798	6800
TDS- ch	449	999	2399	3399	3400
TDS- inf	336.75	749.25	1799.25	2549.25	2550
Zn- ad	38	40	na	na	na
Zn- ch	19	20	na	na	na
Zn- inf	14.25	15	na	na	na

Types: ad = adult; ch = child; inf = infant
Based on a default WI rates at 16 degrees Celcius
na – not applicable

RefDoc – DR

The following table presents a series of reference doses based primarily on a mg/kgBW/d basis, and are adapted from the EPA, WHO and DWA&F drinking guidelines.

The reference doses termed "Allowable Daily Doses" (ADD) are derived from predominantly three different sources, the EPA, WHO and DWA&F, and may be taken to be an estimated daily exposure that is *without* appreciable risk of deleterious effects over lifetime exposure (EPA, 1998).

RefDoc - DR for the RCLPS model.

WQC	RDI	TDI (mg/kgBW/d)	ADD – adults (mg/kgBW/d)	PTWI mg/kgBW	NOAEL mg/kgBW/d	LOAEL mg.kgBW/d
Al			0.0165d	7		
As			0.001q	0.015		0.017 mg/L
Ba		0.051	0.07e		0.51	
Be			0.005e			
B		0.088	0.09e		8.8	
Sb			0.0004e			0.43
Cd		0.01-0.035 mg/d	0.00017q	0.007		0.175 mg/d
Ca			2.64d			
Cr			0.0016d			
Cl			6.6q			
Cu		1-3 mg/d	0.033d	3.5		
F			0.033qd			
Fe			0.033qd	5.6		
Pb			0.0003d	0.025		
Mg			2.31d			
Mn		20 mg/d	0.013q			
K			1.65qd			
Hg		0.002-0.02 mg/d	0.00003d	0.005		
Mo		0.1 mg/d	0.005e			
Ni		0.1 mg/d	0.02e			
Silv	0.007 mg/d					
Na			6.6qd			
SO4			6.6d			
Se	0.001 mg/d		0.000d6		0.004	0.03 (0.8 –cs)
Sr			0.6e			
Th			0.00007e			
V			0.0033d			
Zn	15-20 mg/d		0.33d	7		

RefDoc – DR – source material for the RCLPS model.

WQC	ADD – adults (mg/kgBW/d)	*Source*
Al	0.0165d	dwaf
As	0.001q	qwds
Ba	0.07e	epa
Be	0.005e	epa
B	0.09e	epa
Sb	0.0004e	epa
Cd	0.00017q	qwds
Ca	2.64d	dwaf
Cr	0.0016d	dwaf
Cl	6.6q	qwds
Cu	0.033d	dwaf
F	0.033qd	q+d
Fe	0.033qd	q+d
Pb	0.0003d	dwaf
Mg	2.31d	dwaf
Mn	0.013q	q
K	1.65qd	q+d
Hg	0.00003d	dwaf
Mo	0.005e	epa
Ni	0.02e	epa
Silv		
Na	6.6qd	q+d
SO_4	6.6d	d
Se	0.000d6	d
Sr	0.6e	e
Th	0.00007e	e
V	0.0033d	d
Zn	0.33d	d

3.5 RCLPS – Livestock User Group

The basis of the RCLPS model is identical to that for Livestock in previous CIRRA versions in the evaluation of risk based on water, animal, environmental and nutritional detail. As such, a risk assessment is still performed with all the detail the user provides. However, two main modifications apply.

The first modification is to cater for the results to be formulated along a best-fit principle for multiple livestock types, and also for multiple livestock breeds and production levels. This is in effect similar to performing many single *.wqs sample files in CIRRA for each separate type, breed, and production level, with all sharing the common component of the environment and water, with certain nutritional elements also shared. The key change in the RCLPS is the selection of a default category within a livestock type WIRRD, and the presentation to the user of the results based on a ranking system. To present all the evaluated results would defeat the purpose of aiding the management of the water source as the information presented would be too large for a decision to be effected. As such, the livestock component in the RCLPS model conducts risk assessments as described in WRC Final Report K5/644, and the reader is referred to that report for the modelling detail.

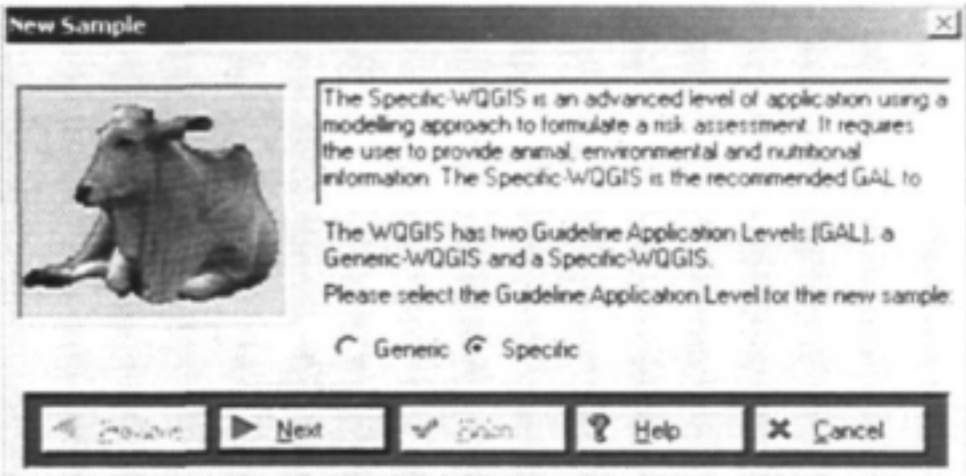
The second *modification* deals with setting new reference values for specific WQCs that may pose a significant consumer health hazard. The guideline limits are described for the Generic Guideline Application Level in the WRC Final Report K5/644 apply. However, modifications occur by way of two generic GAL types, namely Livestock Type I and Livestock Type II, designated as RefDoc-LTI and RefDoc-LTII. Livestock Type I refers to the generic guideline application limits for identifying PHCs and COCs for those systems where a close association does not exist between the animals and humans with reference to the sustainable reliance by humans, specifically sensitive domestic user groups, with reference to the ingestion of animal products. Livestock Type II refers to the generic guideline application limits under conditions where rural communities utilise livestock in a sustainable production system, and caters for the possible consumer health hazards related to the increased exposure of PHCs for humans consuming animals products (milk, meat and/or organs). Those WQCs which are known to be potentially hazardous to human health, and which are cumulative in nature, and/or approximate a linear relationship with water concentration and milk concentration, are set at more conservative limits under Livestock Type *II* limits. The modifications are presented in Table 3.2. The relevant references are provided.

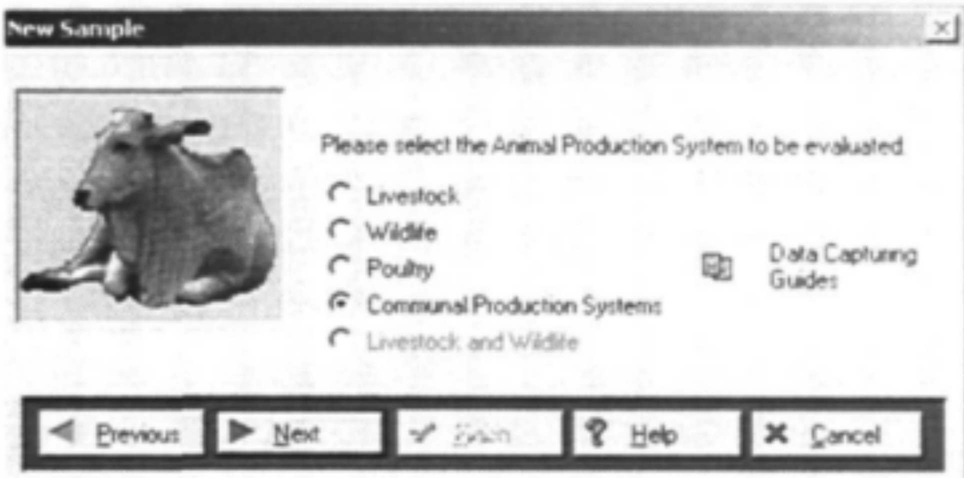
Table 3.2 Guideline modifications for Generic RCLPS

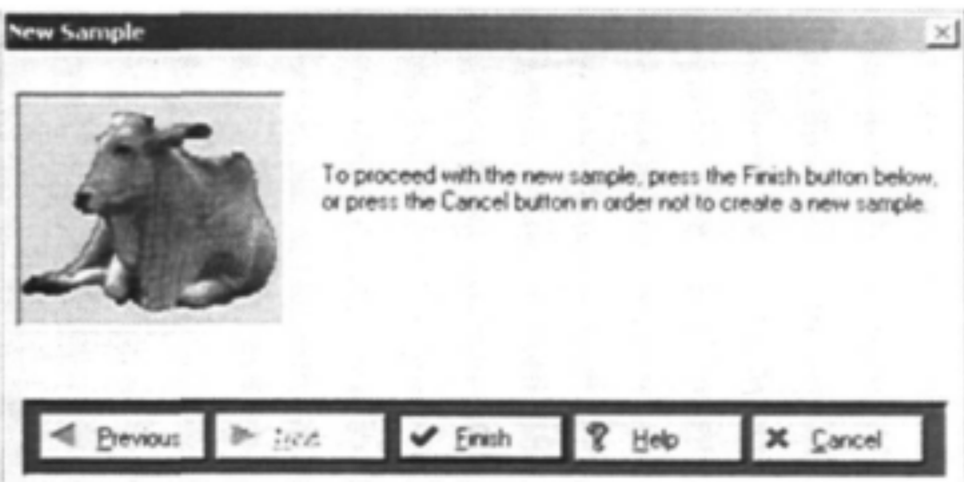
WQC	RefDoc-LTI mg/L	RefDoc-LTII mg/L
As	0.05	0.01 (DWA&F, 1996)
Cd	0.01	0.005 (DWA&F, 1996)
Cr	1	0.05 (DWA&F, 1996)
Co	1	0.05 (Smith, 1988)
Fe	10	5 (Quality of Domestic Water Supplies, 1998)
Pb	0.05	0.01 (DWA&F, 1996)
Mn	10	4 (Quality of Domestic Water Supplies, 1998)
Ni	1	0.02 (WHO, 1993)
Se	0.05	0.02 (DWA&F, 1996)
Zn	20	10 (DWA&F, 1996)

3.6 User Interface screen images for the RCLPS model

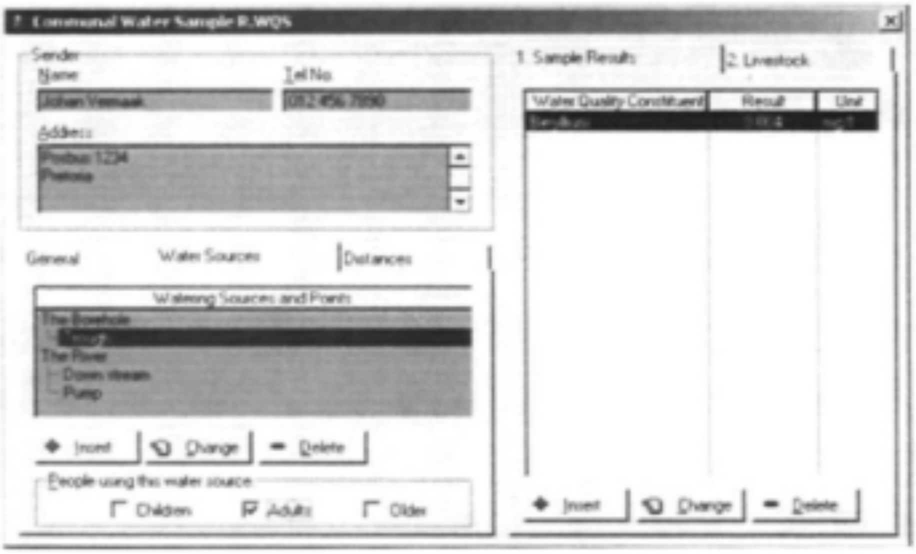
The following pages provide some of the screens available for the data capturing section of the RCLPS model. The screen images represent the user interface portion of the program. The two other main sections that reside within the software are the source code (modelling), and documentation data dictionaries for the reference material and supporting information. The images are presented in this report to indicate to the reader the document-driven Windows format of CIRRA, an attribute which should enable easy navigation for all levels of computer literacy.

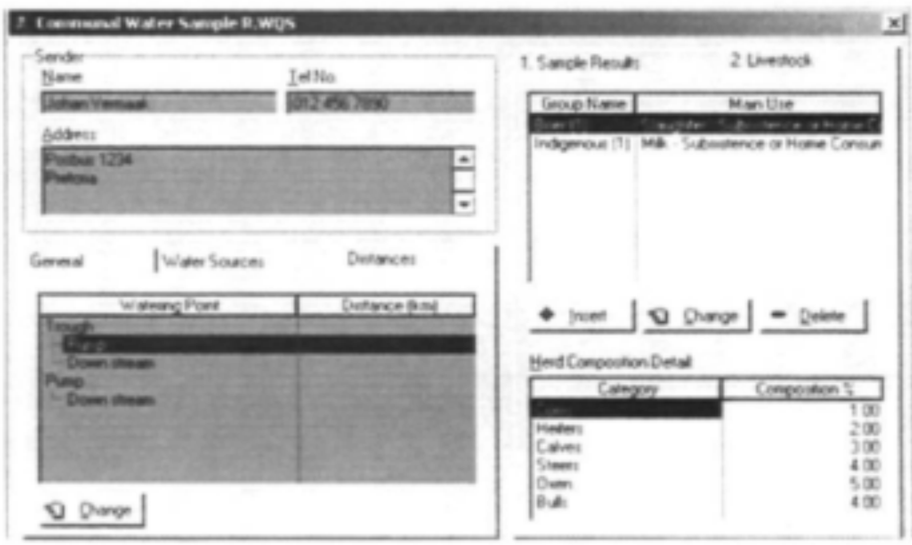

New Sample
The Specific-WQGIS is an advanced level of application using a modelling approach to formulate a risk assessment. It requires the user to provide animal, environmental and nutritional information. The Specific-WQGIS is the recommended GAL to
The WQGIS has two Guideline Application Levels (GAL), a Generic-WQGIS and a Specific-WQGIS.
Please select the Guideline Application Level for the new sample:
Generic
Specific
Next
Help
Cancel

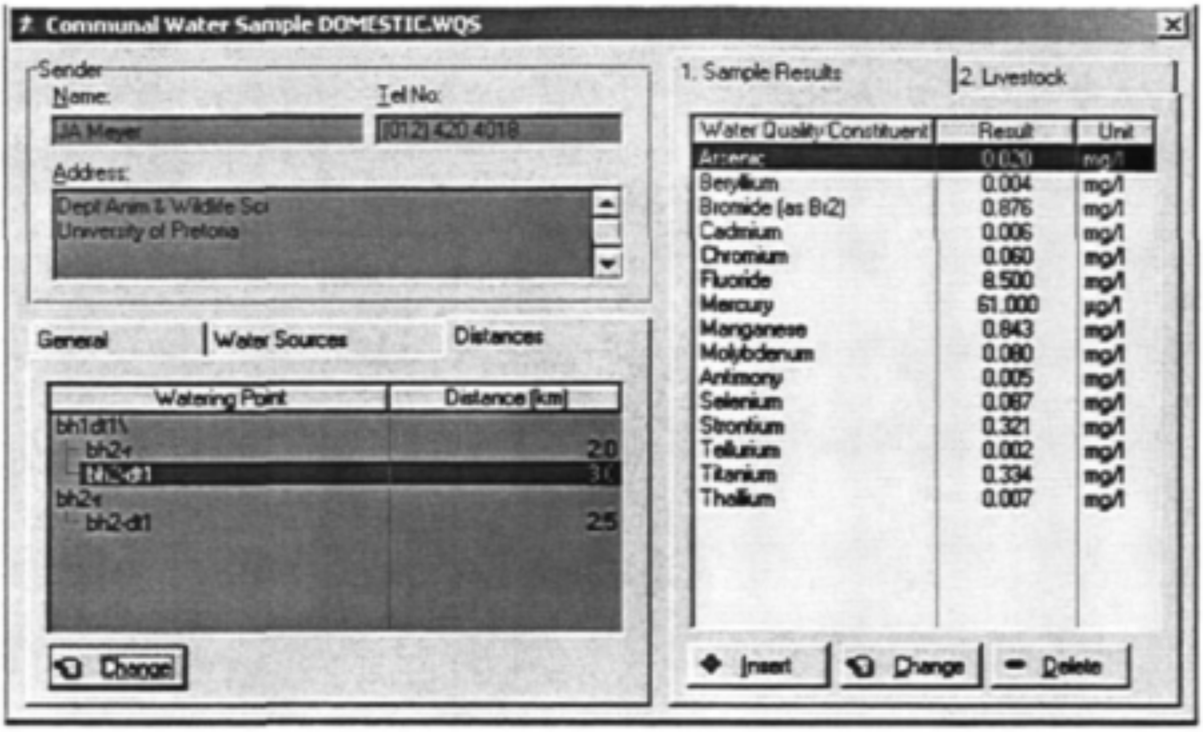

New Sample
Please select the Animal Production System to be evaluated
Livestock
Wildlife
Poultry
Communal Production Systems
Livestock and Wildlife
Data Capturing Guides
Previous
Next
Help
Cancel

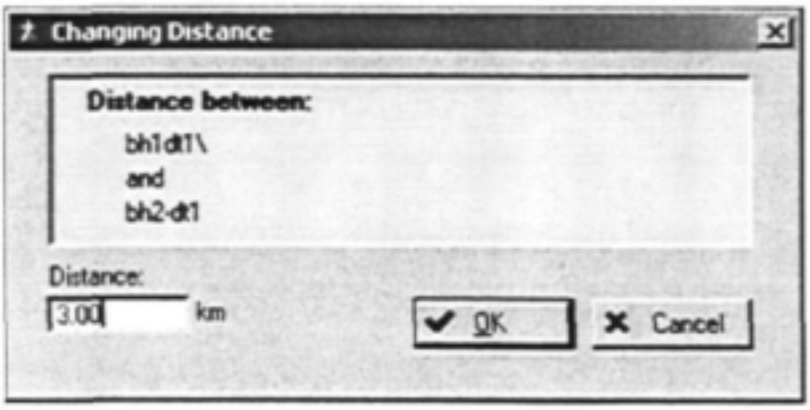

New Sample
To proceed with the new sample, press the Finish button below, or press the Cancel button in order not to create a new sample.
Previous
Finish
Help
Cancel

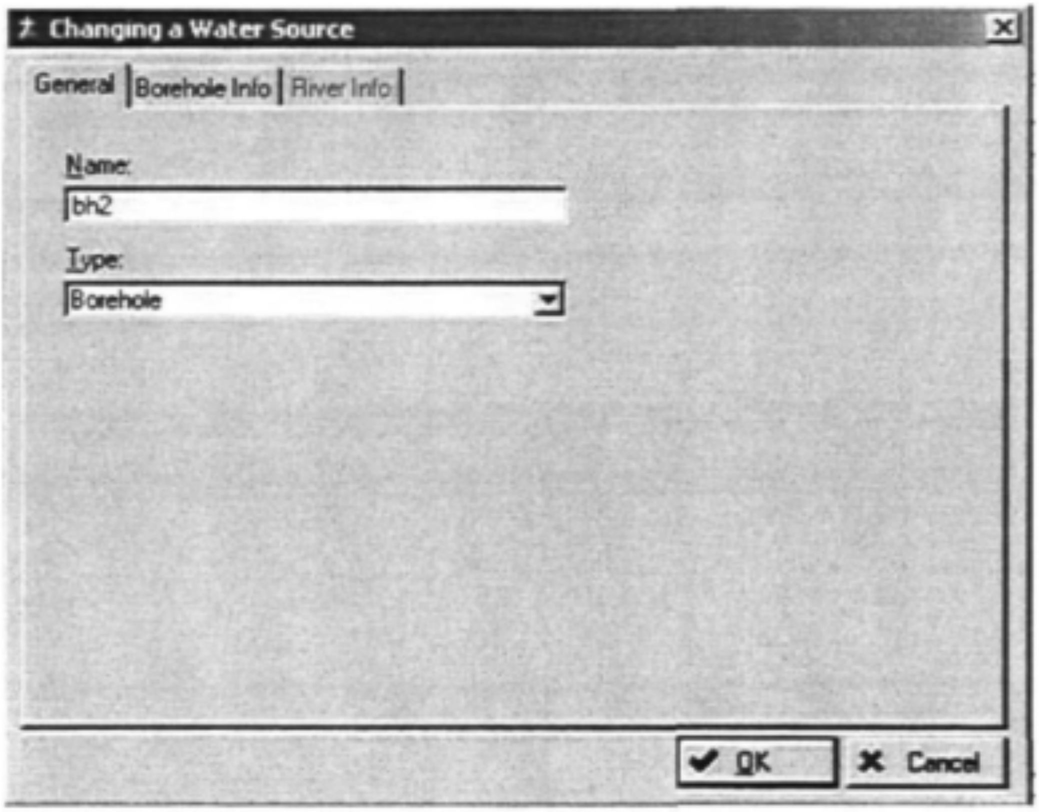

Communal Water Sample R.WQS
Sender
Name
Tel No
Johan Vermaak
012 456 7890
Address
Posbus 1234
Pretoria
General
Water Sources
Distances
Sample
Date
Time
GAL
Add Site Specific Detail
Farm/Other
Name
Farm Number
Contact Number
District
1. Sample Results
2. Livestock
Water Quality Constituent
Result
Unit
Insert
Change
Delete

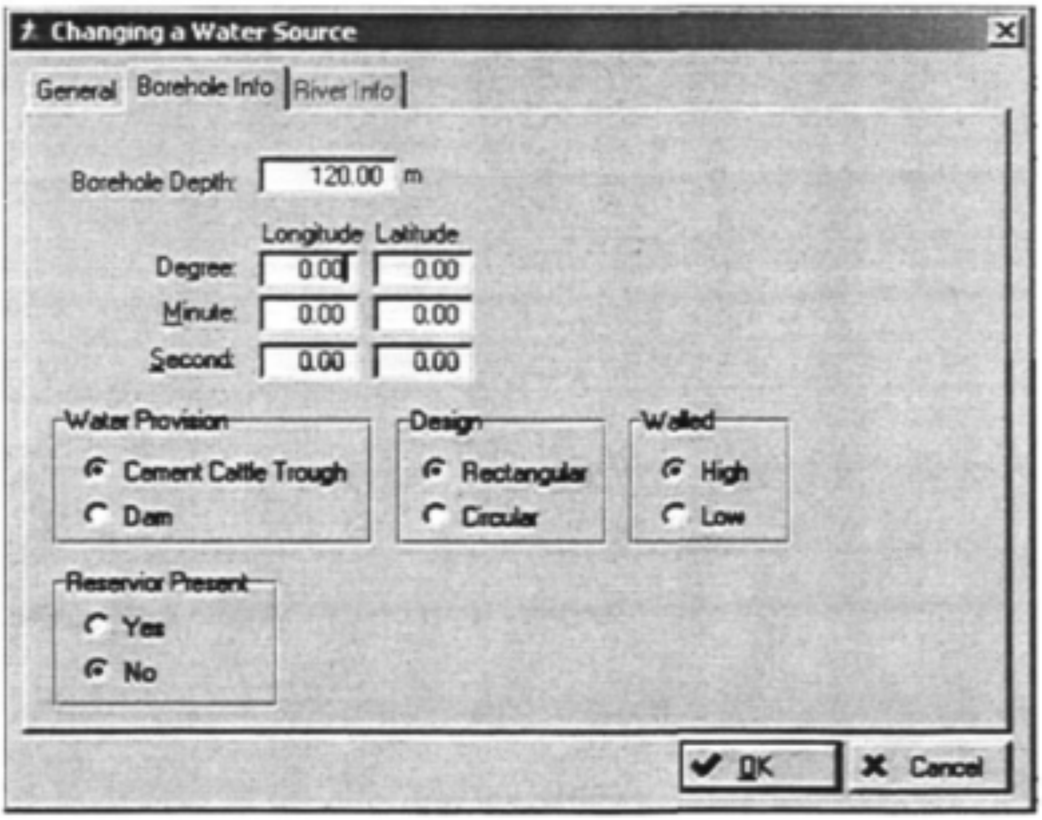

Communal Water Sample R.WQS
Sender
Name
Tel No
Johan Vermaak
012 456 7890
Address
Posbus 1234
Pretoria
General
Water Sources
Distances
Watering Sources and Points
The Borehole
The River
Down stream
Pump
Insert
Change
Delete
People using this water source
Children
Adults
Older
1. Sample Results
2. Livestock
Water Quality Constituent
Result
Unit

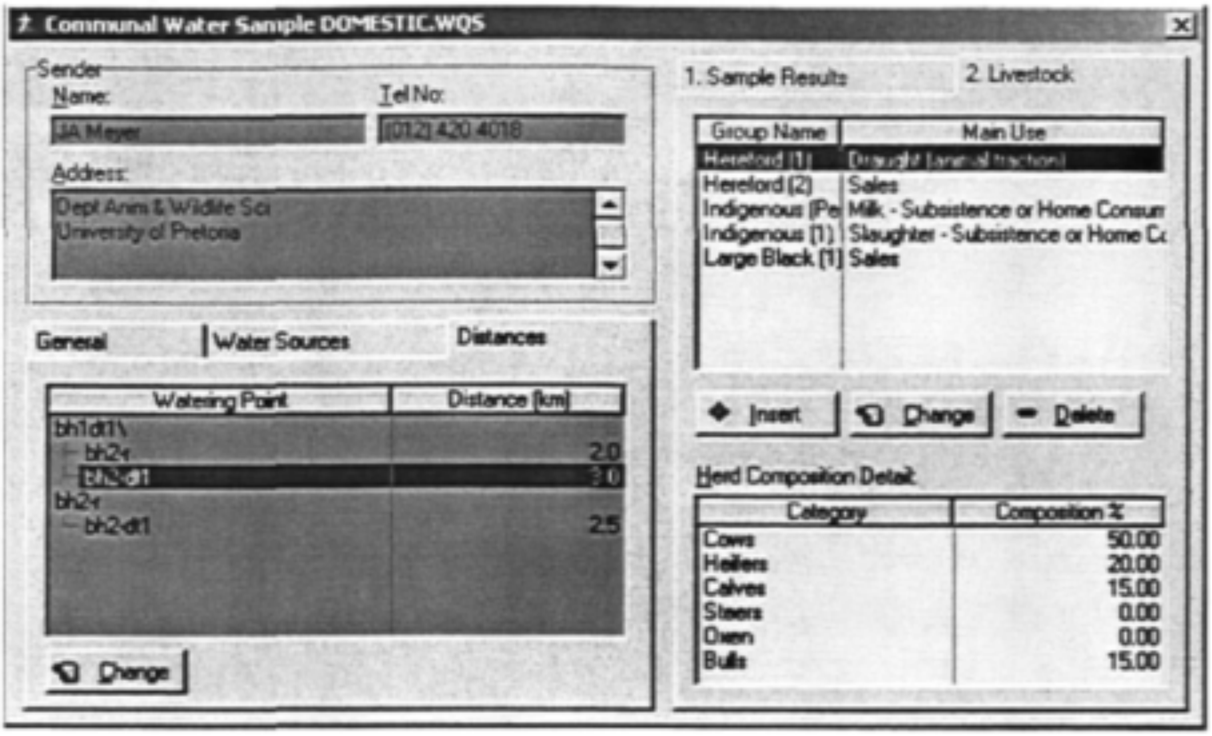

Communal Water Sample R.WQS
Sender
Name
Tel No
Johan Vermaak
012 456 7890
Address
Posbus 1234
Pretoria
General
Water Sources
Distances
Watering Point
Distance (km)
Trough
Down stream
Pump
Down stream
Change
1. Sample Results
2. Livestock
Group Name
Main Use
Indigenous (1)
Milk - Subsistence or Home Consum
Insert
Change
Delete
Herd Composition Detail
Category
Composition %
1.00
Heifers
2.00
Calves
3.00
Steers
4.00
Oxen
5.00
Bulls
4.00

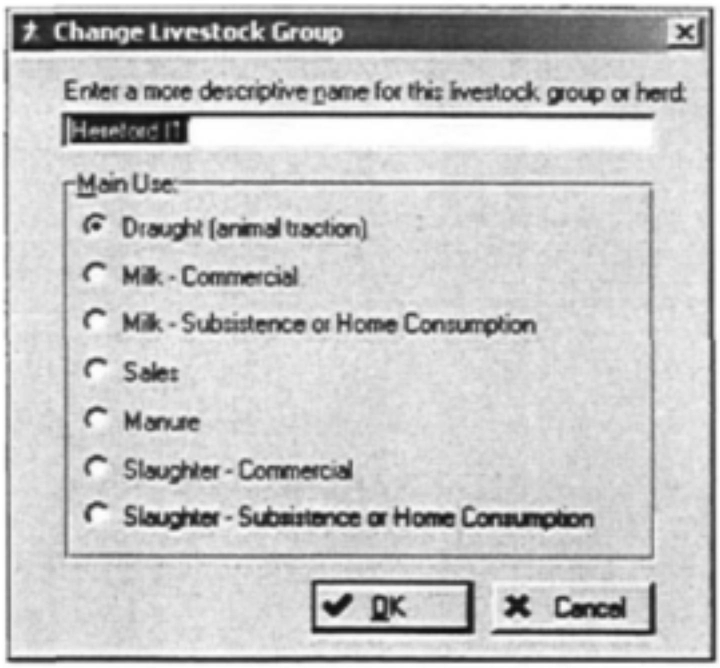

Communal Water Sample DOMESTIC.WQS
Sender
Name:
Tel No:
JA Meyer
(012) 420 4018
Address:
Dept Anim & Wildlife Sci
University of Pretoria
General
Water Sources
Distances
Watering Point
Distance (km)
bh1dt1\
bh2-r
2.0
bh2-dt1
3.0
bh2-r
bh2-dt1
2.5
Change
1. Sample Results
2. Livestock
Water Quality Constituent
Result
Unit
Arsenic 0.020 mg/l
Beryllium 0.004 mg/l
Bromide (as Br2) 0.876 mg/l
Cadmium 0.006 mg/l
Chromium 0.060 mg/l
Fluoride 8.500 mg/l
Mercury 61.000 µg/l
Manganese 0.843 mg/l
Molybdenum 0.080 mg/l
Antimony 0.005 mg/l
Selenium 0.087 mg/l
Strontium 0.321 mg/l
Tellurium 0.002 mg/l
Titanium 0.334 mg/l
Thallium 0.007 mg/l
Insert
Change
Delete

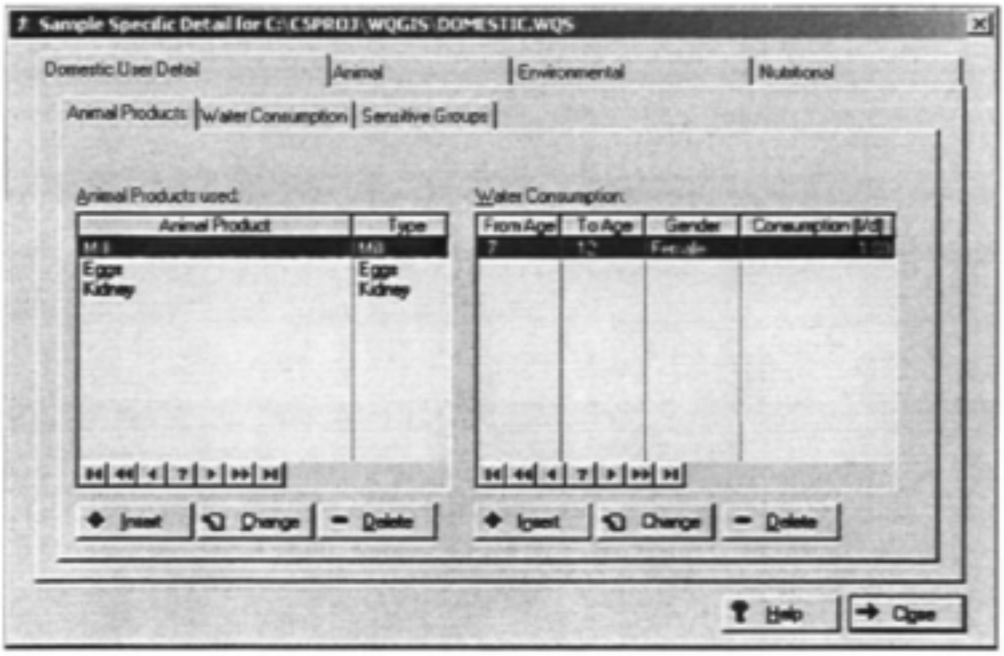

Changing Distance
Distance between:
bh1dt1\
and
bh2-dt1
Distance:
3.00
km
OK
Cancel


Changing a Water Source
General
Borehole Info
River Info
Name:
bh2
Type:
Borehole
OK
Cancel

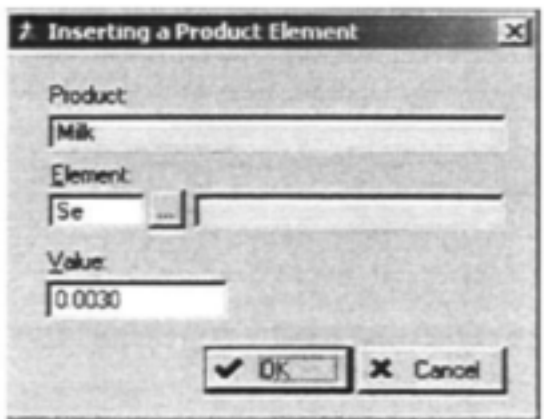

Changing a Water Source
General
Borehole Info
River Info
Borehole Depth:
120.00
m
Longitude
Latitude
Degree:
0.00
0.00
Minute:
0.00
0.00
Second:
0.00
0.00
Water Provision
Cement Cattle Trough
Dam
Design
Rectangular
Circular
Walled
High
Low
Reservior Present
Yes
No
OK
Cancel

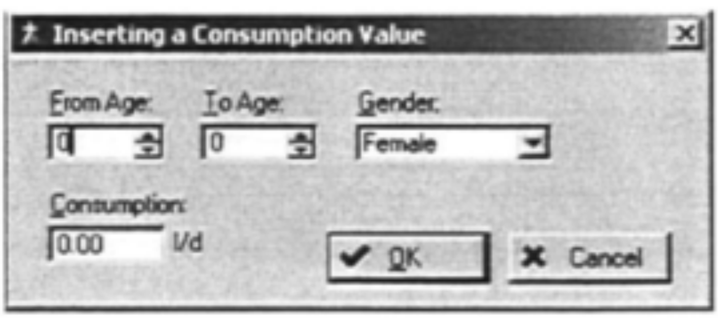

Communal Water Sample DOMESTIC.WQS
Sender
Name:
Tel No:
JA Meyer
(012) 420 4018
Address:
Dept Anim & Wildlife Sci
University of Pretoria
General
Water Sources
Distances
Watering Point
Distance (km)
bh1dt1\
bh2-r
2.0
bh2-dt1
bh2-r
bh2-dt1
2.5
Change
1. Sample Results
2. Livestock
Group Name
Main Use
Hereford (1)
Draught (animal traction)
Hereford (2)
Sales
Indigenous (Pe
Milk - Subsistence or Home Consum
Indigenous (1)
Slaughter - Subsistence or Home Co
Large Black (1)
Sales
Insert
Change
Delete
Herd Composition Detail:
Category
Composition %
Cows
50.00
Heifers
20.00
Calves
15.00
Steers
0.00
Oxen
0.00
Bulls
15.00

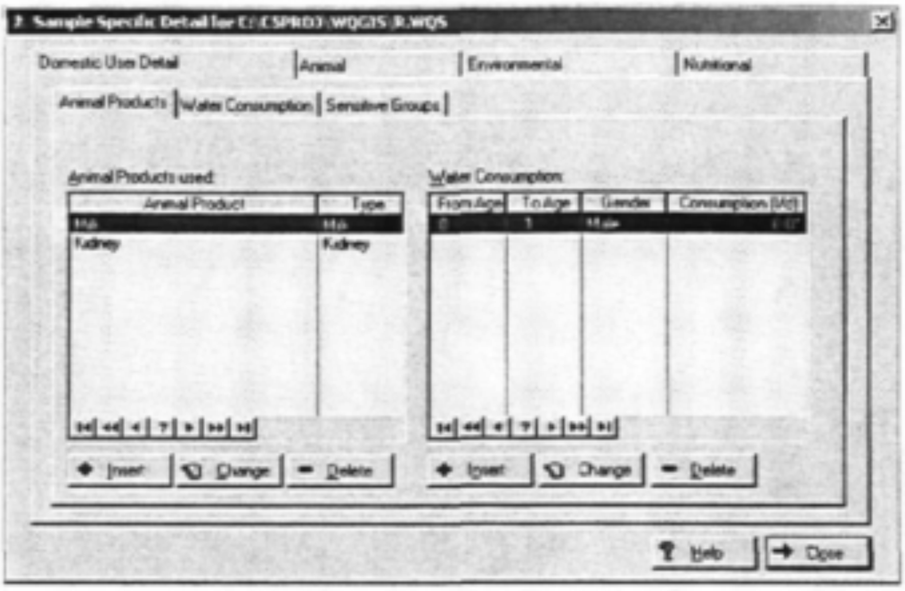

Change Livestock Group
Enter a more descriptive name for this livestock group or herd:
Hereford (1)
Main Use:
Draught (animal traction)
Milk - Commercial
Milk - Subsistence or Home Consumption
Sales
Manure
Slaughter - Commercial
Slaughter - Subsistence or Home Consumption
OK
Cancel

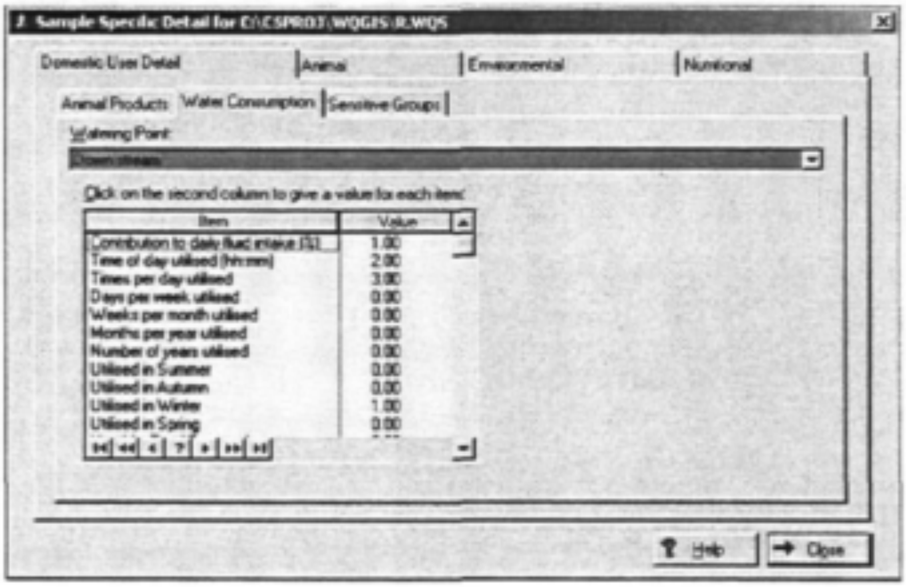

Sample Specific Detail for C:\CSPROJ\WQGIS\DOMESTIC.WQS
Domestic User Detail
Animal
Environmental
Nutritional
Animal Products
Water Consumption
Sensitive Groups
Animal Products used:
Animal Product
Type
Milk
Eggs
Kidney
Water Consumption:
From Age
To Age
Gender
Consumption [l/d]
7
12
Female
Insert
Change
Delete
Help
Close

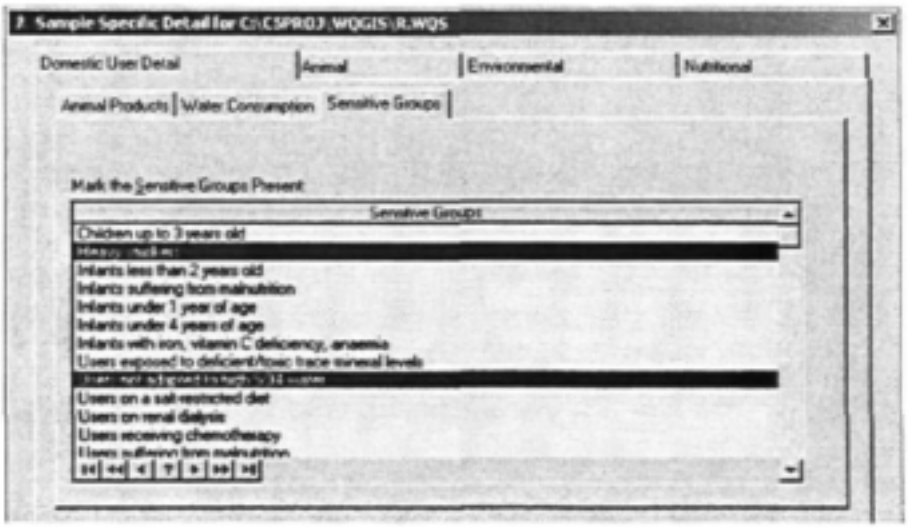

Inserting an Animal Product
Type:
Description:
Milk
Element
Value
Insert
Change
Delete
OK
Cancel

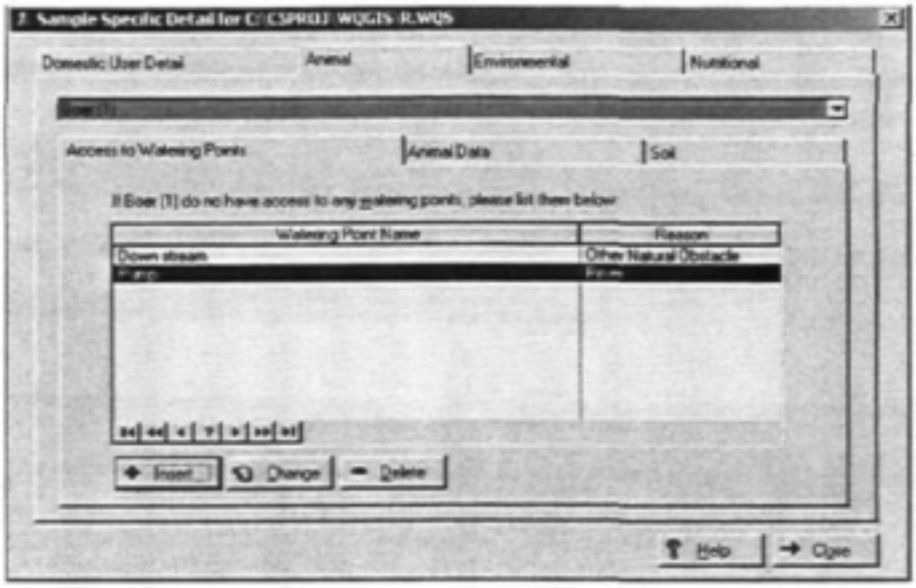

Inserting a Product Element
Product:
Milk
Element:
Se
Value:
0.0030
OK
Cancel

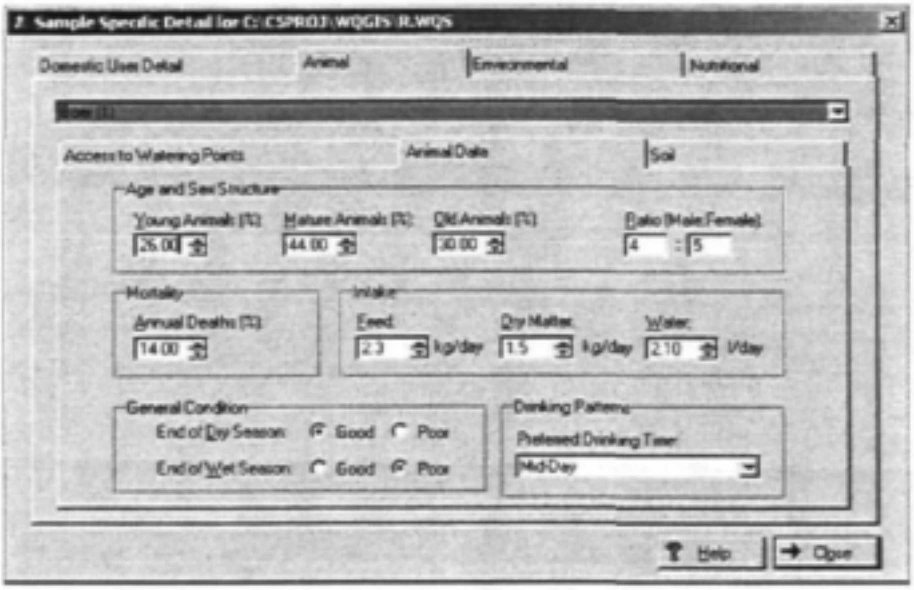

Inserting a Consumption Value
From Age:
To Age:
Gender:
0
0
Female
Consumption:
0.00
l/d
OK
Cancel

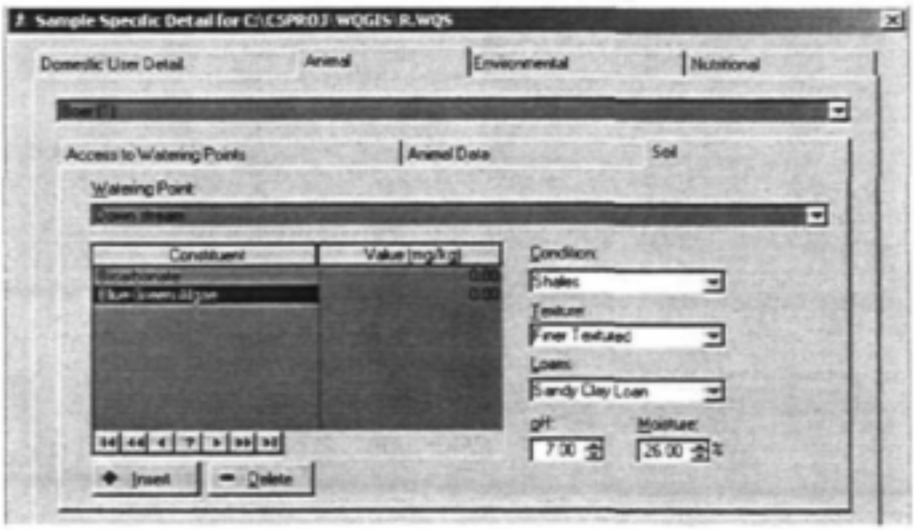

Sample Specific Detail for C:\CSPROJ\WQGIS\R.WQS
Domestic User Detail
Animal
Environmental
Nutritional
Animal Products
Water Consumption
Sensitive Groups
Animal Products used:
Animal Product
Type
Kidney
Kidney
Water Consumption:
From Age
To Age
Gender
Consumption (l/d)
Insert
Change
Delete
Help
Close

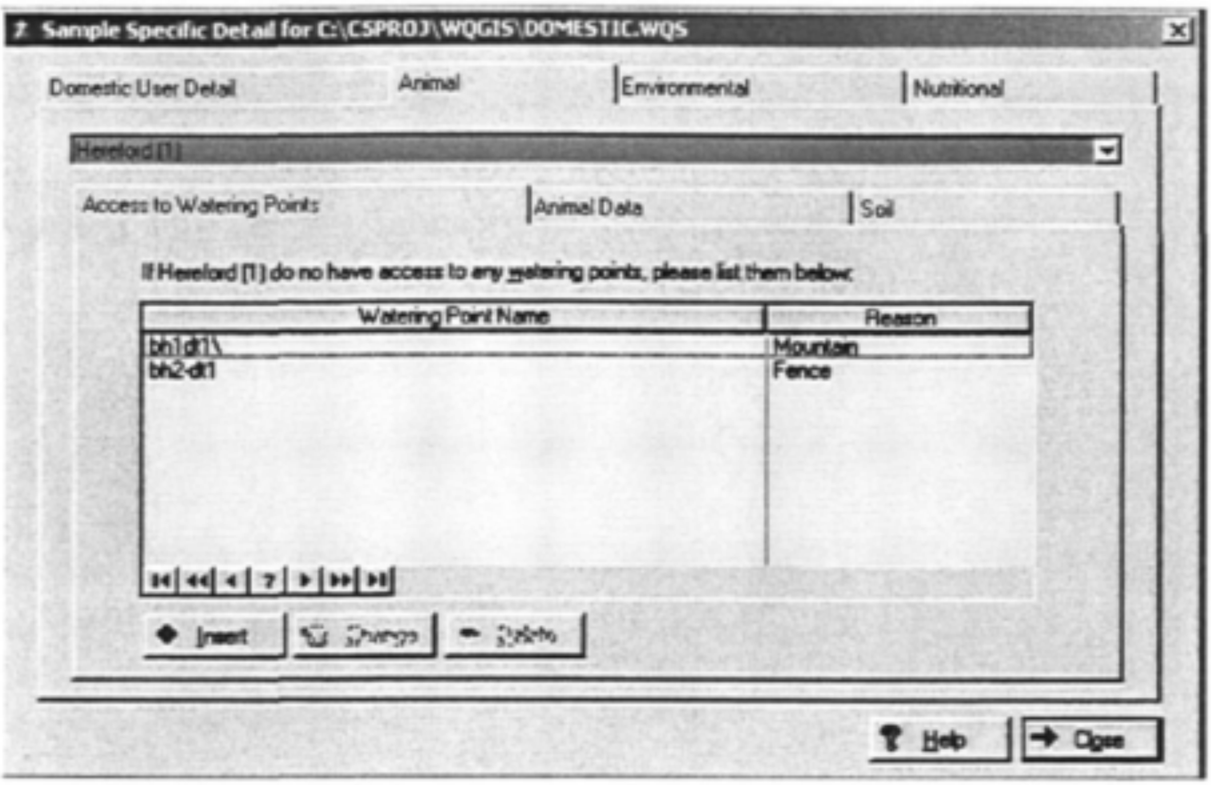

Sample Specific Detail for C:\CSPROJ\WQGIS\R.WQS
Domestic User Detail
Animal
Environmental
Nutritional
Animal Products
Water Consumption
Sensitive Groups
Watering Point:
Click on the second column to give a value for each item:
Item
Value
Contribution to daily fluid intake (%)
1.00
Time of day utilised (hh:mm)
2.00
Times per day utilised
3.00
Days per week utilised
0.00
Weeks per month utilised
0.00
Months per year utilised
0.00
Number of years utilised
0.00
Utilised in Summer
0.00
Utilised in Autumn
0.00
Utilised in Winter
1.00
Utilised in Spring
0.00
Help
Close


Sample Specific Detail for C:\CSPROJ\WQGIS\R.WQS
Domestic User Detail
Animal
Environmental
Nutritional
Animal Products
Water Consumption
Sensitive Groups
Mark the Sensitive Groups Present:
Sensitive Groups
Children up to 3 years old
Infants less than 2 years old
Infants suffering from malnutrition
Infants under 1 year of age
Infants under 4 years of age
Infants with iron, vitamin C deficiency, anaemia
Users exposed to deficient/toxic trace mineral levels
Users on a salt-restricted diet
Users on renal dialysis
Users receiving chemotherapy


Sample Specific Detail for C:\CSPROJ\WQGIS\R.WQS
Domestic User Detail
Animal
Environmental
Nutritional
Access to Watering Points
Animal Data
Soil
Watering Point Name
Reason
Down stream
Other Natural Obstacle
Insert
Change
Delete
Help
Close

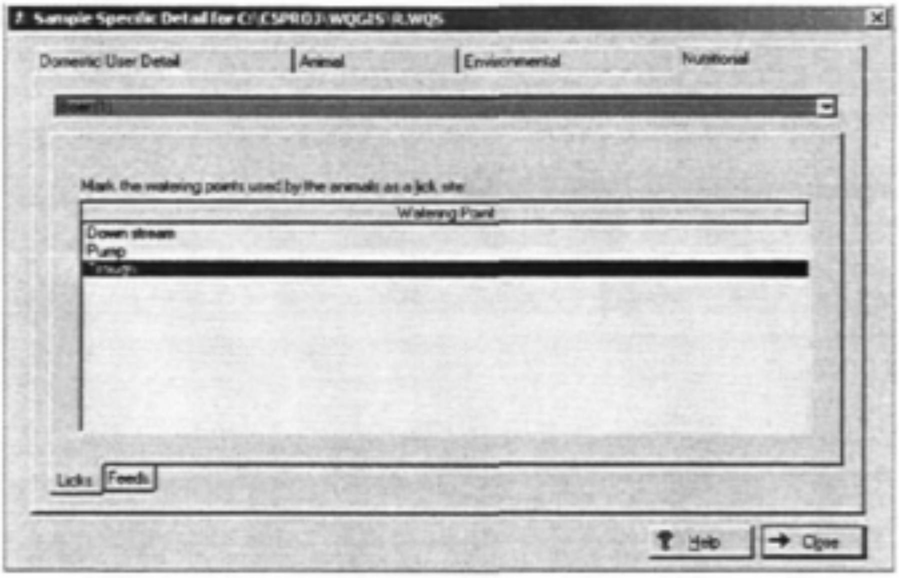

Sample Specific Detail for C:\CSPROJ\WQGIS\R.WQS
Domestic User Detail
Animal
Environmental
Nutritional
Access to Watering Points
Animal Data
Soil
Age and Sex Structure
Young Animals (%)
Mature Animals (%)
Old Animals (%)
Ratio (Male:Female)
26.00
44.00
30.00
4
5
Mortality
Annual Deaths (%)
14.00
Intake
Feed
Dry Matter
Water
2.3
kg/day
1.5
kg/day
2.10
l/day
General Condition
End of Dry Season
Good
Poor
End of Wet Season
Good
Poor
Drinking Pattern
Preferred Drinking Time
Mid-Day
Help
Close

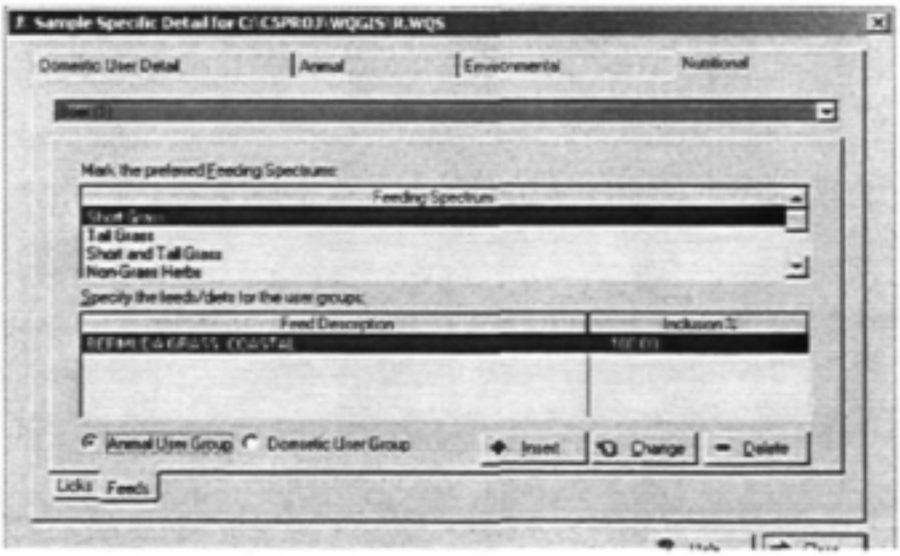

Sample Specific Detail for C:\CSPROJ\WQGIS\R.WQS
Domestic User Detail
Animal
Environmental
Nutritional
Access to Watering Points
Animal Data
Soil
Watering Point
Constituent
Value (mg/kg)
0.00
0.00
Condition
Shales
Texture
Finer Textured
Loam
Sandy Clay Loam
pH
7.00
Moisture
26.00
%
Insert
Delete

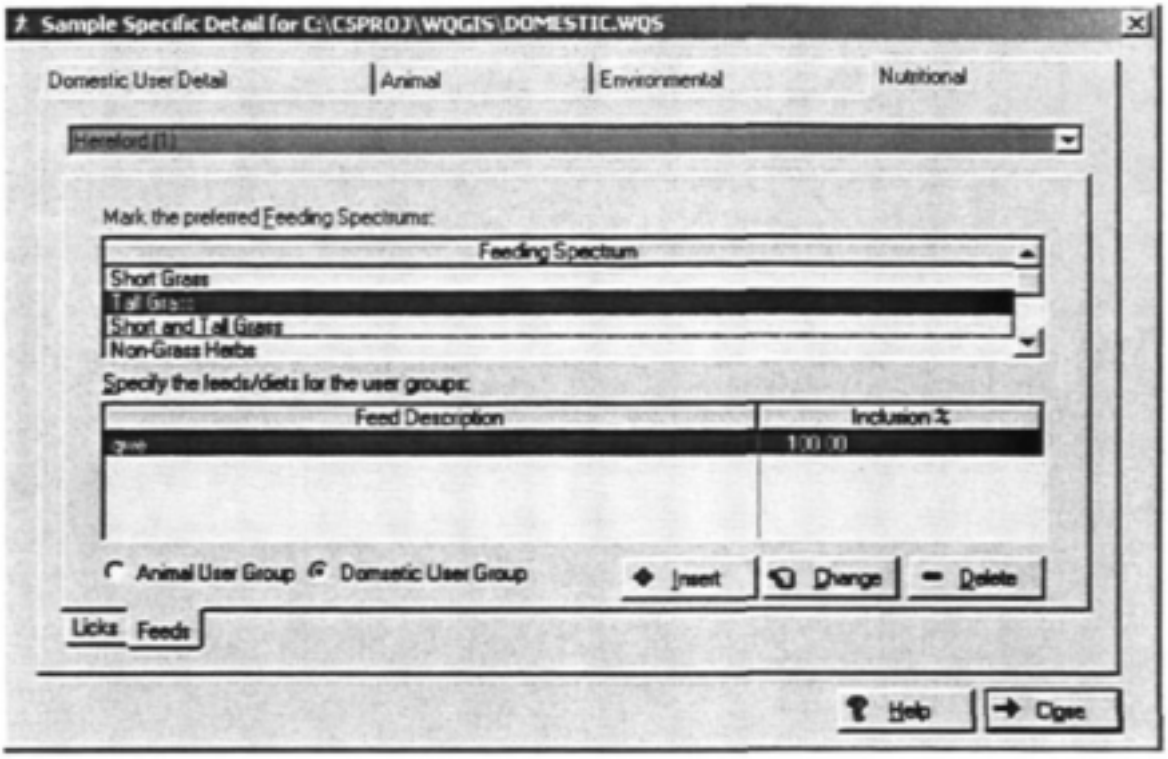

Sample Specific Detail for C:\CSPROJ\WQGIS\DOMESTIC.WQS
Domestic User Detail
Animal
Environmental
Nutritional
Hereford [1]
Access to Watering Points
Animal Data
Soil
If Hereford [1] do no have access to any watering points, please list them below:
Watering Point Name
Reason
bh1dt1\
Mountain
bh2-dt1
Fence
Insert
Help
Close

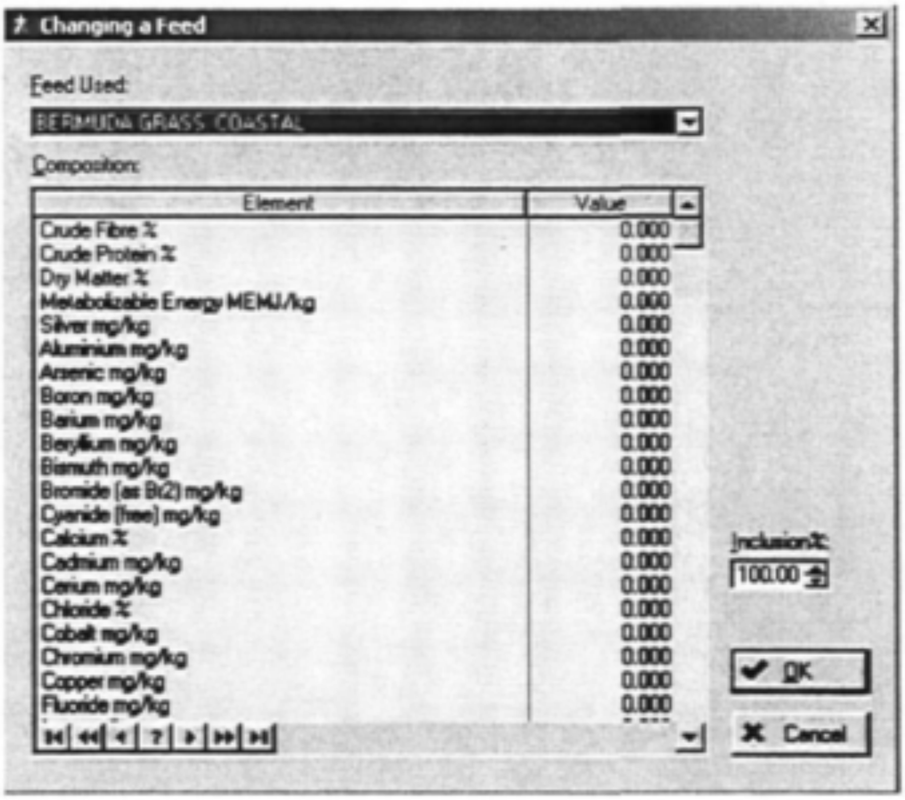

Inserting an Inaccessable Point
Watering Point:
bh1dt1\
Reason why the watering point is inaccessable:
Reason
Natural Obstacle
Mountain
River
Other Natural Obstacle
Manmade Obstacle
Fence
Road
Other Manmade Obstacle
OK
Cancel

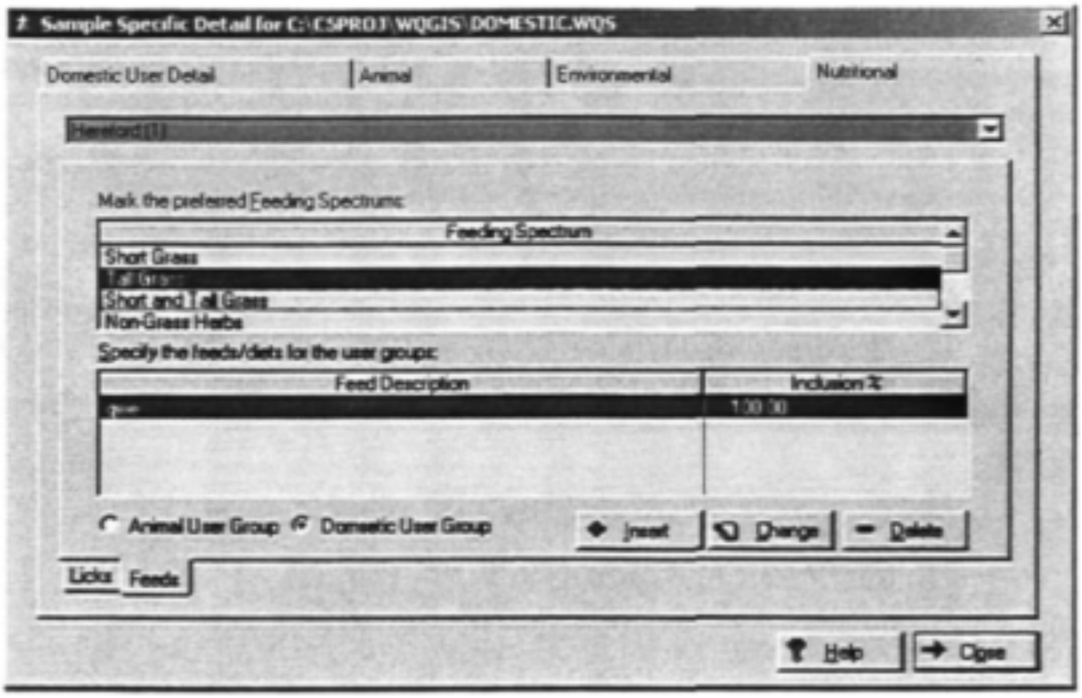

Sample Specific Detail for C:\CSPROJ\WQGIS\R.WQS
Domestic User Detail
Animal
Environmental
Nutritional
General
Rainfall
Temperature
Biome
Altitude
240
mm p.a.
26.0 °C
Nama-Karoo
1,400
meters above sea level
Mark the preferred veld types:
Veld Types
Fynbos : Western Cape Province
Desert and Succulent Karoo : Western Northern and Western Ca
Arid Karoo : Central Northern Cape Province
Forests : Western Cape Province and Eastern Cape Province
Valley Bushveld : Eastern Cape Province and KwaZulu/Natal
Lowveld : Mpumalanga and KwaZulu/Natal
Help
Close

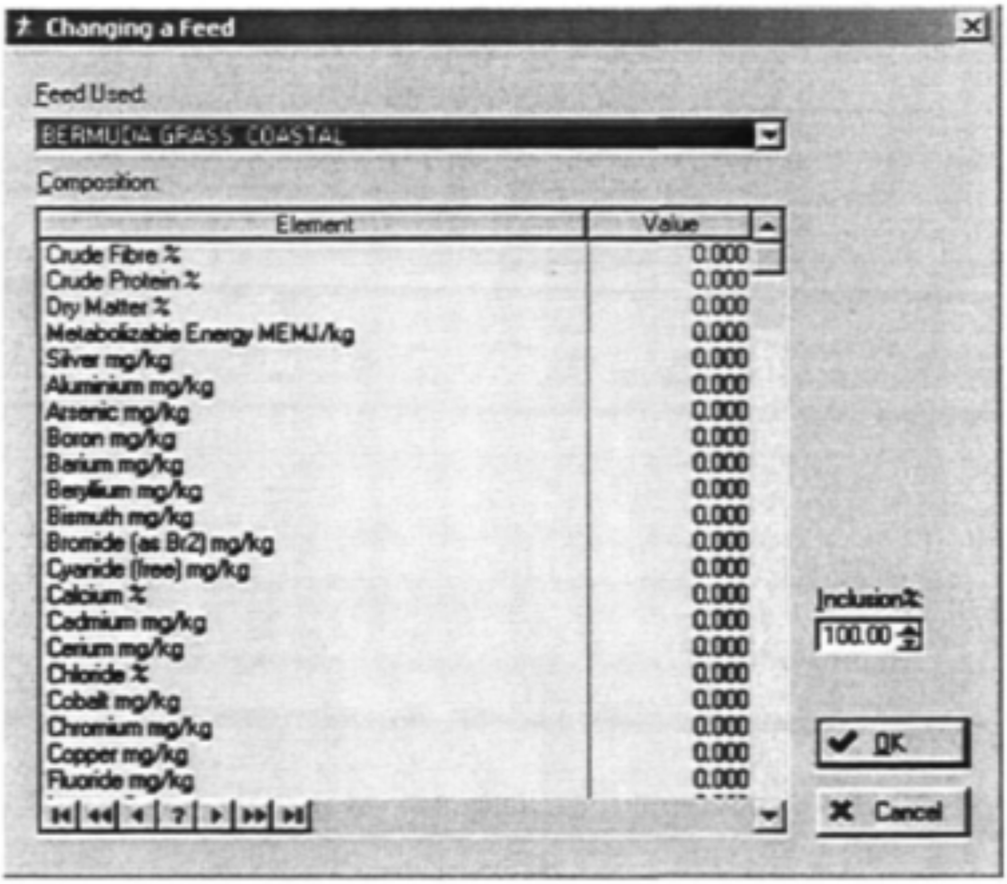

Sample Specific Detail for C:\CSPROJ\WQGIS\R.WQS
Domestic User Detail
Animal
Environmental
Nutritional
Mark the watering points used by the animals as a lick site:
Watering Point
Down stream
Pump
Licks
Feeds
Help
Close

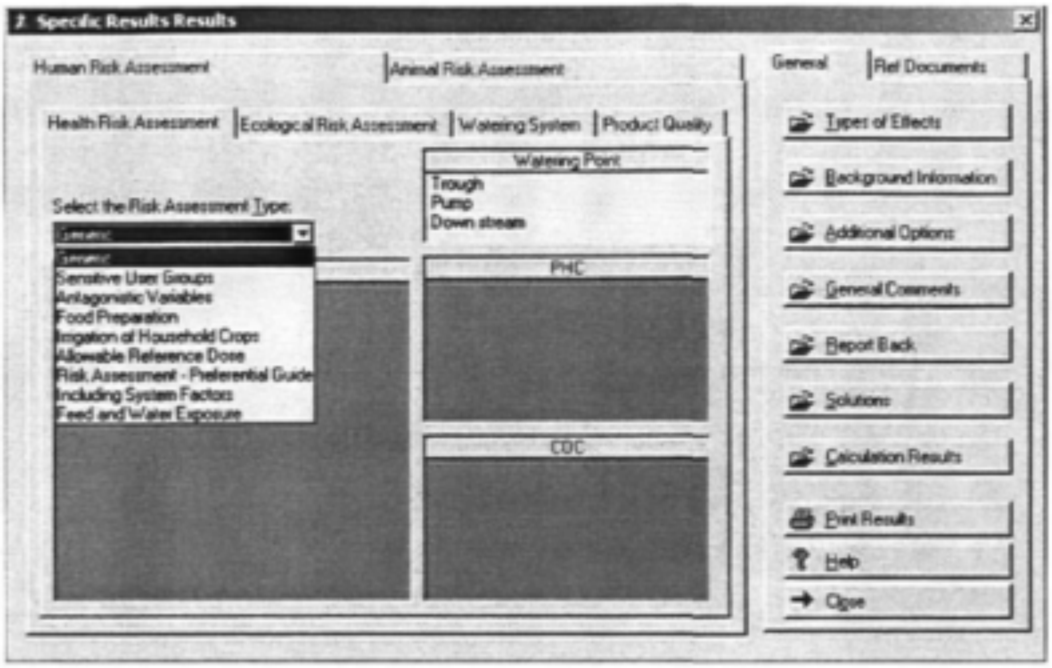

Sample Specific Detail for C:\CSPROJ\WQGIS\R.WQS
Domestic User Detail
Animal
Environmental
Nutritional
Mark the preferred Feeding Spectrums:
Feeding Spectrum
Tall Grass
Short and Tall Grass
Non-Grass Herbs
Specify the feeds/diets for the user groups:
Feed Description
Inclusion %
Animal User Group
Domestic User Group
Insert
Change
Delete
Licks
Feeds

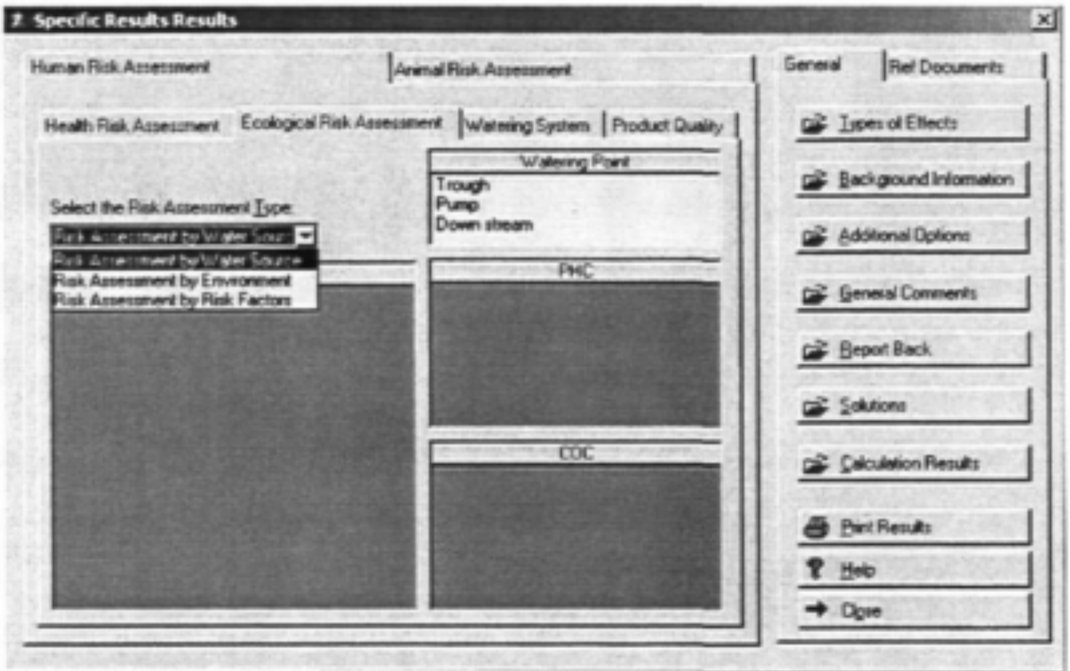

Sample Specific Detail for C:\CSPROJ\WQGIS\DOMESTIC.WQS
Domestic User Detail
Animal
Environmental
Nutritional
Hereford (1)
Mark the preferred Feeding Spectrums:
Feeding Spectrum
Short Grass
Tall Grass
Short and Tall Grass
Non-Grass Herbs
Specify the feeds/diets for the user groups:
Feed Description
Inclusion %
100.00
Animal User Group
Domestic User Group
Insert
Change
Delete
Licks
Feeds
Help
Close

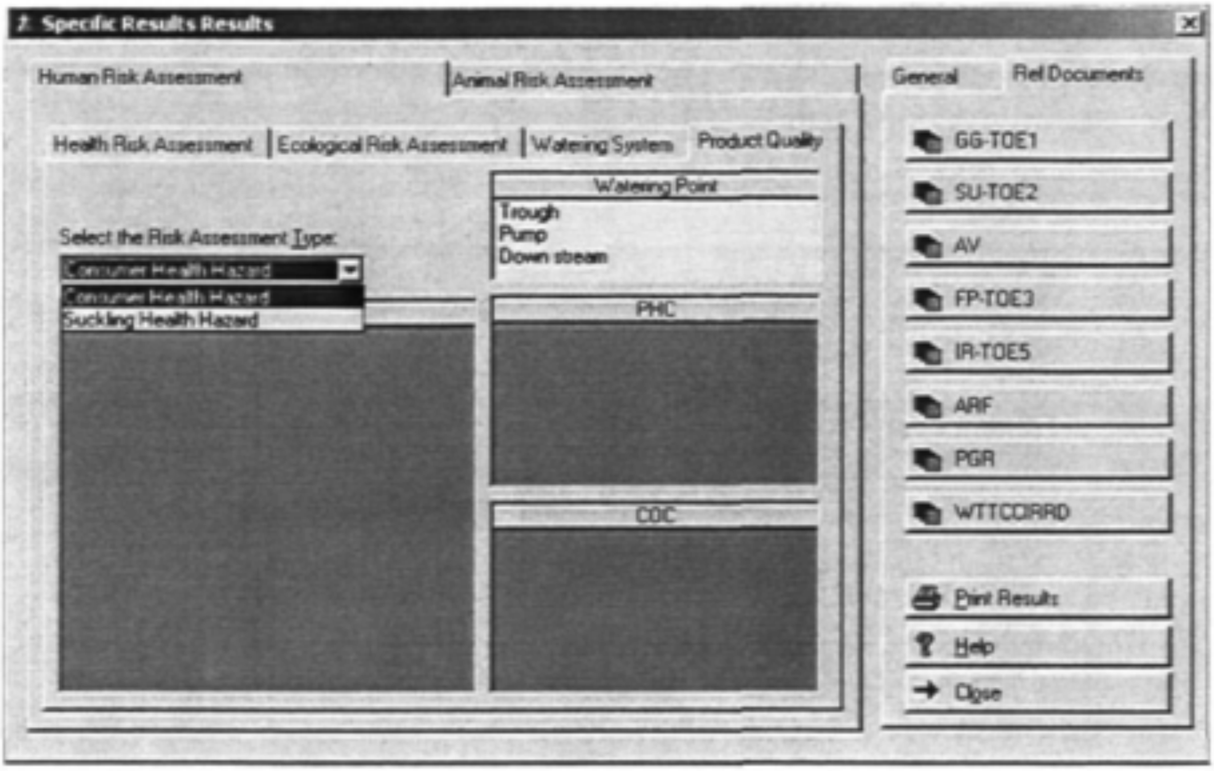

Changing a Feed
Feed Used:
BERMUDA GRASS COASTAL
Composition:
Element
Value
Crude Fibre % 0.000
Crude Protein % 0.000
Dry Matter % 0.000
Metabolizable Energy MEMJ/kg 0.000
Silver mg/kg 0.000
Aluminium mg/kg 0.000
Arsenic mg/kg 0.000
Boron mg/kg 0.000
Barium mg/kg 0.000
Beryllium mg/kg 0.000
Bismuth mg/kg 0.000
Bromide (as Br2) mg/kg 0.000
Cyanide (free) mg/kg 0.000
Calcium % 0.000
Cadmium mg/kg 0.000
Cerium mg/kg 0.000
Chloride % 0.000
Cobalt mg/kg 0.000
Chromium mg/kg 0.000
Copper mg/kg 0.000
Fluoride mg/kg 0.000
Inclusion%:
100.00
OK
Cancel


Sample Specific Detail for C:\CSPROJ\WQGIS\DOMESTIC.WQS
Domestic User Detail
Animal
Environmental
Nutritional
Mark the preferred Feeding Spectrums:
Feeding Spectrum
Short Grass
Short and Tall Grass
Non-Grass Herbs
Specify the feeds/diets for the user groups:
Feed Description
Inclusion %
Animal User Group
Domestic User Group
Insert
Change
Delete
Licks
Feeds
Help
Close


Changing a Feed
Feed Used:
BERMUDA GRASS COASTAL
Composition:
Element
Value
Crude Fibre %
Crude Protein %
Dry Matter %
Metabolizable Energy MEMJ/kg
Silver mg/kg
Aluminium mg/kg
Arsenic mg/kg
Boron mg/kg
Barium mg/kg
Beryllium mg/kg
Bismuth mg/kg
Bromide (as Br2) mg/kg
Cyanide (free) mg/kg
Calcium %
Cadmium mg/kg
Cerium mg/kg
Chloride %
Cobalt mg/kg
Chromium mg/kg
Copper mg/kg
Fluoride mg/kg
0.000
Inclusion%:
100.00
OK
Cancel


Specific Results Results
Human Risk Assessment
Animal Risk Assessment
General
Ref Documents
Health Risk Assessment
Ecological Risk Assessment
Watering System
Product Quality
Watering Point
Trough
Pump
Down stream
Select the Risk Assessment Type:
Sensitive User Groups
Antagonistic Variables
Food Preparation
Irrigation of Household Crops
Allowable Reference Dose
Risk Assessment - Preferential Guide
Including System Factors
Feed and Water Exposure
PHC
COC
Types of Effects
Background Information
Additional Options
General Comments
Report Back
Solutions
Calculation Results
Print Results
Help
Close


Specific Results Results
Human Risk Assessment
Animal Risk Assessment
General
Ref Documents
Health Risk Assessment
Ecological Risk Assessment
Watering System
Product Quality
Watering Point
Trough
Pump
Down stream
Select the Risk Assessment Type:
Risk Assessment by Environment
Risk Assessment by Risk Factors
PHC
COC
Types of Effects
Background Information
Additional Options
General Comments
Report Back
Solutions
Calculation Results
Print Results
Help
Close


Specific Results Results
Human Risk Assessment
Animal Risk Assessment
General
Ref Documents
Health Risk Assessment
Ecological Risk Assessment
Watering System
Product Quality
Watering Point
Trough
Pump
Down stream
Select the Risk Assessment Type:
Consumer Health Hazard
Consumer Health Hazard
Suckling Health Hazard
PHC
COC
GG-TOE1
SU-TOE2
AV
FP-TOE3
IR-TOE5
ARF
PGR
WTTCCIRRD
Print Results
Help
Close

CHAPTER 4

WATER QUALITY INVESTIGATIONS IN SELECTED RURAL COMMUNAL LIVESTOCK PRODUCTION SYSTEMS

4.1 Introduction

This chapter presents water quality investigations conducted in a number of selected communities which all share a close association with livestock and subterranean water, and should be read in conjunction with the RCLPS model described in Chapter 3. The purpose of these investigations was primarily to obtain water quality samples from those water sources, and watering points, on which the communities and their livestock relied. Due to the extensive nature of some of the communities, it was not possible to pre-arrange sample collection from every village or dwelling, although most collection phases were preceded by discussion groups with the farmers groups, or relevant local authorities. Thus, some samples were not obtainable at the time of conducting the sampling phase, and this is reflected in the different number and location of samples collected from the same area over different sampling phases. In some instances these differences are due to some boreholes being abandoned (usually due to palatability problems), and in others due to the Chief locking the borehole in an attempt to "save" the water for the winter. This practice was found to be quite common in villages in the Jericho District. The possible ramifications of this practice are dealt with in the relevant discussion sections. The sampling phases also provided an opportunity to discuss the varied roles of livestock and water within the different communities with extension officers and farmers.

4.2 Methods

The common procedures employed for the water quality investigations are presented in this section. Issues unique to each area investigated are presented under the "Methods" section in the appropriate chapter.

4.2.1 Water sample collection and analyses

Water samples were collected in 250 ml sterilised plastic containers obtained from the Institute for Soil Climate and Water (Pretoria, ARC), according to techniques prescribed by the ISCW (1998). The ISCW also conducted the laboratory analyses of all the samples, and also prepared the sample containers where necessary (for example, sample preservation with $HgCl_2$ for NO_3 determination). Samples were preferably taken from the point of use, for example a tap in the case of domestic users, or drinking trough, in the case of livestock use. In some cases samples were collected from the borehole and reservoir, dependent on the nature of the available water sources to the users involved, and the watering techniques. Long reservoir residence times on multiple watering points were sampled. Samples were kept cool in polystyrene containers and delivered within 48 hours to the ISCW water laboratory. Constituents analysed for were:

Full quantitative analysis:

fluoride, nitrite, nitrate, chloride, sulphate, phosphate, carbonate, bicarbonate, sodium, potassium, calcium, magnesium, boron, pH, total dissolved solids.

Semi-quantitative analysis (ICP-AES scan):

Be, Li, Ti, V, Cr (total), Mn, Co, Ni, Zn, Cu, As, Br, Se, Sr, Mo, Cd, In, Sn, Sb, Te, W, Pt, Au, Hg, Tl, Pb, Bi, U.

The reader is referred to Volume 1 of the WRC Final Report K5/644 for more information.

4.2.2 Guidelines and acronyms used for water quality assessment

Risk assessments for livestock and wildlife were formulated using the software program CIRRA, Version 1.03. The reader is referred to WRC Final Report, K5/644 for further information.

Due to the shared utilisation observed in the rural communities investigated a generic level risk assessment was conducted for domestic drinking purposes. These results form the focus of the water quality investigations for the RCLPS model. Although several primary guideline references were used to conduct the water quality assessment, three main sets were used. These were the 1996 Department of Water Affairs and Forestry Water Quality Guidelines for Domestic Use (DWA&F, 1996), the Quality of Water for Domestic Supplies, Volume 1: Assessment Guide (Quality of Domestic Water Supplies, 1998), and the 1998 USEPA Domestic Drinking Water Maximum Contaminant Level (MCL) guidelines (USEPA, 1998). For those constituents for which neither of these two references offer a guideline, guidelines as described by Kempster *et al.*, (1985), Smith (1988) and the WHO (1993) were used.

Due to the harsh environmental factors prevalent in the areas sampled, and in the interests of erring on the conservative side, in cases where more than one guideline is reported for a particular constituent, the lower guideline reported was used. This is in accordance with the recommendations of how to apply developed guidelines under local conditions (WHO, 1993). Concentrations recorded which exceeded the DWA&F (1996) guideline for category C, the maximum recommended limit (MRL) for the WHO (1993) guidelines, or the MCL for USEPA guidelines, were reported as potentially hazardous constituents (PHC). Constituents that recorded values within 10% of a guideline limit were reported as constituents of concern (COC). Definitions of these terms appear below.

- PHC: indicates that the WQC in question is likely to result in adverse effects
- COC: indicates that the WQC in question could conceivably become a PHC due to concentration variations, such as seasonal fluctuation in the water source or evaporative effects, and should therefore be monitored.

Two exceptions were made in the case of F and TDS to the 10% COC rule. Due to the endemic fluorosis problem, the high altitude effect on renal glomerular filtration rate (Janse van Rensburg & Pitout, 1991), and high temperatures experienced in the area reviewed, concentrations exceeding 0.5 mg F/L were recorded as a COC.

Acronyms used:

MPL	maximum permissible level (Kempster *et al.*, 1985; Smith 1988)
RL	Recommended level (Kempster *et al.*, 1985; Smith 1988)
CL	Crisis level (Smith, 1988)
Cat C/D/E	Category level (Quality of Domestic Water Supplies, 1998)
MRL	Maximum recommended limit (WHO, 1993)
TWQR	Target Water Quality Range (DWA&F 1996)
AV	Antagonistic variable (Underwood & Suttle, 1999)
HA	Health Advisory (USEPA, 1998)

Department of Water Affairs and Forestry (1996) Domestic Use Guidelines and Quality of Domestic Water Supplies. Vol 1: Assessment guide (1998)

These guidelines make use of different categories to indicate the fitness for use of the water. Only categories C, D and E for drinking health were used. The reader is referred to both documents for the actual guideline values.

Category:	Types of effects	Recommendation
A	No adverse effects	water fit for use
B	No significant adverse effects	water fit for use
C	Possible adverse effects in sensitive groups	water fit for use monitor constituent levels
D	Adverse chronic effects likely	use with caution (only limited exposure for sensitive groups)
E	Acute adverse effects likely	Not fit for use/serious health effects in all users/acute health effects in all users

In this report, these appear as Cat C, Cat D, and Cat E.

USEPA Drinking Water Guidelines (revised 1998):

The USEPA provide two main sets of guidelines, Primary Drinking Water Regulations and Secondary Drinking Water Regulations. Primary guidelines make use of a maximum contaminant level (MCL) and a maximum contaminant level goal (MCLG). A MCL is defined as "the maximum permissible level of a contaminant in water which is delivered to any user of a public water system". All States are required to comply with the MCL standards, whereas a MCLG is defined as "a non-enforceable concentration of a drinking water contaminant that is protective of adverse human health effects and allows an adequate margin of safety". Some States in the USA apply the MCLG as a MCL. Secondary Drinking Water Regulations make use of secondary maximum contaminant levels (SMCL), which are non-enforceable guidelines, although the EPA recommends them to the States as reasonable goals, and some States do adopt them as enforceable regulations.

In addition, Drinking Water Health Advisories (HA) and Drinking Water Equivalent Levels (DWEL) are issued by the EPA for some WQC. The HA fall under four groups ranging from a one-day HA to a lifetime HA. The definition of a lifetime HA is "the concentration of a chemical in the drinking water that is not expected to cause any adverse non-carcinogenic effects over a lifetime of exposure, with a margin of safety". The DWEL is a lifetime exposure concentration protective of adverse, non-carcinogenic health effects, which assumes all of the exposure to a contaminant is from a drinking water source. For cases where no MCL, MCLG or SMCL is available, a HA or DWEL is used.

National Primary and Secondary Drinking Water Regulations (mg/l) (revised 1998)

WQC	MCLG	MCL	SMCL
Aluminium	na	na	0.05 to 0.2
Antimony	0.006	0.006	
As	na	0.05	
Barium	2	2	
Beryllium	0.004	0.004	
Cadmium	0.005	0.005	
Chloride	na	na	250
Chromium(t)	0.1	0.1	
Copper	1.3	1.3 (action level)	1
Cyanide	0.2	0.2	
F	4	4	2
Iron	na	na	0.3
Lead	0	0.015 (action level)	
Manganese	na	na	0.05
Inorg Hg	0.002	0.002	
NO3 (as N)	10	10	
NO2 (as N)	1	1	
Nickel	0.1	na	
Se	0.05	0.05	
Silver	na	na	0.1
Sulphate	na	na	250
Thallium	0.0005	0.002	
TDS	na	na	500
Zn	na	na	5

Notes:
An Action Level is an additional post water treatment trigger for prevention/removal.
The EPA is considering lowering the MCL for Arsenic to 0.01 mg/l.
The F MCL is under review.
Mo* - level cited is a health advisory limit for long term exposure for a 70 kg adult.

DWEL AND LIFELONG HA from EPA (mg/l)

WQC	DWEL	HA
Sb		30
Ba	2	2
Be	0.2	
B	3	0.6
Cd	0.02	0.005
Cr(t)	0.02	0.1
Hg	0.001	0.002
Mo	0.2	0.04
Ni	0.6	0.1
Silver	0.2	0.1
Na	20	
Sr	90	17
Th	0.0023	0.0005
Zn	10	2

Additional guidelines:

These guidelines are taken from those formulated by Kempster *et al.* (1985) and Smith (1988) and are predominantly based on the median values reported in international literature, cited as MPL (maximum permissible levels). They offer a guideline for those constituents not dealt with by the DWA&F or the USEPA guidelines. Some of these proposals also include a crisis limit (CL).

WQC	**MPL (mg/L)**	**CL (mg/L)**
Li	5	10
Sb	0.1	0.2
Bi	0.5	1
Br	3 (1*)	6
Ce	2	4
Au	0.005	0.01
Ti	0.2	1
Te	0.005	0.01
Li	5	
Mo	0.1	0.2
W	0.5	1
Sr	2 (0.1**)	

Note: Br* = presence can lead to bromate formation. Recommended Limit = 1 mg/l used
Sr** = AV

Antagonistic Variable

An antagonistic variable (AV) is a constituent with unsubstantiated toxicity, but which may indirectly lead to trace mineral imbalances due to interference with the absorption of other trace minerals (Underwood & Suttle, 1999). With regard to fluoride toxicity, molybdenum is an AV. Due to the possible antagonistic effects of Sr on Ca (Sargent *et al.*, 1966), and the occurrence of endemic fluorosis in the area sampled, 0.1 mg/L was taken as a trigger for COC classification for Sr. Zinc is as an additional example of a constituent that, at a certain concentration (0.1 mg/L), may not have any direct adverse effects, but possibly interfere with the absorption of essential trace elements.

4.3 Results

4.3.1 Barolong Resettlement Area:

4.3.1.1 Introduction

The Barolong Resettlement Area is located in the North West Province in the Potchefstroom District. Sampling commenced in 1998 with the expectation that farmers would be settled by 1999. At the time of writing this report a dispute between the two main tribes claiming rights to the land had not yet been resolved. However, people had settled there prior to 1998, and continue to live there under a rural livestock production system context. The area contains a full spectrum of domestic and livestock user groups. Many of the inhabitants are permanent, whilst others commute between the area and nearby towns, mainly Potchefstroom.

Although a river is located in the central portion of the area, it does not contain water all year round, and the main source of water is from subterranean sources. One natural earth dam and a shale dam are also used, both by humans and stock, although fish are caught and consumed from at least one dam. Apart from these water sources the predominant form of water is from five boreholes, of which only three were in working order. All of these boreholes were used for drinking purposes by humans and livestock.

In total the area comprises 3486 ha of farming land inhabited by 62 livestock farmers, although at least twice this amount of people reside permanently on the farms in association with those persons tending to the farm and livestock. The only school present uses the same subterranean water source as a large central feedlot containing 60 head of cattle, using water from one borehole as the only water supply.

A 7000 ha wildlife section has been proclaimed within the Barolong Resettlement Area, with all the livestock having already been removed from the area. The main water supply is from three boreholes, but the only drinking trough found to contain water was sourced from the Potchefstroom Municipality water supply which also provides the Promosa Location with its water.
The following livestock numbers were established in June 1998 for the Barolong Resettlement Area:

533	cattle – mostly Brahman and Bonsmara types
118	sheep
225	goats
22	pigs

Numerous types of poultry were observed, including ducks, turkeys, chickens and geese.

4.3.1.2 Methods

Two sampling phases were conducted, a summer phase in 1998, and a winter phase in 1999. Samples were collected in conjunction with extension officers working in the area. All available water sources were sampled. No analyses were conducted for Te or Be.

4.3.1.3 Results: Sampling phase I: Barolong Resettlement Area (Feb 1998)

1 = Reservoir for Borehole #1 (Pholerigomo)

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	**WQC**	Measured (mg/l)	Relevant Guideline (mg/l)
Br	1.688	0.01 - MCL	As	0.008	0.01 - TWQR
Se	0.047	0.05 - Cat C	Sr	0.3	0.1 - AV
Ti	0.408	0.2 - MPL	Zn	0.11	0.1 - AV

2 = Drinking Trough for Borehole #1 (Pholerigomo)

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	**WQC**	Measured (mg/l)	Relevant Guideline (mg/l)
Br	2.092	0.01 – MCL	Sr	0.3	0.1 - AV
Mn	0.172	0.05 – TWQR			
Ti	0.348	0.2 – MPL			

3 = Drinking trough for Borehole #1 (Pholerigomo)

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	**WQC**	Measured (mg/l)	Relevant Guideline (mg/l)
Br	1.598	0.01 – MCL	Sr	0.245	0.1 - AV
Mn	0.076	0.05 – TWQR	Zn	0.259	0.1 - AV
Ti	0.274	0.2 – MPL			

4 = Tub drinking trough for Borehole #2 (Radimo)

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	**WQC**	Measured (mg/l)	Relevant Guideline (mg/l)
Br	0.550	0.01 – MCL	Zn	1.199	0.1 - AV

5 = Drinking trough for Borehole #3 (Radimo)

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	**WQC**	Measured (mg/l)	Relevant Guideline (mg/l)
Br	0.788	0.01 – MCL	Sr	0.107	0.1 - AV
Se	0.024	0.02 – TWQR			
Ti	0.128	0.2 – MPL			

6 = Inflow pipe to reservoir for Borehole #3 (Radimo)

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	**WQC**	Measured (mg/l)	Relevant Guideline (mg/l)
Br	1.035	0.01 – MCL	As	0.008	0.01 - TWQR
Se	0.056	0.05 - Cat C	Sr	0.171	0.1 - AV
Ti	0.257	0.2 – MPL			

7 = Reservoir for Borehole # 3 (Radimo)

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	**WQC**	Measured (mg/l)	Relevant Guideline (mg/l)
Br	1.601	0.01 - MCL	Sr	0.121	0.1 - AV
Se	0.056	0.05 - Cat C			
Ti	0.178	0.2 - MPL			

8 = Reservoir for Borehole # 3 (Radimo)

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	**WQC**	Measured (mg/l)	Relevant Guideline (mg/l)
Br	0.822	0.01 - MCL	Sr	0.507	0.1 - AV
Pb	0.012	0.015 - AL	Zn	1.828	0.1 - AV
Mn	0.968	0.05 - TWQR			
Hg	0.001	0.001 - TWQR			
Ti	0.509	0.2 - MPL			

9 = Reservoir for Borehole # 4

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	**WQC**	Measured (mg/l)	Relevant Guideline (mg/l)
As	0.017	0.01 - TWQR			
Se	0.061	0.05 - Cat C			

10 = Drinking Trough for Borehole #4

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	**WQC**	Measured (mg/l)	Relevant Guideline (mg/l)
Br	0.706	0.01 - MCL			
Se	0.039	0.05 - Cat C			

11 = River (Kgaphamadi)

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	**WQC**	Measured (mg/l)	Relevant Guideline (mg/l)
Br	2.672	0.01 - MCL			
Mn	0.026	0.05 - TWQR			
Hg	0.003	0.001 - TWQR			

16 = Earth Dam

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	**WQC**	Measured (mg/l)	Relevant Guideline (mg/l)
Br	3.495	0.01 - MCL	Sr	0.115	0.1 - AV
NO2	5.96	1 - TWQR			

21 =Game Reserve dam

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	**WQC**	Measured (mg/l)	Relevant Guideline (mg/l)
As	0.012	0.01 - TWQR			
Br	5.262	0.01 - MCL			
Se	0.065	0.05 - Cat C			
Hg	0.003	0.001 - TWQR			

31 = Municipal water to Promosa – wildlife drinking trough

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	WQC	Measured (mg/l)	Relevant Guideline (mg/l)
Br	0.75	0.01 - MCL	Sr	0.112	0.1 - AV
Se	0.033	0.05 - Cat C			
NO2	1.67	1 - TWQR			

41 = Shale Dam

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	WQC	Measured (mg/l)	Relevant Guideline (mg/l)
Br	9.812	0.01 - MCL			

A summary of the occurrence of PHCs and COCs is presented in Table 4.3.1.1.

Table 4.3.1.1 Summary statistics for the main PHCs and COCs identified from 15 water samples collected in the Barolong Resettlement Area during February 1998.

WQC	PHC	COC	Average (mg/L)	SD (mg/L)	Median (mg/L)	Range (mg/L)	
(n) / WP	41	15				Minimum	Maximum
	2.73	1.00					
As	2	2	0.0056	0.0044	0.005	0	0.017
Br	14	0	2.351	2.423	1.607	0.55	9.812
Hg	3	0	0.001	0.002	0	0	0.007
Mn	4	0	0.088	0.247	0.011	0	0.969
Se	2	0	0.026	0.024	0.024	0	0.065
Ti	3	0	0.140	0.174	0.051	0	0.509
Sr	0	9	0.155	0.130	0.112	0.024	0.507
Zn	0	4	0.214	0.486	0.018	0	1.497

Table 4.3.1.2 Comparison between drinking trough and reservoir results.

Description	Drinking trough		Reservoir and other	
Number of watering points sampled	5		10	
Number of watering points containing PHCs and COCs	PHC 5	COC 4	PHC 10	COC 6
Average PHCs and COCs per watering point	PHC 2.4	COC 1	PHC 2.9	COC 1
Highest number of PHCs and COCs recorded within one watering point	PHC 3	COC 2	PHC 5	COC 3
Total PHCs and COCs recorded for all watering points	PHC 12	COC 5	PHC 29	COC 10
Major WQCs involved	PHC Br = 5; Mn = 2 Se = 2; Ti = 3	COC Sr = 3 Zn = 2	PHC As = 2; Br = 9 Hg = 3; Mn = 2 NO2 = 2; Pb = 1 Se = 6; Ti = 4	COC As = 2 Sr = 6 Zn = 2

4.3.1.4 Results: Sampling phase 2: Barolong Resettlement Area (June 1999)

10 = Drinking Trough for Borehole #4

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	WQC	Measured (mg/l)	Relevant Guideline (mg/l)
Be	0.013	0.004 -MCL	Zn	0.313	0.1 - AV
Hg	0.004	0.001 - TWQR			
Te	0.012	0.01 - CL			

9 = Reservoir for Borehole # 4

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	**WQC**	Measured (mg/l)	Relevant Guideline (mg/l)
Be	0.017	0.004 - MCL	Sr	0.310	0.1 - AV
Br	0.180	0.01 - MCL			
NO_3	35	26 - TWQR			
Mn	0.133	0.05 - TWQR			
Se	0.08	0.05 – Cat C			
Te	0.016	0.01 – CL			

5 = Drinking trough for Borehole #3 (Radimo)

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	**WQC**	Measured (mg/l)	Relevant Guideline (mg/l)
Be	0.009	0.004 -MCL	Sr	0.23	0.1 AV
NO_3	34	26 - TWQR	Zn	0.107	0.1 - AV
Se	0.048	0.02 - TWQR			

8 = Reservoir for Borehole # 3 (Radimo)

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	**WQC**	Measured (mg/l)	Relevant Guideline (mg/l)
As	0.027	0.01 - TWQR	Sr	0.161	0.1 - AV
Be	0.011	0.004 - MCL	Zn	0.191	0.1 - AV
Br	0.164	0.01 - MCL			
Mn	0.059	0.05 - TWQR			
Te	0.013	0.01 - CL			

3B – New borehole - reservoir (Radimo)

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	**WQC**	Measured (mg/l)	Relevant Guideline (mg/l)
As	0.014	0.01 - TWQR	Sr	0.107	0.1 - AV
Te	0.011	0.01 - CL			

19B – New borehole - trough (Radimo)

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	**WQC**	Measured (mg/l)	Relevant Guideline (mg/l)
As	0.04	0.01 – TWQR	Zn	0.644	0.1 - AV
Be	0.016	0.004 - MCL			
Br	0.281	0.01 - MCL			
Cd	0.055	0.05 - Cat E			
Mn	0.104	0.05 - TWQR			
Se	0.06	0.05 - Cat C			
Te	0.037	0.01 - CL			

(i) 4B – New borehole 2 – reservoir (Radimo)

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	**WQC**	Measured (mg/l)	Relevant Guideline (mg/l)
Be	0.005	0.004 - MCL			
Br	0.098	0.01 - MCL			
Mn	0.114	0.05 - TWQR			
Hg	0.003	0.001 - TWQR			
Te	0.008	0.005 - MPL			

(i) 27B – New borehole 2 - drinking trough (Radimo)

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	**WQC**	Measured (mg/l)	Relevant Guideline (mg/l)
As	0.035	0.01 - TWQR			
Be	0.006	0.004 - MCL			
Br	0.244	0.01 - MCL			
Mn	0.131	0.05 - TWQR			
Hg	0.002	0.001 - TWQR			
NO_2	4.91	1 – MCL			
Se	0.078	0.05 - Cat C			
Te	0.003	0.01 - CL			

21 =Game Reserve dam

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	**WQC**	Measured (mg/l)	Relevant Guideline (mg/l)
As	0.012	0.01 – TWQR	Cd	0.037	0.005 - TWQR
Be	0.004	0.004 – MCL	Sr	0.184	0.1 - AV
Br	0.130	0.01 – MCL			
Mn	0.073	0.05 – TWQR			
Hg	0.002	0.001 – TWQR			
Se	0.059	0.05 - Cat C			
SO_4	203	200 – TWQR			
Te	0.012	0.01 – CL			
Ti	0.103	0.1 – RL			
TDS	566	450 – TWQR			

2 = Drinking Trough for Borehole #1 (Pholerigomo)

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	**WQC**	Measured (mg/l)	Relevant Guideline (mg/l)
As	0.021	0.01 - TWQR	Sb	0.0056	0.006 - MPL
Be	0.014	0.004 - MCL			
Br	0.182	0.01 - MCL			
Mn	0.074	0.05 - TWQR			
Te	0.011	0.01 - CL			

1 = Reservoir for Borehole #1 (Pholerigomo)

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	**WQC**	Measured (mg/l)	Relevant Guideline (mg/l)
As	0.031	0.01 - TWQR			
Se	0.025	0.02 - TWQR			
Te	0.032	0.01 - CL			

3 = Drinking trough for Borehole #1 (Pholerigomo)

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	**WQC**	Measured (mg/l)	Relevant Guideline (mg/l)
Be	0.005	0.004 - MCL1	Zn	0.105	0.1 - AV
Mn	0.081	0.05 – TWQR			
Hg	0.004	0.001 – TWQR			
Se	0.06	0.05 - Cat C			
Te	0.02	0.01 – CL			

4 = Tub drinking trough for Borehole #2 (Radimo)

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	**WQC**	Measured (mg/l)	Relevant Guideline (mg/l)
Be	0.004	0.004 – MCL	F	0.88	1 - TWQR
Br	0.512	0.01 – MCL	Sr	0.212	0.1 - AV
Mn	0.103	0.05 – TWQR	Zn	0.128	0.1 - AV
Se	0.028	0.02 - TWQR			
SO_4	202	200 - TWQR			
TDS	563	450 - TWQR			
Te	0.04	0.01 - CL			
Ti	0.105	0.1 - RL			

11 = River (Kgaphamadi)

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	**WQC**	Measured (mg/l)	Relevant Guideline (mg/l)
Be	0.008	0.004 - MCL			
Se	0.02	0.02 - TWQR			
Te	0.019	0.01 - CL			

(iii) New Borehole – reservoir (Radimo)

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	**WQC**	Measured (mg/l)	Relevant Guideline (mg/l)
As	0.028	0.01 - TWQR	Cd	0.004	0.005 - TWQR
Be	0.01	0.004 - MCL			
Br	0.317	0.01 - MCL			
Mn	0.061	0.05 - TWQR			
Hg	0.005	0.001 - TWQR			
Se	0.065	0.05 Cat C			
Te	0.027	0.01 - CL			

(iii) New Borehole – drinking trough

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	**WQC**	Measured (mg/l)	Relevant Guideline (mg/l)
As	0.066	0.01 - TWQR	Cr	0.03	0.05 - TWQR
Be	0.016	0.004 - MCL	Au	0.004	0.005 - MPL
Br	0.446	0.01 - MCL			
Mn	0.155	0.05 - TWQR			
Hg	0.002	0.001 - TWQR			
Se	0.122	0.05 - Cat C			
Te	0.067	0.005 - MPL			

41 = Shale Dam

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	**WQC**	Measured (mg/l)	Relevant Guideline (mg/l)
Be	0.02	0.004 - MCL	Sr	0.206	0.1 - AV
Br	0.211	0.01 - MCL	Zn	0.266	0.1 - AV
Mn	0.055	0.05 - TWQR			
SO_4	202	200 - TWQR			
Te	0.036	0.01 - CL			
TDS	559	450 - TWQR			

21B = New Borehole Tap (Radimo)

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	WQC	Measured (mg/l)	Relevant Guideline (mg/l)
Br	0.283	0.01 - MCL	Mo	0.013	0.04 - HAV
Mn	0.084	0.05 - TWQR	Sr	0.193	0.1 - AV
Hg	0.004	0.001 - TWQR	Zn	0.438	0.1 - AV
SO_4	207	200 - TWQR			
Te	0.023	0.01 - CL			
Ti	0.115	0.1 - RL			
TDS	558	450 - TWQR			

24B – New Borehole - reservoir

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	WQC	Measured (mg/l)	Relevant Guideline (mg/l)
As	0.018	0.01 - TWQR	Sr	0.113	0.1 - AV
Br	0.412	0.01 - TWQR			
Mn	0.097	0.05 - TWQR			
Se	0.042	0.05 - Cat C			
U	0.03	0.01 - CL			

25B – New Borehole – drinking trough

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	WQC	Measured (mg/l)	Relevant Guideline (mg/l)
As	0.043	0.01 - TWQR	Sr	0.238	0.1 - AV
Be	0.015	0.004 - MCL	NO3	25.3	26 - TWQR
Br	0.374	0.01 - MCL			
Mn	0.135	0.05 - TWQR			
Se	0.121	0.05 - Cat C			
Te	0.026	0.01 - CL			

31 = Municipal water to Promosa – wildlife drinking trough

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	WQC	Measured (mg/l)	Relevant Guideline (mg/l)
As	0.036	0.01 - TWQR			
Br	0.558	0.01 - MCL			
Cd	0.006	0.005 - Cat C			
Mn	0.166	0.05 - TWQR			
Se	0.022	0.2 - TWQR			
Te	0.019	0.01 - CL			

16 = Earth Dam

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	WQC	Measured (mg/l)	Relevant Guideline (mg/l)
Be	0.012	0.004 - MCL	Sr	0.113	0.1 - AV
Br	0..252	0.01 - MCL	U	0.017	0.02 - TWQR
Mn	0.119	0.05 - TWQR	As	0.0088	0.01 - TWQR
NO_2	38.48	1 - MCL			
Se	0.058	0.05 - Cat C			
Te	0.018	0.01 - CL			

A summary of the occurrence of PHCs and COCs is presented in Table 4.3.1.3.

Table 4.3.1.3. Summary statistics for the main PHCs and COCs identified from 22 water samples collected in the Barolong Resettlement Area during July 1999.

WQC	PHC	COC	Average (mg/L)	SD (mg/L)	Median (mg/L)	Range (mg/L)	
(n) / WP	124	29				Minimum	Maximum
	5.63	1.31					
As	12	1	0.017	0.018	0.013	0	0.066
Be	17	0	0.008	0.006	0.0085	0	0.20
Br	16	0	0.211	0.175	0.196	0	0.558
Hg	5	0	0.001	0.001	0	0	0.005
Mn	16	0	0.082	0.048	0.082	0	0.166
SO_4	4	0	38.1	79.8	0	0	207
Se	14	0	0.042	0.036	0.035	0.002	0.122
Te	19	0	0.018	0.011	0.0185	0	0.04
TDS	5	0	310	144	256	109	566
Sr	0	11	0.126	0.077	0.103	0.037	0.310
Zn	0	8	0.128	0.163	0.083	0	0.664

4.3.1.5 Discussion

The first and second sampling phases differ with each phase reflecting a different pattern of WQCs which are classed as PHCs.

The only working borehole (samples 1,2 and 3 for sampling phase 1) in the Pholerigomo section supplied a cement reservoir which was cleaned every three months, and on inspection appeared very clean. However, this reservoir also supplied a one meter circular drinking trough which was located at a low point with ground sloping upwards away from it. Intense utilisation of this trough, aggravated by poor design and placement, resulted in a very muddy area extending over six meters from the trough, which was heavily polluted with fecal matter. Most drinking troughs sampled in the area suffered from a similar problem. Ironically, although this increases the incidence of foot-rot and the spread of various pathogens and parasites, due to the depth of the mud it did appear to prevent animal fecal matter from entering the drinking trough as the animals could not climb out of the mud and into the trough, an occurrence frequently observed in the Jericho and Immerpan Districts.

The results for boreholes 1, 3 and 4 obtained in the first sampling phase suggest that Se values tend to decrease in the drinking trough, perhaps due to precipitation, whereas Br values appear to do the reverse, as illustrated for boreholes 1 and 3. Strontium values appear to remain relatively constant. The higher values obtained for some reservoirs, for example those for borehole 3, suggest different extraction rates due to varying degrees of utilisation of the drinking trough by livestock. This is demonstrated for borehole 3 with the second reservoir differing substantially from the first. According to the herdsman the second reservoir (sample 8) was used seldom. Increased corrosion of metal structures within the water delivery system could possibly account for the increased heavy metal concentrations recorded. The presence of nitrite in the natural earth dam is most probably correlated to the large amount of fecal matter observed around the watering point, and the direction of runoff being towards the dam. The runoff direction is aggravated by a low water level, although the low level observed was apparently normal. The high nitrite value recorded in the drinking trough sourced by municipal water is possibly due to avian fecal matter, as a large number of Cattle Egrets seem to gather around the trough.

More boreholes were sampled in phase two, mainly as they had been fixed since the first phase. The spectrum of PHCs and COCs found were similar. Some PHC values declined in the samples between the first and second phases, notably for Br, Mn and As for borehole 1, whilst others increased, as evidenced by the Se, and Br values for borehole 4. In some cases nitrate values increase, possibly due to increase avian presence over the second period sampled, but definitely due to increased livestock utilisation in the case of the natural earth dam.

The variable nature of the results are thus mostly due to differences in reservoir and drinking trough extraction, but the types of constituents present are fairly consistent, if not between sampling phases, certainly for sections within the area.

4.3.2 Zeerust District - Rietgat and Hartebeeslaagte Communities

4.3.2.1 Introduction

The rural area of Rietgat consists of thirty-six farmers with a total of 1326 cattle, all relying on eight boreholes for human and livestock use. For the Hartebeeslaagte, twenty-six farmers utilise three boreholes for human and livestsock use, which comprises 442 cattle, 239 goats, and 9 sheep.

4.3.2.2 Methods

A total of eight watering points were sampled during the month of May 1997, the majority of which were single structures incorporating circular reservoirs with a combined circular drinking trough. Duplicate samples were collected for each watering point, one from the reservoir, for which the sample was preserved for nitrate determinations, and one from the drinking trough.

4.3.2.3 Results

1 Drinking trough

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	**WQC**	Measured (mg/l)	Relevant Guideline (mg/l)
Br	0.028	0.01 - MCL			
Ti	0.538	0.1 - RL	Sr	0.402	0.1 - AV
U	0.02	0.02 - MCL	Zn	0.215	0.1 - AV

1 Reservoir

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	**WQC**	Measured (mg/l)	Relevant Guideline (mg/l)
Br	0.04	0.01 - MCL			
Ti	0.498	0.1 - RL	Sr	0.391	0.1 - AV
Se	0.026	0.02 - TWQR	Zn	0.192	0.1 - AV
U	0.021	0.02 - MCL			

2 Drinking trough

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	**WQC**	Measured (mg/l)	Relevant Guideline (mg/l)
Br	0.047	0.01 - MCL			
Se	0.021	0.02 - TWQR	Sr	0.226	0.1 - AV
Ti	0.154	0.1 - RL			
Hg	0.002	0.001 - TWQR			

2 Reservoir

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	**WQC**	Measured (mg/l)	Relevant Guideline (mg/l)
Br	0.07	0.01 - MCL			
Ti	0.158	0.1 - RL	Sr	0.222	0.1 - AV

3 Drinking trough

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	**WQC**	Measured (mg/l)	Relevant Guideline (mg/l)
Br	0.033	0.01 - MCL			
Ti	0.265	0.1 - RL	Sr	0.209	0.1 - AV
Hg	0.058	0.001 - TWQR			

3 Reservoir

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	**WQC**	Measured (mg/l)	Relevant Guideline (mg/l)
Br	0.08	0.01 - MCL	Sr	0.216	0.1 - AV
Ti	0.288	0.1 - RL	Zn	0.272	0.1 - AV

4 Drinking trough

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	**WQC**	Measured (mg/l)	Relevant Guideline (mg/l)
Br	0.05	0.01 - MCL	Ni	0.01	0.02 - RL
Ti	0.315	0.1 - RL	Sr	0.2	0.1 - AV
Hg	0.033	0.001 - TWQR	Zn	0.114	0.1 - AV

4 Reservoir

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	**WQC**	Measured (mg/l)	Relevant Guideline (mg/l)
Br	0.074	0.01 - MCL	Ni	0.01	0.02 - RL
Ti	0.318	0.1 - RL	Sr	0.198	0.1 - AV
			Zn	0.44	0.1 - AV

5 Drinking trough

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	**WQC**	Measured (mg/l)	Relevant Guideline (mg/l)
Br	0.033	0.01 - MCL			
Hg	0.04	0.001 - TWQR			
Ti	0.1	0.1 - RL			
V	0.127	0.1 - TWQR			

5 Reservoir

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	**WQC**	Measured (mg/l)	Relevant Guideline (mg/l)
Br	0.083	0.01 - MCL	Sr	0.249	0.1 - AV
Ti	0.308	0.1 - RL			
U	0.07	0.02 - MCL			

6 Drinking trough

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	**WQC**	Measured (mg/l)	Relevant Guideline (mg/l)
Br	0.032	0.01 - MCL	Zn	0.118	0.1 - AV
Ni	0.022	0.02 - RL			
Hg	0.033	0.001 - TWQR			
Ti	0.143	0.1 - RL			

6 Reservoir

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	**WQC**	Measured (mg/l)	Relevant Guideline (mg/l)
Br	0.082	0.01 - MCL	Zn	0.133	0.1 - AV
Ni	0.034	0.02 - RL			
Ti	0.154	0.1 - RL			

7 Drinking trough

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	**WQC**	Measured (mg/l)	Relevant Guideline (mg/l)
Br	0.043	0.01 - MCL	NO_3	22	26 - TWQR
Hg	0.087	0.001 - TWQR	Ni	0.01	0.02 - RL
Ti	0.620	0.1 -RL	Sr	0.365	0.1 - AV

7 Reservoir

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	**WQC**	Measured (mg/l)	Relevant Guideline (mg/l)
Br	0.069	0.01 - MCL	NO_3	22	26 - TWQR
Ti	0.688	0.2 - MPL	Ni	0.013	0.02 - RL
			Sr	0.355	0.1 - AV

8 Drinking trough

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	**WQC**	Measured (mg/l)	Relevant Guideline (mg/l)
Br	0.044	0.01 - MCL	Ni	0.017	0.02 - RL
Hg	0.163	0.001 - TWQR	Sr	0.697	0.1 - AV
Ti	0.817	0.2 - MPL	Zn	0.345	0.1 - AV

8 Reservoir

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	WQC	Measured (mg/l)	Relevant Guideline (mg/l)
Br	0.069	0.01 - MCL	Ni	0.01	0.02 - RL
Ti	0.736	0.2 - MPL	Sr	0.63	0.1 - AV
			Zn	0.257	0.1 - AV

A summary of the occurrence of PHCs and COCs is presented in Table 4.3.2.1.

Table 4.3.2.1 Summary statistics for the main PHCs and COCs identified from 16 water samples collected in the Rietgat and Hartebeeslaagte communities.

WQC	PHC	COC	Average (mg/L)	SD (mg/L)	Median (mg/L)	Range (mg/L)	
(n) / WP	47	30				Minimum	Maximum
	2.937	1.875					
Br	16	0	0.0557	0.0196	0.0485	0.023	0.083
Hg	7	0	0.052	0.053	0.037	0	0.163
NO3	0	2	4.13	7.22	1.5	0	22
Ni	4	4	0.011	0.009	0.01	0	0.034
Se	1	1	0.04	0.008	0	0	0.026
Ti	19	0	0.381	0.236	0.312	0.092	0.817
U	3	0	0.0124	0.020	0.004	0	0.07
V	1	0	0.009	0.032	0	0	0.127
Sr	0	13	0.285	0.187	0.224	0.033	0.697
Zn	*0*	9	*0.134*	*0.140*	*0.116*	*0*	*0.44*

Table 4.3.2.2. Comparison between drinking trough and reservoir results.

Description	Drinking trough		Reservoir	
Number of watering points sampled	8		8	
Number of watering points containing PHCs and COCs	PHC 8	COC 8	PHC 8	COC 8
Average PHCs and COCs per watering point	PHC 2.37	COC 1.75	PHC 1.5	COC 2
Highest number of PHCs and COCs recorded within one watering point	PHC 3	COC 3	PHC 3	COC 3
Total number of PHCs and COCs recorded for all watering points	PHC 27	COC 14	PHC 20	COC 16
Major WQCs involved	PHC Br = 8; Ti = 8; Hg = 7 **Ni = 2; U = 1** V = 1	COC Ni = 2; NO_3 =1 Se = 1; Sr = 6; Zn = 4	PHC Br = 8; Ti = 8 Ni = 2 U = 2; Se = 1	COC Sr = 7 Zn = 5 Ni = 2 NO_3 =1

4.3.2.4 Discussion

Mercury was found to be the WQC that presents the greatest risk to both human and animal health in the Rietgat and Hartebeeslaagte communities. For all the watering points except number 1 the levels recorded exceeded the recommended TWQR. For the watering points 2, 4, 5, and 6, the DWA&F (1996) lists the possible adverse effects as "risk of neurotoxicity with consequent serious disabilities with continuous exposure", whilst for watering points 3, 7 and 8, the possible adverse effects are cited as "risk of neurotoxicity with continuous exposure, particularly to organic mercury compounds. Acute effects may occur, particularly with organic mercury compounds".

The risk to humans may be significantly increased due to the cumulative nature of the toxin and the eating preferences of people in the community, which include a preference for internal organs and tissues known to accumulate mercury. As the people in these communities depend heavily on their own livestock as a food source, exposure to mercury from the consumption of livestock tissues may be significant contributors to the total ingestion of mercury by humans. This is especially relevant for those families experiencing daily milk consumption, both of animal and maternal origin (Lonnerdal, 1999). As the watering points sampled are also used for subsistence crop production, food preparation, and in some cases used to supply dams from which fish are caught and consumed, the total potential exposure to mercury would appear to be very high, specifically as no alternative water supplies are available. There were no signs that the farmers collected rainwater for household consumption. The majority of the people present in the community consisted of infants (under 2 years of age), pregnant women, adults (over 40 years of age) and in the case of Rietgat, a school with children (under 12 years of age), all of which are high-risk groups (WHO, 1993). No value was obtained for mercury for reservoir samples as mercury chloride was the preservative used for nitrate estimation.

Comparisons between the samples taken from the reservoir and drinking trough for each watering point reveal that for six of the watering points (numbers 2 - 7) the reservoir tended to yield higher values, whilst for two of the watering points (numbers 1 and 8), the reverse was true, with the exception of Br, which always returned higher values in the drinking trough. It was observed that for these two watering points no recent signs of livestock activity were evident. This appears to provide a possible explanation for the differences obtained with numbers 2 to 7 being due to a quick rate of emptying and refilling in the circular troughs with large numbers of animals present, and the reverse being true for numbers 1 and 8. The watering point designs found allowed for water delivery to the drinking trough from a pipe collecting water from the bottom of the reservoir, offering an explanation for the lower concentrations obtained in the drinking trough for numbers 2 to 7, as reservoir samples were collected from the surface.

4.3.3 Jericho District: Summer Phase

4.3.3.1 Introduction

Water samples were collected from several communities in the Jericho District, located ca. 150 – 200 km North West of Pretoria. During clinical evaluations of livestock by the Veterinary Faculty at Medunsa, a series of symptoms suggestive of neurological disorders were observed, apparently in animals that appeared otherwise healthy, thus ruling out energy or protein deficiency as a causative factor. Discussions with farmers and members of the communities revealed a pressing water quantity and water quality problem. The water quantity problem resulted in the closure of boreholes during summer months in an attempt to conserve the water source for the dry winter months. The quality problems was related to two main observations, namely, the refusal of stock to consume certain borehole water, and a rapid loss of condition of some species when exposed to certain water sources. A number of reproductive disorders were also noted by veterinary clinicians in the area. Due to these experiences water samples were collected from most communities in the Jericho District.

4.3.3.2 Methods

Two sampling phases were conducted, one during the end of summer and the other at the end of winter during 1999. Samples were collected according to methods as described in section 4.2 by members of the Veterinary Faculty at Medunsa, and samples were analysed by the ISCW water laboratory. Different sources were sampled between the two seasons as many either contained no water in the winter, or had the pump removed.

4.3.3.3 Results

4.3.3.3.1 – Summer phase sampling for Jericho District(February)

Tolwane School: (1.1)

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	**WQC**	Measured (mg/l)	Relevant Guideline (mg/l)
Br	0.377	0.01 – MCL	Sr	0.464	0.1 - AV
Be	0.004	0.004 – MCL			
TDS	457	450 – TWQR			
Ti	0.424	0.2 – MPL			

Madiba school (1.2)

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	**WQC**	Measured (mg/l)	Relevant Guideline (mg/l)
Br	0.334	0.01 – MCL	Sr	0.769	0.1 - AV
Ti	0.308	0.2 – MPL	F	0.52	1 – Cat C
			TDS	426	450 – TWQR

Apies (2)

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	**WQC**	Measured (mg/l)	Relevant Guideline (mg/l)
Br	0.248	0.01 – MCL	Sr	0.326	0.1 - AV
Be	0.033	0.004 – MCL			
F	7.7	3.5 – Cat E			
Na	119	100 – TWQR			

Pienaars river

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	**WQC**	Measured (mg/l)	Relevant Guideline (mg/l)
Br	0.650	0.01 – MCL	Sr	0.135	0.1 – AV
Be	0.033	0.004 – MCL	V	0.01	
Ti	0.174	0.1 – RL			

Hebron (3)

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	WQC	Measured (mg/l)	Relevant Guideline (mg/l)
As	0.192	0.05 – Cat C	Cr	0.022	0.05 - TWQR
Be	0.033	0.004 – MCL			
Cd	0.054	0.02 – Cat D			
Pb	0.037	0.01 – TWQR			
Mn	0.065	0.05 – TWQR			
Mo	0.092	0.07 – MRL			
Se	2.292	0.02 – TWQR			
Sb	0.033	0.006 – MCL			
Te	0.311	0.01 - CL			
Tl	0.018	0.01 - MPL			

Vaalbossloot 5 (4.1)

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	WQC	Measured (mg/l)	Relevant Guideline (mg/l)
As	0.288	0.05 - Cat C	Cr	0.034	0.05 – TWQR
Br	0.079	0.01 - MCL	Sr	0.129	0.1 - AV
Be	0.051	0.004 - MCL			
Cd	0.115	0.05 - Cat E			
Pb	0.03	0.01 - TWQR			
Hg	0.179	0.001 - TWQR			
Mn	0.451	0.4 - Cat C			
Mo	0.204	0.2 - CL			
Se	1.526	0.02 - TWQR			
Sb	0.077	0.006 - MCL			
Te	0.461	0.01 - CL			
Ti	0.183	0.1 – RL			
Tl	0.027	0.02 - CL			

Vaalbossloot 6 (4.2)

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	WQC	Measured (mg/l)	Relevant Guideline (mg/l)
Be	0.021	0.004 - MCL	TDS	413	450 – TWQR
Cd	0.08	0.05 - Cat E	Sr	0.158	0.1 - AV
Mo	0.086	0.07 - MRL			
Hg	0.444	0.001 - TWQR			
Se	0.334	0.02 - TWQR			
Sb	0.045	0.006 - MCL			
Te	0.461	0.01 - CL			
Tl	0.051	0.02 - CL			

Jonathan

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	WQC	Measured (mg/l)	Relevant Guideline (mg/l)
Be	0.015	0.004 - MCL	Cd	0.002	0.005 – Cat C
F	2.74	1.5 – Cat D	Cr	0.027	0.05 - TWQR
Mn	0.28	0.4 – Cat C	Sr	0.179	0.1 – AV
Na	101	100 – TWQR			
Ti	0.200	0.2 - MPL			

Rantlapane 1 (6.1)

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	**WQC**	Measured (mg/l)	Relevant Guideline (mg/l)
Br	0.227	0.01 - MCL	Cr	0.027	0.05 - TWQR
Be	0.015	0.004 - MCL	Sr	0.994	0.1 - AV
F	1.74	1.5 - Cat -D			
Mn	0.14	0.05 – TWQR			
Hg	0.018	0.001 - TWQR			
NO_3	43.6	44 - Cat C			
Se	0.334	0.02 – TWQR			
TDS	643	450 – TWQR			
Te	0.117	0.01 – CL			
Ti	0.2	0.2 – MPL			
U	0.038	0.02 – MCL			

Rantlapane (2)

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	**WQC**	Measured (mg/l)	Relevant Guideline (mg/l)
Br	0.175	0.01 – MCL	Mo	0.01	0.07 – MRL
Cd	0.008	0.005 - Cat C	Sr	0.234	0.1 – AV
Mn	0.14	0.05 – TWQR			
Hg	0.041	0.001 – TWQR			
Se	0.093	0.02 - TWQR			
Te	0.031	0.01 - CL			

Rantlapane (3)

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	**WQC**	Measured (mg/l)	Relevant Guideline (mg/l)
Br	0.457	0.01 – MCL	Sr	0.259	0.1 – AV
Cd	0.01	0.005 - Cat C			
F	1.21	1 - TWQR			
Mn	0.17	0.05 – TWQR			
Se	0.041	0.02 - TWQR			
Te	0.01	0.01 - CL			

Rantlapane 4 (6.4)

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	**WQC**	Measured (mg/l)	Relevant Guideline (mg/l)
As	0.141	0.05 - Cat C	Cr	0.021	0.05 - TWQR
Br	0.408	0.01 - MCL	Sr	0.149	0.1 - AV
Be	0.02	0.004 - MCL			
Cd	0.053	0.05 - Cat E			
Hg	0.258	0.001 - TWQR			
Mn	0.256	0.05 – TWQR			
Mo	0.087	0.07 - MRL			
Se	1.125	0.02 - TWQR			
Sb	0.047	0.006 - MCL			
Tl	0.017	0.01 - MPL			
U	0.02	0.02 - MCL			

Rantlapane (5)

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	**WQC**	Measured (mg/l)	Relevant Guideline (mg/l)
Sb	0.016	0.006 – MCL	Mo	0.014	0.07 - MRL
Br	0.282	0.01 – MCL	Sr	0.102	0.1 – AV
Be	0.004	0.004 – MCL			
Cd	0.007	0.005 - Cat C			
Mn	0.260	0.05 – TWQR			
Te	0.036	0.01 – CL			

Rantlapane 6 (6.6)

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	**WQC**	Measured (mg/l)	Relevant Guideline (mg/l)
As	0.145	0.05 - Cat C	Sr	0.230	0.1 - AV
Be	0.013	0.004 - MCL			
Cd	0.03	0.02 - Cat D			
Pb	0.018	0.01 - TWQR			
Hg	0.03	0.001 - TWQR			
Mn	0.113	0.05 – TWQR			
Se	1.056	0.02 - TWQR			
Sb	0.013	0.006 - MCL			
Te	0.211	0.01 - CL			

Madiyane (7.1)

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	**WQC**	Measured (mg/l)	Relevant Guideline (mg/l)
Be	0.036	0.004 - MCL	Cr	0.027	0.05 - TWQR
Cd	0.114	0.05 - Cat E	Sr	0.181	0.1 - AV
Pb	0.038	0.01 - TWQR	TDS	445	450 - TWQR
Hg	0.313	0.001 - TWQR			
Mn	0.061	0.05 – TWQR			
Mo	0.111	0.07 - MRL			
Se	1.115	0.02 - TWQR			
Sb	0.097	0.006 - MCL			
Te	0.299	0.01 - CL			
Tl	0.02	0.02 - CL			
U	0.034	0.02 - MCL			

Koedoespoort 1 (8.1)

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	**WQC**	Measured (mg/l)	Relevant Guideline (mg/l)
Br	0.395	0.01 - MCL	Cr	0.025	0.05 - TWQR
Be	0.021	0.004 - MCL	Mo	0.045	0.07 - MRL
Cd	0.04	0.05 - Cat E	Sr	1.137	0.1 - AV
Pb	0.034	0.01 - TWQR			
Hg	0.253	0.001 - TWQR			
Mn	0.114	0.05 – TWQR			
Se	0.711	0.02 - TWQR			
Sb	0.044	0.006 - MCL			
Tl	0.017	0.01 - MPL			
TDS	658	500 - SMCL			
U	0.068	0.02 - MCL			

Koedoespoort 2 (8.2)

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	**WQC**	Measured (mg/l)	Relevant Guideline (mg/l)
Br	0.467	0.01 - MCL	Cr	0.027	0.05 - TWQR
Be	0.029	0.004 - MCL	Sr	0.137	0.1 - AV
Cd	0.082	0.05 - Cat E			
Pb	0.052	0.01 - TWQR			
Hg	0.082	0.001 - TWQR			
Mn	0.186	0.05 – TWQR			
Mo	0.052	0.07 - MRL			
Se	1.450	0.02 - TWQR			
Sb	0.065	0.006 - MCL			
Te	0.563	0.01 - CL			

Koedoespoort 3 (8.3)

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	**WQC**	Measured (mg/l)	Relevant Guideline (mg/l)
Br	0.457	0.01 - MCL	Sr	0.123	0.1 - AV
Be	0.043	0.004 - MCL	U	0.018	0.02 - MCL
Cd	0.070	0.05 - Cat E			
Pb	0.054	0.01 - TWQR			
Hg	0.178	0.001 - TWQR			
Mo	0.164	0.07 - MRL			
Mn	0.283	0.05 – TWQR			
Se	0.801	0.02 - TWQR			
Sb	0.085	0.006 - MCL			
Te	0.516	0.01 - CL			

Jericho (9.1)

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	**WQC**	Measured (mg/l)	Relevant Guideline (mg/l)
Be	0.036	0.004 - MCL	Cr	0.026	0.05 - TWQR
Cd	0.068	0.05 - Cat E	Sr	0.162	0.1 - AV
Pb	0.017	0.01 - TWQR			
Hg	0.077	0.001 - TWQR			
Mo	0.093	0.07 - TWQR			
Mn	0.146	0.05 – TWQR			
Se	1.236	0.02 - TWQR			
Sb	*0.107*	*0.006 - MCL*			
Te	0.515	0.01 - CL			
Tl	0.019	0.01 - MPL			
U	0.048	0.02 - MCL			

Wilgerkuil (10.1)

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	**WQC**	Measured (mg/l)	Relevant Guideline (mg/l)
Br	0.271	0.01 - MCL	Sr	0.381	0.1 - AV
Cd	0.022	0.02 - Cat D	U	0.016	0.02 - MCL
Hg	0.081	0.001 - TWQR			
Mn	0.096	0.05 – TWQR			
Sb	0.107	0.006 - MCL			
Se	0.147	0.02 - TWQR			

Wilgerkuil (10.2)

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	WQC	Measured (mg/l)	Relevant Guideline (mg/l)
Br	0.498	0.01 - MCL	Sr	0.855	0.1 - AV
Cd	0.03	0.02 - Cat D			
Pb	0.023	0.01 - TWQR			
Hg	0.081	0.001 - TWQR			
Mn	0.218	0.05 - TWQR			
Se	0.216	0.02 - TWQR			
Sb	0.107	0.006 - MCL			
Tl	0.01	0.01 - MPL			
Te	0.212	0.01 - CL			
TDS	581	450 - TWQR			

Wilgerkuil (10.4)

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	WQC	Measured (mg/l)	Relevant Guideline (mg/l)
Br	0.279	0.01 - MCL	Mo	0.049	0.05 - HA
Be	0.011	0.004 - MCL	Sr	0.722	0.1 - AV
Cd	0.027	0.005 - Cat C			
Cl	316	200 - Cat C			
F	1.29	1 - Cat C			
Pb	0.044	0.01 - TWQR			
Hg	0.047	0.001 - TWQR			
Mn	0.055	0.4 - Cat C			
Na	195	200 - Cat C			
Se	0.438	0.02 - TWQR			
Sb	0.026	0.006 - MCL			
Te	0.140	0.01 - CL			
Tl	0.013	0.01 - MPL			
TDS	805	450 - TWQR			
U	0.02	0.02 - MCL			

Waterval 1 (11.1)

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	WQC	Measured (mg/l)	Relevant Guideline (mg/l)
As	0.147	0.05 - Cat C			
Br	0.281	0.01 - MCL			
Be	0.024	0.004 - MCL			
Cd	0.043	0.005 - Cat C			
F	2.03	1.5 - Cat -D			
Hg	0.025	0.001 - TWQR			
Mn	0.154	0.4 - Cat C			
Se	1.075	0.02 - TWQR			
Sb	0.038	0.006 - MCL			
Te	0.202	0.01 - CL			
Tl	0.02	0.02 - CL			
U	0.032	0.02 - MCL			

Waterval 3 (11.3)

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	**WQC**	Measured (mg/l)	Relevant Guideline (mg/l)
Br	0.266	0.01 - MCL	Ba	0.534	0.7 – MRL
Be	0.025	0.004 - MCL	Mo	0.049	0.05 - HA
Cd	0.105	0.05 - Cat E			
F	7.09	3.5 - Cat E			
Pb	0.03	0.01 - TWQR			
Hg	0.229	0.001 - TWQR			
Mn	0.280	0.4 - Cat C			
Na	208	200 - Cat C			
Se	1.583	0.02 - TWQR			
Sb	0.041	0.006 - MCL			
Te	0.131	0.01 - CL			
TDS	567	450 - TWQR			
U	0.039	0.02 - MCL			

Waterval 4 (11.4)

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	**WQC**	Measured (mg/l)	Relevant Guideline (mg/l)
Br	0.380	0.01 - MCL			
Be	0.023	0.004 - MCL			
Cd	0.017	0.005 - Cat C			
Pb	0.026	0.01 - TWQR			
Hg	0.182	0.001 - TWQR			
Mo	0.089	0.07 - MRL			
Mn	0.083	0.4 - Cat C			
Se	1.031	0.02 - TWQR			
Sb	0.037	0.006 - MCL			
Te	0.243	0.01 - CL			
Tl	0.028	0.02 - CL			

Waterval 5 (11.5)

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	**WQC**	Measured (mg/l)	Relevant Guideline (mg/l)
Br	0.275	0.01 - MCL	Sr	0.155	0.1 - AV
Be	0.031	0.004 - MCL			
Cd	0.113	0.05 - Cat E			
Pb	0.090	0.01 - TWQR			
Hg	0.124	0.001 - TWQR			
Mo	0.074	0.07 - MRL			
Mn	0.172	0.4 - Cat C			
NO_3	157	89 - Cat D			
Se	1.266	0.02 - TWQR			
Sb	0.036	0.006 - MCL			
Te	0.290	0.01 - CL			
Tl	0.046	0.02 - CL			

Waterval 6 (11.6)

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	WQC	Measured (mg/l)	Relevant Guideline (mg/l)
As	0.197	0.05 - Cat C	Cr	0.041	0.05 - TWQR
Br	0.196	0.01 - MCL			
Be	0.039	0.004 - MCL			
Cd	0.034	0.05 - Cat E			
Pb	0.088	0.01 - TWQR			
Hg	0.129	0.001 - TWQR			
Mo	0.177	0.07 - MRL			
Mn	0.150	0.4 - Cat C			
Se	2.008	0.02 - TWQR			
Sb	0.095	0.006 - MCL			
Te	0.700	0.01 - CL			
Tl	0.045	0.02 - CL			

Rooiwal 1 (12.1)

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	WQC	Measured (mg/l)	Relevant Guideline (mg/l)
As	0.201	0.05 - Cat C	Cr	0.032	0.05 - TWQR
Br	0.628	0.01 - MCL	Pb	0.01	0.015 - MPL
Be	0.036	0.004 – MCL	Sr	0.515	0.1 - AV
Cd	0.072	0.05 - Cat E	TDS	426	450 - TWQR
F	1.40	1 - Cat C	U	0.018	0.02 - MCL
Hg	0.197	0.001 - TWQR			
Mn	0.319	0.05 - TWQR			
Mo	0.073	0.07 - MRL			
Se	1.468	0.02 - TWQR			
Sb	0.064	0.006 - MCL			
Te	0.271	0.01 - CL			
Tl	0.014	0.01 - MPL			

Rooiwal 2 (12.2)

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	WQC	Measured (mg/l)	Relevant Guideline (mg/l)
As	0.142	0.05 - Cat C	Sr	0.128	0.1 - AV
Br	0.326	0.01 - MCL			
Be	0.027	0.004 - MCL			
Cd	0.062	0.05 - Cat E			
F	2.74	1.5 - Cat -D			
Pb	0.017	0.01 -TWQR			
Hg	0.231	0.001 - TWQR			
Mn	0.097	0.05 - TWQR			
Mo	0.088	0.07 - MRL			
Se	1.140	0.02 - TWQR			
Sb	0.035	0.006 - MCL			
Te	0.365	0.01 - CL			
Tl	0.037	0.02 - CL			
U	0.026	0.02 - MCL			

Legonyane 1 (13.1)

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	**WQC**	Measured (mg/l)	Relevant Guideline (mg/l)
Sb	0.069	0.006 - MCL			
Br	0.083	0.01 - MCL			
Be	0.033	0.004 - MCL			
Cd	0.052	0.05 - Cat E			
Pb	0.016	0.015 - MPL			
Hg	0.145	0.001 - TWQR			
Mn	0.348	0.05 - TWQR			
Mo	0.059	0.07 - MRL			
Se	0.600	0.02 - TWQR			
Te	0.199	0.01 - CL			
Tl	0.021	0.02 - CL			

Legonyane 2 (13.2)

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	**WQC**	Measured (mg/l)	Relevant Guideline (mg/l)
Br	0.172	0.01 - MCL			
Be	0.022	0.004 - MCL			
Cd	0.038	0.02 - Cat D			
Hg	0.234	0.001 - TWQR			
Mn	0.573	0.05 - TWQR			
Mo	0.082	0.07 - MRL			
Sb	0.057	0.006 - MCL			
Se	0.824	0.02 - TWQR			
Te	0.152	0.01 - CL			
Tl	0.017	0.01 - MPL			
Ti	0.209	0.200 - MPL			

Soutpansleegte 8 (14.8)

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	**WQC**	Measured (mg/l)	Relevant Guideline (mg/l)
Br	0.285	0.01 - MCL	U	0.019	0.02 – MCL
Be	0.044	0.004 - MCL			
Cd	0.056	0.05 - Cat E			
Pb	0.05	0.01 - TWQR			
Hg	0.183	0.001 - TWQR			
Mo	0.099	0.07 - MRL			
Mn	0.112	0.05 - TWQR			
Se	1.899	0.02 - TWQR			
Sb	0.077	0.006 - MCL			
Te	0.282	0.01 - CL			
Tl	0.020	0.02 - CL			

Fafung 1 (15.1)

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	**WQC**	Measured (mg/l)	Relevant Guideline (mg/l)
Br	0.085	0.01 - MCL	Ba	0.554	0.7 - MRL
Be	0.043	0.004 - MCL	Sr	0.141	0.1 - AV
Cr	0.329	0.05 - TWQR			
Pb	0.034	0.01 – TWQR			
Mn	2.459	0.4 - Cat C			
Ni	0.175	0.1 – MCL			
Ti	4.531	0.200 – MPL			

Fafung 3 (15.3)

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	**WQC**	Measured (mg/l)	Relevant Guideline (mg/l)
Br	0.013	0.01 - MCL	Ba	0.585	0.7 - MRL
Be	0.031	0.004 – MCL	Sr	0.119	0.1 - AV
Cr	0.170	0.1 - Cat C			
Pb	0.01	0.01 – TWQR			
Mn	1.314	0.4 - Cat C			
Ti	2.226	0.200 – MPL			

Fafung 4 (15.4)

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	**WQC**	Measured (mg/l)	Relevant Guideline (mg/l)
Br	0.279	0.01 - MCL	Cr	0.028	0.05 - TWQR
Be	0.042	0.004 – MCL	Sr	0.187	0.1 - AV
Cd	0.143	0.05 - Cat E			
F	1.06	1 - Cat C			
Pb	0.018	0.015 - MCL			
Hg	0.323	0.001 - TWQR			
Mo	0.078	0.07 - MRL			
Mn	0.141	0.05 - TWQR			
Se	0.580	0.02 - TWQR			
Sb	0.051	0.006 - MCL			
Te	0.319	0.01 - CL			
Tl	0.010	0.01 - MPL			
U	0.030	0.02 - MCL			

Fafung 5 (15.5)

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	**WQC**	Measured (mg/l)	Relevant Guideline (mg/l)
Br	0.426	0.01 - MCL	Sr	0.163	0.1 - AV
Be	0.035	0.004 - MCL			
Ba	0.732	0.7 - MRL			
Cr	0.312	0.05- TWQR			
F	5.01	3.5 - Cat –E			
Pb	0.032	0.01 – TWQR			
Mn	2.761	0.4 - Cat C			
Ni	0.119	0.1 –MCL			
K	185	50 - Cat C			
Ti	4.131	0.2 – MPL			
TDS	492	450 – TWQR			

Fafung 8 (15.8)

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	WQC	Measured (mg/l)	Relevant Guideline (mg/l)
Br	0.011	0.01 - MCL			
Be	0.028	0.004 – MCL			
Cr	0.156	0.05 – TWQR			
Pb	0.021	0.01 – TWQRL			
Mn	1.643	0.4 - Cat C			
Ti	2.522	0.2 – MPL			

Fafung 9 (15.9)

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	WQC	Measured (mg/l)	Relevant Guideline (mg/l)
Br	0.384	0.01 - MCL	Cr	0.026	0.05 - TWQR
Be	0.042	0.004 - MCL	Sr	0.103	0.1 - AV
Cd	0.053	0.05 - Cat E			
Pb	0.068	0.01 - TWQR			
Hg	0.123	0.001 - TWQR			
Mo	0.086	0.07 - MRL			
Mn	0.170	0.05 - TWQR			
Se	1.080	0.02 - TWQR			
Sb	0.046	0.006 - MCL			
Te	0.373	0.01 - CL			
Tl	0.011	0.01 - MPL			

Tolwane river (1)

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	WQC	Measured (mg/l)	Relevant Guideline (mg/l)
Be	0.007	0.004 - MCL	Cr	0.011	0.05 - TWQR
Br	0.483	0.01 - MCL	Sr	0.136	0.1 - AV
Mn	0.05	0.05 - TWQR	Te	0.004	0.005 - RL
Ti	0.237	0.200 - MPL			

Toloane 2 (20.2)

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	WQC	Measured (mg/l)	Relevant Guideline (mg/l)
Sb	0.079	0.006 - MCL	Sr	0.127	0.1 - AV
Br	0.240	0.01 - MCL			
Be	0.033	0.004 - MCL			
Cl	182	100 – TWQR			
Cd	0.087	0.05 - Cat E			
Pb	0.053	0.01 - TWQR			
Hg	0.153	0.001 - TWQR			
Mn	0.105	0.05 - TWQR			
Mo	0.109	0.07 - MRL			
Na	183	100 – TWQR			
Se	1.890	0.02 - TWQR			
Te	0.309	0.01 - CL			
TDS	631	450 - TWQR			
Tl	0.048	0.02 - CL			
U	0.039	0.02 - MCL			

Toloane 3 (20.3)

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	WQC	Measured (mg/l)	Relevant Guideline (mg/l)
Sb	0.150	0.006 - MCL	Cr	0.024	0.05 - TWQR
Br	0.175	0.01 - MCL	Sr	0.224	0.1 - AV
Be	0.040	0.004 - MCL			
Cd	0.186	0.05 - Cat E			
Pb	0.062	0.015 - MCL			
Hg	0.602	0.001 - TWQR			
Mo	0.093	0.07 - MRL			
Mn	0.203	0.05 - TWQR			
Se	1.408	0.02 - TWQR			
Te	0.695	0.01 - CL			
Tl	0.088	0.02 - CL			
U	0.053	0.02 - MCL			

Table 4.3.3.1 Summary statistics for the main PHCs and COCs identified from 41water samples.

WQC	PHC	COC	Average (mg/L)	SD (mg/L)	Median (mg/L)	Range (mg/L)	
(n) / WP	386	68				Minimum	Maximum
	9.414	1.658					
As	8	0	0.039	0.074	0	0	0.288
Sb	28	0	0.037	0.037	0.036	0	0.700
Be	36	0	0.025	0.014	0.028	0	0.051
Br	35	0	0.261	0.176	0.275	0	2.292
Cd	30	1	0.046	0.045	0.038	0	0.186
Cr	4	15	0.039	0.072	0.019	0.003	0.329
F	11	1	1.087	0.747	0.53	0.01	7.77
Hg	28	0	0.118	0.116	0.082	0	0.444
Pb	24	1	0.026	0.024	0.021	0	0.090
Mn	35	0	0.35	0.61	0.15	0.01	2.76
Mo	20	5	0.055	0.052	0.049	0	0.204
Se	30	0	0.752	0.685	0.711	0	2.292
Te	28	1	0.209	0.202	0.199	0	0.700
Tl	22	0	0.016	0.019	0.012	0	0.085
Ti	12	0	0.433	1.025	0.1	0.033	4.531
TDS	8	4	294.3	200.5	251	63	805
Sr	0	32	0.254	0.268	0.149	0.034	1.137
U	12	4	0.016	0.016	0.011	0	0.068

The highest recorded number of PHCs and COCs within a watering point was 15 and 5 respectively. All 41 watering points contained PHCs, whilst 36 contained COCs.

Table 4.3.3.2. Summary statistics for important ratios influencing fluoride toxicity.

Ratios	F:Ca	F:TDS	F:B	F:Sr	F:Mo	F:pH
RGR*	>166.66	>500	>4.166	<0.166	<0.0067	>1.333
Average	34.8	253.6	0.202	0.207	0.282	11.4
SD	37.4	248.8	0.244	0.192	0.317	21.9
Median	29.1	178.9	0.169	0.134	0.208	5.06
Minimum	1.67	0.203	9E-04	0	0	1.1
Maximum	142	803.8	0.705	0.63	1.049	80

* = Recommended Guideline Ratio (WQC/F)

A F:pH correlation of 0.047 was obtained.

4.3.3.3.2 Winter phase sampling for Jericho District

Tolwane School: (1.1)

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	**WQC**	Measured (mg/l)	Relevant Guideline (mg/l)
Br	0.01	0.01 – MCL	Sr	0.460	0.1 – AV
Cl	113	100 – TWQR			
Hg	0.004	0.001 - TWQR			
Mn	0.350	0.05 – TWQR			
TDS	515	450 – TWQR			

Madiba school (1.2)

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	**WQC**	Measured (mg/l)	Relevant Guideline (mg/l)
Br	0.015	0.01 – MCL	Sr	0.634	0.1 - AV
			Cd	0.002	0.005 - TWQR
			TDS	410	450 – TWQR

Apies (2)

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	**WQC**	Measured (mg/l)	Relevant Guideline (mg/l)
Br	0.095	0.01 – MCL	Sr	0.183	0.1 - AV
Be	0.005	0.004 – MCL			
F	7.55	3.5 – Cat E			
Na	10.3	100 – TWQR			
Te	0.004	0.002 - RL			

Pienaars river

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	**WQC**	Measured (mg/l)	Relevant Guideline (mg/l)
Br	0.297	0.01 – MCL	Sr	0.13	0.1 – AV
Ni	0.034	0.02 – MRL	V	0.01	0.1 - TWQR
Ti	0.103	0.1 – RL			

Hebron (3)

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	**WQC**	Measured (mg/l)	Relevant Guideline (mg/l)
Br	0.031	0.01 - MCL			
Mn	0.06	0.05 – TWQR			

Vaalbossloot 1

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	**WQC**	Measured (mg/l)	Relevant Guideline (mg/l)
Br	0.121	0.01 – MCL	Sr	0.257	0.1 - AV
NO_3	54	44 – Cat C			

Vaalbossloot 2

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	**WQC**	Measured (mg/l)	Relevant Guideline (mg/l)
Br	0.150	0.01 – MCL	Sr	0.247	0.1 - AV
NO_3	54	44 – Cat C			
TDS	492	450 – TWQR			

Vaalbossloot 4

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	**WQC**	Measured (mg/l)	Relevant Guideline (mg/l)
Br	0.111	0.01 – MCL	Sr	0.185	0.1 - AV
NO_3	145	89 – Cat D			
TDS	493	450 – TWQR			

Jonathan

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	**WQC**	Measured (mg/l)	Relevant Guideline (mg/l)
Be	0.009	0.004 - MCL	Cd	0.002	0.005 – Cat C
Br	0.207	0.01 – MCL	Sr	0.479	0.1 – AV
Cl	226	200 – Cat C			
F	1.3	1.5 – Cat D			
Na	152	100 – TWQR			
TDS	667	450 – TWQR			
Ti	0.181	0.2 - MPL			
U	0.023	0.02 - MCL			

Rantlapane 1

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	**WQC**	Measured (mg/l)	Relevant Guideline (mg/l)
Cl	135	100 – TWQR	Sr	103	0.1 - AV
NO_3	47	44 - Cat C			
Na	163	100 – TWQR			
TDS	824	450 - TWQR			

Rantlapane (2)

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	**WQC**	Measured (mg/l)	Relevant Guideline (mg/l)
Br	0.014	0.01 – MCL	Sr	0.214	0.1 – AV
Pb	0.017	0.016 - MCL			
Ni	0.026	0.02 – MRL			
Hg	0.010	0.001 – TWQR			

Madiyane (7.1)

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	**WQC**	Measured (mg/l)	Relevant Guideline (mg/l)
Be	0.004	0.004 - MCL	Sr	0.263	0.1 - AV
Br	0.326	0.01 – MCL			
Te	0.014	0.01 - CL			
Ti	0.181	0.100 - RL			

Koedoespoort 1

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	WQC	Measured (mg/l)	Relevant Guideline (mg/l)
Br	0.033	0.01 - MCL	Sr	1.179	0.1 - AV
Cl	201	200 – Cat C			
Hg	0.002	0.001 – TWQR			
Na	213	200 – Cat C			
TDS	918	500 – SMCL			
U	0.054	0.02 – MCL			

Koedoespoort 2

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	WQC	Measured (mg/l)	Relevant Guideline (mg/l)
Br	0.031	0.01 – MCL	Sr	0.238	0.1 - AV
Hg	0.007	0.001 – TWQR			
Mn	0.250	0.05 – TWQR			

Jericho (9.1)

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	WQC	Measured (mg/l)	Relevant Guideline (mg/l)
Be	0.004	0.004 - MCL	Cr	0.022	0.05 - TWQR
Br	0.025	0.01 - MCL	Sr	0.187	0.1 - AV
F	3.77	3.5 – Cat E			
Hg	0.003	0.001 - TWQR			
Mn	0.320	0.05 – TWQR			
Ni	0.024	0.02 - MRL			
Ti	0.449	0.200 - MPL			

Wilgerkuil (10.1)

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	WQC	Measured (mg/l)	Relevant Guideline (mg/l)
Br	0.300	0.01 - MCL	Sr	0.450	0.1 - AV
Hg	0.002	0.001 - TWQR			
Na	101	100 - TWQR			

Wilgerkuil (10.2)

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	WQC	Measured (mg/l)	Relevant Guideline (mg/l)
Br	0.064	0.01 - MCL	Cd	0.004	0.005 - TWQR
Cu	1.282	1 - TWQR	Sr	0.885	0.1 - AV
Cl	139	100 – TWQR			
Hg	0.009	0.001 - TWQR			
Mn	0.12	0.05 - TWQR			
Na	137	100 – TWQR			
TDS	715	450 – TWQR			

Wilgerkuil (10.3)

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	**WQC**	Measured (mg/l)	Relevant Guideline (mg/l)
Br	0.138	0.01 - MCL	Cd	0.004	0.005 - TWQR
Cl	359	200 - Cat C	Sr	1.223	0.1 - AV
Hg	0.005	0.001 - TWQR			
NO_3	30	26 – TWQR			
Na	186	200 - Cat C			
Ti	0.105	0.1 - RL			
TDS	973	450 - TWQR			

Waterval 1 (11.1)

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	**WQC**	Measured (mg/l)	Relevant Guideline (mg/l)
Br	0.031	0.01 - MCL			
F	1.7	1.5 - Cat -D			

Waterval 2

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	**WQC**	Measured (mg/l)	Relevant Guideline (mg/l)
Br	0.037	0.01 - MCL			
F	1.87	1.5 - Cat -D			

Waterval 3 (11.3)

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	**WQC**	Measured (mg/l)	Relevant Guideline (mg/l)
As	0.01	0.01 – TWQR	Sr	0.135	0.1 - AV
Br	0.066	0.01 – MCL	U	0.017	0.02 – MCL
F	4.91	3.5 - Cat E			
Mn	0.27	0.05 – TWQR			
Na	174	100 – TWQR			
Ti	0.117	0.100 – RL			
TDS	639	450 - TWQR			

Rooiwal 1 (12.1)

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	**WQC**	Measured (mg/l)	Relevant Guideline (mg/l)
As	0.012	0.01 - TWQR	Cr	0.029	0.05 - MRL
Br	0.121	0.01 - MCL	F	0.96	1 - Cat C
Be	0.008	0.004 – MCL	Sr	0.154	0.1 - AV
Pb	0.083	0.016 - MCL	Ni	0.019	0.02 - MRL
Mn	0.39	0.05 - TWQR			
Ti	0.424	0.200 - MPL			

Soutpansleegte 1

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	**WQC**	Measured (mg/l)	Relevant Guideline (mg/l)
Br	0.084	0.01 - MCL	Cd	0.003	0.005 - TWQR
Be	0.01	0.004 - MCL	Sr	0.277	0.1 - AV
F	3.58	3.5 – Cat E			
NO_3	34	26 - TWQR			

Soutpansleegte 2

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	**WQC**	Measured (mg/l)	Relevant Guideline (mg/l)
Br	0.062	0.01 - MCL	Sr	0.164	0.1 - AV
Be	0.027	0.004 - MCL			
F	1.55	1.5 – CatC			
NO_3	134	89 – Cat D			

Fafung 1 (15.1)

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	**WQC**	Measured (mg/l)	Relevant Guideline (mg/l)
Br	0.03	0.01 - MCL			
Be	0.007	0.004 - MCL			
Hg	0.005	0.001 - TWQR			
Pb	0.094	0.01 – TWQR			
Mn	0.48	0.4 - Cat C			

Fafung 2

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	**WQC**	Measured (mg/l)	Relevant Guideline (mg/l)
Br	0.037	0.01 - MCL			
Be	0.007	0.004 – MCL			
Hg	0.005	0.001 - TWQR			
Mn	0.79	0.4 - Cat C			
Ti	0.129	0.100 – RL			

Fafung 3

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	**WQC**	Measured (mg/l)	Relevant Guideline (mg/l)
As	0.01	0.01 - TWQR	Sr	0.187	0.1 - AV
Br	0.035	0.01 - MCL	Te	0.004	0.005 - RL
Be	0.188	0.004 – MCL			
Cr	0.099	0.05 - TWQR			
Pb	0.021	0.015 - MCL			
Hg	0.002	0.001 - TWQR			
Mn	0.48	0.4 - Cat C			
Ni	0.049	0.02 - MRL			
Ti	1.19	0.200 – MPL			

Kwarriekraal 1

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	**WQC**	Measured (mg/l)	Relevant Guideline (mg/l)
As	0.01	0.01 – TWQR	Sr	0.103	0.1 - AV
Be	0.026	0.004 – MCL	Te	0.004	0.005 - RL
Br	0.091	0.01 - MCL			
F	4.04	3.5 – Cat E			

Kwarriekraal 2

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	**WQC**	Measured (mg/l)	Relevant Guideline (mg/l)
Be	0.071	0.004 – MCL	F	0.91	1 – Cat C
Br	0.091	0.01 – MCL			
Hg	0.001	0.001 – TWQR			
Ti	0.409	0.2 – MPL			

Kwarriekraal 3

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	**WQC**	Measured (mg/l)	Relevant Guideline (mg/l)
As	0.012	0.01 – TWQR			
Be	0.058	0.004 – MCL			
Br	0.089	0.01 – MCL			
F	4.52	3.5 – Cat E			
Mn	0.100	0.05 – TWQR			

Klipvoorstad 1

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	**WQC**	Measured (mg/l)	Relevant Guideline (mg/l)
As	0.012	0.01 – TWQR			
Be	0.006	0.004 – MCL			
Br	0.095	0.01 – MCL			
Cu	1.467	1 – TWQR			
F	2.48	1.5 – Cat D			

Tolwane river (1)

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	**WQC**	Measured (mg/l)	Relevant Guideline (mg/l)
Br	0.151	0.01 - MCL	Sr	0.287	0.1 - AV
Cl	131	100 – TWQR			
Na	129	100 – TWQR			
TDS	502	450 - TWQR			

Tolwane 2

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	**WQC**	Measured (mg/l)	Relevant Guideline (mg/l)
Br	0.014	0.01 - MCL	Sr	0.100	0.1 - AV
Cl	118	100 - TWQR			
NO_3	26	26 - TWQR			
TDS	478	450 - TWQR			
Na	106	100 – TWQR			

Table 4.3.3.3 Summary statistics for the main PHCs and COCs identified from 33 water samples.

WQC	PHC	COC	Average (mg/L)	SD (mg/L)	Median (mg/L)	Range (mg/L)	
(n) / WP	148	40				Minimum	Maximum
	4.48	1.212					
As	6	0	0.005	0.003	0.004	0	0.012
Be	14	0	0.013	0.036	0	0	0.188
Br	32	0	0.0906	0.085	0.066	0.006	0.326
Cd	0	5	7E-04	0.001	0	0	0.004
Cl	8	0	73.9	75.5	53	5	359
F	11	2	1.204	1.902	0	0	7.55
Hg	12	0	0.00167	0.0028	0	0	0.01
Pb	4	0	0.01	0.02481	0	0	0.094
Mn	11	0	0.12	0.19	0	0	0.790
Na	10	0	74.33	56.12	65	4	213
Ti	10	0	0.141	0.22	0.08	0.008	1.19
TDS	11	1	398.2	229.9	377	97	973
Sr	0	25	0.272	0.305	0.183	0	1.223

The highest recorded number of PHCs and COCs within a watering point was 9 and 3 respectively. All 33 watering points contained PHCs, whilst 36 contained COCs.

Table 4.3.3.4. Summary statistics for important ratios influencing fluoride toxicity.

Ratios	F:Ca	F:B	F:TDS	F:Sr	F:Mo	F:pH
RGR*	>166.66	>4.166	>500.00	<0.166	<0.0067	>1.333
Average	16	0.2	3.885	0.064	1E-04	3.521
SD	17.3	0.45	5.162	0.1	5E-04	2.275
Median	9.52	0.04	2.181	0.027	0	2.629
Minimum	1.72	0.01	0.795	0	0	1.083
Maximum	63.8	1.59	19.23	0.368	0.002	9.022

* = Recommended Guideline Ratio (WQC/F)

A F:pH correlation of 0.283 was obtained.

4.3.3.4 Discussion

The results illustrate the requirement that water sampling and analytical programmes be initiated in areas reliant on groundwater, specifically those areas where the hydrogeochemistry suggests potential risks.

The groundwater chemistry results presented in this progress report for the Jericho communities do indeed suggest severe potential hazards exist. Many of the communities in this District rely on a single subterranean source as the only source of water for periods exceeding 5 months at a time. Other sources are collected rainwater or water purchased from persons who collect water from rivers many kilometers away. Only in isolated instances was collected rainwater used for stock watering, and was usually limited to poultry and a few goats. In most of the communities the same source was used for human drinking water, food preparation, irrigation of subsistence crops, and stock watering. Aspects discussed in Chapter 2 refer.

A confounding factor in the Jericho District is the occurrence of endemic fluorosis, described in the 1950's (Ockert, 1951). The occurrence of related PHCs with possibly similar adverse effects, namely Sr, Cd and

Mo, increase the possibility that disorders have been incorrectly, or rather incompletely, diagnosed. As such, significant aetiological factors may have been overlooked. An obvious reason for this is to be found in the fairly recent analytical techniques enabling the routine determination of these WQCs in laboratories.

4.3.4 Delftzyl and Immerpan Districts

4.3.4.1 Introduction

Previous work conducted on the Delftzyl Agricultural Research Station (Casey *et al.*, 1998), and with beef cattle obtained from Delftzyl Agricultural Research Station, focused on alleviation chronic fluorosis endemic to the area. An alleviator treatment specifically formulated for the subterranean water used at Delftzyl Agricultural Research Station by CIRRA software, addressed both toxicological and palatability aspects. The results were successful for alleviating dental lesions and lameness due to skeletal lesions in beef cattle over the growth from weaning weight to market weight (Meyer, 1998). The treatment was administered to a 5000 L tank on the Delftzyl Agricultural Research Station for the purposes of testing the alleviator treatment under extensive on-farm conditions in Afrikaner cows incorporating placental and milk aspects. As of January 2000 the Control group consisted of 8 animals, whilst the Treatment group consisted of 7 animals. The decline in numbers in the Control group was due to severe skeletal fluorosis inducing lameness resulting in the loss of two animals, whilst in the Treatment group, two cows were lost due to dystocia (non-fluorosis related) problems. Apart from the absence of skeletal symptoms in the Treatment group, a reduction in dental lesions (enamel hypoplasia) was also observed in treatment animals. Clinical evaluations were conducted on a monthly basis.

Water quality assessed from farms in the surrounding area (Casey *et al.*, 1998) revealed that F posed a problem in the majority of subterranean sources sampled. The Immerpan District Rural Resettlement Farms are located on the eastern boundary of Delftzyl Agricultural Research Station, and the eastern portion of the Immerpan district was included in the sampling conducted. It was observed that many of the farms were settled with a typical scenario existing whereby both humans and livestock utilised the same water source. The water quality results indicated many PHCs and COCs to be present in these water sources (Casey *et al.*, 1998), and this prompted further investigation into the remaining farms in the Immerpan district.

The area consists of over 55000 ha of farms, averaging ca. 1000 ha each in size, and characterised by the same extensive dry bushveld as present on Delftzyl Agricultural Research Station. Several herds evaluated presented with clinical signs of skeletal and dental fluorosis. Although not quantified, dental lesions typical of fluorosis and symptoms suggestive of skeletal fluorosis were observed in some of the local residents. For most of the farmers resident, a single borehole is usually the only source of water for distances exceeding 10 km at times. The issues pertaining to the application of alleviator treatments to water in the rural communal livestock production system context have already been dealt with (Chapters 1 and 3). The results presented in this section should be seen within the context of those issues.

4.3.4.2 Methods

The same procedure followed in the Jericho district was used for the Immerpan district. Three sampling phases were conducted, two of which consist of farms bordering the eastern boundary of Delftzyl Agricultural Research Station (western sections of Immerpan) that served as preliminary investigations to determine the extent of the PHCs and COCs present. The third phase comprised those farms in the Immerpan district which were in use by rural farmers in the central and eastern sections. No analyses conducted for *Tellurium*.

4.3.4.3 Results

4.3.4.3.1 Sampling phase 1: Westerm section of Immerpan (March 1998)

Sample 12 IP1

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	**WQC**	Measured (mg/l)	Relevant Guideline (mg/l)
As	0.048	0.01 – TWQR	Sr	0.543	0.1 - AV
Br	54.399	0.01 – MCL			
Cl	402	200 – Cat C			
F	11.34	3.5 – Cat E			
Hg	0.024	0.001 – TWQR			
I	0.709	0.5- RL			
Se	0.023	0.02 – TWQR			
Na	365	200 – Cat C			
TDS	1050	1000 – Cat C			
Ti	0.238	0.2 – MPL			

Sample 3D IP1

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	**WQC**	Measured (mg/l)	Relevant Guideline (mg/l)
As	0.037	0.01 – TWQR	Sr	0.442	0.1 - AV
Br	30.768	0.01 – MCL			
F	16.95	3.5 – Cat E			
Hg	7.195	0.001 – TWQR			
Se	0.04	0.02 – TWQR			
Ti	0.174	0.1 – RL			

Sample 4 IP1

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	**WQC**	Measured (mg/l)	Relevant Guideline (mg/l)
As	0.023	0.01 – TWQR	Sr	0.515	0.1 - AV
Br	31.38	0.01 – MCL			
F	12.68	3.5 – Cat E			
Hg	0.171	0.001 – TWQR			
Se	0.024	0.02 – TWQR			
Ti	0.219	0.2 – MPL			

Sample 5 IP1

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	**WQC**	Measured (mg/l)	Relevant Guideline (mg/l)
As	0.031	0.01 – TWQR	Sr	0.971	0.1 - AV
Br	43.942	0.01 – MCL	Mo	0.024	0.04 - HA
F	5.09	3.5 – Cat E			
Hg	0.064	0.001 – TWQR			
Mn	0.237	0.05 – TWQR			
Se	0.055	0.02 – TWQR			
Ti	0.608	0.2 – MPL			

Sample 6 IP1

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	**WQC**	Measured (mg/l)	Relevant Guideline (mg/l)
As	0.028	0.01 – TWQR	Sr	0.325	0.1 - AV
Br	38.579	0.01 – MCL			
F	18.5	3.5 – Cat E			
Hg	0.058	0.001 – TWQR			
Se	0.034	0.02 – TWQR			
Ti	0.371	0.2 – MPL			

Sample 7 IP1

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	**WQC**	Measured (mg/l)	Relevant Guideline (mg/l)
As	0.054	0.01 – TWQR	Sr	6.044	0.1 - AV
Br	132.678	0.01 – MCL	V	0.196	0.25 - RL -
Cl	2256	1200 – Cat E	Zn	0.208	0.1 - AV
Hg	0.023	0.001 – TWQR			
I	2.506	1 – MPL			
Se	0.295	0.02 – TWQR			
Na	1010	1000 – Cat E			
SO_4	520	1000 – Cat E			
TDS	4658	3400 – Cat E			
Ti	3.301	0.2 – MPL			
U	0.072	0.02 – MCL			

Sample 8 IP1

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	**WQC**	Measured (mg/l)	Relevant Guideline (mg/l)
As	0.017	0.01 – TWQR	Sr	3.420	0.1 - AV
Br	99.829	0.01 – MCL	Zn	0.145	0.1 - AV
Cl	1800	1200 – Cat E			
Hg	0.03	0.001 – TWQR			
I	2.290	1 – MPL			
Se	0.169	0.02 – TWQR			
TDS	2952	2400 – Cat D			
Ti	3.114	0.2 – MPL			

Sample 9 IP1

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	WQC	Measured (mg/l)	Relevant Guideline (mg/l)
As	0.033	0.01 – TWQR	Sr	3.679	0.1 - AV
Br	109.849	0.01 – MCL	U	0.015	0.02 - TWQR
Cl	1689	1200 – Cat E			
Hg	0.029	0.001 – TWQR			
I	2.528	1 – MPL			
Mn	0.414	0.4 – Cat C			
Se	0.163	0.02 – TWQR			
TDS	3087	2400 – Cat D			
Ti	4.414	0.2 – MPL			

Sample 10 IP1

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	WQC	Measured (mg/l)	Relevant Guideline (mg/l)
As	0.02	0.01 – TWQR	Sr	0.471	0.1 - AV
Br	45.713	0.01 – MCL			
Cl	282	200 – Cat C			
Hg	0.015	0.001 – TWQR			
I	2.443	1 – MPL			
Se	0.067	0.02 – TWQR			
TDS	830	450 – TWQR			
Ti	1.426	0.2 – MPL			

Sample 11 IP1

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	WQC	Measured (mg/l)	Relevant Guideline (mg/l)
As	0.03	0.01 – TWQR	Sr	0.453	0.1 - AV
Br	52.426	0.01 – MCL			
Cl	264	200 – Cat C			
Hg	0.008	0.001 – TWQR			
I	1.403	1 – MPL			
Mn	0.203	0.05 – TWQR			
Se	0.036	0.02 – TWQR			
TDS	913	450 – TWQR			
Ti	1.265	0.1 – RL			

Sample 13 IP1

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	WQC	Measured (mg/l)	Relevant Guideline (mg/l)
As	0.025	0.01 – TWQR	Sr	1.733	0.1 - AV
Br	76.52	0.01 – MCL	U	0.018	0.02 - TWQR
Cl	1070	600 – Cat D			
Mn	0.201	0.05 – TWQR			
Hg	0.009	0.001 – TWQR			
I	2.324	1 – MPL			
Se	0.097	0.02 – TWQR			
TDS	2334	1000 - Cat C			
Ti	1.894	0.2 – MPL			

Table 4.3.4.1.Summary statistics for the main PHCs and COCs identified from 11 water samples collected from the western section (IP1) of Immerpan District Farms (March 1998).

WQC	PHC	COC	Average (mg/L)	SD (mg/L)	Median (mg/L)	Range (mg/L)	
(n) / WP	89	17				Minimum	Maximum
	8.0	1.54					
As	11	0	0.031	0.011	0.03	0.017	0.054
Br	11	0	65.097	34.676	52.426	30.768	132.678
Cl	7	0	880.8	767.7	487	282	2256
F	5	0	5.869	7.523	0	0	18.5
Hg	11	0	0.039	0.048	0.024	0	0.171
I	7	0	1.345	1.092	1.403	0.144	2.528
Mn	4	0	0.106	0.138	0.033	0	0.414
Mo	0	1	0.003	0.007	0	0	0.024
Se	12	0	0.0912	0.085	0.055	0.023	0.295
Sr	0	11	1.690	1.885	0.543	0.325	6.044
TDS	7	0	1910.7	1212.1	1427	830	4658
Ti	11	0	1.523	1.418	1.265	0.174	4.142
U	1	2	0.012	0.021	0.004	0	0.072
V	0	1	0.025	0.059	0	0	0.196
Zn	0	2	0.048	0.075	0.01	0	0.218

The number of watering points containing PHCs and COCs were 11. The highest number of PHCs and COCs recorded within one watering point was 14.

Table 4.3.4.2.Summary statistics for important ratios influencing fluoride toxicity.

Ratios	F:Ca	F:B	F:TDS	F:Sr	F:Mo	F:pH
RGR*	>166.66	>4.166	>500.00	<0.0166	<0.0067	>1.333
Average	1.728	0.110	121.97	0.064	0.0009	0.793
SD	2.340	0.095	88.968	0.071	0.0021	0.466
Median	0.810	0.065	84.424	0.040	0	0.664
Maximum	5.893	0.280	280.353	0.190	0.0047	1.611
Minimum	0.289	0.059	68.432	0.0175	0	0.437

* = Recommended Guideline Ratio (WQC/F)

A F:pH correlation of 0.393 was obtained. The following statistics were obtained for the As:Se ratios:

Average	1: 3.047
SD	2.979
Median	1.494
Max	9.941
Min	0.479

4.3.4.3.2 Sampling phase 2: Western Immperpan (November 1998)

Note, no mercury analysis as $HgCl_2$ used as preservative for nitrate determination.

D4 IP2

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	WQC	Measured (mg/l)	Relevant Guideline (mg/l)
As	0.065	0.01 – TWQR	Sr	0.411	0.1 - AV
Be	0.012	0.004 – MCL			
Br	2.798	0.01 – MCL			
Cl	408	200 – Cat C			
F	13.66	3.5 – Cat E			
Se	0.153	0.02 – TWQR			
Na	313	200 – Cat C			
TDS	985	1000 – Cat C			

D5 IP2

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	WQC	Measured (mg/l)	Relevant Guideline (mg/l)
As	0.064	0.01 – TWQR	Sr	0.129	0.1 - AV
Be	0.005	0.004 - MCL			
Br	1.915	0.01 – MCL			
Cl	492429	200 – Cat C			
F	14.48	3.5 – Cat E			
Se	0.129	0.02 – TWQR			
Na	415	200 – Cat C			
TDS	1117	1000 – Cat C			

D6 IP2

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	WQC	Measured (mg/l)	Relevant Guideline (mg/l)
As	0.062	0.01 – TWQR	Te	0.004	0.005 – MPL
Br	1.052	0.01 – MCL			
F	3.75	3.5 – Cat E			
Se	0.12	0.02 – TWQR			
Mn	0.176	0.05 – TWQR			

D7 IP2

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	WQC	Measured (mg/l)	Relevant Guideline (mg/l)
As	0.079	0.01 – TWQR	Sr	0.525	0.1 - AV
Br	2.294	0.01 – MCL	Mo	0.043	0.07 – MRL
Cl	433	200 – Cat C			
F	15.47	3.5 – Cat E			
Mn	0.052	0.05 – TWQR			
Se	0.108	0.02 – TWQR			
Na	495	200 – Cat C			
Te	0.006	0.005 - MPL			
Ti	0.159	0.1 - RL			
TDS	1261	1000 – Cat C			

D8 IP2

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	**WQC**	Measured (mg/l)	Relevant Guideline (mg/l)
As	0.046	0.01 – TWQR	Sr	0.497	0.1 - AV
Be	0.007	0.004 – MCL			
Br	2.314	0.01 – MCL			
Cl	379	200 – Cat C			
F	12.76	3.5 – Cat E			
Se	0.114	0.02 – TWQR			
Na	382	200 – Cat C			
Te	0.007	0.005 – RL			
TDS	1084	1000 – Cat C			

D9 IP2

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	**WQC**	Measured (mg/l)	Relevant Guideline (mg/l)
As	0.058	0.01 – TWQR	Sr	0.693	0.1 - AV
Br	2.404	0.01 – MCL	Mo	0.027	0.07 – MRL
Cd	0.005	0.005 – Cat C	Te	0.004	0.005 – RL
Cl	390	200 – Cat C			
F	7.06	3.5 – Cat E			
Se	0.121	0.02 – TWQR			
Na	353	200 – Cat C			
Ti	0.142	0.1 – RL			
TDS	1087	1000 – Cat C			

D10 IP2

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	**WQC**	Measured (mg/l)	Relevant Guideline (mg/l)
As	0.055	0.01 – TWQR	Sr	3.383	0.1 - AV
Br	10.974	0.01 – MCL	Mo	0.022	0.07 – MRL
Cl	2333	200 – Cat C	V	0.079	0.1 – TWQR
Mg	303	200 – Cat D	Zn	0.112	0.1 - AV
Ni	0.029	0.02 – MRL			
SO_4	372	200 – TWQR			
Se	0.170	0.02 – TWQR			
Na	1014	200 – Cat C			
Te	0.006	0.005 - RL			
Ti	0.585	0.2 – MPL			
TDS	4348	3400 – Cat E			

D12 IP2

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	**WQC**	Measured (mg/l)	Relevant Guideline (mg/l)
Be	0.009	0.004 - MCL	Sr	1.402	0.1 - AV
Br	6.16	0.01 – MCL	U	0.013	0.02 – MCL
Cl	1076	200 – Cat C			
Mg	106	100 – Cat C			
Se	0.078	0.02 – TWQR			
Na	525	200 – Cat C			
Te	0.009	0.005 - RL			
Ti	0.347	0.2 – MPL			
TDS	2006	1000 – Cat C			

D13 IP2

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	**WQC**	Measured (mg/l)	Relevant Guideline (mg/l)
As	0.091	0.05 – Cat C	Sr	1.255	0.1 - AV
Br	5.943	0.01 – MCL	Ni	0.018	0.02 – MRL
Cl	1212	200 – Cat C			
F	3.15	1.5 – Cat D			
Mg	102	100 – Cat C			
Se	0.202	0.02 – TWQR			
Na	604	200 – Cat C			
Ti	0.507	0.2 – MPL			
TDS	2405	2400 – Cat D			
U	0.024	0.02 – MCL			

D16 IP2

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	**WQC**	Measured (mg/l)	Relevant Guideline (mg/l)
As	0.021	0.01 – TWQR	Sr	3.238	0.1 - AV
Br	13.096	0.01 – MCL	U	0.018	0.02 – MCL
Ca	202	150 – Cat C			
Cl	1907	200 – Cat C			
Mg	200	100 – Cat C			
Mn	0.121	0.05 – TWQR			
Ni	0.051	0.02 – MRL			
Se	0.217	0.02 – TWQR			
Na	671	200 – Cat C			
Te	0.013	0.01 – CL			
Ti	0.932	0.2 – MPL			
TDS	3181	2400 – Cat D			

D17 IP2

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	**WQC**	Measured (mg/l)	Relevant Guideline (mg/l)
As	0.062	0.01 – TWQR	Sr	2.717	0.1 - AV
Br	11.019	0.01 – MCL			
Ca	173	150 – Cat C			
Cd	0.005	0.005 – Cat C			
Cl	1847	200 – Cat C			
Mg	186	100 – Cat C			
Mn	0.079	0.05 – TWQR			
Ni	0.051	0.02 – MRL			
Se	0.239	0.02 – TWQR			
Na	557	200 – Cat C			
Te	0.005	0.005 – RL			
Ti	1.109	0.2 – MPL			
TDS	2951	2400 – Cat D			
U	0.024	0.02 – MCL			

D18 IP2

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	**WQC**	Measured (mg/l)	Relevant Guideline (mg/l)
As	0.105	0.01 – TWQR	Sr	2.589	0.1 - AV
Br	11.434	0.01 – MCL			
Ca	181	150 – Cat C			
Cl	1648	200 – Cat C			
Mg	214	200 – Cat D			
Ni	0.049	0.02 – MRL			
Se	0.268	0.02 – TWQR			
Na	699	200 – Cat C			
Te	0.005	0.005 – RL			
Ti	0.905	0.2 – MPL			
TDS	2922	2400 – Cat D			
U	0.028	0.02 – MCL			

D19 IP2

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	**WQC**	Measured (mg/l)	Relevant Guideline (mg/l)
Br	18	0.01 – MCL	Cd	0.004	0.005 - TWQR
Ca	303	300 – Cat D	Sr	5.312	0.1 - AV
Cl	2947	200 – Cat C	Te	0.004	0.005 - RL
Mg	322	200 – Cat D			
Mn	0.408	0.05 – TWQR			
Ni	0.091	0.02 – MRL			
Se	0.206	0.02 – TWQR			
Na	925	200 – Cat C			
Ti	1.504	0.2 – MPL			
TDS	4728	3400 – Cat E			

D20 IP2

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	**WQC**	Measured (mg/l)	Relevant Guideline (mg/l)
Br	3.351	0.01 – MCL	Sr	0.366	0.1 – AV
Cl	262	200 – Cat C	Ni	0.014	0.02 – MRL
F	1.3	1 – Cat C			
Se	0.074	0.02 – TWQR			
Te	0.005	0.005 – RL			
Ti	0.267	0.2 – MPL			
TDS	599	450 – TWQR			

D21 IP2

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	**WQC**	Measured (mg/l)	Relevant Guideline (mg/l)
Br	2.679	0.01 – MCL	Sr	0.246	0.1 – AV
Cl	245	200 – Cat C	Ni		0.02 – MRL
F	1.4	1 – Cat C			
Se	0.019	0.02 – TWQR			
Te	0.007	0.005 – RL			
Ti	0.207	0.2 – MPL			
TDS	547	450 – TWQR			

D22 IP2

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	WQC	Measured (mg/l)	Relevant Guideline (mg/l)
As	0.028	0.01 – TWQR	Sr	0.286	0.1 – AV
Br	2.953	0.01 – MCL			
Cl	304	200 – Cat C			
F	1.52	1.5 – Cat D			
Mn	0.044	0.05 – TWQR			
Se	0.05	0.02 – TWQR			
Ti	0.270	0.2 – MPL			
TDS	641	450 – TWQR			

Table 4.3.4.3. Summary statistics for the main PHCs and COCs identified from 16 water samples collected from the western section (IP2) of Immerpan District Farms (Nov 1998).

WQC	PHC	COC	Average (mg/L)	SD (mg/L)	Median (mg/L)	Range (mg/L)	
(n) / WP	149	29				Minimum	Maximum
	9.31	1.81					
As	12	0	0.046	0.032	0.056	0	0.105
Br	16	0	6.149	5.115	3.152	1.052	18
Cl	15	0	995	884.3	431	108	2947
F	10	0	4.659	5.949	1.46	0	15.47
Mo	0	3	0.027	0.0073	0	0	0.024
Se	16	0	0.141	0.070	0.1251	0.019	0.268
Sr	0	15	1.455	1.537	0.609	0.052	5.312
Na	12	0	459	284.7	455	97	1014
Ti	12	0	0.454	0.436	0.269	0.073	1.504
Te	9	0	0.005	0.0032	0.005	0	0.013
TDS	15	0	1886	1386	1189	326	4728

All watering points contained both PHCs and COCs. The highest number of PHCs and COCs recorded for a single watering point was 11 and 4 respectively.

Table 4.3.4.4. Summary statistics for important ratios influencing fluoride toxicity for F = PHC.

Ratios	F:Ca	F:B	F:TDS	F:Sr	F:Mo	F:pH
RGR*	>166.66	>4.166	>500.00	<0.0166	<0.0067	>1.333
Average	15.587	0.110882	259.330	0.128016	0.001003	2.70708
SD	19.200	0.08699	237.926	0.130916	0.001355	2.456678
Median	2.097	0.086093	120.449	0.068554	0.000382	1.821441
Maximum	45.384	0.309211	763.492	0.398413	0.003824	6.507692
Minimum	0.252	0.023077	72.108	0.013867	6.91E-06	0.597285

* = Recommended Guideline Ratio (WQC/F)

A F:pH correlation of 0.622 was obtained.

The following statistics were obtained for the As:Se ratios:

Average As:Se = 1:144.35

SD 512.94

Median 2.515

Max 2060

Min 1.367

4.3.4.3.3 Sampling phase 3: Central Immerpan farms (March 1999)

Note: No analyses were conducted for Tellurium.

27 - Vooruitgaan - seepage at fountain

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	WQC	Measured (mg/l)	Relevant Guideline (mg/l)
Be	0.081	0.004 - MCL	Sr	0.477	0.1 - AV
Br	0.158	0.01 - MCL	Mo	0.013	0.07 - MRL
Cl	904	600 - Cat D			
F	13.94	3.5 - Cat E			
Hg	0.034	0.001 - TWQR			
Mn	0.159	0.05 - TWQR			
Na	659	400 - Cat D			
Se	0.015	0.01 - TWQR			
TDS	1955	1000 - Cat C			
Ti	0.229	0.2 - MPL			

39 - Hangklip (BH #1)- circular drinking trough

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	WQC	Measured (mg/l)	Relevant Guideline (mg/l)
Be	0.006	0.004 - MCL	Sr	2.372	0.1 - AV
Br	0.567	0.01 - MCL	Ba	1.993	2 - MCL
Cl	1704	1200 - Cat E	Ni	0.025	0.1 - MCL
Hg	0.004	0.001 - TWQR	U	0.011	0.02 - MCL
Ca	580	300 - Cat D			
Mg	123	100 - Cat C			
Na	282	100 - TWQR			
NO3	69	64 - Cat C			
Se	0.039	0.02 - TWQR			
TDS	2887	2400 - Cat D			
Ti	1.041	0.2 - MPL			

34 - Hangklip (BH #2) - circular drinking trough

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	WQC	Measured (mg/l)	Relevant Guideline (mg/l)
Br	0.296	0.01 - MCL	Sr	1.158	0.1 - AV
Cl	1009	600 - Cat D	Be	0.003	0.004 - MCL
Ca	296	150 - Cat - C	Ni	0.01	0.02 - MRL
F	5.6	3.5 - Cat E			
Hg	0.009	0.001 - TWQR			
Se	0.029	0.01 - TWQR			
Na	162	100 - TWQR			
TDS	1584	1000 - Cat C			
Ti	0.671	0.2 - MPL			

45 - Viersteenlaagte (BH #1) - ciruclar drinking trough

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	WQC	Measured (mg/l)	Relevant Guideline (mg/l)
Be	0.009	0.004 - MCL	Sr	0.188	0.1 - AV
Hg	0.008	0.001 – TWQR	Ti	0.092	0.1 - RL
			V	0.048	0.1 - TWQR

33 - Plaatdoring (Weltevreden community)- drinking trough

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	**WQC**	Measured (mg/l)	Relevant Guideline (mg/l)
Be	0.036	0.004 – MCL	Sr	0.587	0.1 - AV
Br	0.058	0.01 – MCL	Mo	0.014	0.07 - MRL
F	7.85	3.5 - Cat E			
Hg	0.004	0.001 – TWQR			
Na	262	200 - Cat C			
Se	0.018	0.01 – TWQR			
NO_3	31.97	26 – TWQR			
TDS	1012	1000 – Cat C			
U	0.081	0.02 – MCL			
Ti	0.109	0.1 – RL			

2 - Van der Merwes Kraal Community*

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	**WQC**	Measured (mg/l)	Relevant Guideline (mg/l)
Be	0.101	0.004 - MCL	Sr	2.055	0.1 - AV
Br	0.544	0.01 - MCL	Zn	0.426	0.1 - AV
Ca	523	300 - Cat D	Ni	0.024	0.1 - RML
Cl	945	600 - Cat D			
F	1.13	1 - Cat C			
Mo	0.146	0.07 - MRL			
Na	620	400 - Cat D			
Se	0.039	0.01 - TWQR			
SO_4	1629	1000 - Cat E			
TDS	3731	3400 - Cat E			
Ti	1.092	0.2 - MPL			

* - Hg not analysed due to sample preservation technique

52 - Viersteenlaagte (BH #2) - circular drinking trough

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	**WQC**	Measured (mg/l)	Relevant Guideline (mg/l)
Be	0.011	0.004 – MCL	Sr	0.829	0.1 - AV
Br	0.266	0.01 – MCL	U	0.016	0.02 - MCL
Ca	184	150 – Cat C	Te	0.003	0.005 - MPL
Cl	619	200 – Cat C			
Hg	0.008	0.001 – TWQR			
Na	166	100 – TWQR			
NO_3	31	26 – TWQR			
Se	0.025	0.02 – TWQR			
TDS	1235	1000 – TWQR			
Ti	0.435	0.2 – MPL			

55 - Fangani (BH #1) - circular drinking trough

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	**WQC**	Measured (mg/l)	Relevant Guideline (mg/l)
Be	0.018	0.004 – MCL	Sr	0.567	0.1 - AV
Br	0.108	0.01 – MCL	F	0.7	1 - TWQR
Cl	207	200 – Cat C	U	0.01	0.02 - MCL
Na	124	100 – TWQR			
TDS	895	450 – TWQR			
Ti	0.317	0.2 – MPL			

30 - Fangani (BH #2) - circular drinking trough (DT#1)

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	WQC	Measured (mg/l)	Relevant Guideline (mg/l)
Be	0.016	0.004 – MCL	Sr	0.454	0.1 - AV
Br	0.077	0.01 – MCL	F	0.84	1 - TWQR
Hg	0.012	0.001 – TWQR	Te	0.003	0.005 - MPL
Na	115	100 – TWQR	V	0.041	0.1 - TWQR
NO3	79	64 - Cat C			
TDS	922	450 – TWQR			
Ti	0.290	0.2 – MPL			

51 - Fangani (BH #2) - house pipe

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	WQC	Measured (mg/l)	Relevant Guideline (mg/l)
Be	0.02	0.004 – MCL	Sr	0.5	0.1 - AV
Br	0.099	0.01 - MCL	F	0.96	1 - TWQR
Cl	203	200 - Cat C	Zn	0.203	0.1 - AV
Hg	0.001	0.001 - TWQR			
Na	121	100 - TWQR			
NO_3	71	64 - Cat C			
TDS	844	450 - TWQR			
Ti	0.259	0.2 - MPL			

25 - Fangani - (BH #2) - drinking trough (DT #2 - long residence time)

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	WQC	Measured (mg/l)	Relevant Guideline (mg/l)
Be	0.021	0.004 - MCL	Sr	0.253	0.1 - AV
Br	0.169	0.01 - MCL	F	0.8	1 - TWQR
Cl	364	200 - Cat C	Zn	0.203	0.1 - AV
Hg	0.147	0.001 - TWQR	Mn	0.045	0.05 - TWQR
Na	195	100 - TWQR			
TDS	1084	1000 - Cat C			
Ti	0.118	0.1 -RL			

46 - Vrisgewag - drinking trough

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	WQC	Measured (mg/l)	Relevant Guideline (mg/l)
Be	0.021	0.004 - MCL	Sr	0.760	0.1 - AV
Br	0.144	0.01 - MCL	F	0.96	1 - TWQR
Cl	378	200 - Cat C	NO3	20	26 - TWQR
Hg	0.007	0.001 - TWQR	Te	0.002	0.005 - MPL
Na	132	100 - TWQR	V	0.044	0.1 - TWQR
Se	0.027	0.02 - TWQR			
TDS	761	450 - TWQR			
Ti	0.291	0.2 - MPL			

31 - Rooifontein (BH #2) - drinking trough

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	**WQC**	Measured (mg/l)	Relevant Guideline (mg/l)
Be	0.01	0.004 - MCL	Sr	0.740	0.1 - AV
NO_3	88	89 - Cat D	Te	0.003	0.005 - MPL
Hg	0.01	0.001 - TWQR			
TDS	576	450 - TWQR			
Ti	0.335	0.2 - MPL			

29 - Foleysrus - circular drinking trough

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	**WQC**	Measured (mg/l)	Relevant Guideline (mg/l)
Be	0.026	0.004 - MCL	Sr	1.134	0.1 - AV
Hg	0.027	0.001 - TWQR	V	0.06	0.1 - TWQR
NO_3	203	177 - Cat E	Te	0.003	0.005 - MPL
TDS	1000	1000 - Cat C			
Ti	0.223	0.2 - MPL			

54 - Restaurant - circular drinking trough

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	**WQC**	Measured (mg/l)	Relevant Guideline (mg/l)
Be	0.026	0.004 - MCL	Sr	0.830	0.1 - AV
Br	0.151	0.01 - MCL	Se	0.018	0.02 - TWQR
Cl	178	100 - TWQR	V	0.045	0.1 - TWQR
F	1.01	1 - TWQR			
Hg	0.003	0.001 - TWQR			
Na	323	200 - Cat C			
NO_3	197	26 - TWQR			
TDS	1188	1000 - Cat C			
Ti	0.107	0.1 - RL			
U	0.02	0.02 - MCL			

53 - Singpore - Inflow pipe to reservoir

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	**WQC**	Measured (mg/l)	Relevant Guideline (mg/l)
Be	0.019	0.004 - MCL	Sr	0.157	0.1 - AV
Br	0.157	0.01 - MCL	F	1.26	1 - TWQR
Cl	390	200 - Cat C	Ti	0.085	0.1 - RL
Hg	0.005	0.001 - TWQR	V	0.13	0.1 - TWQR
Na	212	200 - Cat C	U	0.012	0.02 - MCL
TDS	1121	1000 - Cat C			

44 - Singapore - circular drinking trough

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	**WQC**	Measured (mg/l)	Relevant Guideline (mg/l)
Be	0.026	0.004 - MCL	Sr	0.604	0.1 - AV
Br	0.175	0.01 - MCL	Mn	0.041	0.05 - TWQR
Cl	407	200 - Cat C	Ti	0.099	0.1 - RL
Hg	0.007	0.001 - TWQR	V	0.079	0.1 - TWQR
Na	224	100 - TWQR	U	0.01	0.02 - MCL
Mg	123	100 - Cat C			
TDS	1171	1000 - Cat C			

26 - Marfen (Kortman) - circular drinking trough

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	**WQC**	Measured (mg/l)	Relevant Guideline (mg/l)
As	0.024	0.01 - TWQR	Sr	2.542	0.1 - AV
Be	0.011	0.004 - MCL	V	0.01	0.1 - TWQR
Br	0.992	0.01 - MCL			
Ca	682	300 - Cat E			
Cl	2154	200 - Cat C			
Mg	179	100 - Cat C			
Hg	0.04	0.001 - TWQR			
Ni	0.03	0.02 - MRL			
Na	277	200 - Cat C			
Se	0.067	0.02 - TWQR			
TDS	3436	3400 - Cat E			
U	0.028	0.02 - MCL			
Ti	1.196	0.2 - MPL			

35 - Appelfontein - circular drinking trough

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	**WQC**	Measured (mg/l)	Relevant Guideline (mg/l)
Be	0.022	0.004 - MCL	Sr	0.522	0.1 - AV
Br	0.131	0.01 - MCL			
Cl	352	200 - Cat C			
F	2.97	1 – TWQR			
Hg	0.005	0.001 - TWQR			
NO_3	88.13	89 - Cat D			
Na	187	100 - TWQR			
Se	0.024	0.02 - TWQR			
TDS	797	450 - TWQR			
Ti	0.144	0.1 - RL			

1 - Krokodilkop

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	**WQC**	Measured (mg/l)	Relevant Guideline (mg/l)
As	0.021	0.01 - TWQR	Sr	3.049	0.1 - AV
Be	0.134	0.004 - MCL	Mo	0.032	0.07 - MRL
Br	1.376	0.01 - MCL	Zn	0.539	0.1 - AV
Ca	525	300 - Cat D			
Cl	1970	200 - Cat C			
Mn	0.053	0.05 - TWQR			
Hg	0.908	0.001 - TWQR			
Ni	0.027	0.02 - MRL			
SO_4	1641	1000 – Cat E			
Na	1310	100 – TWQR			
Se	0.127	0.02 – TWQR			
TDS	5468	3400 – Cat E			
Ti	1.093	0.2 – MPL			

22 – IP3

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	**WQC**	Measured (mg/l)	Relevant Guideline (mg/l)
Be	0.009	0.004 - MCL	Sr	0.272	0.1 - AV
Mn	0.55	0.4 – Cat C			
Hg	0.552	0.001 – TWQR			
Ti	0.140	0.1 – RL			

Table 4.3.4.5. Summary statistics for the main PHCs and COCs identified from 21 water samples collected from the Central Immerpan District Farms during March 1999.

WQC	PHC	COC	Average (mg/L)	SD (mg/L)	Median (mg/L)	Range (mg/L)	
(n) / WP	171	64				**Minimum**	**Maximum**
	8.14	3.04					
Be	20	1	0.029	0.033	0.02	0.003	0.13
Br	17	0	0.389	0.372	0.244	0.085	1.196
Cl	15	0	573	627.2	358	57	2154
Ca	6	0	166.2	210.2	80.5	18	682
F	6	6	1.792	3.338	0.82	0	13.84
Hg	19	0	0.085	0.224	0.008	0	0.908
Mo	1	3	0.010	0.031	0	0	0.146
NO_3	9	1	42.5	59.9	18	0	203
Na	17	0	259.9	283.8	176.5	8	1310
Se	10	1	0.024	0.0273	0.0155	0.005	0.127
Sr	0	21	0.960	0.798	0.628	0.188	3.049
Te	0	5	0.0012	0.0013	0.0005	0	0.003
Ti	18	3	0.389	0.372	0.244	0.085	1.196
U	3	5	0.0112	0.017	0.007	0	0.081
V	0	8	0.019	0.033	0.004	0	0.13
TDS	19	0	1486.4	1286.6	1048	226	5468

All watering points sampled contained PHCs and COCs. The highest recorded PHCs and COCs within one watering point was 13 and 5 respectively.

Table 4.3.4.6. Summary statistics for important ratios influencing fluoride toxicity for F = PHC.

Ratios	F:Ca	F:B	F:TDS	F:Sr	F:Mo	F:pH
RGR*	>166.66	>4.166	>500.00	<0.0166	<0.0067	>1.333
Average	77.309	0.557	956.320	0.568	0.0152	5.020
SD	146.478	0.851	1000.117	0.604	0.0428	3.620
Median	27.722	0.214	889.682	0.316	0.0001	6.522
Maximum	462.831	2.725	3301.769	1.818	0.1292	9.362
Minimum	1.291	0.005	128.917	0.034	1.79E-05	0.552

* = Recommended Guideline Ratio (WQC/F)

A F:pH correlation of 0.042 was obtained.

The following statistics were obtained for the As:Se ratios:

Average As:Se = 1:7.226

SD 5.830

Median 5.5

Max 25

Min 1.4

4.3.4.4 Discussion

The water quality results obtained supported those found in the surrounding areas. The occurrence of localised rural communal livestock production systems was high in the Immerpan District, as it was for the Jericho District. The same statements regarding aetiological aspects of endemic fluorosis for the Jericho District also apply.

The degree to which farms in the Immerpan District rely on groundwater is greater than those in the Jericho District, firstly as the distance between settlements is overall greater, secondly, fewer rivers are present, and thirdly, rainfall p.a. is less. An additional factor related to the isolated nature of the dwellings (and associated boreholes) is that the reliance on food sourced from the immediate surrounding, in the form of subsistence crops and livestock products, was greater than many communities in the Jericho District. In the Jericho District a greater amount of movement of people to and from industrial sectors (Rosslyn) occurred, and a greater portion of the diet came from sources not influenced by the local geochemical environment.

Finally, it must be mentioned that the purpose for which Immerpan was developed, namely the resettlement of previously disadvantaged ethnic groups on farms, is possibly compromised by both the hazards present to human health, and environmental and water quality constraints to successful, sustainable, animal production. As such, it is strongly recommended that the alleviator treatment that has been used to successfully reduce dental lesions and skeletal manifestations in Afrikaner cattle on the neighbouring farm, Delftzyl Agricultural Research Station, be expanded to include those livestock types in the Immerpan District. If only to improve animal productivity, the treatment will provide long-term benefits for the communities involved.

4.4 Water quality results – implications for communities

4.4.1 Introduction

As most of the areas investigated in this report contain a similar spectrum of PHCs and COCs, the ramifications of exposure to these WQCs are presented together in one section. The aim is not to present an exhaustive review of the possible types of effects related to exposure, but rather to provide a brief overview to the reader who may not be familiar with the constituents concerned.

4.4.2 Main PHCs recorded in the communal areas investigated

The following table presents the main PHCs recorded in the communal areas investigated. Although a direct comparison is not valid as the areas are geographically different, the table does give an indication of which WQCs are prevalent as PHCs. As indicated in each of the area chapters, some of the PHCs recorded were recorded in all areas, whereas others were only recorded in one area. Those occurring in all of the areas are designated as "High Incidence", those in more than one area as "Medium Incidence", whilst those for only a single area are designated as "Isolated Incidence".

Table 4.4.1 Main potentially hazardous constituents recorded in the communal areas.

WQC	PHC	COC	average	Incidence
As	40	3	0.022	High
Be	87	0	0.0188	High*
Br	130	0	1.192	High
Hg	56	3	0.0397	High
Se	91	2	0.1705	High
Ti	58	9	0.323	High
Sr	0	126	0.501	High
F	51	3	2.184	Medium
Te	56	6	0.0777	Medium
Mo	29	9	0.0307	Medium
Mn	66	0	0.16	Medium
Zn	0	21	0.158	Medium
V	1	21	0.014	Medium
Sb	28	0	0.037	Isolated
Cd	30	3	0.023	Isolated
Cr	4	15	0.039	Isolated
Tl	22	0	0.016	Isolated
Pb	28	1	0.026	Isolated

* not analysed in some samples

4.4.3 Possible types of effects

When attempting to establish the probable types of effects that may develop in animals and humans exposed to the PHCs recorded in the communal areas, one question poses a central dilemma. The question is:

> ***"Do the high concentrations recorded in the water source act as a valuable source of trace element supplement to the diets of both animals and humans, or do they contribute a significant additional burden to a diet already supplying amounts in excess of requirements?"***

For some WQCs exposure to the concentrations recorded for a single day alone may be regarded as having adverse effects as a consequence. For other WQCs with wider margins between requirement and toxicity, the situation is less certain.

A number of other questions are relevant:

- "To what extent do the site-specific risk factors present increase the probability of disorders due to trace element imbalances?"
- "To what extent does the semi-arid environment increase water intake and hence ingestion of constituents (Jericho and Immerpan Districts)?"
- "To what extent do the localised geochemical factors increase total exposure and intake (dust, water, food, animal products) of constituents?"
- "To what extent does a disorder, possibly subclinical and chronic, of one constituent, mask, or complicate the diagnosis, of the adverse effects of other constituents, for example endemic fluorosis in the Jericho District?"
- "To what extent (and duration) do high concentrations of one WQC protect against high concentrations of another? For example, does Se enhancing bile excretion of As (Hirunuma *et al.*, 1999) protect against As accumulation, and will this result in an induced a Se-deficiency over long-term exposure?"

There are many more questions, most of which have been dealt with in the opening chapters. One of the difficulties in answering them lies in the inherent variability in trace element requirements, for both animals and humans. Specific recommendations for a nutrient vary considerably from country to country (King, 1999). The Mn and Mo requirements of adults are almost always met by the dry matter intake (Anke *et al.*, 1999). If this is true then daily intake via the drinking water may have long-term, possibly subchronic, adverse effects not yet identified. The use of molecular biomarkers to establish trace element status is growing and will hopefully answer many of these questions in the near future. For the purposes of this report, published guidelines addressing the probable types of effects associated with the water concentrations recorded will be presented for the main PHCs observed. Lastly, it must be mentioned that some of these guidelines were derived with the limit determined by practical laboratory detection limits, and not toxicological data. For some constituents adverse effects have been recorded at levels below these laboratory detection limits. It appears likely that as detection technology improves, some of the guideline limits may be adjusted accordingly.

4.4.4 High Incidence PHCs

4.4.4.1 Arsenic

Accumulation of As occurs easily, firstly as inorganic As compounds found in water are absorbed readily, and excretion is slow. Inorganic As is a documented human carcinogen (WHO, 1993). Single, once-off exposure to a high concentration can have serious effects (DWA&F, 1996). Both chronic and acute poisoning occurs, with chronic poisoning characterised by skin lesions, of which some are carcinogenic, and acute poisoning characterised by peripheral nervous system damage, upper and lower respiratory, gastrointestinal and cardiovascular failure, and may result in death.

Studies in West Bengal (India) have revealed 6 million people to be consuming groundwater containing As at concentrations above 0.05 mg/L, of which ca. 300 000 people present with arsenical skin lesions (Chowdhury *et at.*, 1999). Hair, nail and urine results suggest that 77% of those exposed have an As burden, suggesting many people to be sub-clinically affected. The USEPA is currently reviewing the MCL for As of 0.05 mg/L, with the indication that it will be reduced to somewhere between 0.005 and 0.02 mg/L.

4.4.4.2 Beryllium

Beryllium and Be compounds have been classified by the WHO (1993) as probable carcinogens with no convincing evidence available demonstrating a biological role. Most studies deal with Be exposure via inhalation and resultant respiratory disorders. Suitable oral exposure effects data are limited, although Be has been shown to interact with DNA causing gene-mutations, chromosomal aberrations, and sister chromatid exchange in cultured mammalian somatic cells. Intestinal lesions associated with high Be water intake have been recorded (USEPA, 1998). Most well documented adverse effects are due to inhalation and resultant Acute Beryllium Disease and Chronic Beryllium Disease, both of which involve damage to lung tissue and can cause death. Very little information exists regarding adverse effects due to the ingestion of Beryllium, although short-term ingestion via water is less toxic than inhalation. Long-term effects due to water ingestion can cause damage to bones, lungs and cancer. Although absorption from the digestive tract is low, some of the samples analysed exceed the recommended guidelines by a significant degree. Fish do not appear to accumulate beryllium to any great extent.

4.4.4.3 Bromide

Excessive bromide intake leads to depression and weight loss, with most bromide-salts considered toxic. Bromine is the only liquid non-metallic element, and poses a serious health hazard. Bromide occurs in sea-water as the sodium salt, and recovered commercially by oxidation to bromine.

4.4.4.4 Mercury

Most guidelines for domestic drinking water are based on the more toxic methylmercury. Mercury is a cumulative toxin principally affecting the nervous system, with both organic and inorganic forms capable of producing toxicity. Given the high values consistently recorded in the communities investigated, although primarily of the inorganic form, it would appear that Hg should be added to any checklist of PHCs for groundwater rural supplies.

4.4.4.5 Selenium

Although an essential element, the range between requirement and toxicity is narrow, and according to Underwood & Suttle (1999) Se is the most hazardous trace element supplemented in livestock rations. Chronic exposure via the water and feed to levels in excess of requirements can cause discoloration of skin, pathological deformation of nails, alopecia, excessive tooth decay, loss of cognitive abilities, and listlessness. This is of relevance in the Jericho and Immerpan Districts as both have a high incidence of fluorosis, making it difficult to distinguish between Se and F as to the causative WQC, or relative contribution by each WQC, in the manifestation of the dental lesions observed. It is noteworthy that the DWA&F have reduced the recommended TWQR and that the USEPA does not have a Reference Concentration for Se (reference dose = 0.005 mg/kg/d). The occurrence of teratogenic effects due to Se excess has been reported in pigs, sheep and cattle, but not yet quantified in humans (ATSDR, 1989; USEPA, 1998). A further complication is that known deficiency disorders may not produce clinical manifestations that differentiate between those caused by chronic selenosis. It is interesting to note that the DWA&F (1996) guidelines state for the 0.02 – 0.05 mg/L range that although "no adverse health effects with short to medium-term use", the guideline also recommends that potable water concentrations should never exceed 0.05 mg/L. The Quality of Domestic Water Supplies (1998) do not list Se in the guidelines, despite noting that the information is based on the DWA&F (1996) guidelines, and that the guide hopes to contribute to providing safe water for all South Africans, and defines one the intended users of the guide as Water Resource Developers who should use the guide to assess whether a water source is safe for supply to domestic users. The concentrations recorded in the areas investigated in this report tend to indicate that the importance of drinking water Se contributions to the total Se intake of people has been overlooked. This is especially true in the rural context given the known positive correlation between water Se levels and Se levels in livestock milk, and maternal breast milk.

4.4.4.6 Strontium

According to Anke *et al.* (1999) drinking water is of decisive importance for Sr intake. Most guidelines do not have an upper limit for naturally occurring Sr as it is protective of radioactive ^{90}Sr (Smith, 1988), which appears to be of increasing concern linked to nuclear fall-out. However, given the levels recorded, the interference of both Sr and ^{90}Sr on bone Ca deposition, coupled to the high F levels found in the areas investigated, the wisdom of this is doubtful (Sargent *et al.*, 1966). Evidence also exists for a very rapid foetal uptake of Sr following placental retention (Enomoto *et al.*, 1999), and even an active transport mechanism from maternal blood to the foetus (Krachler *et al.*, 1999) and as such may present a significant risk factor for fluorosis.

4.4.4.7 Titanium

Titanium is regarded as relatively harmless, although there are reports suggesting carcinogenic effects, and Ti has been shown to accumulate in silica-containing tissues. Smith (1988) reported a crisis limit of 0.2 mg/L, and when viewed in conjunction with the high incidence of values far in excess of this limit, the importance of the need to ascertain a health-based limit becomes clear. Groundwater concentrations of Ti have been recorded as being higher than previously thought (Cummings, 1989).

4.4.5 Medium Incidence

4.4.5.1 Fluoride

Water-borne F appears to be readily absorbed, especially under low pH conditions. Placental transfer has been documented for many species, as has water related milk levels. Adverse effects are ascribed to dental and skeletal effects, but increasing evidence appears to implicate a number of other systemic effects, primarily those influencing immune and reproductive factors. The reader is referred to previous WRC reports as they cover the topic of F toxicology comprehensively (Meyer, 1992; Meyer, 1998).

4.4.5.2 Tellurium

Tellurium does not appear to have an essential biological role. All Te compounds are regarded as highly toxic capable of producing teratogenic effects.

4.4.5.3 Molybdenum

Molybdenosis has been identified as a risk factor in the development of atherosclerosis in humans (Ivanov *et al.*, 1999). Cattle are the least tolerant of excess Mo, followed by sheep, with pigs the most tolerant (Underwood & Suttle, 1999). Clinical manifestations vary between species, but growth retardation, weight loss or anorexia occur in most. The sulphate content of the water can reduce Mo retention significantly (Grace & Suttle, 1979).

4.4.5.4 Manganese

High absorption rates have been documented for Mn in infants and young animals. Neurotoxicity has been documented, but via the inhalation route, although animal studies have shown drinking water with high Mn to cause neurotoxicity and other adverse effects. Intakes of hazardous concentrations via the drinking water may occur over the long-term, but are unlikely in the short-term due to the off-putting taste and colour imparted at levels greater than 1 mg/L (Quality of Domestic Water Supplies, 1998). Active transport of Mn from maternal blood to the foetus has been observed (Krachler *et al.*, 1999).

4.4.5.5 Zinc

The WHO (1993) concluded that a health-based guideline was not required for Zn. The Quality of Domestic Water Supplies (1998) allocates a no-adverse-effect Category A status to Zn concentrations of less than 20 mg/L, and an insignificant-adverse-effect Category B status to greater concentrations. However, the DWA&F (1996) guidelines indicate that some instances of chronic toxicity may occur at concentrations exceeding 10 mg/L, with acute toxicity possible at concentrations greater than 50 mg/L.

4.4.5.6 Vanadium

Vanadium tends to decrease in the body with increasing age (Anke *et al*, 1999). Within the rural production context it is noteworthy that the burning of coal increases inhalation of V significantly, and can be regarded as a hazard for man (Cremer & Cornelis, 1999). Vanadium is used for chemoproctection against certain cancers. Excess V in livestock causes diuresis, naturesis, diarrhoea, anorexia and hypertension, with renal and hepatic damage often irreversible (Nechay, 1984). Vanadium was reported to have the highest rate of placental uptake compared to several other trace minerals by Enomoto *et al.* (1999).

4.4.6 Isolated Incidence

4.4.6.1 Antimony

Potential health risks are listed as increase in blood cholesterol and a decrease in blood sugar, in the National Primary Drinking Water Regulations from the USEPA Office of Water (USEPA, 1998).

4.4.6.2 Cadmium

Food is a major source of Cd, and smoking a demonstrated risk factor. Cadmium is a cumulative toxin, and accumulates predominantly in renal tissue, (half-life of 22 years). Renal damage with proteinuria appears to be the main adverse effect due to oral exposure, with inhalation having carcinogenic effects. Decreased bone mineral density has been reported prior to the onset of renal dysfunction (Ohta *et al.*, 1999). Subchronic Cd exposure and concomitant low dietary Fe has been observed to disrupt placental steroid production and maternal blood levels of reproductive hormones in late pregnancy (Piasek *et al.*, 1999).

4.4.6.3 Chromium

Chromium (VI) is readily absorbed compared with Cr (III). Chromium (III) does not appear to be carcinogenic, whilst Cr(VI) does. Adverse mutagenic effects due to the consumption of water containing Cr (VI) is decreased if water is consumed on an empty stomach. Chromium tends to accumulate in the body with increasing age (Anke *et al.*, 1999).

4.4.6.4 Thallium

Thallium does not appear to have an essential biological role, and Tl compounds are regarded as extremely toxic, and cumulative in biological tissues. Adverse effects may take several days to appear. Teratogenic effects have been recorded. Alopecia and renal, liver and intestinal problems may also occur.

4.4.6.5 Lead

Lead is a cumulative toxin, with placental transfer well documented. Young children absorb Pb up to 5 times more than adults. Most Pb accumulates in skeletal tissue, with central and peripheral nervous system damage, with prenatal exposure causing significant behavioural and cognitive defects.

4.5 Conclusion

Some of the PHCs recorded as having an "Isolated incidence", such as Sb, Tl and Cr, were only present in the water source at elevated levels at certain times of the year, as can be observed in the results for the Jericho District between the two sampling phases. Other "Isolated incidence" PHCs, such as Cd and Pb, were present in the Jericho District at elevated concentrations throughout the two sampling phases. These variations are of particular importance in terms of animal and human health when occurring simultaneously with times of increased water demand, such as lactation and high environmental temperatures. The elevated concentrations of Sb, Tl and Cr recorded in the Jericho District occurred during the hot summer months. Fractured aquifers, large variation in rainfall volume and times of year, variable aquifer recharge rates and withdrawal periods, all contribute to the complexity of predicting the seasonal changes in water quality. With these factors as a backdrop to the elevated concentrations recorded, the value of a water quality monitoring programme linked to management strategies for reducing risk, cannot be over emphasised.

A few issues deserve attention. Firstly, the extent by which the WQCs exceed the WQGs available is significantly large. The uncertainty that exists with respect to the types of effects that may occur is not confined to single WQCs, but is extended when seen in the context of the occurrence of multiple WQCs exceeding the guidelines within single water sources. The indirect adverse effects possible due to induced deficiencies presents a major obstacle in diagnosing disorders related to high concentrations of single, or multiple, constituents (see Chapter 2). Many of the water sources sampled are the only source of water for a community, both for animals and humans, further emphasising the increased geochemical risk present with geographically localised production systems.

Water concentrations of Fe, Zn, Cu and Mn do not appear to have a significant correlation in breast milk, whereas maternal Se status is closely correlated to milk Se (Lonnerdal, 1999). Given the high incidence of Se as a PHC in the areas investigated, the probability of overexposure to Se for infants is high.

CHAPTER 5

WILDLIFE PRODUCTION SYSTEM MODEL

5.1 Introduction

Without water wildlife cannot survive, and in a water scarce country such as South Africa, the pressures placed on the available resources are resulting in increased levels of water pollution (Quality of Domestic Water Supplies, 1998). The provision of water of an acceptable quality, coupled to the protection of water resources for long term sustainability, are critical managerial issues for a wildlife enterprise. Water quality is often an underrated aspect in game ranch management (Meyer, 1999).

At present no formal WQGs exist for wildlife. Some isolated studies investigate the effects of supplying water on wildlife movement, behaviour, and the environment. The main deficiency with these studies is insufficient documentation of site-specific information, rendering extrapolation to other environments questionable. Very few studies focus on the effects of WQCs on wildlife health. These studies do not enable risk assessment formulation, largely due to insufficient water chemistry information, complexities between trace mineral interactions and overriding palatability effects, but increasingly emphasis is being placed on the geochemical factors influencing water quality, and the resultant role of water on supplying a significant amount of animal macro- and trace element requirements (Louw, 1984; Winter, 1985; Knight *et al*., 1988; Bowell *et al*., 1996; McDowell & Conrad, 1986; Meyer, 1998).

In the field of WQGs for human consumption, until 1996 the vast majority of local guidelines were based on international guidelines, mostly unsubstantiated in the southern African context. Since 1993 two new versions of WQGs have emerged from the Department of Water Affairs and Forestry (DWA&F, 1993; DWA&F, 1996; Meyer *et al*., 1997) addressing domestic to agricultural user groups, illustrating the rapid growth and change within the field as analytical techniques allow for increased documentation of adverse effects occurring in user groups.

The main inadequacy of published WQGs, namely the isolated static mg/L basis, applies to wildlife just as it does for commercial livestock production systems, where different ingestion levels occur across varying environmental conditions. Synergistic and antagonistic factors due to interactions between WQCs, the user, and the environment, are often more deterministic that the chemical concentration of a WQC.

Although CIRRA, Version 2.03, takes into account synergistic and antagonistic factors and is based on a modelling approach, using ingestion rates on a mg WQC/metabolic mass, using the exponent $LW^{0.82}$ for water turnover/d basis, its main application if for commercial livestock production. Whilst in many instances the toxicological modelling outputs are valid for wildlife, this is not always so. Main reasons for this are different nutritional factors, highly varied water source utilisation and hence ingestion, and different production conditions and aims. Assessing the suitability of water for wildlife is a complex task, primarily as multiple specie types utilise the same source, ranging from ruminant to monogastric species, and water-dependant non-mobile herbivores to non-water dependant mobile herbivores (Thrash, 1993).

5.2 Main water quality issues for wildlife

5.2.1 Water quality constituents

Water contains inorganic and organic constituents which may be a valuable supplement for wildlife. High concentrations and/or imbalances between constituents can, however, be hazardous. "Good quality" water does not imply pure water, nor does it imply clear water with acceptable smell or taste. Murky water with colour or unpleasant odour may be safe to drink, whereas clear water may contain pathogens or potentially hazardous constituents that are harmful. As a result, water that may well be fit for use by wildlife is often rejected in favour of water often incorrectly perceived to be of a better quality. As the water quality reports of the Pilanesberg National Park, Klaserie Area and Selati Game Ranch indicate, there are many groundwater and surface water sources in South Africa that, with incorrect management procedures, can be potentially hazardous to wildlife.

Table 5.1 provides information of a sample taken from a game ranch near the Phalaborwa district. The concentrations and constituents involved are not atypical, with similar examples having been recorded in other areas in South African subterranean water sources (Meyer *et al.*, 2000). Even using a very general water intake guideline of 4% body weight (Bothma, 1996), and ignoring site-specific risk factors, the resultant trace mineral dose ingested from the water is significant when compared to mineral requirements for these elements (Underwood & Suttle, 1999; NRC, 1996), and can lead to both direct toxicity and induced deficiencies. The primary problem in identifying the effects due to the ingestion of potentially hazardous constituents is that they are invariably subclinical in nature, and specifically in the case of wildlife, affected animals are seldom observed. Furthermore, a differential diagnosis is often required to establish the role of a PHC. Interactions between constituents in the water source complicate the matter further, and may alleviate adverse effects, or may exacerbate the effects of PHCs. None of the concentrations appearing in Table 5.1 will have a significant effect on the colour or palatability of the water source, and game will readily consume such water, creating the incorrect impression that it is fit for use. Furthermore, due to the varied spectrum of wildlife that may be present on a game ranch, significant differences may exist in terms of species tolerances to WQCs.

Table 5.1 Potentially hazardous water quality constituents from a borehole on a game ranch in the Phalaborwa district.

Water Quality Constituent	Recorded conc. (mg/l)	Guideline (mg/l)*
As	0.193	>0.05 – significant risk of adverse effects in sensitive groups
Se	2.291	>0.05 – significant risk of adverse effects in sensitive groups; >0.1 - danger of selenium toxicity
Be	0.043	>0.004 - risk of adverse effects in sensitive groups
Mo	0.092	>0.02 - risk of adverse chronic and acute effects
Cd	0.055	>0.02 - risk of adverse chronic and acute effects
Sb	0.032	>0.006 – maximum contaminant level
Te	0.311	>0.01 - crisis limit

* Adapted from: Department of Water Affairs and Forestry (1996); USEPA (1998), Kempster *et al*, (1985)

Water of poor quality can result in serious financial losses, especially where rare wildlife may die. Financial losses may also occur due to reduced growth and reproductive rates, and increased equipment replacement intervals. The action of providing a watering point for wildlife has an impact on the environment. This not only influences factors such as soil infiltration rates, soil erosion, plant species and plant succession, but can seriously disadvantage certain wildlife species. The provision of artificial water supplies can change normal animal behaviour, for example, nomadic species may become permanent residents. Water palatability plays a major role in influencing the movement of wildlife, with even avian species such as doves and sandgrouse selecting those water sources with the least salinity (Knight, 1989).

5.2.2 Safe water - concentration versus dose

The most complex task in risk assessment for wildlife watering is determining the extent of the exposure of different wildlife species to a PHC. This requires knowledge of the water chemistry of all available water sources, the time spent by species at each watering point (dose intake from water) and knowledge of site-specific risk factors present (synergistic and antagonistic effects). Risk factors may be allocated to water, animal, environment, nutrition, ecology and production system. Examples are a high concentration of a constituent in feed or supplement provided, time of day when water is consumed, altitude of game ranch, seasonal variations in water quality and peak lactation times, to mention but a few. Some relevant aspects include:

- Are the species at risk non-water dependent (giraffe, eland), non-mobile water dependent (impala, waterbuck, warthog) or mobile water dependent (burchell's zebra, blue wildebeest)? Can they access alternative watering points and ingest water of a different chemical composition resulting in a different dose intake?
- Does the feeding spectrum of the species at risk, increase or decrease risk (chemical composition, nutritive factors, moisture percentage)?
- Does the breeding season coincide with poor water quality/dry periods?

- How does the spacing, design and placement of watering points advantage or disadvantage different species (tall grass requirement - sable, roan; cluster of watering points - waterbuck) by influencing habitat and plant species diversity?
- Do the species require water for thermo-regulation (mud pools or cattle troughs)?
- Does the game ranch fencing type, and design, allow for species at risk to obtain water from neighbouring farms?

Species which select for plant parts and plant species, such as steenbok, are suited to risk assessment concerning total trace mineral ingestion predictions, as both animal tissue (used for assay and histopathological examination), water and feed samples can be obtained to provide a representative indication of total exposure.

5.2.3 Dangerous concentrations?

Unfortunately the concentration at which a constituent will have an adverse effect is not fixed. Taking F as an example, site-specific factors such as temperature, feed salt, protein and fat percentage, physiological adaptation to environment, and even altitude, all influence F toxicology. A concentration of as little as 5 mg F/L may be toxic one situation, but 10 mg F/L may be safe in another. The correct concentration of Ca, total dissolved solids (TDS), Mg, B, Sr and Mo are all needed because they influence F toxicity. As a result, single value guidelines are misleading and conservative in nature, and it is best to perform a comprehensive risk assessment modelling approach enabling the calculation to be performed on an ingestion basis (mg F/kg$^{0.82}$ BW/day). In cases of suspected water quality problems, specialist advice should be sought. An example of some types of information required to assess the water source in the context of intended usage is given in Table 5.2.

Table 5.2 Some information required to perform a risk assessment for water quality.

Information type required	**Examples of detail required**
Water quality	Inorganic and organic water quality constituent concentrations
Water source	Type of source, design of watering system, placement of source; distance from alternative sources
Animal specific information	Wildlife species present, physiology, water intake, feed intake
Environment specific information	Environment type, habitat type, temperature, altitude, soil analyses
Nutritional information	Feed and lick composition, forage/browse trace mineral content, moisture percentage

5.2.4 Typical problems that occur

The following typical problems can occur with water quality for wildlife:

- Water that tastes bad to wildlife can severely reduce water and feed intake, with subsequent losses of body weight, milk production and general health. Sudden exposure to highly saline water can drastically reduce initial intakes, followed by high intakes that may have fatal consequences. The constituents SO_4, Mg, Na, Ca and TDS are primarily involved. Usually, the ratios between constituents are more important than the concentrations alone. Most species can adapt to high WQC concentrations if exposure is incremental and continuous.

- Constituents which, at certain concentrations, under certain conditions, act as a poison, are termed "potentially hazardous", and may impair health or cause death. Toxicological problems depend on the constituent involved, but range from chronic factors such as reduced growth, to acute factors which may be fatal. Fluoride, TDS, Cl, SO_4, NO_3, and several trace minerals (Se, Hg, Te, Be, U, Cd, Mo) pose the main threats, but the condition of the animal, nutritional status and production system specifics play an important role (Meyer & Casey, 1999).

- Water temperatures can rise significantly in black PVC pipes exposed to the sun. Burying the pipes at least 100mm alleviates the build-up of carbonate encrustation. Regular cleaning of drinking troughs and reservoirs not only prevents excessive salt build-up, but also results in improved water quality.

- Metals may accumulate in animal tissues and products such as milk (and hence influence suckling young), although most do not represent serious health risks following the short-term exposure. Milk is usually well protected against As, Cd, Hg, and F, but not against Pb and Se, although with very high levels in water and feed, a concurrent increase in milk for other constituents will most probably occur (NRC, 1996; Underwood & Suttle, 1999). Many metals may accumulate in tissues such as muscle, bone, brain, liver and kidney, although other than Hg and pesticides most do not accumulate to an extent where they pose a significant consumer health risk for the consumption of wildlife products.

- Natural or artificial water sources impact on the wildlife species present and on the ecosystem, which in turn affects habitat utilisation, soil and vegetative parameters. Depending on alternative water source availability, water palatability can determine game movement and watering patterns, resulting in sensitive species avoiding the water source, whilst non-sensitive species may increase their watering due to lessened competition around the drinking point. The presence or absence of specific species consequently influences the surrounding area. The type of effect depends on the species involved (large water dependent herbivores versus small territorial monogastric species), the distance to the nearest alternative source, geographical barriers and seasonal rainfall patterns.

- Water provision placement and design influences the drinking frequency of certain types of game, with some preferring secluded watering points to open ones. The physical structure can also attract or repel certain species. A combination of these factors can alter the time of day during which the species consume water. This alone can significantly influence the suitability of the source, as in hot, dry areas, the concentration of some constituents can differ enough between sunrise and midday so as to result in a different constituent ingestion rate and hence dose intake over an extended period.

- The distance between water sources, permanent and temporary, habitat diversity and ecosystem stability must be taken into account in order to cater for the requirements of certain species. Migration and forage utilisation patterns, habitat requirements for successful breeding, rearing of young and maintenance, all influence water provision. Manipulation of water provision is a valuable mechanism for allocating poor quality resources to less sensitive species, and a method for mitigating against potentially hazardous effects.

5.2.5 Identifying animal health problems

Whilst problems associated with taste are relatively easy to observe, toxicological problems may go by unnoticed, or they may be attributed to other factors such as poor nutrition or internal parasites. Some effects observed are a reduction in reproductive efficiency, fertility, the viability of offspring, growth rate, and resistance to disease. Clinical symptoms for specific poisons may also be noted. A major problematic factor in terms of diagnosing health related disorders in wildlife is the difficulty of observing and measuring health. Firstly, depending on the size of the area, and purposes for which the wildlife are kept, adverse effects experienced by some species may go by unnoticed. Due to the typical subclinical, chronic course followed by many PHCs, adverse effects may only become noticed at an advanced stage. Some of these animals may be caught by predators, which may reduce a managers opportunity even further of observing animals which are experiencing difficulties. Growth and health parameters often measured routinely in livestock may be very difficult, if not entirely impractical, to obtain in some wildlife species. Obtaining a representative number of samples also presents a problem. Identifying site-specific factors such as chemical composition of the primary feeding spectrum, geographical and pedological factors can provide valuable insight regarding the changes in mineral concentrations over seasons (Jumba *et al.*, 1996) which need to be considered in association with the mineral intake from drinking water.

With all these factors, the importance of knowing the quality of the water provided to wildlife, and the various types of effects the water may have on the species present, and ecological norms, becomes apparent as a proactive management procedure.

5.2.6 Extent of problems in South African water sources

Many groundwater sources currently used for wildlife watering in South Africa cause adverse effects. The types of problems encountered differ from region to region, game ranch to game ranch, and even borehole to borehole, on the same game ranch. Although certain areas do show have a high incidence of occurrence of a specific hazard (e.g. fluorosis), on-site variation is usually significant. This is true even between a borehole source and a drinking trough. In some areas a correlation exists between the chemicals present in groundwater which increase risk, an example being the correlation between F, TDS and Ca. Some problems are due to naturally occurring levels, others are due to varying forms of contamination. Surface water problems also occur, but tend to involve different WQCs, such as toxic algae. The water quality results presented in Chapter 6 indicate the localised nature of occurrence of certain PHCs in the aquatic environment.

5.2.7 What can be done by the manager?

Differences between game ranching and livestock production regarding grazing methods and the subsequent access to water sources introduce a complex variable, namely predicting the ingestion from a single water source. In livestock systems this is usually fairly easy as the animals are maintained in a camp with only one drinking trough, and information such as the number, body weight and type of animals consuming water is often known. With wildlife the degree of free-ranging movement, territorial aspects and feeding patterns can result in sufficient reductions in intake from potentially hazardous water sources so as to render them fit for use, despite hazardous constituent concentrations. This is particularly true in the case of cumulative toxins, but for some constituents an intermittent intake can be more deleterious than a continual one.

No meaningful action can occur without measurement of that which is to be managed. The first step is to analyse the water. The second step is to identify the potential hazards present with the use of a WQG, with the aim of recommending what the chemical composition should be, not just to prevent adverse effects from occurring, but to achieve optimal water utilisation. The manager can manipulate the water quality by the addition of chemicals to the water, or the manager can manipulate the effects due to the consumption of water, either by supplementary feeding or influencing the ingestion of water from key watering points. Knowledge of the seasonal variations in water quality and physiological stages of high risk wildlife species is essential in encouraging or discouraging animal presence at key watering points.

5.2.8 Water quality monitoring

Water quality monitoring provides the information required to manage water sources utilised in a wildlife enterprise, such as knowledge of potential hazards and trends regarding aquifer recharge rates, deteriorating water quality and possible pollution sources. Drastic concentration changes can occur between seasons. Monitoring of water quality allows the manager to allocate water during periods of poor quality to less sensitive species. For example, in the case of F, non-lactating mature female animals would be given access to high fluoride waters as opposed to young growing animals. This is because young growing animals have a higher water turnover rate and are more at risk to dental and skeletal adverse effects due to the ingestion of F.

Key watering points should be identified within a wildlife enterprise and be monitored on a quarterly basis. A full analysis including a semi-quantitative scan should be obtained from the nearest water laboratory, which should be able to advise on the correct methods for collecting water samples.

5.3 WPS Model

5.3.1 Introduction to WPS Model

The objective of the WPS model is to allow the user to enter relevant information obtained from the actual game ranch/reserve which can be compared to reference material in order for a risk assessment to be conducted. The risk assessment will thus take into account the significant site-specific factors that may increase or decrease risk for the management norms evaluated. In order to make an informed judgement regarding how safe water is for use, water quality properties must be measured and compared with a reference value which is usually in the form of a guideline. Due to the inherent variability related to biological cause and effect relationships, WQGs are used as opposed to water quality standards, and these enable judgement on the following norms to be made:

- Animal health and productivity.
- Watering system equipment.
- Environmental factors.
- Safety of wildlife products for human consumption.

As described in section 5.2, the dose intake, over varying lengths of time dependent on the constituent concerned, is one of the most critical factors that will determine whether a WQC will be beneficial or detrimental to animal health. It is thus easily understood how a single watering point with a potentially hazardous concentration of a WQC may, in the final instance, be tolerated without having any adverse effects, should alternative watering points with significantly lower concentrations, also be utilised within a short time interval by the same species. This dilution effect is of particular relevance to those species that move over extended territories, termed mobile, as opposed to those which are non-mobile, and tend to remain in a small, defined territory. Of equal importance is the dilution effect gained from moisture present in the diets of the different species which either increase, or decrease, the constituent ingestion obtained from drinking water. Placing the different species at the watering points available is one of the main tasks of the WPS model. It requires knowledge of the wildlife species present, the habitats present, the potential hazards and placement of the watering points available, and the freedom of movement and accessibility to these points for different wildlife species.

The user is referred to the WRC Final Report K5/644 (WRC, 1998) for a more in-depth discussion of the principles of modelling for risk assessment, the use of ingestion-based reference documents to accomplish the site-specific evaluation of a water source, and technical information pertaining to software programming language and platforms used.

5.3.2 Procedures and relevant Reference Documents

The WPS model consists of three general sections as experienced by the user. The first may be collectively termed data capturing screens, and comprises general and site-specific information. The second section presents the user with the risk assessment results, and the third is a combination of solution options that create "dummy" sample files allowing the user to manipulate certain variables and evaluate the outcome thereof. To aid this, supporting information in the form of background information on types of effects and calculation results, are also provided.

Five different risk assessments, termed Levels, are performed. The first, termed Level 1 RA, provides a generic application level assessment per watering point. Level 2 RA provides a water point exposure matrix assessment, where the predicted intake from multiple water sources is taken into account. This allows for the potential dilution effect to be included, and is possibly one of the most beneficial aspects of the WPS model, as it prevents the incorrect *contextual* classification of a watering point. This is due to the fact that dilution effects, apparent when total ingestion is calculated, may in effect allow a water source containing hazardous levels to be utilised without adverse effects. Level 3 RA ustilises site-specific, and species specific, risk factors to be taken into account. A few information types used are those for the environment, toxicology, and species feeding spectrum preferences. A Feed Exposure Matrix is compiled for Level 4 RA, and incorporates PHCs present in the feed in a total ingestion, per constituent, basis. Level 5 RA addresses ecological issues due to the watering point and presence/absence of associated wildlife species.

The results of the risk assessments are provided in a number of different forms. For example, an output of Level 2 RA is termed a watering point exposure risk assessment (WPERA). Further rankings, according to WQC, WP, wildlife species, including and excluding system factors, are provided. An added benefit of this method is that it allows for an educated user, familiar with the user group and game ranch, to accept or dismiss possibilities based on site-specific, specialist knowledge. It also allows for the planning of a game ranch in terms of both water provision design (which water sources, reservoirs and watering points to use), placement (which suitable habitats to encourage/discourage tolerant and sensitive user groups respectively), and most suitable wildlife species selection. A schematic of the WPS model is provided in figure 5.1

5.3.2.1 Data capturing screens for multiple watering points

As opposed to most livestock production systems which normally reside in association with a single watering point for a period of time, or indeed permanently, wildlife may have a choice of multiple watering points. Some species may consume from different points during a single day. This necessitates a capability to capture multiple water chemistry data, and detail concerning each watering point. This detail is required as it provides a means for establishing the possible preference a species will have for a watering point, based on its design, accessibility, and habitat placement. This information is used for two risk assessment outputs, one for animal health, the other for ecological impact assessment. Needless to say, this capability required complex software programming to enable multiple sample files to reside within a single sample file, which is in reality a "ranch" file. The screen prints provided are self-explanatory.

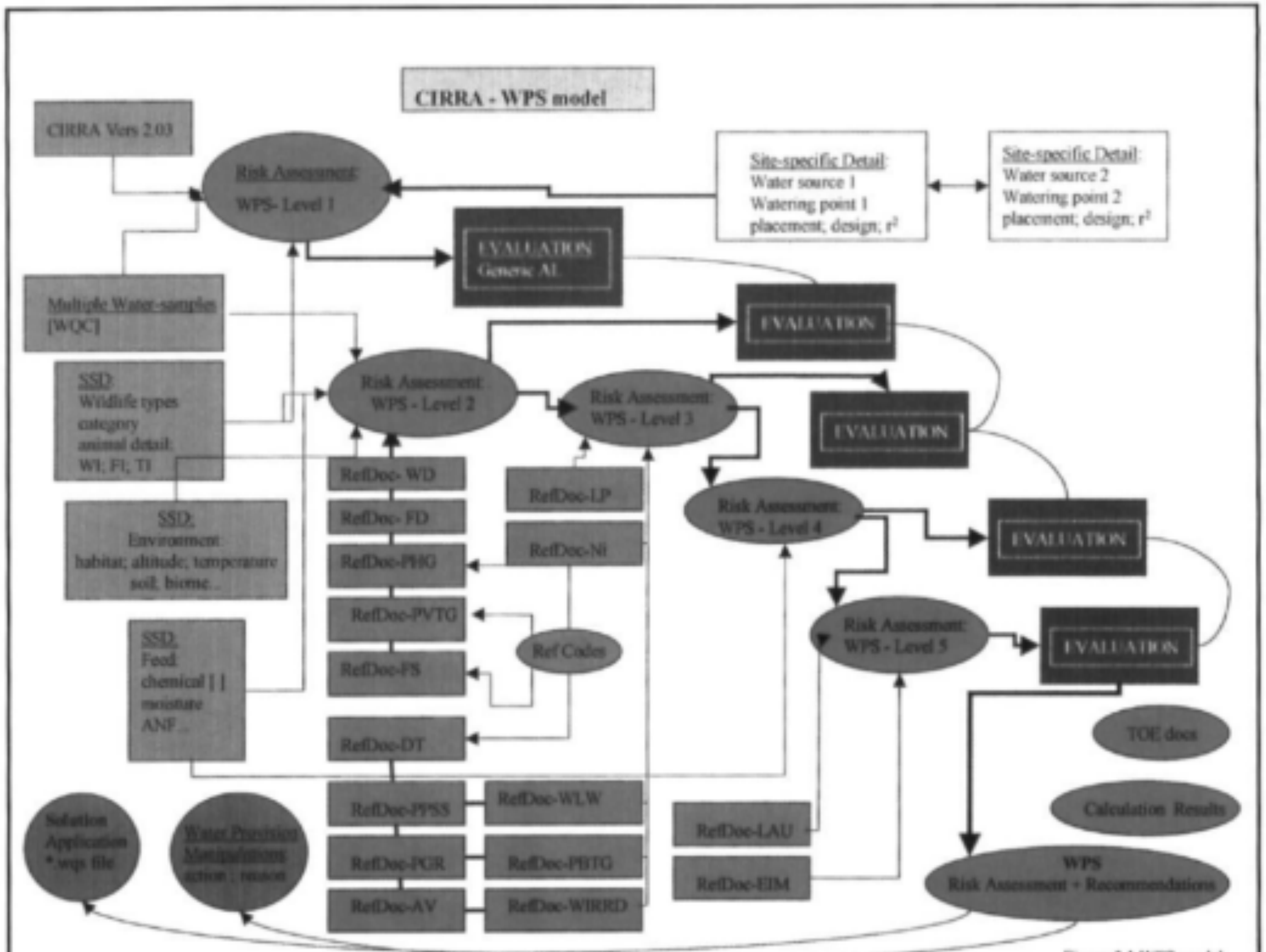


Figure 5.1 WPS model

5.3.2.2 Level 1 RA – Generic application

At the most simplistic level water sources may be ranked independently of the wildlife species present, using the inherent toxicity present within each water source to assess the fitness of use. However, as mentioned above, the presence of a potentially toxic constituent in a water source does not in itself constitute a hazard. Site-specific factors may partially or fully mitigate toxicity. Similarly, the occurrence of low concentrations of constituents with a low order of toxicity, does not prevent a hazardous situation from occurring. Furthermore, the presence of other constituents in the water and/or feed may induce toxicity across a wide range of water concentrations. But, due to the vast differences in the feeding habits, water intakes, and inherent adaptability to certain constituents, between the different wildlife species that may be present, this entry level classification, termed Level 1, is provided to the user. The results are provided per watering source, and watering point. This enables the user to identify any watering system effects observed at the watering point that may be contributing to PHCs and COCs, as opposed to those present in the water source. It is analogous to a GAL risk assessment excluding system factors, as used in CIRRA Version 1.03. The reader is referred to the Final Report K5/644 for more detailed information.

5.3.2.3 Level 2 RA

5.3.2.3.1 Water Exposure Matrix

This procedure uses information provided by the user in the data capturing screens for water, water chemistry, wildlife species present, habitats present, and other relevant information, to formulate a series of possible ingestion matrixes. The user is prompted for information regarding accessibility of the various watering points to the species present, and the presence or absence of each species at the watering points.

The matrix is compiled for all possible watering point combinations, for all WQCs provided, and the output is designated at Level 2.1. Should user information render a matrix line as false, it is then omitted from the next step that links species to the matrix lines. The output of this second step is designated as Level 2.2. It should be clear that this produces an enormous amount of data, from which the most probable true matrix lines are selected. For example, a game ranch with five watering sources and five watering points, and chemical data for 46 WQCs, produces a matrix with 1380 line outputs. This is the benefit of conducting these risk assessments in a software environment, as time taken to conduct the same procedure manually, with an increased possibility for errors, would prevent many persons from performing a risk assessment.

Matrix Rules:

Resultant Concentration = X, where X = (WP1....WP^i)/n^{i}WP

Equal ranking rule: If X1 = X2, then,

where X contains WP1 – WPi with lowest [WQC] = lower risk ranking (contains lowest [WQC], or where X1+X2 contain lowest [WQC], X containing highest [WQC] = higher risk ranking.

Table 5.3.1 Partial example of a Water Exposure Matrix for WPS.

WP Exposure Matrix:	Resultant Concentration (mg F/L) for: (WP1....WP^i)/n^{i}WP	Ranking of WPs: Least risk = 1, most risk = 30
1	3 (mg F/L)	12*
2	6 (mg F/L)	30
3	1 (mg F/L)	1
4	5 (mg F/L)	28
5	1.5 (mg F/L)	2
12	4.5	26
13	2	5
14	4	24
15	2.25	6
23	3.5	19*
24	5.5	29
25	3.75	22*
34	3	13
35	1.25	3
45	3.25	15
123	3.33	17
124	4.66	27
125	3.5	20*
134	3	11
135	1.83	4
145	3.16	14
234	4	25
235	2.83	9
345	2.5	7
1234	3.75	21*
1235	2.87	10
1245	3.87	23
1345	2.62	8
2345	3.37	18
12345	3.3	16

* see Matrix rules

Reference documents are contained within the following sub-levels. User defined data overrides the reference documents (as for previous modelling performed for livestock watering), but in the absence of this data, the RefDocs allow for the linking of wildlife species to watering point combinations, in a {WP1..WPi}= true/false format. These reference documents rely on species mobility and known distances travelled for certain species, their dependency on water, obstacles preventing access to certain watering points, and habitat preferences for each species present. The end result is a series of risk assessments, by wildlife species, based on the predicted WPs accessed and the PHCs and COCs contained therein. This is termed a watering point exposure risk assessment (WPERA), and forms an output of the Level 2 evaluation.

5.3.2.3.2 Reference Documents used for Level 2 Risk Assessment

The following series of reference documents and reference codes provide information that is used to either place the animal in a preferred habitat, for the purposes of linking it to probable water point exposure, and to evaluate possible risk factors per wildlife type based on inherent species factors.

RefDoc – WD (Water Dependency)

The following table presents the reference material used in assigning risk factors to wildlife species. Note that the classifications are not absolutes, only relative differences between species according to the current body of knowledge. Some species may be water dependent, but also adapted to arid conditions, hence both classifications are referred to.

RefDoc - WD for the WPS model.

Non-water dependent Herbivores – Browsers Damara Duiker Cape grysbok Klipspringer Steenbok Suni	Non-water dependent Herbivores – Browsers + Grazers Eland Gemsbuck Giraffe Grey Rhebuck Nyala Springbok	Non-water dependent Herbivores – Grazers Oribi
Water dependent Herbivores – Browzers Bushbuck Bushpig Red Duiker Black Rhino Sitatunga	Water dependent Herbivores – Browzers + Grazers Elephant Sharpes Grysbok Impala Kudu	Water dependent Herbivores – Grazers Black Wildebeest Blue Wildebeest Blesbuck Bontebok Burchells Zebra Buffalo Lichtenburg Hartebeest Hippo Hartmans Zebra Mountain Zebra Reedbuck White Rhino Tssesebe Warthog Waterbuck
Mobile Water dependent Herbivores Burchells Zebra Blue Wildebeest Buffalo Blue Duiker White Rhino	Non-mobile Water Dependent Herbivores Impala Warthog Waterbuck	Intermediate water Dependent Herbivores – bulk feeders Red Hartebeest Mountain Reedbuck
Adapted To Arid Conditions Eland Gemsbuck Kudu Mountain Zebra Red Hartebeest Springbuck Ostrich	Possible non-water dependent species Giraffe Common Reedbuck Eland Sable Antelope Roan Antelope	

RefDoc – PVTG (Preferred Veld Types Guide)

The following RefDoc is provided as a preferred veld types guide.

RefDoc - PVTG for the WPS model.

Wildlife Species	**Preferred veld type code***
Blesbok	d; k; l; m
Black Wildebeest	d; k; l; m
Blue Wildebeest	g;h:l;j:k;m
Bontebok	a
Buffalo	a;f;g;h;l;m
Burchell's Zebra	f;g;h:l;j;k:l;m
Bushbuck	e;f;g;h;l
Bushpig	e;f;g;h;l
Eland	all except e
Elephant	e;f;g;h;l
Gemsbok	b;c;d;h;j;k
Giraffe	c;d;g;h;l;j
Grey Duiker	all
Grey Rhebuck	all except e;j
Hippopotamus	g;h;l
Impala	g;h;l
Klipspringer	all except e
Kudu	c;d;f;g;h;l;j
Mountain Reedbuck	c;d;f;g;h;l
Mountain Zebra -Cape -Hartman's	 -a; c -a; c
Nyala	f;g;h;l
Oribi	g;k;l;m
Ostrich	all except e
Red Duiker	e
Red Hartebeest	b;c;h;l;j;k
Reedbuck	a;g;h;l;k;l;m
Roan antelope	g;h;l
Sable antelope	g;h;l
Springbok	b;c;d;j;k
Steenbok	all except e
Tsessebe	g;h;l
Warthog	a;f;g;h;l;j;k;m
Waterbuck	g;h;l

* see Reference Codes to Veld Types.

Reference Codes – Veld Types

Veld Type	Code
Fynbos: western Cape Province	a
Desert and succulent Karoo: western Northern and western Cape; southern Karoo, Namaqualand and Richtersveld	b
Arid Karoo: central Northern Cape Province	c
Great Karoo: central Northern Cape Province and southern Fee State	d
Forests: western Cape Province and eastern Cape Province	e
Valley bbushbeld: eastern Cape Province and KwaZule/Natal	f
Lowveld: Mpumalanga and KwaZulu/Natal	g
Sweet bushveld, mopaniveld and turf thornveld: Northern Province	h
Northern Province bushveld: sour and mixed	I
Kalahari: Northern Cape Province	j
Short and mixed grassland: Free State, Mpumalanga and north-west Provinces	k
Mountain grassveld: KwaZulu/Natal, Lesotho and eastern Cape Province	l
Tall grassveld: Mpumalanga, Pietersburg Plateau, KwaZulu/Natal	m

Reference Codes to Biomes

Biome	Veld Type Code*
Savanna	f;g;h;I;j
Nama-Karoo	b;c;d
Grassveld	k;l;m
Succulent Karoo	b;c;d
Fynbos	a
Desert	b;c;d
Forest	e;m;g

* see Reference Codes to Veld Types.

RefDoc – PHG (Preferential Habitat Guide)

The following RefDoc is provided as a preferential habitat guide.

RefDoc – PHG for the WPS model.

Wildlife Species	Preferential habitat type code*
Blesbok	4.2
Black Wildebeest	2.2
Blue Wildebeest	4.1.1.1
Bontebok	2.3
Buffalo	4.1.1.2
Burchell's Zebra	4.1.1.3
Bushbuck	3.1.1;3.3
Eland	4
Gemsbok	4.1.1.4;4.1.2;4.1.3;4.1.4
Giraffe	4.1.1.4
Grey Duiker	3.4
Grey Rhebuck	1.4;1.6;1.7
Hippopotamus	5.1
Impala	4.1.1
Klipspringer	1.1;1.3;1.6
Kudu	4.1
Mountain Reedbuck	1.2;1.5;1.6
Mountain Zebra	1.8
Nyala	3.1;4.1.1.4
Oribi	2.1
Red Duiker	3.1;3.2;3.3
Red Hartebeest	2.1;4.1.1.3;4.1.4;4.3
Reedbuck	4.1.1.3;5.2
Roan antelope	4.1.1.3
Sable antelope	4.1.1.2;4.3.2
Springbok	4.1.1.3;4.3.1
Steenbok	4.3.3
Tsessebe	4.4
Warthog	4.1.1.3;2.1
Waterbuck	4.1.1.3;2.1

* see Reference Codes to Habitat Types.

Reference Codes – Habitat Types

Level A	Level B	Level C	Level D
1. Mountain	1.1) cliffs 1.2) dry, scattered bushes, trees 1.3) hillocks 1.4) high slopes 1.5) low splopes, dry 1.6) stony hills, stony patches or slopes 1.7) plateaux, grass cover 1.8) plains		
2. Plains	2.1) flood, vlei, short grassland 2.2) open, grassland 2.3) sea level, fynbos		
3. Thicket	3.1) dense shrub 3.2) forest 3.3) riparian 3.4) shade and shelter	3.1.1) permanent water 3.1.2) no permanent water	
4. Veld	4.1) bushveld 4.2) highveld, grassland 4.3) open 4.4) grassland/bushveld edge	4.1.1) open 4.1.2) sparse, dry 4.1.3) dry 4.1.4) semi-desert	4.1.1.1) trees, shrubs 4.1.1.2) tall grass, shade 4.1.1.3) grassland 4.1.1.4) dry
5. Water	5.1) open 5.2) open with reeds		

RefDoc – PBTG (Preferred Bushveld Types Guide)

The following RefDoc is provided as a broad reference to the preferred bushveld types guide. The reason for including different veld, habitat and bushveld types is to cater for the different levels of detail the user may have regarding the site-specific details of the ranch.

RefDoc - PBTG for the WPS model.

Wildlife Species	Preferred bushveld type code*
Blue Wildebeest	aa b
Buffalo	bb c
Burchell's Zebra	a bb
Bushbuck	bb cc
Bushpig	c
Damara dik-dik	b cc
Duiker	a bb cc
Eland	a bb
Elephant	bb c
Giraffe	bb c
Kudu	a bb c
Nyala	cc
Oribi	b
Red Duiker	c
Red Hartebeest	a b
Reedbuck	aa bb
Springbok	a
Steenbok	aa bb
Tsessebe	aa b
White Rhino	aa bb
Warthog	bb c
Waterbuck	bb c

* see Reference Codes to bushveld Types. Double letters of the same code within a row imply a preference for that bushveld type over the other code within the row. Same number letters within a row imply equal preferences.

Reference Codes – Bushveld Types

Bushveld Type	Code
grassveld	a
open bushveld	b
dense bushveld	c

RefDoc – FS (Feeding Spectrums)

The following RefDoc provides a method of linking any chemical data on the types of plants, grasses, browse, and other feeds, to wildlife species. As such, the total exposure to PHCs present in the water and feed may thus be estimated in order to establish if certain species are more at risk than other, specifically for those wildlife types resident in habitats with PHCs in both feed and water. The RefDoc also provides a rough estimation for the moisture percentage present in the feed, a factor which can significantly reduce drinking water intake.

RefDoc – FS for the WPS model.

Wildlife Type	Feeding Spectrum Code
Blesbok	1.1
Black Wildebeest	1.1
Blue Wildebeest	1.1
Bontebok	1.1
Buffalo	1.2
Burchell's Zebra	1.3
Bushbuck	3:2:1.1
Bushpig	
Eland	3:2:1
Elephant	
Gemsbok	1.1:3
Giraffe	2:3
Grey Duiker	1:2:3
Grey Rhebuck	1:2:3
Hippopotamus	
Impala	1.1:3
Klipspringer	2:3
Kudu	2:3
Mountain Reedbuck	1.2:3
Mountain Zebra	
-Cape	1.3
-Hartman's	
Nyala	1:2:3
Oribi	1.2
Ostrich	
Red Duiker	
Red Hartebeest	1.1:3
Reedbuck	1.2
Roan antelope	1.2
Sable antelope	1.2:3
Springbok	1.1:3
Steenbok	1.2:2:3
Tsessebe	1.2.
Warthog	1.1
Waterbuck	1.2:3

* see Reference Codes to Feeding Spectrum.

Reference Codes – Feeding Spectrum

Feeding Spectrum	Code
Grass	
- short	1.1
- tall	1.2
- short and tall	1.3
Non-grass herbs	2
Leaves	3
Fresh Meat	4
Carcass	5

RefDoc – FD (Fence Detail)

Information concerning the fences present on the ranch are compared to the documented effectiveness of the fence to prevent wildlife types from crossing them (jumping, climbing through, digging under). The relevant data collected is:

height

top strand height

electrification and position of live wires

ground insert

mesh

5.3.2.4 Level 3 Risk Assessment

The reader is referred to the WRC Final Report K5/644 for site-specific information incorporation factors as detailed on the Animal Detail Tab and the Environmental Detail Tab. These deal with biomes, temperature, altitude and soil factors. Temperature grids, adapted form the latitude and longitude values entered for the water sample are taken as a default should the user not specify the detail in the Environmental Detail Tab (see WRC, 1998). The Level 3 RA includes factors, species-specific and site-specific, that may increase and decrease risk. Soil information includes an input for geophagia, both incidental and deliberate. The RefDoc for periods of higher water turnover is dealt with in this report as it is unique to the WPS model.

RefDoc – PPSS (Plant parts and species selection)

The following RefDoc is for those species that may be at risk of trace mineral imbalances should predisposing concentrations be present in specific plant parts (pp) and for specific plant species (ps). Those animals selecting both for plant parts and plant species have less potential for dilution, in the case of excesses, or addition, in the case of deficiencies, due to less variation in the diet. Note that most have a benefit due to a higher moisture percentage of the type of diet consumed, but this can be negligible during certain seasons, and during times of drought.

RefDoc – PPSS for the WPS model.

Wildlife Species	Selection
Blue Wildebeest	pp
Burchells Zebra	pp
Bushbuck	pp
Damara	pp
Blue Duiker	pp
Common Duiker	pp
Red Duiker	pp
Gemsbuck	pp
Giraffe	pp + ps
Kudu	pp
Mountain Reedbuck	ps
Mountain Zebra	pp
Nyala	pp
Oribi	pp + ps
Roan	ps
Sable	ps
Springbok	pp
Steenbok	pp + ps
Suni	pp
Tssesebe	ps
Warthog	pp

RefDoc – DT

The following RefDoc is based on observations relating to the preferred time of day that certain species choose to drink water. Note that these are highly variable, and can change from ranch to ranch. The risk rating is greater for those consuming during the day as opposed to those at night, as not only do the drinking times influence [WQC], but animals habitually consuming water during midday tend to obtain more of their water requirement from drinking water, whereas those consuming during the night, evening, or dawn, tend to consume less of their requirement from the drinking water (other contributions, dew etc.). The user is also provided an input screen for actual observations made on site regarding time and frequency per day of water intake. Information regarding the design and placement of the watering point is also linked to documented wildlife species preferences.

RefDoc – DT for the WPS model.

Wildlife with low risk	Wildlife with medium risk	Wildlife with high risk
buffalo	black wildebeest	gemsbok
eland	blue wildebeest	warthog
elephant	blesbok	zebra
kudu	bontebok	
black rhino	bushbuck	
nyala	duiker	
	giraffe	
	impala	
	red hartebeest	
	reedbuck	
	white rhino	
	roan antelope	
	sable antelope	
	springbok	
	tsessebe	
	waterbuck	

RefDoc – WIRRD (Water Ingestion Rate Reference Document) + WLW (Wildlife Live Weight)

The purpose of this RefDoc is to correct for differences in body weight (BW) as they pertain to water turnover rates, and to correct for the influence of ambient temperature on water intake. A number of simplistic formulae exist for wildlife, and where appropriate, these are included. More complex regressions are used from research conducted for livestock, and although direct extrapolation is not inferred, the regressions do provide for a more accurate method of incorporating these references. The calculation results are provided for the user, on an ingestion rate basis, for some of the wildlife species. Although it is strongly recommended that the reader consult the WRC Final Report K5/644 that describes the WIRRD for livestock production systems at length, the purpose of the WIRRD for the WPS is not the same. The major reason for this is that the comparison basis for the WPS is to provide information on which between-wildlife species ingestion rates, and hence risk, can be estimated. For the livestock production systems, the central basis of comparison is within-breed, allowing the manager to determine which components of the herd/flock are most at risk. For obvious reasons, this is not viable in most wildlife ranching enterprises, as the components of a herd are not controlled (separated) by camps and kraals, but rather roam freely within a large perimeter fence. The RefDoc – WLW provides a rough guide to wildlife live weight should the user be unable to provide the figures in the Animal Detail Tab. Data on mature age is also provided as a guide to the user.

RefDoc - WLW for the WPS model

Wildlife Species	Rough estimate of live weight (kg)*
Blesbok	70 (61) [48]
Black Rhino	850 (880)
Black Wildebeest	180 (160) [60]
Blue Wildebeest	250 (180) [60]
Bontebok	61 (55) [48]
Buffalo	800 (750) 60
Burchell's Zebra	320 (320) [48]
Bushbuck	50 (30)
Bushpig	62 (59) [24]
Damara dik-dik	4 (4.5) [6]
Eland	650 (460) [84]
Elephant	5500 (4000) [25]
Gemsbok	240 (210)
Giraffe	1192 (828) [120]
Grey Duiker	16.5 (18.5) [6]
Grey Rhebuck	20 (20)
Grysbok (Cape)	10 (10.5)
Grysbok (Sharpe's)	7.5 (7.7)
Hippopotamus	1490 (1321)
Impala (common)	50 (40) [36-48]
Klipspringer	10 (13)
Kudu	250 (200)
Mountain Reedbuck	30 (28) [15-20]
Mountain Zebra -Cape -Hartman's	 235 (245) [30] 300 (245) [30]
Nyala	108 (62) [72]
Oribi	14 (14.2)
Red Duiker	12 (12) [6]
Red Hartebeest	150 (120)
Reedbuck	78 (51)
Roan antelope	270 (250)
Sable antelope	230 (210)
Springbok	41 (37) [11-12]
Steenbok	11 (11.5)
Tsessebe	140 (126) [36]
Warthog	100 (70)
White Rhino	2100 (1600)
Waterbuck	260 (180) [40]

* ( ) = females [ ] = mature age in months.

RefDoc – LP (Lactation Period)

Those animals with clearly defined increased water turnover periods provide the manager with a period during which water quality management becomes important in terms of the sensitive user groups involved, typically pregnant and lactating females, and suckling young. As such, knowledge of the change in water quality of the various sources available at that time of year is vital if the manager is to allocate and control access to reduce the possible adverse effects. The importance of water quality during this time has been proved sufficiently in international literature, and does not require repeating here.

Identifying the breeding season differences amongst wildlife in a particular area usually highlights the fact that different species are at risk at different seasons. Linking the seasons to changes in water quality, quantity available from different sources, and changes in feeding spectrum quality, allows for an informed decision to be made with regard to the types of licks to be provided, the habitats in which to place them, and the management issues surrounding water provision. The RefDoc – LP refers to a high water intake period due to an increase water demand during lactation (and late trimester). This RefDoc provides the months during which respective female animals are at higher risk due to an increase in drinking water ingestion, and thus provide links to times during which water quality monitoring should be conducted. These are also linked to those animals that consume water during midday, early morning, or late evening and at night. These may also be ranked according to risk for those following winter seasons in summer rainfall areas. The WPS model creates a matrix comprising the wildlife species present (as selected by user input) and formulates according to incidence, the month at which the majority of the animals are at risk. This would be the priority month during which water quality information should be collected.

RefDoc – LP for the WPS model.

Wildlife Species	Lactation Code*
Blesbok	11;12
Black Wildebeest	12;1
Blue Wildebeest	11;12
Bontebok	9;10
Buffalo	*1;2*
Burchell's Zebra	12;1;2
Bushbuck	10;11
Bushpig	
Eland	8;9;10
Elephant	
Gemsbok	8;9
Giraffe	2;3;8;9;10
Grey Duiker	1-12
Grey Rhebuck	11;12
Hippopotamus	
Impala	12;1
Klipspringer	12;1
Kudu	1;2;3
Mountain Reedbuck	10;11;12;1
Mountain Zebra -Cape -Hartman's	 3 11;12;1;2;3;4
Nyala	8;9;10;11;4
Oribi	11;12
Ostrich	
Red Duiker	
Red Hartebeest	9;10;11
Reedbuck	12;1;2;3;4;5
Roan antelope	1-12
Sable antelope	2;3
Springbok - summer rain - winter rain	 9;10;11;12;1 7
Steenbok	9;10;3
Tsessebe	9;10
Warthog	11;12
Waterbuck	10;2;3

* where 1 = January, 12 = December.

Examples of WPS lactation month water quality monitoring recommendations:

- NorthWest Province – Typical complement:

Specie		High intake period			
impala		**D**			
blesbok		**D**			
blue wildebeest	N	**D**	J	F	
burchell's zebra	N	**D**	J	F	
warthog	N	**D**	J	F	M

Output = Recommended sampling period = December

- Dry, open sparse habitat:

Specie		High intake period				
gemsbok		**S**				
giraffe		**S**	O			
nyala	A	**S**	O	N		
red hartebeest	A	**S**	O	N		
springbok	A	**S**	O	N	D	J

Output = Recommended sampling period = September

- Open bushveld, tall grass, shade, water, reeds near open water:

Specie			High intake period			
giraffe			**F**			
impala			**F**			
kudu		J	**F**	M		
reedbuck		J	**F**	M		
sable	D	J	**F**	M		
waterbuck	D	J	**F**	M	A	M

Output = Recommended sampling period = February

5.3.2.5 Level 4 Risk Assessment

The chemical composition of feed ingested by the various wildlife species present may be entered in the Nutritional Detail Tab, and is used to assess total exposure to PHCs. The Feeding Spectrum RefDocs are used to assist the allocation of feed types to wildlife species. The user is also provided with different levels of detail, dependent on the information available. Lick information is also catered for. The reader is referred to the WRC Final Report K5/644 for a detailed description of the modelling thereof.

5.3.2.6 Level 5 – Ecological Risk Assessments

The environmental objectives of a wildlife enterprise do not remain solely with the wildlife species, but due to the intricate link between the animals present and the environment, extend to ecology as well. Level 5 risk assessments are conducted to provide the user with an indication of some of the relevant aspects pertaining to the environment as a direct, or indirect, consequence of providing water.

RefDoc – SZ (Sacrifice Zone)

RefDoc – SZ provides a valuable means for predicting the impact of the watering point on habitat diversity, and possible soil erosion, due to the pressure exerted on the immediate environment due to the presence of animals in the vicinity.

RefDoc – SZ for WPS model.

Zone	Description	Preferred distances zone extends from watering point
Zone 1	Trampled to dust	< 100 m
Zone 2	Grazed short + trampled	< 1.6 km
Zone 3	Grazed evenly short	< 5 km
Zone 4	Lightly and selectively grazed	< 8 km
Zone 5	Utilised little or not at all, unpalatable grasses accumulate	>8 km

* adapted from Thrash (1993)

RefDoc – LAU (large animal units)

The following RefDoc links recommended stocking rates for various bushveld habitats.

RefDoc – LAU for WPS model.

Bushveld Habitat	Recommended LAU/100ha
Mopani veld	4-5
Terminalia sandveld	6-8
Kalahari sandveld	6-7
Combretum veld	8
Wild syringa veld	8-9
Mixed broad-leaved veld	10-12
Acacia tortillis veld	12
Knobthorn-marula veld	10-12
Turf thornveld	12

RefDoc – EIM (Ecological Index Method)

The RefDoc – EIM is used to identify the first 200 plant species counted at each watering point, with the model performing calculations for percentages and values to each species with appropriate ratings to arrive at a grazing value (GV). In the interest not duplicating detail, the complete list is not provided in this report, as it appears in the list-boxes in the software program. The RefDoc – EIM provides a numeric value with the following interpretations that influence predisposing factors to animal health relevant to adverse effects due to water quality (which may be adjusted by the user with specialist knowledge according to the relevant region):

EI = 0-399 poor quality veld

EI = 400-600 moderate quality veld

EI = 600-1000 good quality veld

RefDoc – EIM for the WPS model.

Selection from list provided	Grazing Values assigned
Indicator plants of the herbaceous layer	
Pioneer plants	
Intermediate stage plants	
Climax or optimal grazing stage plants	
Grasses	
Decreasers	10
Increasers I	7
Increasers IIa	4
Increasers IIb	4
Increasers IIc	1
Invaders	1

* adapted from Danckwerts & Teague (1989).

Other aspects influenced by the effect of providing a watering point in an area that are addressed by the WPS model:

1 -Standing crop estimate linked to fire intensity required to control bush encroachment.

2 -Soil factors: Infiltration capacity adjacent to watering point.

-Distance between watering points and wildlife species present: Estimate effect of decline in stands of tall grass on breeding requirements of sable, roan and common reedbuck.

3 -Dung deposits: Linked to reference information per wildlife species.

-Large Stock Units.km^2: Number within 0.5 km of each watering point used to assess grazing pressure and stocking density.

4 -Estimate of bush encroachment around each watering point: This provides an indication of the palatability of the water source, within the context of LSU and LAU information. A list is provided for the user to identify within a 30 m radius of the watering point for:

plants with thorns

plants without thorns

exotic plants

5.3.3 Wildlife user group: Carnivores

Many game ranchers do not consider water quality to be of any great importance for carnivores, as the assumption is made that they do not require free drinking water, but rather fulfil their water requirement from the ingestion of a high moisture percentage diet. Whilst most carnivores are indeed independent of free drinking water, they will however drink readily, and regularly, if water is provided. This is true for lions, cheetahs, leopards, spotted hyaenas, brown hyaenas, wild dogs, and even aardwolves (Bothma & Walker, 1999). During times of hot weather, lions may obtain up to 50% of their water from drinking water.

In many instances the predator-prey relationship influences the amount of drinking water consumed. In the case of the aardwolf, cold temperatures reduce the activity of *Trinervitermers*, effectively lowering the amount of moisture usually obtained from this food source, causing the aardwolf to travel long distances in search of drinking water (Richardson, 1987).

Due to the high vulnerability of many predator offspring during the suckling and weaning phases, the activity of the parent/s may be focused within a core section of the carnivores usual range, resulting in a far greater ingestion of drinking water from one specific source than would normally occur. With the added increase in water intake due to lactation demand, and the long suckling period of some carnivore pups, a water source containing PHCs located near the den, may result in adverse health effects in growing pups/cubs for those WQCs with linear relationships between water and milk concentrations. In many game ranches in southern Africa, water provision is designed around a watering point that attracts game for tourist viewing purposes, leading to an increased amount of time spent by some carnivores around watering points. This inevitably leads to a more frequent intake of drinking water. Although many carnivores in arid savannas are known to consume wild fruit such as the tsama melon and gemsbok cucumber, these have been recorded to contain high percentages of trace minerals (Mills, 1978; Skinner *et al*., 1984; Bothma & Walker, 1999).

Modelling the fitness of use for a water supply that is placed within the range of a carnivore is complicated by a number of issues. Many carnivores appear to have set preferences for the ingestion of various prey body parts. Most cats do not consume the stomach, intestines and viscera of prey killed, but there are exceptions. This is relevant as territorial prey species may have elevated concentrations of PHCs (for example, cadmium and mercury) in certain organs and tissues. When this is combined by a carnivore specialising on one prey species which is water dependant, the resultant total ingestion of PHCs may lead to adverse health effects. As an example, a leopard may reside, or primarily obtain its prey, in a range which contains a sustainable population of warthog, which are water dependant and territorial. The cumulative toxins ingested by the warthog from a water source containing such PHCs may over time have a negative influence on the leopard. This is usually difficult to determine, as it may involve effects such as reduced conception rates and or fecundity.

The water sources utilised by wildlife are influenced by the nature and distribution of vital natural resources, such as cover, food supply and water. Ranges tend to be more stable in southern Africa, as opposed to East Africa, as prey does not migrate to the same extent.

5.3.3.1 Risk factors relevant for carnivores

- **Increased Water demand**

Some relevant issues incorporated by the CIRRA model for WPS are:

Low Risk Carnivores with no clear mating season:

Lions, leopard, cheetah, caracal,

High Risk Carnivores with a clear mating season:

Wild dogs (end of impala rut – weak impalas)

Hyaenas (impala kidding)

Carnivore young dependant on milk:

	Only milk :	Still milk up to:
Lions	6mts	12 mts
Leopard	8 weeks	12 weeks
Cheetah	6 weeks	12 weeks
Caracal		16 weeks
Wild dog	2 weeks	10 weeks
Hyaena	1 yr	18 mts
Brown Hyn	2 weeks	14 mts
Aardwolf		5 mts

Lactation period:

Lions	=	8-9 months
Hyaena	=	1 year

Cubs with restricted movement:

Lions, leopard (for 6 months).

Wild dog – during the breeding season reside for extended periods at 1 den.

- **Single feed sources**

Any wildlife species focusing on a single feed source increases the possible risk due to the consumption of PHCs in the feed. Those species with more variability in their diets have more potential for a dilution effect from the ingestion of PHCs. The link between prey in diet variation and activity and habitats shared may be carried over to carnivores specialising in that prey species. Although large variation exists between the same species in different areas, and even in the same area, the following potential carnivore risk groups are identified:

Carnivores that may focus on 1 prey type:

Lions – may even focus on a sex (more female buffaloes than male)

Leopard.

Caracal

The feeding preference and behaviour of carnivores influences the ingestion of PHCs from prey body parts, some of which may have adverse long-term effects on health and reproduction. Although little research has been conducted on this topic, recent research focus on the predisposing effects in human diets due to trace elements on factors ranging from the immune system to circulating reproductive hormone levels, would seem to indicate that it warrants attention.

This must be seen in the context of the life span of many carnivores, which is typically long by comparison with many livestock species who are either marketed at a slaughter weight, or culled once passed their efficient reproductive cycles. The following data is incorporated into the model for WPS for carnivores.

Sources of uptake of PHCs in carnivore prey species:

It is noteworthy that 47% of lions stomachs in KNP are empty on post mortum examination. This is an important risk factor in terms of the increased uptake of many heavy metal in a more acid medium, typical of an empty stomach in monogastric species (Underwood & Suttle, 1999). Lions are also infrequent eaters, eating in the KNP on average every 1-4 days, with a maximum interval of 13 days.

Lions	-	seldom eat stomach, but do eat intestines.
Lions	-	buttocks
Lionesses and cubs	-	eat viscera
Leopard	-	eviscerate prey, but seldom eat viscera
Cheetah	-	not intestines, heart or liver – will lap blood
Caracal	-	not stomach, intestines
Wild dog	-	eat everything
Hyaena	-	eat everything
Brown hyaena	-	entrails first

The following carnivores drink readily if water is available:

Lions – no clear preference for water quality

Leopard

Cheetah

Wilddogs – drink regularly

Hyaena, Spotted and Brown

Alternative water sources:

Lions	-	lick fur, plants pulled from ground to eat roots (geophagia), in hot weather may obtain 50% of water from drinking water. Female with cubs increases drinking water intake.
Leopard	-	fruits
Spotted Hyaena	-	fruits
Brown Hyaena	-	fruit, tsama melon, gemsbok cucumber

Geophagia information:

Lions	-	roots
Aardwolf	-	50 % droppings = sand
Cheetah	-	kick sand onto viscera

Relevant references to this section include:

Eloff (1973); Green *et al.* (1984); Bothma (1996); Neser *et al.* (1997); Bothma & Walker (1999); Apps (1999).

5.3.4 Reporting of results

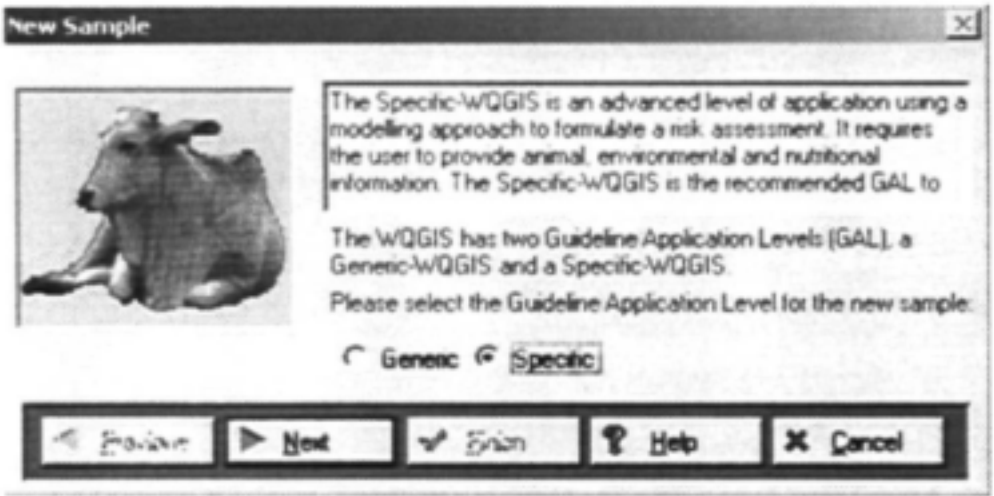
On first glance, the Results Screens appear rather complex, but due to the inherent variability of cause and effect relationships, irreducible randomness, and many potential sources of input bias, specifically with wildlife production systems, the results are presented on different system levels to the user. This enables the user to track the origin of the PHCs, from the water source independently of the environment, in association with the animal species present, and then in association with the entire system. In presenting the results in this manner the user may also be guided as to the points in the systems where mitigation treatments or action may be an option.

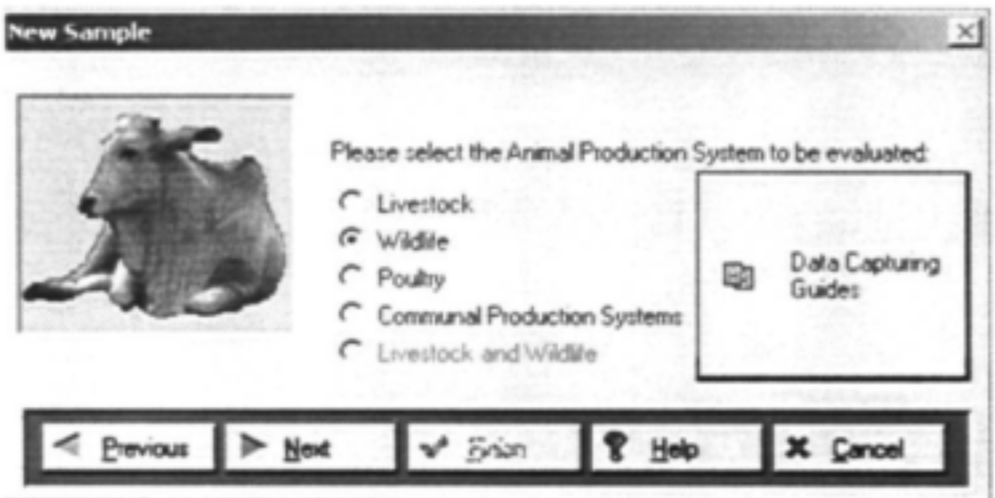
The *.wqs format of CIRRA software enables "Save As" functions to apply changes to the system to be evaluated in 'dummy' sample files. The system is in effect recreated and the user may alter a number of inputs, from lick supplied to structural changes to the wildlife population or ranch fences and watering points, to name but a few. This procedure is adopted as the methods viable will differ from enterprise to enterprise. The WPS model does however suggest those actions that may have a significant ameliorating effect, with the accompanying reasons. This is done per watering point, and indicates the species most affected. An example is the alteration of the palatability of the water to increase, or decrease, the utilisation by select species on that watering point. Increases may effect a proportionate increase in ingestion of a water source with less PHCs compared to a water source with more PHCs (or greater [PHC]), whereas decreases may allow for the opposite in terms of the ingestion of WQCs with toxicological consequences, and at the same time reducing the grazing/browsing pressure on soil and herbaceous plant communities within the vicinity of the watering point.

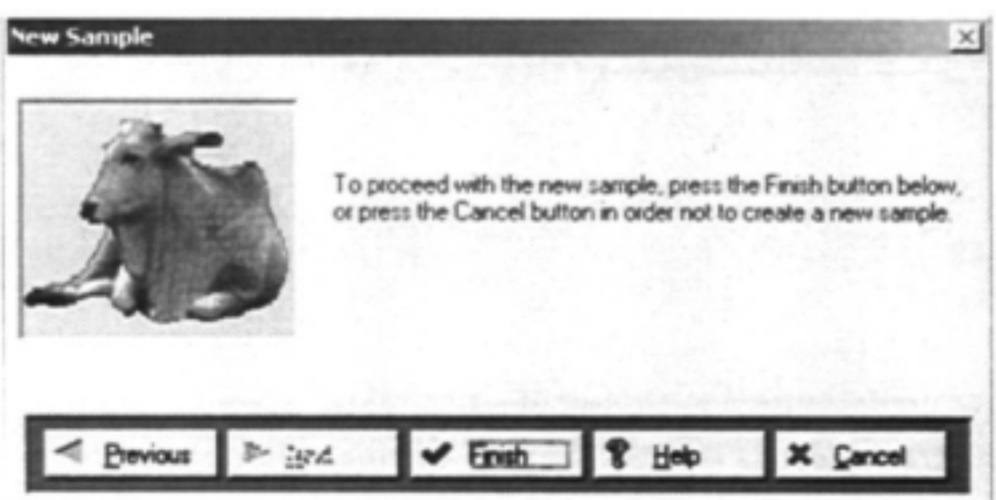
Two recommendations made under the "Water Provision Management" screens are sourced from the WRC Final Report K5/644, namely those for palatability calculations, and those alleviator treatments, both of which provide the user with the actual types and amounts of chemicals recommended for addition to a water reservoir, based on the volume capacity of the reservoir. The new *.wqs file also corrects the Water Sample data to account for changes in chemical composition.

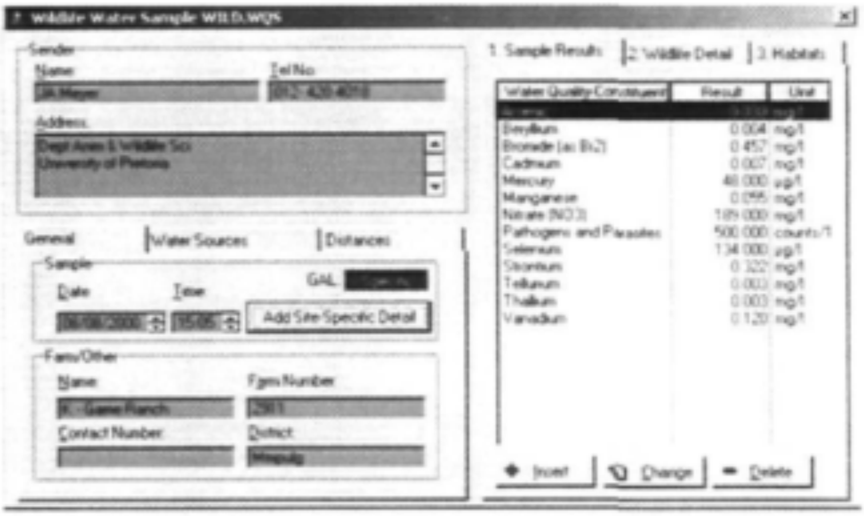
5.4 User Interface screens for the WPS model

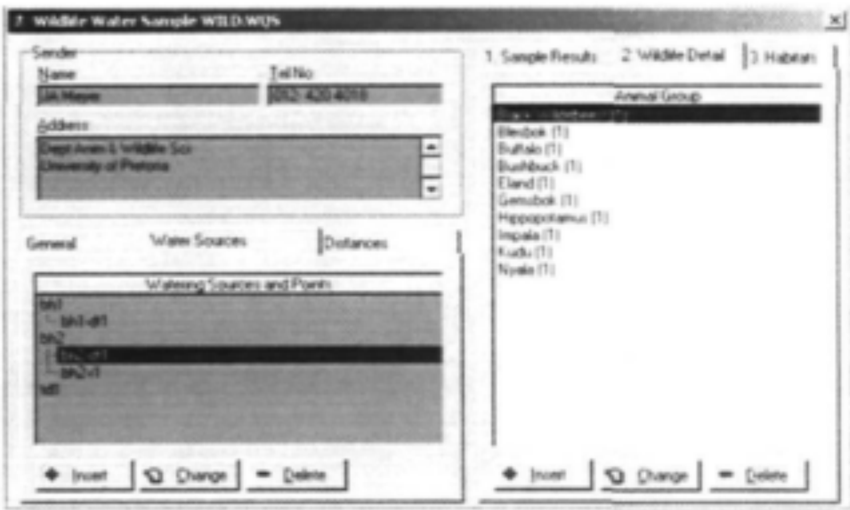
The following pages provide some of the screens available for the data capturing section of the WPS model. The screen images represent the user interface portion of the program. The two other main sections that reside within the software are the source code (modelling), and documentation data dictionaries for the reference material and supporting information. The images are presented in this report to indicate to the reader the document-driven Windows format of CIRRA, an attribute which should enable easy navigation for all levels of computer literacy.

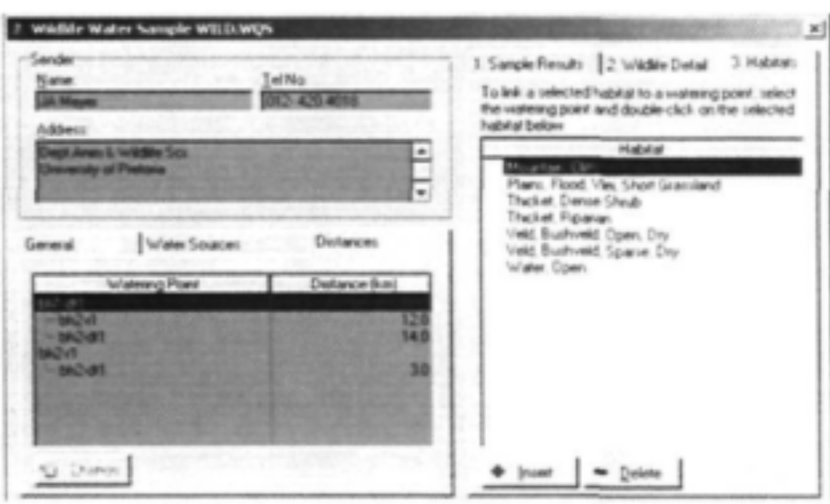

New Sample
The Specific-WQGIS is an advanced level of application using a modelling approach to formulate a risk assessment. It requires the user to provide animal, environmental and nutritional information. The Specific-WQGIS is the recommended GAL to
The WQGIS has two Guideline Application Levels (GAL), a Generic-WQGIS and a Specific-WQGIS.
Please select the Guideline Application Level for the new sample:
Generic
Specific
Previous
Next
Finish
Help
Cancel

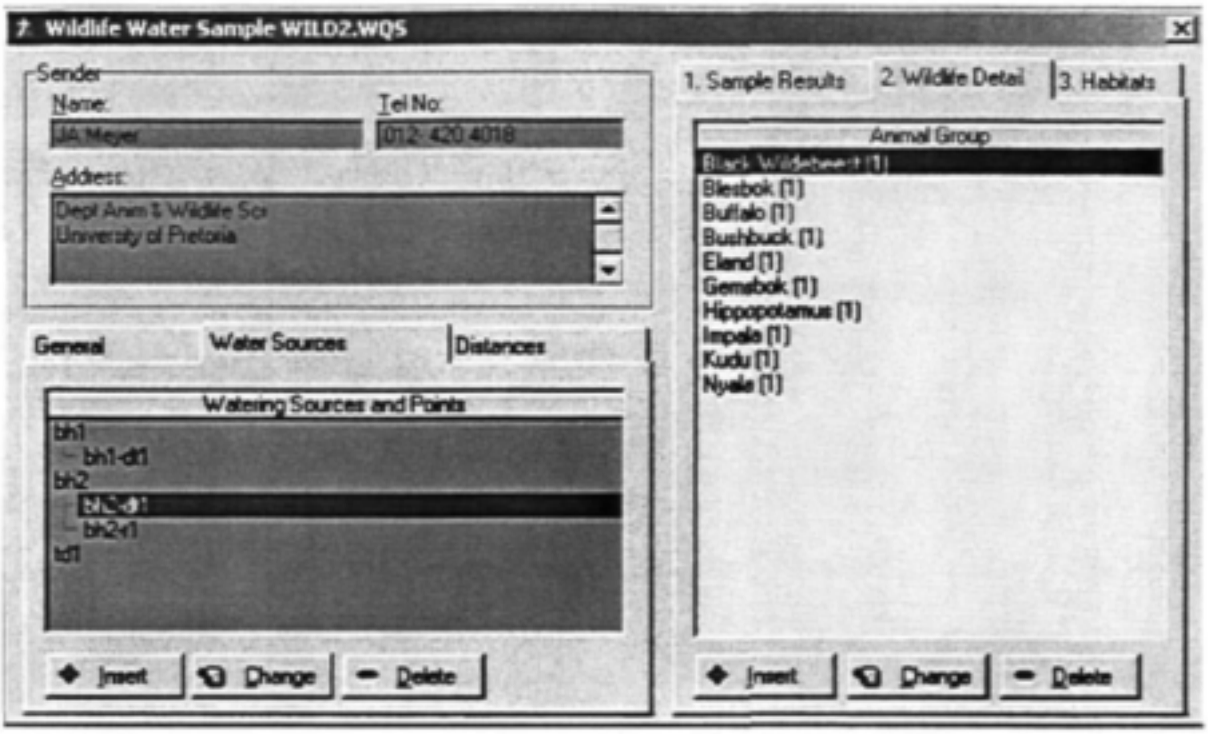

New Sample
Please select the Animal Production System to be evaluated:
Livestock
Wildlife
Poultry
Communal Production Systems
Livestock and Wildlife
Data Capturing Guides
Previous
Next
Finish
Help
Cancel


New Sample
To proceed with the new sample, press the Finish button below, or press the Cancel button in order not to create a new sample.
Previous
Next
Finish
Help
Cancel

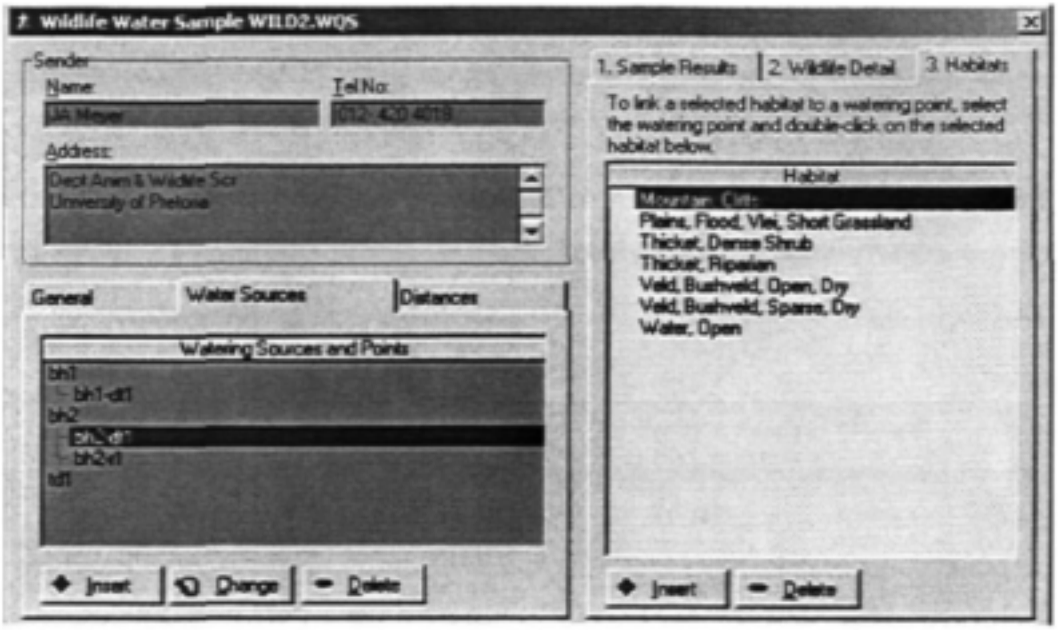

Wildlife Water Sample WILD.WQS
Sender
Name
Tel No
Address
General
Water Sources
Distances
Sample
Date
Time
GAL
Add Site Specific Detail
Farm/Other
Farm Number
Contact Number
District
1. Sample Results
2. Wildlife Detail
3. Habitats
Result
Unit
Insert
Change
Delete

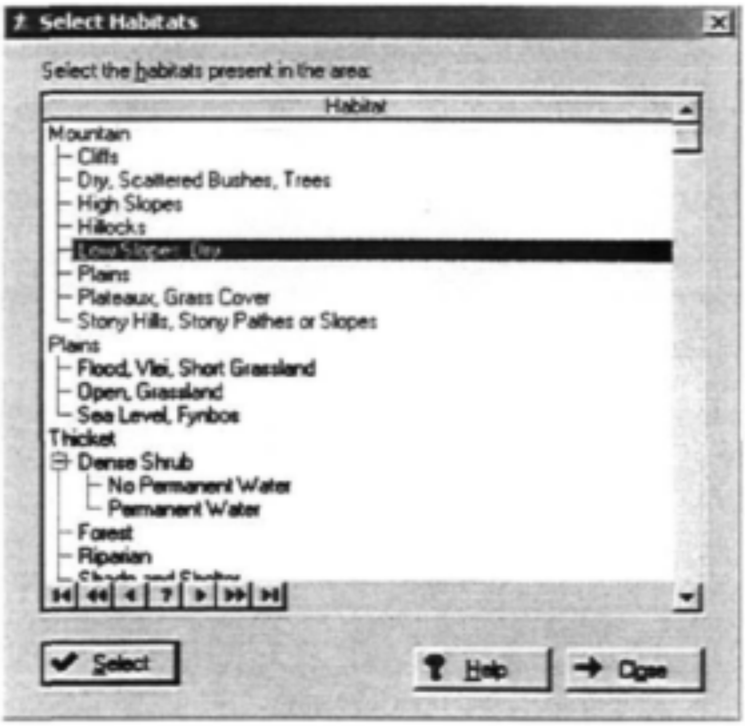

Wildlife Water Sample WILD.WQS
Sender
Name
Tel No
Address
General
Water Sources
Distances
1. Sample Results
2. Wildlife Detail
3. Habitats
Animal Group
Insert
Change
Delete

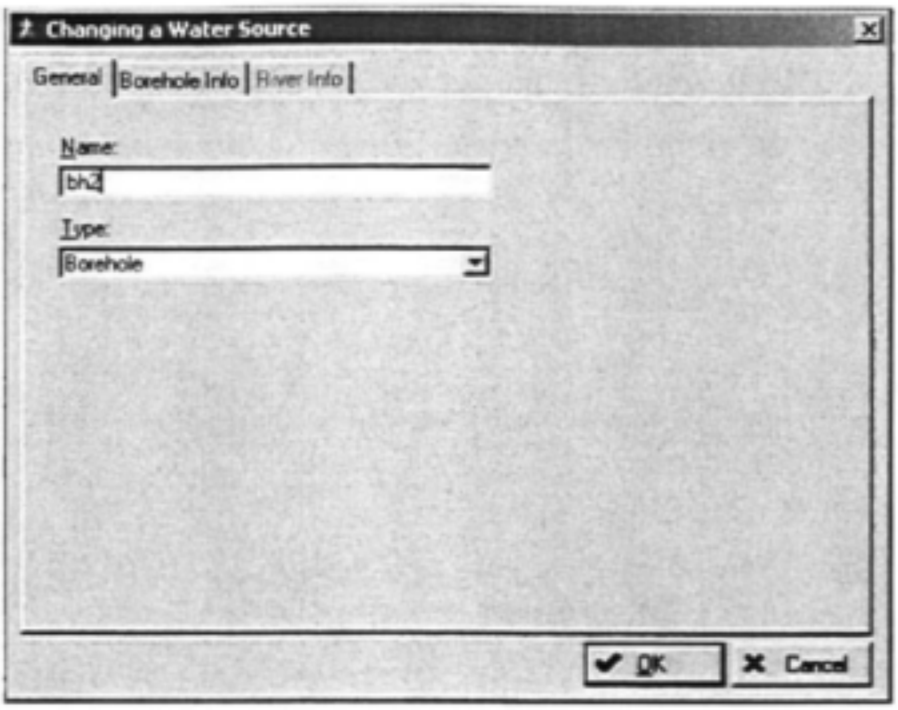

Wildlife Water Sample WILD.WQS
Sender
Name
Tel No
Address
General
Water Sources
Distances
Watering Point
Distance (km)
1. Sample Results
2. Wildlife Detail
3. Habitats
Habitat
Insert
Delete

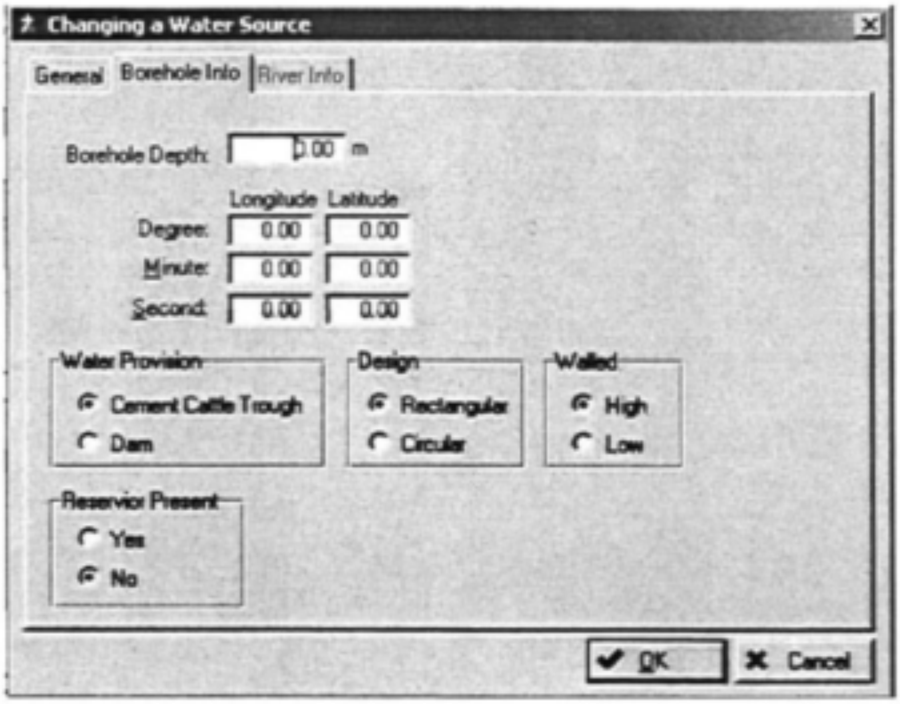

Wildlife Water Sample WILD2.WQS
Sender
Name:
Tel No:
JA Meyer
012 420 4018
Address:
Dept Anim & Wildlife Sci
University of Pretoria
General
Water Sources
Distances
Watering Sources and Points
bh1
bh1-dt1
bh2
bh2-dt1
bh2-r1
td1
Insert
Change
Delete
1. Sample Results
2. Wildlife Detail
3. Habitats
Animal Group
Black Wildebeest (1)
Blesbok (1)
Buffalo (1)
Bushbuck (1)
Eland (1)
Gemsbok (1)
Hippopotamus (1)
Impala (1)
Kudu (1)
Nyala (1)
Insert
Change
Delete

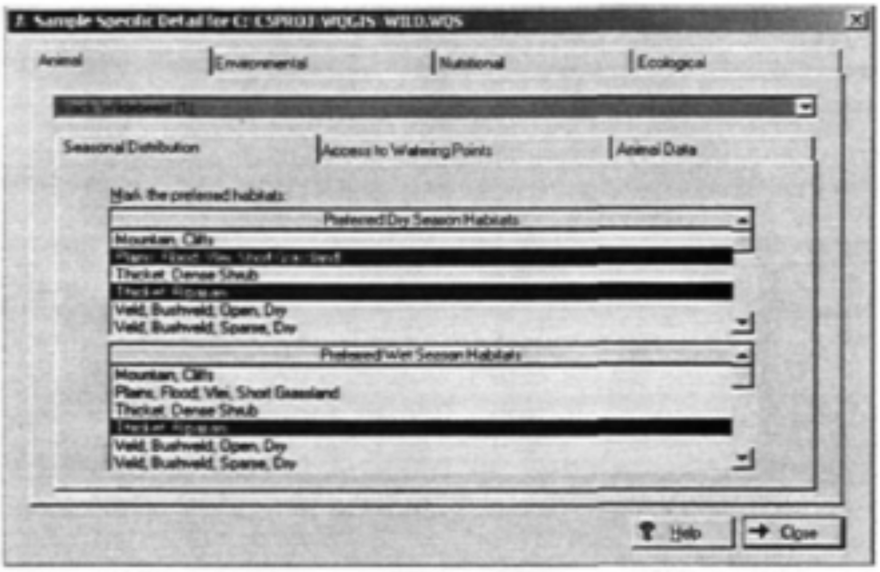

Select Animal Types
Select one or more wildlife animal types:
Description
Black Wildebeest
Blesbok
Blue Wildebeest
Bontebok
Buffalo
Bushbuck
Bushpig
Cape Mountain Zebra
Eland
Elephant
Gemsbok
Giraffe
Grey Duiker
Grey Rhebuck
Hartmanns Mountain Zebra
Hippopotamus
Impala
Klipspringer
Select
Help
Close

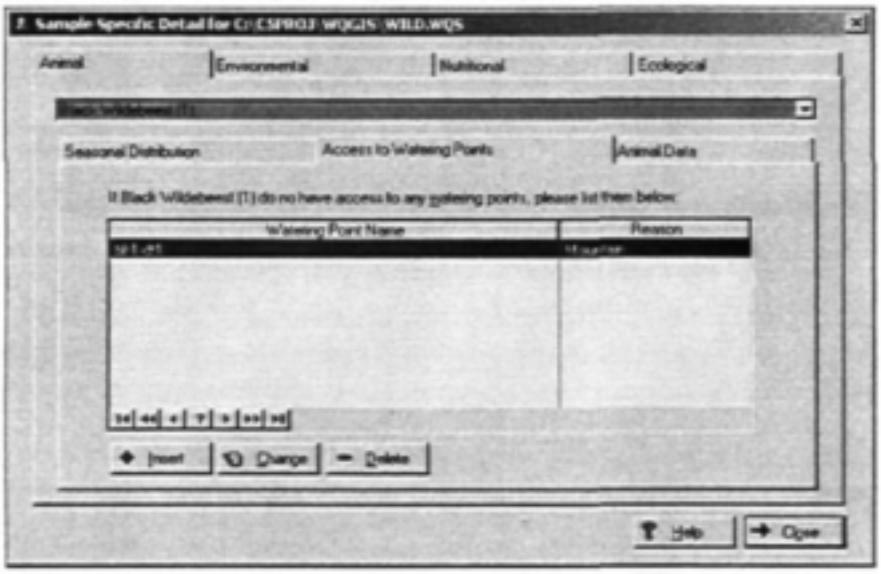

Wildlife Water Sample WILD2.WQS
Sender
Name:
Tel No:
Address:
General
Water Sources
Distances
Watering Sources and Points
bh1
bh1-dt1
bh2
td1
Insert
Change
Delete
1. Sample Results
2. Wildlife Detail
3. Habitats
To link a selected habitat to a watering point, select the watering point and double-click on the selected habitat below.
Habitat
Plains, Flood, Vlei, Short Grassland
Thicket, Dense Shrub
Thicket, Riparian
Veld, Bushveld, Open, Dry
Veld, Bushveld, Sparse, Dry
Water, Open
Insert
Delete

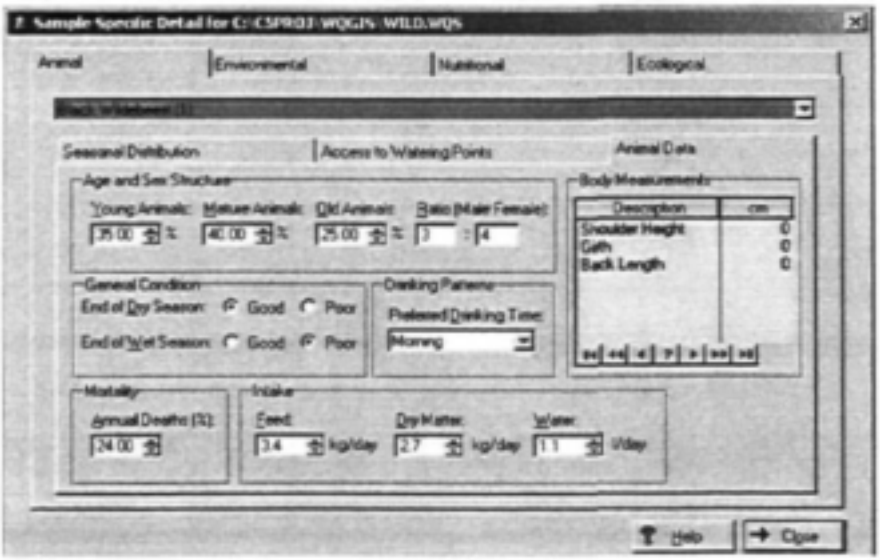

Select Habitats
Select the habitats present in the area:
Habitat
Mountain
Cliffs
Dry, Scattered Bushes, Trees
High Slopes
Hillocks
Plains
Plateaux, Grass Cover
Stony Hills, Stony Pathes or Slopes
Plains
Flood, Vlei, Short Grassland
Open, Grassland
Sea Level, Fynbos
Thicket
Dense Shrub
No Permanent Water
Permanent Water
Forest
Riparian
Select
Help
Close


Changing a Water Source
General
Borehole Info
River Info
Name:
bh2
Type:
Borehole
OK
Cancel


Changing a Water Source
General
Borehole Info
River Info
Borehole Depth:
0.00
m
Longitude
Latitude
Degree:
0.00
0.00
Minute:
0.00
0.00
Second:
0.00
0.00
Water Provision
Cement Cattle Trough
Dam
Design
Rectangular
Circular
Walled
High
Low
Reservior Present
Yes
No
OK
Cancel

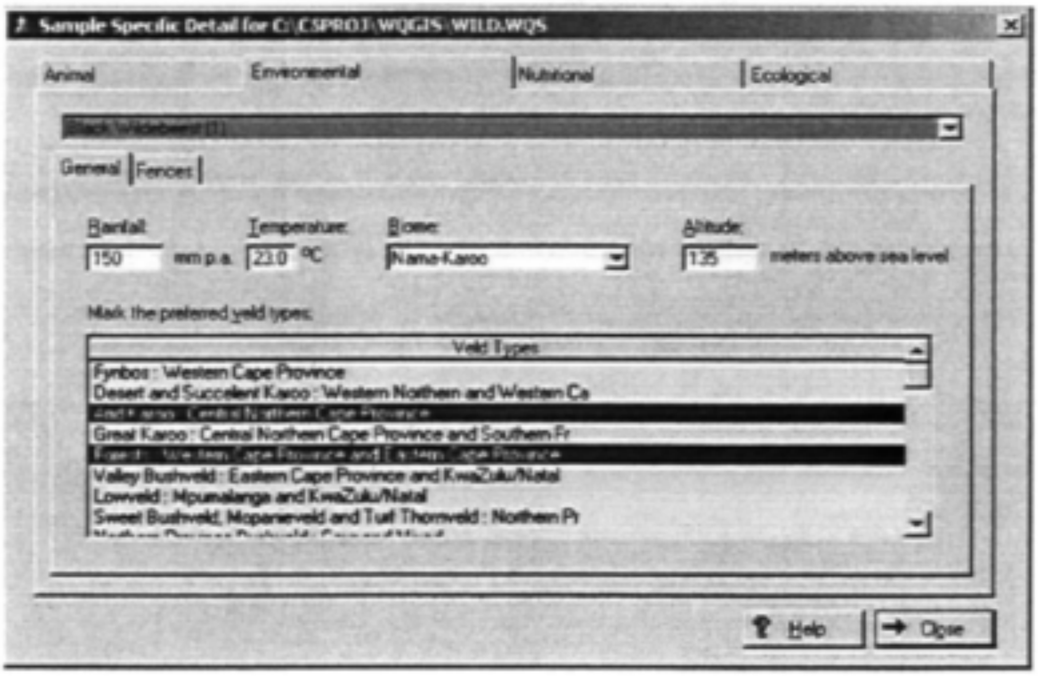

Sample Specific Detail for C:\CSPROJ\WQGIS\WILD.WQS
Animal
Environmental
Nutritional
Ecological
Seasonal Distribution
Access to Watering Points
Animal Data
Mark the preferred habitats:
Preferred Dry Season Habitats
Mountain, Cliffs
Thicket, Dense Shrub
Veld, Bushveld, Open, Dry
Veld, Bushveld, Sparse, Dry
Preferred Wet Season Habitats
Mountain, Cliffs
Plains, Flood, Vlei, Short Grassland
Thicket, Dense Shrub
Veld, Bushveld, Open, Dry
Veld, Bushveld, Sparse, Dry
Help
Close

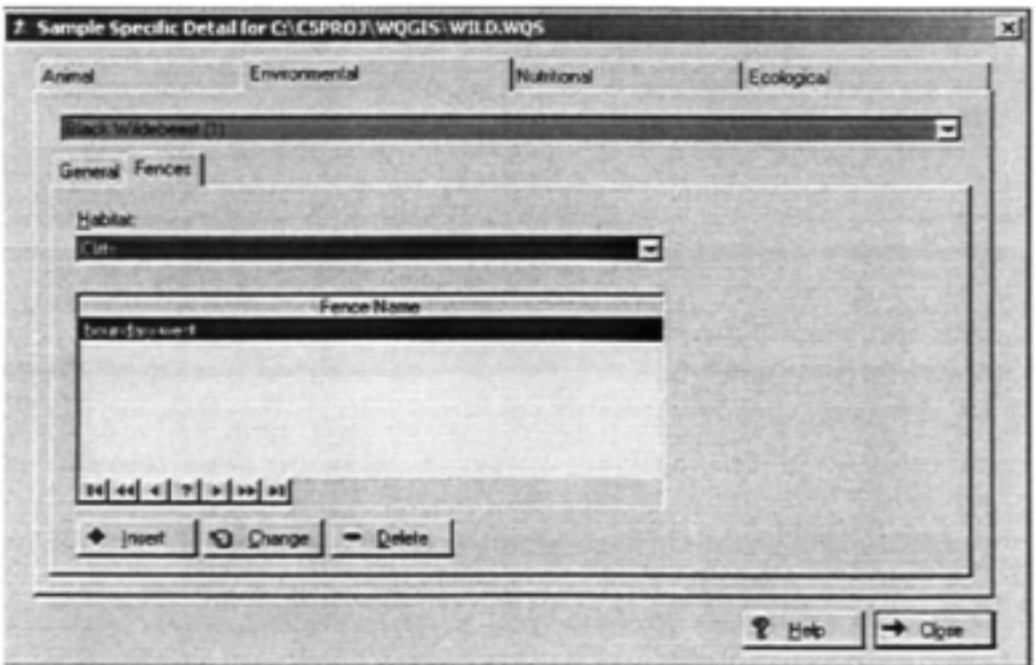

Sample Specific Detail for C:\CSPROJ\WQGIS\WILD.WQS
Animal
Environmental
Nutritional
Ecological
Seasonal Distribution
Access to Watering Points
Animal Data
If Black Wildebeest (T) do no have access to any watering points, please list them below:
Watering Point Name
Reason
Insert
Change
Delete
Help
Close

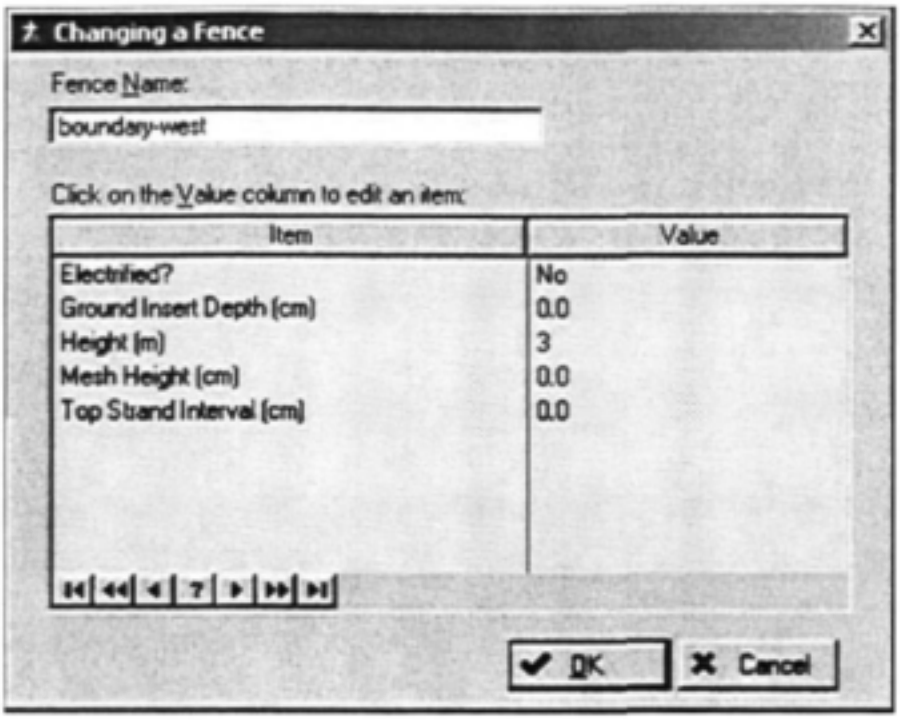

Sample Specific Detail for C:\CSPROJ\WQGIS\WILD.WQS
Animal
Environmental
Nutritional
Ecological
Seasonal Distribution
Access to Watering Points
Animal Data
Age and Sex Structure
Young Animals:
Mature Animals:
Old Animals:
Ratio (Male:Female):
35.00
40.00
25.00
3
4
Body Measurements
Description
cm
Shoulder Height
Girth
Back Length
General Condition
End of Dry Season:
Good
Poor
End of Wet Season:
Good
Poor
Drinking Patterns
Preferred Drinking Time:
Morning
Mortality
Annual Deaths (%):
24.00
Intake
Feed:
3.4
kg/day
Dry Matter:
2.7
kg/day
Water:
11
l/day
Help
Close

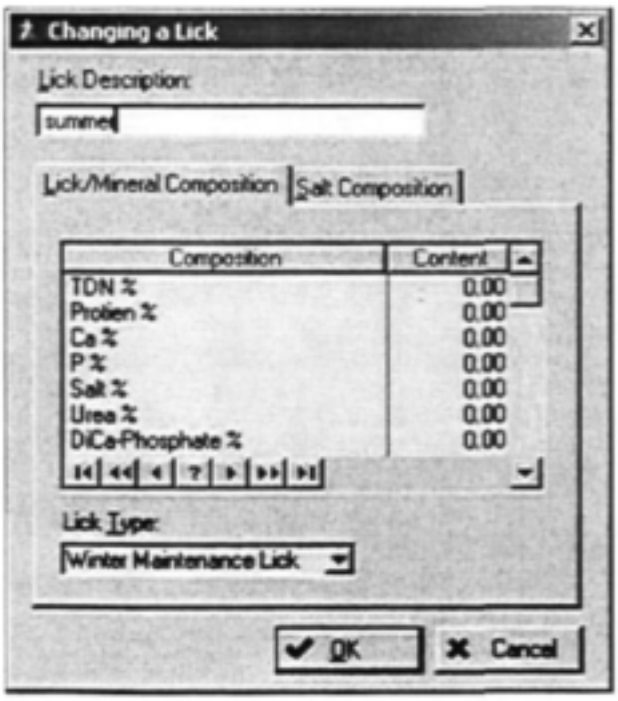

Inserting an Inaccessable Point
Watering Point:
Reason why the watering point is inaccessable:
Reason
Natural Obstacle
Mountain
River
Other Natural Obstacle
Manmade Obstacle
Fence
Road
Other Manmade Obstacle
OK
Cancel

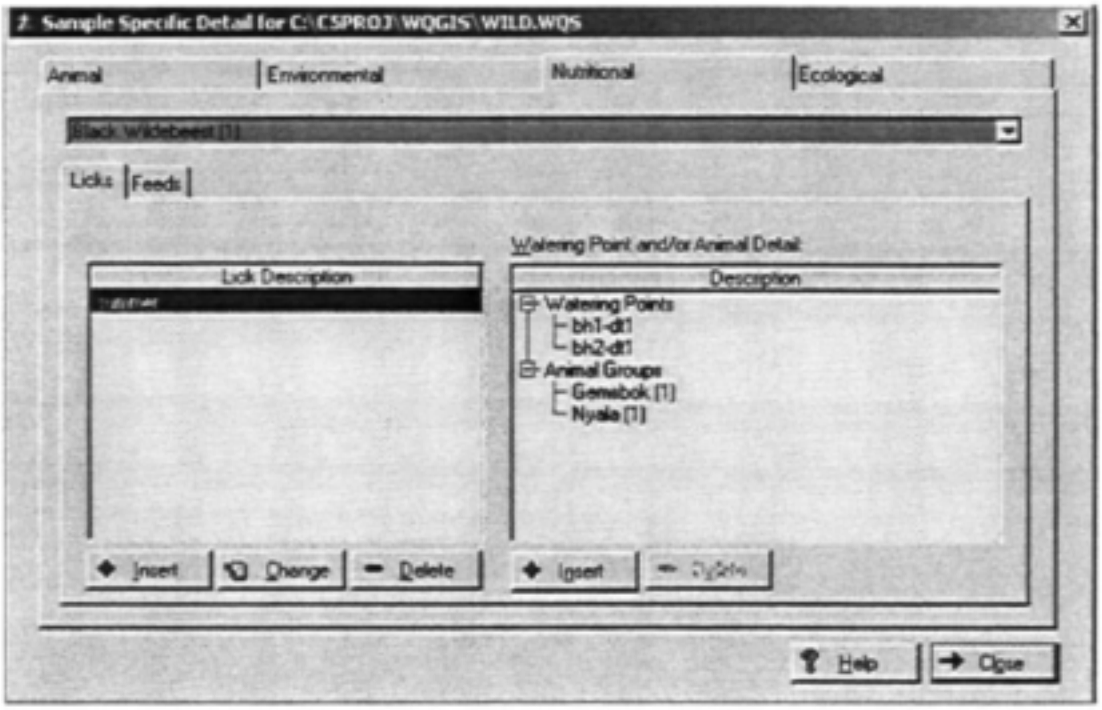

Sample Specific Detail for C:\CSPROJ\WQGIS\WILD2.WQS
Animal
Environmental
Nutritional
Ecological
Seasonal Distribution
Access to Watering Points
Animal Data
Age and Sex Structure
Young Animals:
Mature Animals:
Old Animals:
Ratio (Male:Female):
Body Measurements
Description
cm
Shoulder Height
General Condition
End of Dry Season:
Good
Poor
End of Wet Season:
Good
Poor
Drinking Patterns
Preferred Drinking Time:
Morning
Mortality
Annual Deaths (%):
Intake
Feed:
kg/day
Dry Matter:
kg/day
Water:
l/day
Help
Close

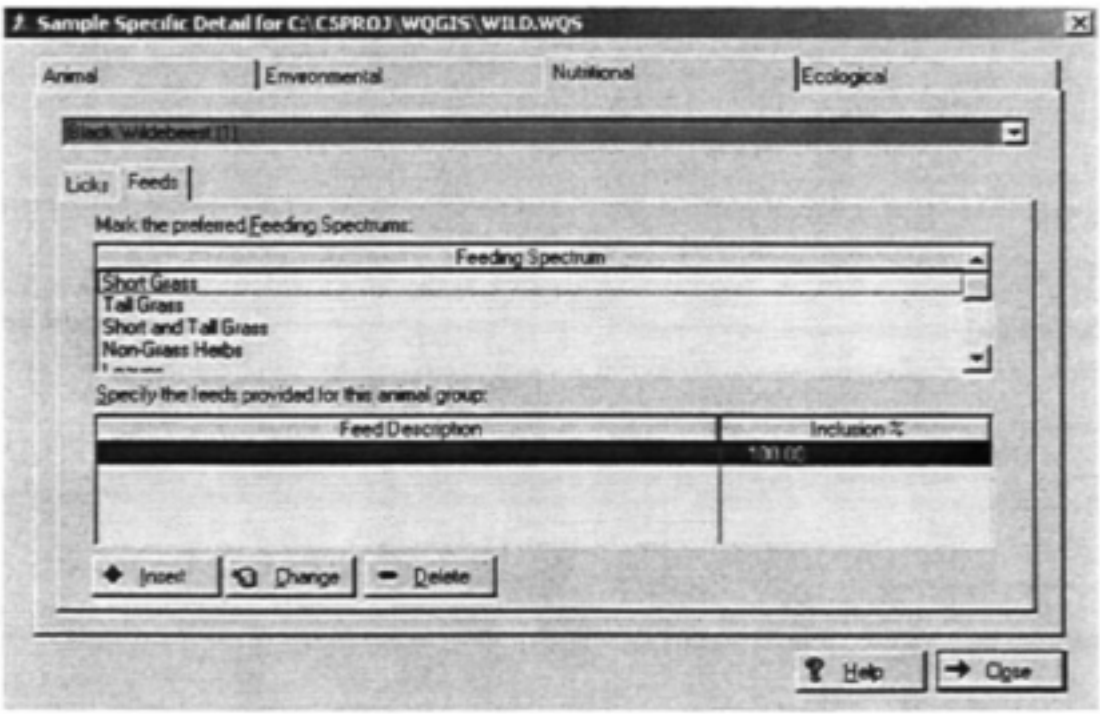

Sample Specific Detail for C:\CSPROJ\WQGIS\WILD.WQS
Animal
Environmental
Nutritional
Ecological
General
Fences
Rainfall:
150
mm p.a.
Temperature:
23.0 °C
Biome:
Nama-Karoo
Altitude:
135
meters above sea level
Mark the preferred veld types:
Veld Types
Fynbos : Western Cape Province
Desert and Succulent Karoo : Western Northern and Western Ca
Great Karoo : Central Northern Cape Province and Southern Fr
Valley Bushveld : Eastern Cape Province and KwaZulu/Natal
Lowveld : Mpumalanga and KwaZulu/Natal
Sweet Bushveld; Mopaneveld and Turf Thornveld : Northern Pr
Help
Close

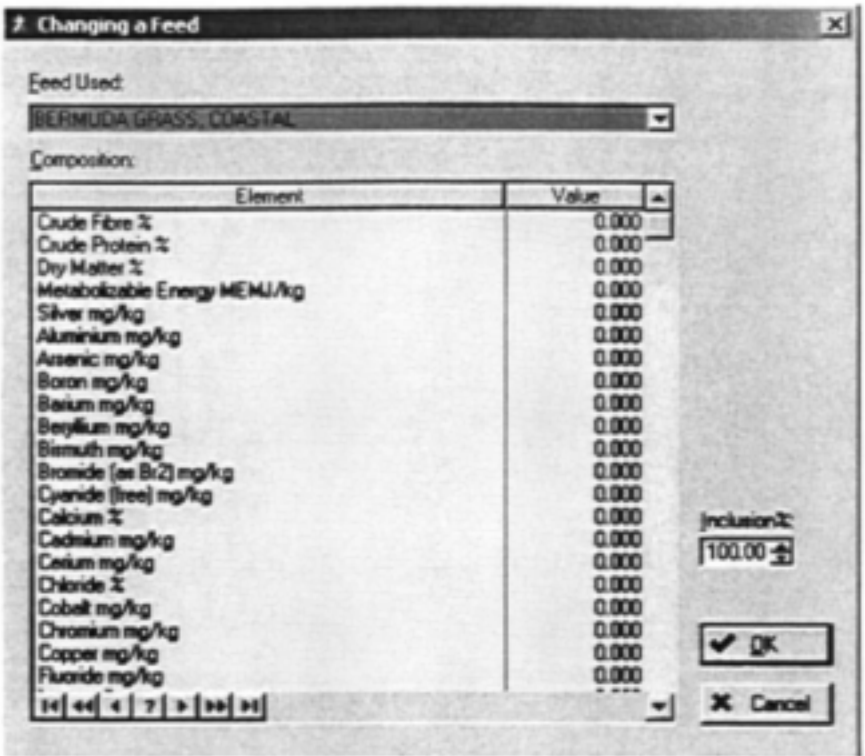

Sample Specific Detail for C:\CSPROJ\WQGIS\WILD.WQS
Animal
Environmental
Nutritional
Ecological
General
Fences
Habitat:
Fence Name
Insert
Change
Delete
Help
Close


Changing a Fence
Fence Name:
boundary-west
Click on the Value column to edit an item:
Item
Value
Electrified?
No
Ground Insert Depth (cm)
0.0
Height (m)
3
Mesh Height (cm)
0.0
Top Strand Interval (cm)
0.0
OK
Cancel

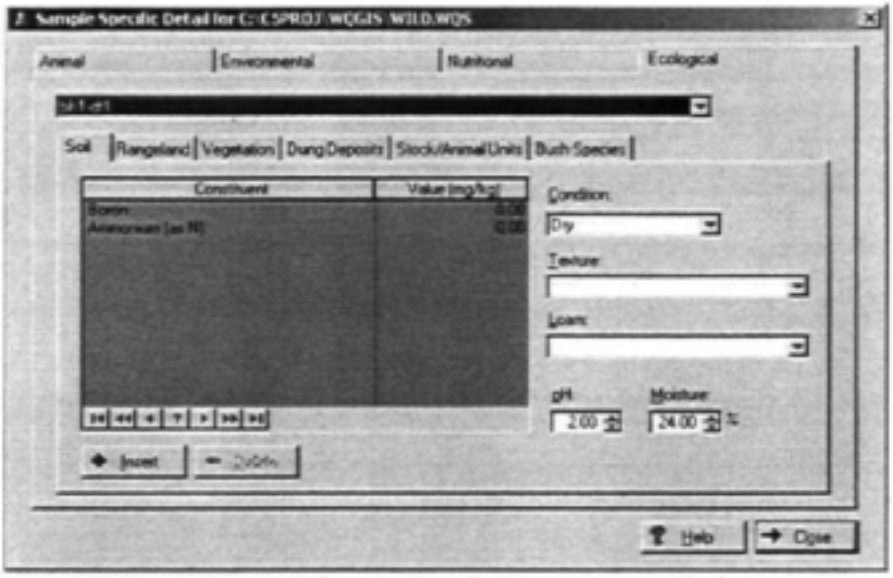

Changing a Lick
Lick Description:
summer
Lick/Mineral Composition
Salt Composition
Composition
Content
TDN %
0.00
Protien %
0.00
Ca %
0.00
P %
0.00
Salt %
0.00
Urea %
0.00
DiCa-Phosphate %
0.00
Lick Type:
Winter Maintenance Lick
OK
Cancel

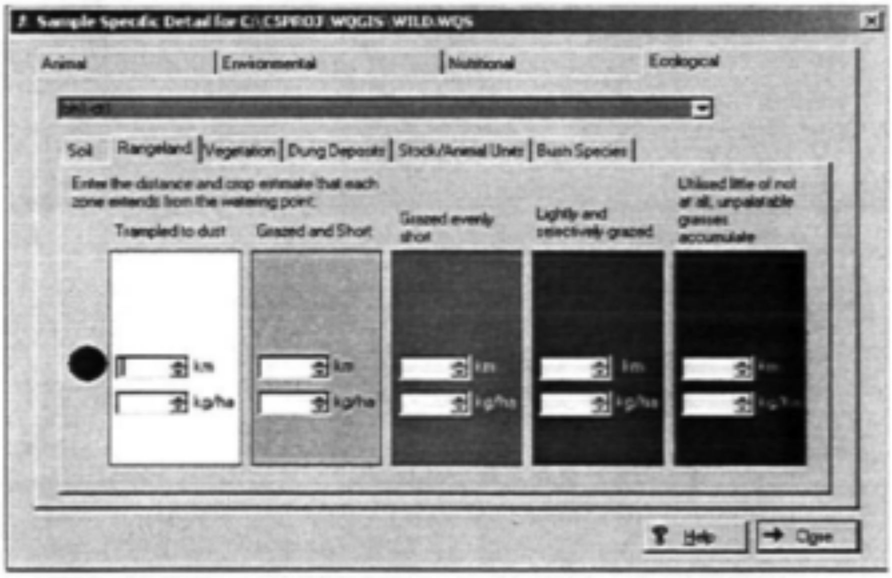

Sample Specific Detail for C:\CSPROJ\WQGIS\WILD.WQS
Animal
Environmental
Nutritional
Ecological
Black Wildebeest (1)
Licks
Feeds
Watering Point and/or Animal Detail:
Lick Description
Description
Watering Points
bh1-dt1
bh2-dt1
Animal Groups
Gemsbok (1)
Nyala (1)
Insert
Change
Delete
Insert
Help
Close

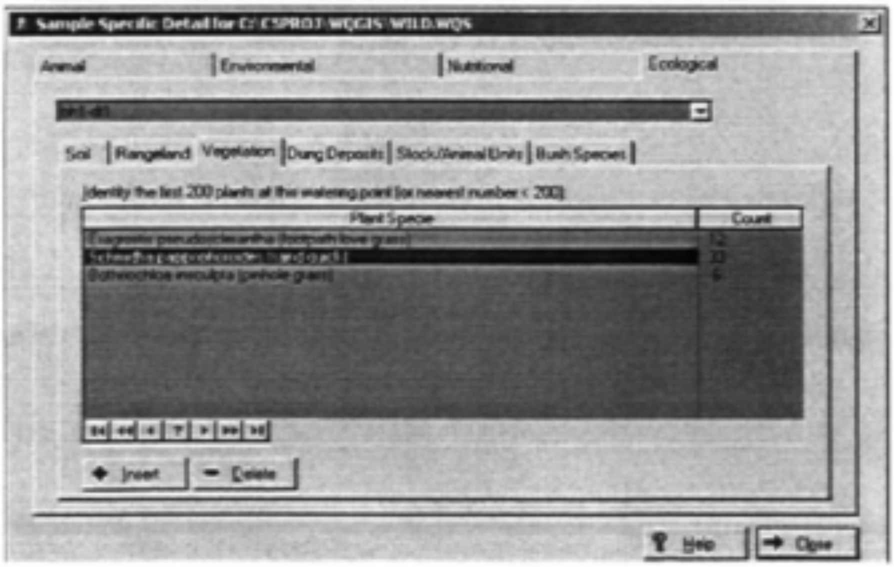

Sample Specific Detail for C:\CSPROJ\WQGIS\WILD.WQS
Animal
Environmental
Nutritional
Ecological
Black Wildebeest (1)
Licks
Feeds
Mark the preferred Feeding Spectrums:
Feeding Spectrum
Short Grass
Tall Grass
Short and Tall Grass
Non-Grass Herbs
Specify the feeds provided for this animal group:
Feed Description
Inclusion %
100.00
Insert
Change
Delete
Help
Close

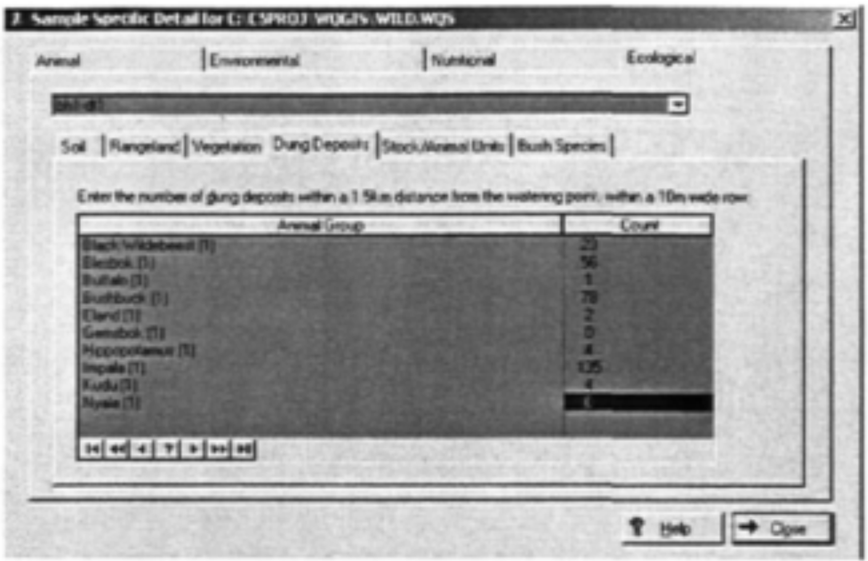

Changing a Feed
Feed Used:
BERMUDA GRASS, COASTAL
Composition:
Element
Value
Crude Fibre %
Crude Protein %
Dry Matter %
Metabolizable Energy MEMJ/kg
Silver mg/kg
Aluminium mg/kg
Arsenic mg/kg
Boron mg/kg
Barium mg/kg
Beryllium mg/kg
Bismuth mg/kg
Bromide (as Br2) mg/kg
Cyanide (free) mg/kg
Calcium %
Cadmium mg/kg
Cerium mg/kg
Chloride %
Cobalt mg/kg
Chromium mg/kg
Copper mg/kg
Fluoride mg/kg
0.000
Inclusion%:
100.00
OK
Cancel

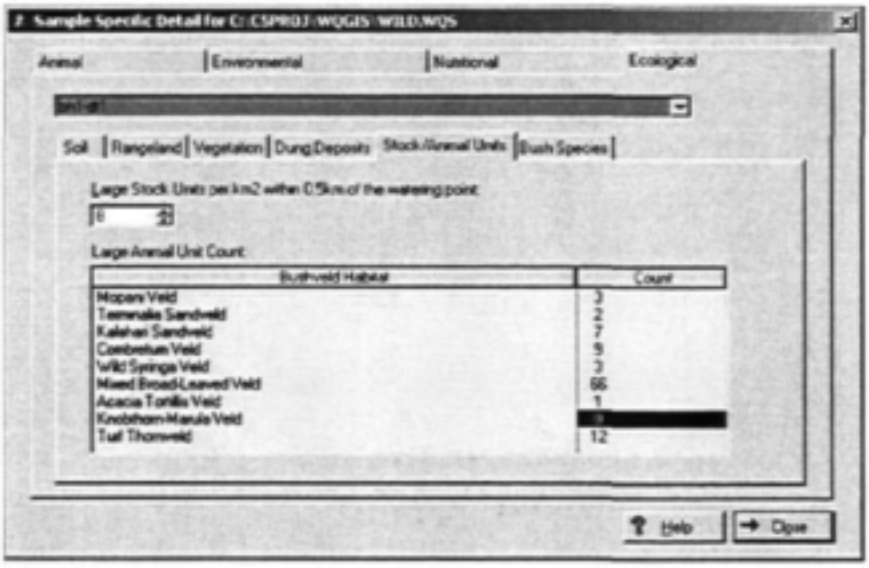

Select a Plant Specie
Name
Common
Plant Specie
BUSHES
DESIRABLE PLANTS: FOOD PLANTS
INTERMEDIATE GRASSES
PALATABLE GRASSES
UNDESIRABLE PLANTS: FOOD PLANTS, INVADERS AND P
UNDESIRABLE PLANTS: TOXIC PLANTS
UNPALATABLE OR UNDESIRABLE GRASSES
PLANT SPECIES PART 1
CLIMAX OR OPTIMAL GRAZING STAGE PLANTS
INTERMEDIATE STAGE PLANTS
PIONEER PLANTS
PLANT SPECIES PART 2
DECREASERS
INCREASERS I
INCREASERS IIa
INCREASERS IIb
INCREASERS IIc

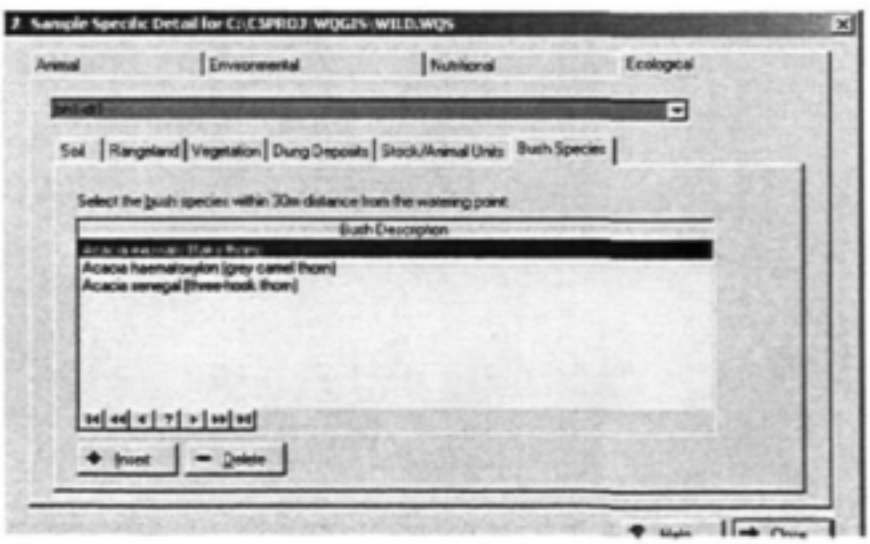

Sample Specific Detail for C:\CSPROJ\WQGIS\WILD.WQS
Animal
Environmental
Nutritional
Ecological
Soil
Rangeland
Vegetation
Dung Deposits
Stock/Animal Units
Bush Species
Constituent
Value (mg/kg)
Boron
Ammonium (as N)
Condition:
Dry
Texture:
Loam:
pH:
Moisture:
Insert
Help
Close


Sample Specific Detail for C:\CSPROJ\WQGIS\WILD.WQS
Animal
Environmental
Nutritional
Ecological
Soil
Rangeland
Vegetation
Dung Deposits
Stock/Animal Units
Bush Species
Enter the distance and crop estimate that each zone extends from the watering point:
Trampled to dust
Grazed and Short
Grazed evenly short
Lightly and selectively grazed
Utilised little of not at all, unpalatable grasses accumulate
km
kg/ha
Help
Close

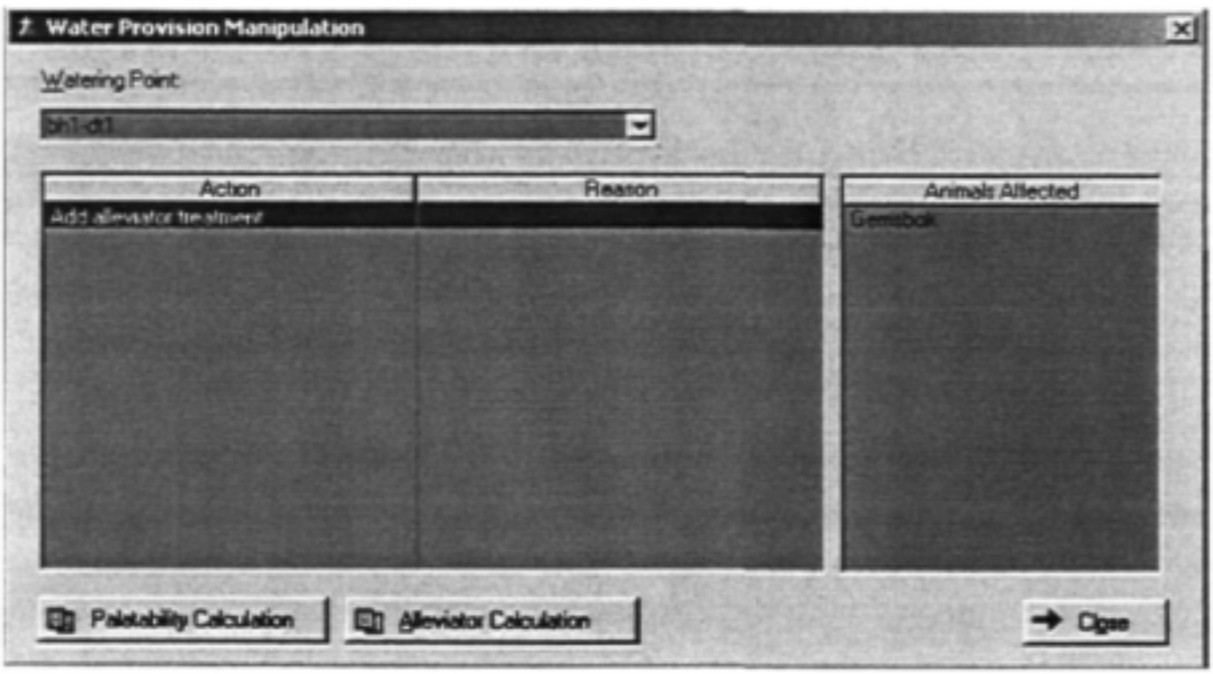

Sample Specific Detail for C:\CSPROJ\WQGIS\WILD.WQS
Animal
Environmental
Nutritional
Ecological
Soil
Rangeland
Vegetation
Dung Deposits
Stock/Animal Units
Bush Species
Plant Specie
Count
Insert
Delete
Help
Close


Sample Specific Detail for C:\CSPROJ\WQGIS\WILD.WQS
Animal
Environmental
Nutritional
Ecological
Soil
Rangeland
Vegetation
Dung Deposits
Stock/Animal Units
Bush Species
Animal Group
Count
Help
Close


Sample Specific Detail for C:\CSPROJ\WQGIS\WILD.WQS
Animal
Environmental
Nutritional
Ecological
Soil
Rangeland
Vegetation
Dung Deposits
Stock/Animal Units
Bush Species
Large Animal Unit Count
Bushveld Habitat
Count
Mopani Veld
Terminalia Sandveld
Kalahari Sandveld
Combretum Veld
Wild Syringa Veld
Mixed Broad-Leaved Veld
Acacia Tortilis Veld
Knobthorn-Marula Veld
Turf Thornveld
3
2
7
9
3
66
1
12
Help
Close


Sample Specific Detail for C:\CSPROJ\WQGIS\WILD.WQS
Animal
Environmental
Nutritional
Ecological
Soil
Rangeland
Vegetation
Dung Deposits
Stock/Animal Units
Bush Species
Select the bush species within 30m distance from the watering point
Bush Description
Acacia haematoxylon (grey camel thorn)
Acacia senegal (three-hook thorn)
Insert
Delete


Select a Bush Specie
Name
Bush Species
EXOTIC PLANTS
Acacia decurrens (silver wattle)
Acacia mearnsii (black wattle)
Agave sisalana (sisal)
Caesalpinia decapetala (Mauritius thorn)
Cereus peruvianus (queen of the night)
Chomolaena odorata (triffid weed)
Eucalyptus spp (blue gum)
Lantana camara (lantana)
Melia azedarach (syringa)
Opunthia ficus-indica (prickly-pear)
Prosopsis glandulosa (mesquite)
Seshania punicea (sesbania)
Solanum mauritianum (bug tree)
Stoebe vulgaris (bankrupt bush)
PLANTS WITH THORNS
Acacia burkei (black monkey thorn)
Acacia caffra (common hook-thorn)
Acacia erubescens (blue thorn)
Acacia exuvialis (flaky thorn)
Acacia fleckii (blade thorn)
Acacia gerrardii (red thorn)
Acacia haematoxylon (grey camel thorn)
Acacia hebeclada (candle acacia)
Acacia karroo (sweet thorn)
Acacia mellifera subsp. detinens (black thorn)
Select
Close


Water Provision Manipulation
Watering Point:
bh1-dt1
Action
Reason
Animals Affected
Add alleviator treatment
Gemsbok
Palatability Calculation
Alleviator Calculation
Close

5.5 Conclusion

The role played by water quality in wildlife enterprises may be easily overlooked for a number of reasons. Adverse chronic and acute health effects may go unnoticed due to difficulties in observing certain species, and in monitoring game without the process of observation itself confounding the symptoms. The presence of a variety of species that differ significantly in their tolerance to potentially hazardous constituents complicates the interpretation of the types of effects a water source may have on wildlife. Water quality and habitat may deteriorate but be ascribed to climatic factors and/or poor management practices.

Despite a number of inadequacies, tabulated guidelines (mg/L format) do provide a conservative estimate of risk and may be used as an indication of potential risk. At the highest level risk is predicted for monogastric versus ruminant animals, and at the lowest level for wildlife in general.

Constituent ingestion based guidelines involve a multi-disciplinary site-specific approach, and are understandably complex. They are based on a predicted (or measured) constituent ingestion rate (from all sources) used in conjunction with animal, environmental and nutritional detail. The formulation of risk assessments and possible solutions is done via modelling, primarily for palatability, toxicology, physiology and significant interactions. The production system environment can alter the risk factors present, and as a result play a significant role in worsening the problems, or alleviating them. Failure to account for the risk factors when assessing the fitness of a water source destined for use by wildlife results in an inaccurate assessment. This could result in water being dismissed as unfit for use when in fact it may be a valuable source of minerals. Alternatively, it may be classed as fit for use and offered to wildlife, and in the process incur losses in terms of animal health, reproduction and growth.

Knowledge of the significant system factors empowers the game ranch manager to base managerial decisions on information. It is these risk factors and site-specific production factors that afford the manager an opportunity to solve problems that occur, and manage resources with long-term sustainability an objective. Should adverse effects be recorded, or predicted, a water source should still not be classed as unfit for use. There are options for mitigation that should be investigated first, ranging from feed and water manipulation, wildlife species manipulation, to the removal of sensitive species.

Alleviator solutions take the form of:

- the addition of chemical treatments to the water source;
- manipulation of the ration or supplement fed;
- manipulation of wildlife production factors (such as allowing less sensitive categories within a herd to consume poor quality water);
- manipulation of grazing and browsing preferences; and
- manipulation of watering practices.

All of the above can reduce the severity of adverse effects, enabling water with potentially hazardous constituents to still be utilised without incurring a significant financial loss. As the water quality results in chapter 6 indicate, drinking water may provide significant amounts of macro- and trace elements to the diet of the user. The potential exits for water with hazardous levels of WQCs, with appropriate management strategies, to provide a valuable nutritive source of many essential elements, as opposed to being dismissed out of hand as unsuitable, or problematic, water sources.

To realise this potential the manager must possess knowledge of water and feed quality, within a site-specific context. This holds true for game ranches that already exist and for the planning of a water provision supply for envisaged game ranch enterprises, or mixed farming with wildlife and livestock.

CHAPTER 6

WATER QUALITY INVESTIGATIONS FOR WILDLIFE

6.1 Introduction

This chapter presents the water quality results from three areas, the Pilanesberg National Park (PNP), Klaserie Area, and Selati Game Ranch. The purpose of these investigations was to obtain guidance as to the main PHCs, COCs, and types of risk factors present, in wildlife production systems.The risk assessments provided in this report offer a generic guideline application for water sources collected from the various areas for wildlife collectively. Knowledge of the fitness of use of the different water sources within these areas can also enable the ranking thereof according to the hazards they may pose to wildlife in general, and to specific sensitive wildlife species in particular, and hence enable key watering points to be identified. Recommendations can also be formulated regarding key information detail which is needed to perform a specific guideline application risk assessment.

Although the following norms affected by water quality received attention, the main focus of this report is the norm dealing with the health of wildlife:

- Animal health effects (toxicology and palatability)
- Animal Product Quality (bioaccumulation of toxic substances in animal tissue)
- Watering Equipment (scaling, corrosion, sedimentation etc.)
- Ecological Impact (watering point on environment, direct and indirect)

6.2 Methods

6.2.1 Water sample collection

Samples were collected according to techniques prescribed by the ISCW (1998) and for more detail the reader is referred to the WRC Final Report K5/644 (Casey *et al.*, 1998). The collection of the water samples was conducted by the section ranges in the various areas, and due to the vast areas involved, some samples were collected over one or two weeks. Samples were delivered to the ISCW Water Laboratory within one day of being available for collection.

6.2.2 Risk assessment formulation

Two sets of water quality guidelines were used as the primary guideline references for risk assessment, namely the 1996 Department of Water Affairs and Water Quality Guidelines for Agricultural Use, Livestock Watering Forestry (DWA&F, 1996), the Quality of Domestic Water Supplies (1998), and the 1999 USEPA Domestic Drinking Water Maximum Contaminant Level (MCL) guidelines (see Chapter 4 -

Methods). The latter guidelines are incorporated for those constituents for which the DWA&F do not offer a guideline. For a few constituents for which neither of these two references offer a guideline, the maximum permissible level (MPL) based on the international median value reported was used (Kempster *et al.*, 1985; Smith, 1988). The relevant guideline limits are provided in the results section.

Due to the harsh environmental factors prevalent in the areas sampled, and in the interests of erring on the conservative side, in cases where more than one guideline is reported for a particular constituent, the lower guideline reported was used. Concentrations recorded which exceeded the Quality of Domestic Water Supplies (1998) guideline for category C, or the MCL for the USEPA guidelines, are reported as potentially hazardous constituents (PHC). Constituents which recorded values within 10% of a guideline limit, or which interact significantly with reported PHCs (induce toxicity and/or deficiency), are reported as constituents of concern (COC). Definitions of these terms appear below.

- PHC: indicates that the WQC in question is likely to result in adverse effects
- COC: indicates that the WQC in question could conceivably become a PHC due to concentration variations, such as seasonal fluctuation in the water source or evaporative effects, and should therefore be monitored.

Two exceptions were made in the case of F and TDS to the 10% COC rule. Due to the endemic fluorosis problem, the high altitude effect on renal glomerular filtration rate (specifically the PNP), and high temperatures experienced in the area reviewed (specifically the PNP and Klaserie Area), concentrations exceeding 1 mg F/L were recorded as a COC. Due to the effects of increased salinity (TDS) on water intake, TDS concentrations exceeding 500 mg/L were also recorded as a COC.

The nomenclature used in the results section stems from different methods of reporting the likely effects associated with a WQC concentration. The USEPA guidelines use a maximum contaminant level (MCL) which is defined as "the maximum permissible level of a contaminant in water which is delivered to any user of a public water system". These are enforceable by federal law and in some cases are the same as the maximum contaminant level goal (MCLG), which are non-enforceable, but represent the recommended WQC concentrations present in water supplied to a specific user group. Some of the guidelines include a crisis limit (CL), which refer to the immediate requirement for water quality managerial and/or health advisory intervention/action.

The maximum recommended level (MRL) equates to a Category C rating and implies that adverse effects may occur in sensitive users, and the constituent levels should be monitored. Exceeding the MRL may result in adverse chronic effects, and the water source should be used with caution, with only limited exposure for sensitive groups should be allowed. An antagonistic variable (AV) is a constituent with unsubstantiated toxicity, but which may increase the toxicity of another WQC, either directly or indirectly. With regard to fluoride toxicity, molybdenum is an AV.

6.3 Areas investigated

6.3.1 The Pilanesberg National Park (PNP)

6.3.1.1 Introduction

This report presents the first of two envisaged water sampling phases, namely a summer phase, with samples collected between late September and early October 1999. The PNP was chosen as an area for water quality investigation for two main reasons. Firstly, it represents an ideal opportunity for assessing the viability of various water treatment possibilities due to its relatively small size compared to the KNP, also within a variation of habitats and wildlife types. Secondly, although a unique geological feature, it was chosen due to the similar spectrum of WQCs having been identified in preliminary water sampling, as those found in the rural livestock production systems of the Jericho District. As such, the intention is to collect the appropriate animal tissues and utilise scintigraphy and the irridation of selected organs via a Safari-I Research Reactor in conjunction with multicompartment analysis, for the purpose of evaluating the effects on the anatomy of various organs from exposure PHCs with effects not yet quantified, such as Sr, Tl, Te and Sb. These results would be a valuable guide for animal, and human health, investigations. Facilities at the Institute for Life Sciences, Medical Faculty, University of Pretoria, will be used for this purpose, and the water quality investigation presented in this report is part of the first stage of identifying whether the WQCs occur at sufficient concentrations to warrant further investigations.

A total of 43 samples were collected in the last week of October 1999, before the summer rains commenced.

6.3.1.2 Results

H 12 -25.26212 27.2123

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	WQC	Measured (mg/l)	Relevant Guideline (mg/l)
Br	0.292	0.01 – MCL	Sb	0.005	0.006 – MCL
Hg	0.007	0.001 – TWQR	Sr	0.193	0.1 – AV
Au	0.01	0.01 – CL	Zn	1.029	0.1 - AV
Se	0.044	0.02 - TWQR			

H 1 -25.26351 27.21098

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	**WQC**	Measured (mg/l)	Relevant Guideline (mg/l)
As	0.021	0.01 - TWQR	Sr	1.059	0.1 - AV
Br	0.212	0.01 – MCL			
F	1.7	1.5 – Cat D			
Se	0.051	0.05 - MCL			
Te	0.03	0.01 – CL			

Tlou Dams -25.25717 27.06582

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	**WQC**	Measured (mg/l)	Relevant Guideline (mg/l)
As	0.027	0.02 – TWQR	Mo	0.013	0.04 – HA
Br	0.174	0.01 – MCL	Sr	1.41	0.1 – AV
F	4.18	3.5 - Cat E			
Au	0.009	0.005 – MCL			
Mn	1.147	0.4 – MCL			
Hg	0.022	0.001 – TWQR			
Se	0.132	0.05 – MCL			
Te	0.04	0.01 – CL			

Makorwane Dam -25.25971 27.08507

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	**WQC**	Measured (mg/l)	Relevant Guideline (mg/l)
Br	0.141	0.01 – MCL	Sr	1.277	0.1 – AV
F	2.89	1.5 - Cat D			
Mn	0.138	0.05 – TWQR			
Se	0.129	0.05 – MCL			
Te	0.034	0.01 – CL			

Malatse Dam -25.21668 27.19488

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	**WQC**	Measured (mg/l)	Relevant Guideline (mg/l)
Be	0.013	0.004 – MCL	Mo	0.025	0.04 – HA
Br	0.204	0.01 – MCL	Sr	1.209	0.1 – AV
F	4.28	3.5 - Cat E			
Hg	0.003	0.001 – TWQR			
Mn	0.143	0.05 – TWQR			
Se	0.216	0.05 – MCL			

Nare Crossing -25.2442 27.0483

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	**WQC**	Measured (mg/l)	Relevant Guideline (mg/l)
Br	0.872	0.01 – MCL	As	0.015-	0.02 – TWQR
F	3.74	3.5 - Cat E	Mo	0.025	0.04 – HA
Au	0.0119	0.01 – CL	Sr	1.14	0.1 – AV
Mn	0.922	0.4 – MCL			
Se	0.046	0.02 – TWQR			
Te	0.016	0.01 – CL			

Tilodi Dam 1 -25.25553 27.19675

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	WQC	Measured (mg/l)	Relevant Guideline (mg/l)
As	0.035	0.01 – TWQR	Sb	0.003	0.006 – MCL
Br	0.643	0.01 – MCL	Sr	0.859	0.1 – AV
F	2.80	1.5 – Cat D			
Mn	0.662	0.4 – MCL			
Hg	0.002	0.001 – TWQR			
Se	0.204	0.05 – MCL			
Te	0.022	0.01 – CL			

Kemonate Taps 1 -25.24224 27.18141

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	WQC	Measured (mg/l)	Relevant Guideline (mg/l)
Br	0.084	0.01 – MCL	Sb	0.003	0.006 – MCL
F	8.28	3.5 - Cat E	Sr	1.53	0.1 – AV
Mn	0.120	0.05 – TWQR	TDS	411	450 – TWQR
Se	0.133	0.05 – MCL			

Kololo Tap Water -25.24622 27.052

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	WQC	Measured (mg/l)	Relevant Guideline (mg/l)
As	0.034	0.01 - TWQR	Cd	0.003	0.005 – Cat C
Br	0.164	0.01 – MCL	Sr	3.076	0.1 – AV
F	2.45	1.5 - Cat D			
Au	0.012	0.01 – CL			
Mn	0.07	0.05 – TWQR			
Hg	0.006	0.001 – TWQR			
Se	0.134	0.05 - MCL			
Te	0.02	0.01 – CL			

Manyane Borehole -25.26316 27.21189

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	WQC	Measured (mg/l)	Relevant Guideline (mg/l)
As	0.039	0.01 - TWQR	Sb	0.003	0.006 – MCL
Br	0.114	0.01 – MCL	Sr	1.133	0.1 – AV
F	1.8	1.5 – Cat D	U	0.015	0.02 – MCL
Hg	0.001	0.001 – TWQR			
Mn	0.063	0.05 – TWQR			
Se	0.117	0.05 – MCL			

Kemonate Taps 2 -25.24263 27.18148

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	**WQC**	Measured (mg/l)	Relevant Guideline (mg/l)
As	0.024	0.01 - TWQR	Sr	1.506	0.1 – AV
Be	0.008	0.004 – MRL	TDS	420	450 – TWQR
Br	0.106	0.01 – MCL			
F	8.29	3.5 – Cat E			
Au	0.009	0.01 – CL			
Hg	0.002	0.001 – TWQR			
Mn	0.126	0.05 – TWQR			
Se	0.077	0.05 – MCL			
Te	0.022	0.01 – CL			

Tilodi Dam 2 -25.25543 27.19663

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	**WQC**	Measured (mg/l)	Relevant Guideline (mg/l)
As	0.024	0.01 - TWQR	Sr	0.806	0.1 – AV
Br	0.17	0.01 – MCL			
Au	0.007	0.005 - MPL			
F	2.57	1.5 - Cat D			
Hg	0.002	0.001 – TWQR			
Mn	0.82	0.4 – Cat C			
Se	0.102	0.05 - MCL			

Nkakane Dam -25.27764 27.18058

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	**WQC**	Measured (mg/l)	Relevant Guideline (mg/l)
Be	0.03	0.004 – MCL	Mo	0.023	0.04 – HA
Br	0.048	0.01 – MCL	Sr	0.366	0.1 – AV
F	2.59	1.5 - Cat D			
Hg	0.006	0.001 – TWQR			
Mn	0.579	0.4 – Cat C			
Se	0.082	0.05 - MCL			
Te	0.035	0.01 – CL			
Ti	0.123	0.1 – MRL			

Tshwene/Kubu Borrow pit -25.25497 27.1112

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	**WQC**	Measured (mg/l)	Relevant Guideline (mg/l)
Be	0.006	0.004 – MCL	Sr	0.781	0.1 – AV
Br	0.318	0.01 – MCL			
Cd	0.014	0.005 – Cat C			
F	3.15	1.5 - Cat D			
Mn	0.484	0.4 – Cat C			
Se	0.232	0.05 – MCL			
Te	0.012	0.01 – CL			

PC Pump -25.2477 27.10554

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	WQC	Measured (mg/l)	Relevant Guideline (mg/l)
As	0.058	0.05 – Cat C	Sr	1.718	0.1 – AV
Sb	0.007	0.006 – MCL			
Be	0.032	0.004 – MCL			
Br	0.164	0.01 – MCL			
F	3.5	3.5 - Cat E			
Mn	0.203	0.05 – TWQR			
Se	0.097	0.05 – MCL			
Te	0.047	0.01 – CL			

Mankwe pump -25.25612 27.13102

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	WQC	Measured (mg/l)	Relevant Guideline (mg/l)
Br	0.22	0.01 – MCL	Sb	0.004	0.006 – MCL
F	1.47	1.5 - Cat D	Sr	2.361	0.1 – AV
Hg	0.008	0.001 – TWQR	Zn	0.532	0.1 – AV
Mn	0.103	0.05 - TWQR			
Se	0.037	0.02 - TWQR			
Te	0.007	0.005 – MPL			

Mankwe Dam -25.26354 27.16154

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	WQC	Measured (mg/l)	Relevant Guideline (mg/l)
As	0.041	0.01 – TWQR	Mo	0.019	0.04 – HA
Br	0.211	0.01 – MCL	Sr	1.314	0.1 – AV
F	3.20	1.5 - Cat D			
Mn	0.06	0.05 – TWQR			
Hg	0.002	0.001 – TWQR			
Se	0.143	0.05 – MCL			
Te	0.018	0.01 - CL			

Kubu Borrow Pit -25.3034 27.08181

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	WQC	Measured (mg/l)	Relevant Guideline (mg/l)
As	0.061	0.05 – Cat C	Sr	1.622	0.1 – AV
Be	0.053	0.004 – MCL			
Br	0.237	0.01 – MCL			
F	5.81	3.5 - Cat E			
Au	0.009	0.01 – CL			
Mn	0.338	0.05 – TWQR			
Hg	0.012	0.001 – TWQR			
Mo	0.062	0.07 – MRL			
Se	0.273	0.05 – MCL			
Ti	0.378	0.1 – MRL			
Te	0.021	0.01 – CL			

Salt Pans -25.23329 27.22267

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	**WQC**	Measured (mg/l)	Relevant Guideline (mg/l)
As	0.072	0.05 – MRL			
Be	0.031	0.004 – MCL			
Br	0.274	0.01 – MCL			
Cr	0.082	0.05 - MRL			
Cl	208	200 – Cat C			
F	142	3.5 - Cat E			
Mo	0.081	0.07 – MRL			
Mn	0.174	0.05 – TWQR			
Hg	0.004	0.001 – TWQR			
Na	722	400 – Cat D			
Se	0.198	0.05 – MCL			
Ti	0.344	0.1 – MRL			
TDS	1733	1000 – Cat C			
Te	0.017	0.01 – CL			

Bakubung Outflow -25.34242 27.0638

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	**WQC**	Measured (mg/l)	Relevant Guideline (mg/l)
As	0.045	0.0 – TWQR	Sb	0.004	0.006 – MCL
Be	0.013	0.004 – MCL	Sr	2.441	0.1 – AV
Br	0.491	0.01 – MCL	Mo	0.029	0.04 – HA
F	1.8	1.5 - Cat D			
Au	0.013	0.01 - CL			
Hg	0.002	0.001 – TWQR			
Mn	0.177	0.05 – TWQR			
Se	0.165	0.05 – MCL			
Ti	0.107	0.1 – MRL			
Te	0.012	0.01 – CL			

Bakubung Hippo Pool -25.34165 27.05841

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	**WQC**	Measured (mg/l)	Relevant Guideline (mg/l)
Be	0.025	0.004 – MCL	Sr	2.365	0.1 – AV
Br	0.438	0.01 – MCL			
Cl	180	100 – TWQR			
Cd	0.015	0.005 – Cat C			
Au	0.011	0.01 – CL			
Mn	0.419	0.4 – Cat C			
Hg	0.011	0.001 – TWQR			
Na	130	100 – TWQR			
Se	0.277	0.05 – MCL			
Te	0.034	0.01 – CL			
TDS	532	450 – TWQR			
Ti	0.138	0.1 – MRL			
U	0.02	0.02 – MCL			

Lengau Dam -25.32392 27.05533

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	**WQC**	Measured (mg/l)	Relevant Guideline (mg/l)
As	0.056	0.05 – Cat C	Sb	0.004	0.006 – MCL
Be	0.011	0.004 – MCL	Cd	0.003	0.005 – TWQR
Br	0.171	0.01 – MCL	Sr	1.851	0.1 – AV
F	2.86	1.5 - Cat D			
Mn	0.130	0.05 - TWQR			
Hg	0.002	0.001 – TWQR			
Se	0.199	0.05 – MCL			
Te	0.017	0.01 – CL			

Tshukudu Dam -25.29694 27.0299

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	**WQC**	Measured (mg/l)	Relevant Guideline (mg/l)
As	0.061	0.05 – Cat C	Ba	1.061	2 – MCL
Be	0.817	0.004 – MCL	Cd	0.004	0.005 – TWQR
Br	0.101	0.01 – MCL	Sr	2.963	0.1 – AV
Pb	0.064	0.016 - MCL	Zn	0.312	0.1 – AV
Hg	0.001	0.001 – TWQR			
Mn	2.995	0.4 – Cat C			
Se	0.235	0.05 – MCL			
Ti	2.596	0.1 – MRL			
Te	0.061	0.01 – CL			
U	0.059	0.02 – MCL			

Tshukudu Tap water -25.30118 27.02952

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	**WQC**	Measured (mg/l)	Relevant Guideline (mg/l)
Be	0.021	0.004 – MCL	Sr	1.936	0.1 – AV
Br	0.153	0.01 – MCL	Zn	0.73	0.1 – AV
F	3.87	3.5 - Cat E			
Mn	0.168	0.05 - TWQR			
Se	0.092	0.05 – MCL			
Te	0.026	0.01 – CL			

Tshukudu Borehole -25.29694 27.02258

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	**WQC**	Measured (mg/l)	Relevant Guideline (mg/l)
Be	0.034	0.004 – MCL	Sr	1.972	0.1 – AV
Br	0.157	0.01 – MCL	U	0.014	0.02 – MCL
F	3.78	3.5 - Cat E			
Mn	0.099	0.05 - TWQR			
Se	0.079	0.05 – MCL			

Leeufontein Dam -25.27921 27.05302

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	**WQC**	Measured (mg/l)	Relevant Guideline (mg/l)
As	0.011	0.01 - TWQR	Sb	0.004	0.006 – MCL
Be	0.024	0.004 – MCL	Sr	2.445	0.1 – AV
Br	0.202	0.01 – MCL			
F	6.13	3.5 - Cat E			
Mn	0.4	0.4 – Cat C			
Hg	0.002	0.001 – TWQR			
Se	0.052	0.05 – MCL			
Ti	0.688	0.1 – MRL			

Ruighoek -25.28115 27.01582

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	**WQC**	Measured (mg/l)	Relevant Guideline (mg/l)
As	0.055	0.05 – Cat C	Sb	0.005	0.006 – MCL
Be	0.009	0.004 – MCL	Mo	0.023	0.04 – HA
Br	0.26	0.01 – MCL	Sr	1.536	0.1 – AV
F	6.55	3.5 - Cat E			
Mn	0.087	0.05 – TWQR			
Hg	0.001	0.001 – TWQR			
Se	0.308	0.05 – MCL			
Te	0.015	0.01 – CL			

Batlako Dam -25.25723 27.0081

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	**WQC**	Measured (mg/l)	Relevant Guideline (mg/l)
As	0.064	0.05 – Cat C	Mo	0.026	0.04 – HA
Br	0.136	0.01 – MCL	Sr	1.279	0.1 – AV
F	2.12	1.5 - Cat D			
Mn	0.088	0.05 – TWQR			
Se	0.255	0.05 – MCL			
Te	0.022	0.01 – CL			

Bailie Lower Springs -25.24529 26.9974

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	**WQC**	Measured (mg/l)	Relevant Guideline (mg/l)
As	0.064	0.05 – MRL	Sr	1.033	0.1 – AV
Sb	0.006	0.006 - MCL	Zn	0.105	0.1 – AV
Be	0.080	0.004 – MCL			
Br	0.049	0.01 – MCL			
Cr	0.091	0.05 - MRL			
Mn	0.356	0.4 – Cat C			
Se	0.346	0.05 – MCL			
Ti	1.91	0.1 – MRL			
Te	0.052	0.01 – CL			

Driefontein Springs -25.23255 26.99954

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	WQC	Measured (mg/l)	Relevant Guideline (mg/l)
As	0.033	0.01 - TWQR	Sb	0.005	0.006 – MCL
Be	0.014	0.004 – MCL	Sr	2.676	0.1 – AV
Br	0.096	0.01 – MCL			
F	3.29	1.5 - Cat D			
Mn	0.130	0.05 – TWQR			
Se	0.212	0.05 – MCL			
Ti	0.18	0.1 – MRL			
Te	0.03	0.01 – CL			

Metswedi Taps -25.20747 27.04532

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	WQC	Measured (mg/l)	Relevant Guideline (mg/l)
Be	0.04	0.004 – MCL	Sb	0.005	0.006 – MCL
Br	0.12	0.01 – MCL	Sr	1.088	0.1 – AV
Mn	0.062	0.05 – TWQR			
Hg	0.007	0.001 – TWQR			
Se	0.196	0.05 – MCL			
Te	0.049	0.01 – CL			

Metswedi Borehole -25.20891 27.04588

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	WQC	Measured (mg/l)	Relevant Guideline (mg/l)
As	0.054	0.05 – Cat C	Cu	0.212	1 – TWQR
Be	0.026	0.004 – MCL	Sr	1.016	0.1 – AV
Br	0.208	0.01 – MCL	Zn	0.130	0.1 – AV
Mn	0.062	0.05 – TWQR			
Hg	0.015	0.001 – TWQR			
Se	0.203	0.05 – MCL			
Te	0.019	0.01 – CL			

Nare Camp Taps -25.17789 27.02087

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	WQC	Measured (mg/l)	Relevant Guideline (mg/l)
As	0.052	0.05 – Cat C	Cd	0.003	0.005 – TWQR
Be	0.024	0.004 – MCL	Sr	4.519	0.1 – AV
Br	0.028	0.01 – MCL	Zn	0.219	0.1 – AV
F	1.64	1.5 - Cat D			
Au	0.009	0.005 - MPL			
Hg	0.01	0.001 – TWQR			
Mn	0.104	0.05 – TWQR			
Se	0.332	0.05 – MCL			
Te	0.03	0.01 – CL			
TDS	458	450 - TWQR			

Legkraal Key Staff Taps -25.15578 27.02426

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	**WQC**	Measured (mg/l)	Relevant Guideline (mg/l)
Br	0.334	0.01 – MCL	Sr	0.306	0.1 – AV
Au	0.01	0.01 – CL			
Mn	0.067	0.05 – TWQR			
Hg	0.001	0.001 – TWQR			
Se	0.097	0.05 – MCL			

Legkraal Springs -25.15028 27.00929

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	**WQC**	Measured (mg/l)	Relevant Guideline (mg/l)
As	0.090	0.05 – Cat C	Sb	0.005	0.006 – MCL
Br	0.609	0.01 – MCL	Sr	0.142	0.1 – AV
Be	0.034	0.004 – MCL			
Cr	0.054	0.05 - MRL			
Cl	463	200 – Cat C			
F	49.4	3.5 – Cat E			
Mo	0.066	0.07 – MRL			
Mn	0.170	0.05 – TWQR			
Na	605	600 – Cat D			
SO_4	145	100 – TWQR			
Se	0.325	0.05 – MCL			
Te	0.042	0.01 – CL			
TDS	1516	1000 – Cat C			

Blinkwater Spruit Pool -25.20228 27.11177

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	**WQC**	Measured (mg/l)	Relevant Guideline (mg/l)
As	0.020	0.01 - TWQR	Mo	0.023	0.04 – HA
Sb	0.006	0.006 - MCL	Sr	1.344	0.1 – AV
Be	0.015	0.004 – MCL			
Br	0.074	0.01 – MCL			
Au	0.012	0.01 – CL			
Mn	0.107	0.05 – TWQR			
Se	0.156	0.05 – MCL			
Te	0.015	0.01 – CL			

Ratlogo Hide Taps -25.20822 27.12569

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	**WQC**	Measured (mg/l)	Relevant Guideline (mg/l)
As	0.038	0.05 – Cat C	Sr	2.262	0.1 - AV
Br	0.175	0.01 – MCL	Zn	3.71	0.1 - AV
Be	0.023	0.004 – MCL			
Cd	0.006	0.005 – MRL			
F	1.21	1 – Cat C			
Pb	0.016	0.015 – MCL			
Mn	0.122	0.05 – TWQR			
Hg	0.005	0.001 – TWQR			
Se	0.219	0.05 – MCL			
Te	0.075	0.01 – CL			

Pilanesberg Centre Taps -25.24853 27.10944

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	WQC	Measured (mg/l)	Relevant Guideline (mg/l)
Br	0.152	0.01 – MCL	Sb	0.005	0.006 - MCL
Be	0.019	0.004 – MCL	Sr	1.718	0.1 - AV
F	3.14	1.5 – Cat D	Se	0.017	0.02 - TWQR
Mn	0.154	0.05 – TWQR	Zn	0.192	0.1 - AV
Hg	0.001	0.001 – TWQR			
Te	0.04	0.01 – CL			

Mankwe Camp Taps -25.25644 27.1302

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	WQC	Measured (mg/l)	Relevant Guideline (mg/l)
Br	0.092	0.01 – MCL	Cr	0.03	0.05 - MRL
Be	0.016	0.004 – MCL	Mo	0.023	0.04 – HA
Cd	0.006	0.005 – Cat C	Sr	2.414	0.1 – AV
F	1.59	1.5 – Cat D	Zn	1.688	0.1 - AV
Mn	0.130	0.05 – TWQR			
Hg	0.006	0.001 – TWQR			
Se	0.174	0.05 – MCL			
Tl	0.002	0.002 – MCL			
Te	0.046	0.01 – CL			

Little Baile Spring -25.22545 27.07367

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	WQC	Measured (mg/l)	Relevant Guideline (mg/l)
As	0.064	0.05 – Cat C	Sr	0.625	0.1 - AV
Br	0.215	0.01 – MCL	Pb	0.012	0.015 – MCL
Be	0.089	0.004 – MCL	Mo	0.027	0.04 - HA
Cr	0.121	0.1 – MRL	Zn	0.165	0.1 – AV
F	2.73	1.5 - Cat D			
Au	0.009	0.005 – MPL			
Mn	0.603	0.4 – Cat C			
Hg	0.01	0.001 – TWQR			
Se	0.522	0.05 – MCL			
Ti	1.59	0.1 – MRL			
Te	0.045	0.01 – CL			

Mankwe River Outflow -25.291 27.18066

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	WQC	Measured (mg/l)	Relevant Guideline (mg/l)
As	0.082	0.05 – Cat C	Cd	0.003	0.005 – Cat C
Sb	0.008	0.006 – MCL	Mo	0.058	0.07 – MRL
Br	0.361	0.01 – MCL	Sr	1.76	0.1 – AV
Be	0.019	0.004 – MCL			
Cr	0.052	0.05 – MRL			
F	4.69	3.5 - Cat E			
Au	0.008	0.005 – MPL			
Mn	0.295	0.05 – TWQR			
Se	0.251	0.05 – MCL			
Te	0.037	0.01 – CL			

Springbok Pan Borrow Pit -25.31484 27.18376

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	**WQC**	Measured (mg/l)	Relevant Guideline (mg/l)
As	0.028	0.02 – TWQR	Cr	0.034	0.05 – MRL
Br	0.31	0.01 – MCL	Mo	0.026	0.04 – HA
Be	0.014	0.004 – MCL	Sr	1.365	0.1 – AV
F	2.2	1.5 – Cat D			
Au	0.008	0.005 – MPL			
Mn	1.136	0.4 – Cat C			
Sb	0.012	0.006 – MCL			
Se	0.126	0.05 – MCL			
Te	0.043	0.01 – CL			

Potokwane Taps -25.24399 27.19653

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	**WQC**	Measured (mg/l)	Relevant Guideline (mg/l)
As	0.033	0.02 – TWQR	Sr	2.062	0.1 – AV
Br	0.351	0.01 – MCL	Zn	0.333	0.1 – AV
Be	0.042	0.004 – MCL			
F	2.23	1.5 - Cat D			
Au	0.007	0.005 – MPL			
Mo	2.062	0.07 – MRL			
Mn	0.237	0.05 – TWQR			
Hg	0.002	0.001 – TWQR			
Se	0.107	0.05 – MCL			
Te	0.015	0.01 – CL			

Table 6.3.1. Summary statistics for the main PHCs and COCs identified from 43 water samples collected from the PNP during October 1999.

WQC	**PHC**	**COC**	**Average (mg/L)**	**SD (mg/L)**	**Median (mg/L)**	**Range (mg/L)**	
(n) / WP	342 7.95	96 2.23				**Minimum**	**Maximum**
As	28	1	0.032	0.026	0.03	0	0.71
Sb	5	13	0.0025	0.0029	0	0	0.012
Be	29	1	0.037	0.125	0.014	0	0.817
Br	43	0	0.226	0.170	0.174	0.028	0.872
Cr	5	2	0.029	0.029	0.021	0	0.121
Cd	4	5	0.001	0.003	0	0	0.015
F	36	0	7.568	22.54	2.83	0.53	142
Au	16	0	0.004	0.005	0	0	0.013
Mo	4	13	0.021	0.017	0.017	0.004	0.081
Mn	41	0	0.341	0.51	0.141	0.019	2.995
Hg	28	0	0.003	0.005	0.002	0	0.022
Se	42	1	0.175	0.103	0.17	0.017	0.522
TDS	4	0	277	324	185.5	54	1737
Te	35	0	0.025	0.019	0.022	0	0.075
Ti	10	0	0.223	0.536	0.044	0	2.586
Sr	0	41	1.535	0.887	1.387	0.07	4.519
Zn	0	12	0.227	0.636	0.031	0	3.71

6.3.1.3 Discussion

A total of 286 PHCs were recorded, with all 43 samples received containing multiple PHCs, ranging from mild hazards to severe hazards. For some of the constituents involved, site-specific factors will result in toxic adverse effects occurring at reduced dose intakes, whilst for other constituents systems factors may significantly mitigate potential adverse effects. In order to conduct a risk assessment, additional animal, environmental and nutritional information is required.

The following table presents the preferential guideline ratios with respect to F toxicology. The results are suggestive of the presence of increased risk due to the inverse correlations that exist between ameliorating WQCs and F concentration.

Table 6.3.2. Summary statistics for important ratios influencing fluoride toxicity.

Ratios	F:Ca	F:B	F:TDS	F:Sr	F:Mo	F:pH
RGR*	>166.66	>4.166	>500.00	<0.166	<0.0067	>1.333
Average	15.1	0.06	118	0.778	0.008	4.138
SD	15.4	0.124	156	0.755	0.007	3.745
Median	8.39	0.035	52.9	0.511	0.006	2.814
Maximum	62.8	0.716	794	3.53	0.037	15.59
Minimum	0.03	0.0007	122	0.0005	0.0006	0.065

* = Recommended Guideline Ratio (WQC/F)

The desired pH ratio should be 1:1.33 (6 F : pH of 8.0) or greater. The following correlation coefficient was obtained for F and pH.

F:pH = +0.499

Based on the incidence of occurrence in the aquatic environment, the **primary** WQCs that pose a potential hazard to wildlife may be placed into two main groups, one which comprises those of known toxicokinetics and toxicodynamics (group A), the other comprised of constituents with cause and effect relationships not yet fully described (group B).

Group A: Se; F; Hg; As

Group B: Br; Te; Sr; Be

It should be noted that many other constituents were found at concentrations that pose a serious threat to animal health, although they are not as prevalent as Group A and B constituents. These include:

Cr; Mo; Cd; Sb; Pb; U

Example of probable intake of selenium via drinking water:

Average Se value from PNP samples = 0.175 mg/L

The risk of chronic selenosis for a 75 kg ewe = 7.2 mg Se/d

(Underwood & Suttle, 1999)

-average Se intake (water) @ 15 deg Celcius = 1.658 mg Se/d

-average Se intake (water) @ 30 deg Celcius = 2.792 mg Se/d

Highest Se value from PNP samples = 0.522 mg/L

The risk of chronic selenosis for a 75 kg ewe = 7.2 mg Se/d

(Underwood & Suttle, 1999)

-average Se intake (water) @ 15 deg Celcius = 4.946 mg Se/d

-average Se intake (water) @ 30 deg Celcius = 8.330 mg Se/d

Note that these represent Se intakes from the water alone. Additional intakes via Se accumulator plants and geophagia will add to the Se burden, and could reasonably be expected to be of at least the same magnitude as that ingested from drinking water (Appleton *et al.*, 1996; Underwood & Suttle, 1996). The contribution to the Se load from the water may increase or decrease due to water concentration changes, but more importantly, this represents an intake which is more stable over time (as opposed to forage intake) and is usually a daily, long-term dosage.

Finally, the risk associated with the use of certain watering points must be seen in conjunction with the total risk posed by all PHCs, COCs and AVs occurring within the same source.

6.3.1.4 Recommendations

- The results indicate that the majority of the samples collected contain constituents that exceed both local and international recommended guidelines by large margins. The concentrations recorded for many of the samples strongly suggest that adverse effects will be associated with the ingestion of these water sources by wildlife. As seasonal variation is usually significant, it is strongly recommended that a water quality monitoring programme be implemented. The types of adverse effects that could occur are presented on a constituent basis in Table 6.3.

- Due to the independent risk represented (irrespective of possible ameliorating site-specific factors) by the high concentrations of multiple WQCs recorded, the following water samples are classed as completely unfit for use (Category E - DWA&F, 1998) and it is recommended that management investigate the possibility of their immediate closure:

Water Sample	Reasons for closure:
PNP 19 (Salt Pans)	F = 142; Mo = 0.081; Se = 0.198; As = 0.072
PNP 35 (Legkraal Springs)	F = 49.4; Mo = 0.066; Se = 0.325; As = 0.09
PNP 23 (Tsukudu Dam)	F = 11.54; Be = 0.817; Ti = 2.596; Cr = 0.121;
	Mn = 2.995; As = 0.061; Se = 0.235; Te = 0.061
	Hg, Pb, U

- High risk water samples which should only be offered to wildlife for a period not exceeding 14 days of continuous exposure include:

  PNP 8 Kemonate Taps; PNP 11 Kemonate Taps; PNP 26 Leeufontein Dam;
  PNP 27 Ruighoek; PNP 40 Little Bailie Springs; PNP 43 Potokwane Taps;
  PNP 29 Bailie Lower Springs.

- Those samples which include Te as posing a severe hazard may continue to be utilised, pending further investigation regarding the types of effects attributable to the levels recorded (histopathological examination of selected tissues). This is due to the lack of reference data for wildlife regarding exposure to levels exceeding the crisis limit for humans.

- For most of the PHCs recorded, a hazard assessment regarding the species most at risk (those relying on selected samples as the predominant water source), total exposure (additional ingestion via feed), and site-specific synergistic and antagonistic factors, needs to be conducted prior to formulating specific recommendations.

- Although many of the constituents and related concentrations recorded may be of a natural origin, the decision to open or close a watering point should incorporate information relating to the risk present. Furthermore, the DWA&F requires by law that all managers of water bodies in South Africa attempt to maintain long-term sustainability of those water bodies. As mentioned in the introduction, the presence of high concentrations of toxic constituents does not constitute a hazard. However, the levels recorded are of such a severe nature, that wildlife ingesting from them will incur chronic adverse effects, and in some cases possibly even acute effects. As a result, it is recommended that a water quality monitoring programme be put in place, which should serve as a source of essential background information for any wildlife study conducted or water management action carried out within the park.

Some additional issues:

- The potential for bioaccumulation, and possible biomagnification, exists for some of the PHC's recorded, primarily in aquatic life and selected predators. The main constituents involved are: As, Cd, Cr, F, Hg, Pb, Se, Tl, and Zn.

- Although descriptions of the watering point designs were still outstanding at the time of compiling this report, the low nitrate and nitrite values obtained seem to indicate that over-utilisation and fecal pollution of the watering points do not present a hazard.

- The primary question that needs to be addressed relates not only to the degree and nature of adverse effects which may result due to exposure to the high levels of WQC recorded, but also to the practical management actions which can yield a meaningful opportunity to reduce health risks. The most difficult aspect with regard to establishing the severity of adverse effects occurring in wildlife is to be found in the typical subclinical, chronic, low level route, followed by many of the trace minerals involved. A differential diagnosis is usually required, specifically due to multiple constituent hazards being present within a single water source. The observation of adverse effects is complicated further in wildlife by difficulties in observing sufficient animals for a sufficient amount of time. Unlike livestock production systems, performance data is not available, and the best source of reference material usually consists of tissues collected for assay and histopathological investigation.

- Ecosystem aspects (soil, herbaceous, groundwater quality) must be taken into account when opening or closing a watering point. Possible health effects on wildlife should be taken into consideration in the light of environmental impact the watering point, and subsequent animal presence/absence may have.

- The high F concentrations recorded are expected based on previous finding within the Rustenberg Complex relating to the incidence of endemic fluorosis (Ockerse, 1953). The risk present due to the high F levels may be increased due to the concurrent high incidence of antagonistic constituents within the water source accompanying the high F values, and due to the low number of alleviator constituents present within the same sources. These correlation, primarily between F, TDS, Ca, Mg, and B are typical of groundwater chemistry and have been recorded in the Jericho District, near the PNP, and are presented elsewhere in this report. Additional risk factors include the high ambient temperatures experienced during the summer season and the high altitude of the area.

- Note that the USEPA is currently revising the MCL values for some of the WQCs reported as PHCs in this report, notably that of arsenic and selenium (both expected to be lowered). The guideline limit for

Se used in this report is 0.05 mg/L, but evidence suggests this should be lowered to 0.02 mg/L. This would place even more emphasis on Se as a PHC in the park.

6.3.1.5 Summary of types of effects

The results indicate that for many of the areas sampled constituents exceed both local and international recommended guidelines by large margins. Many exceed crisis limits, or fall into the category E of completely unacceptable. In order to view the large amount of data in a more concise manner, a brief summary is provided in which the degree to which the limits are exceeded is indicated. Classification according to the hazard presented is as follows:

Acronym	Definition	Classification (DWA&F, 1998)
MONHAZ	Monitor potential hazard	COCs present
MILDHAZ	Mild hazard present	Exceeds Category C limit or WQG by a factor of < 10.
SIGNHAZ	Significant hazard present	Exceeds Category D limit or WQG by a factor of >10 but < 20.
SEVHAZ	Severe hazard present	Exceeds WQG by a factor of >20, or Exceeds crisis limit, or Exceeds Category E limit

Table 6.3.3 Classification of PHCs and COCS involved in the PNP - Summer.

Area Sample site	**MONHAZ**	**MILDHAZ**	**SIGNHAZ**	**SEVHAZ**	**Total PHC**
PNP 1	Se; Zn; Sb	Br; Hg		Au	3
PNP 2	F	Br; Se; Sr		Te	4
PNP 3		Br; Mn; Au; F; Sr	Hg; Se	Te	8
PNP 4		Br; F; Sr	Se	Te	5
PNP 5	Mo	Be; Br; F;Sr	Hg	Se	6
PNP 6	Se; Mo	Br; Mn; F; Sr		Te; Au	6
PNP 7	As; Sr	Br; F; Mn; Hg		Se; Te	6
PNP 8		Sr	F; Se		3
PNP 9	Cd	Br; F; Sr; Hg	Se	Au; Te	8
PNP 10	As; F	Br; Sr	Se		3
PNP 11		Be; Br; Se Sr; Au; Hg	F	Te	8
PNP 12	Sr	Br; F; Mn; Hg	Se		5
PNP 13	Sr	Be; F; Hg Mn; Se; Ti		Te	7
PNP 14	Sr	Be; Br; F Mn; Cd		Se; Te	7
PNP 15		Be; Br; F Se; Sr; Sb		Te	7
PNP 16	F; Se; Zn	Br; Hg; Sr			3
PNP 17		Br; F; Hg Mo; Sr	Se	Te	7

PNP 18		As; Br; F Mo; Sr; Ti	Be; Hg	Se; Te	10
PNP 19	Cr Mo	As; Be; Br Hg; Ti	Se	Te; F	8
PNP 20	As F	Be; Br; Cr Hg; Sr; Ti	Se	Te	8
PNP 21	F	Be; Br; Cd Mn; U; Sr	Hg	Se ;Te	9
PNP 22	Cd	As; Be; Br; F; Hg Sr;Ti	Se	Te	9
PNP 23	Ba; Cd	As; Br ; Hg; U; Sr	Pb; Mn; Ti	Be; F; Se; Te	12
PNP 24	Zn	Be; Br ; F; Sr ; Se		Te	6
PNP 25		Be; Br ; F; Sr; Se			5
PNP 26		Be; Br ; Hg Mn; Sr; Se; Ti	F		8
PNP 27		As; Be; Br; Hg; Sr	F	Se; Te	8
PNP 28		As; Br;F; Sr		Se; Te	6
PNP 29	Cr; F	As; Sr	Be; Ti	Se; Te	6
PNP 30		Be; F; Sr; Ti		Se; Te	6
PNP 31		Be; Br; Hg; Sr	Se	Te	6
PNP 32		As ; Be; Br; Sr	Hg	Se; Te	7
PNP 33	Cd; F	As; Be ; Sr	Hg	Se; Te	6
PNP 34	Sr	Be; Br ; Se	Hg		4
PNP 35	Cr; Sr	As ; Be; Br; Mo; Ti		F; Se; Te	8
PNP 36		Be; Sr	Se	Te	4
PNP 37	As; Cd; F	Be; Br ; Hg Pb; Sr; Zn		Se; Te	8
PNP 38		Be; Br ; F; Hg; Sr		Te	6
PNP 39	Cd; F	Be; Tl; Hg; Sr; Zn	Se	Te	7
PNP 40	Sr	As; Br ; Cr F; Pb; Mn	Be; Hg; Ti	Se; Te	11
PNP 41	Cd; Cr	As; Be; Br; Mo; F; Sr		Se; Te	8
PNP 42	Cr	Be; Br; F Sb; Sr; Mn	Se	Te	8
PNP 43	Sr	F; Hg	Be	Se; Mo; Te	6

6.3.2 Selati Game Ranch

6.3.2.1 Introduction

This report deals with samples collected during November 1998 from Selati Game Ranch, located in the Gravelotte District of the Northern Province. The ranch comprises 35 000 ha of farms which were formally beef cattle farms, and have been converted into a collectively owned game ranch incorporating 14 farms. The game ranch has been in existence, in various stages of development, for over 10 years. The Department of Animal and Wildlife Sciences at the University of Pretoria was simultaneously involved in research at Selati Game Ranch investigating an incidence of small body frame size in some antelope species. Possible inferences are dealt with in the discussion.

6.3.2.2 Methods

Samples were collected in accordance with prescribed methods for water quality ICP-AES semi-quantitative scan and full macro-element analyses (ISCW, 1998). Samples were collected from mainly from subterranean sources, predominantly from the point of water intake by game. Natural earth dams were also included. Many of the samples collected were from water sources also used for domestic use, either by workers residing in the area, or by guests at the various game lodges. However, the risk assessments conducted in this report are concerned with wildlife norms only.

6.3.2.3 Results

Open soil Dam-(Borehole # 1) S1

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	**WQC**	Measured (mg/l)	Relevant Guideline (mg/l)
As	0.01	0.01 – TWQR	I	0.227	0.5 – RL
Br	2.814	0.01 – MCL	Sr	0.32	0.1 – AV
Hg	1.91	0.001 – TWQR			
Se	0.023	0.05 – Cat C			
Ti	0.224	0.2 – MPL			

Drinking trough (Borehole # 2) S2

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	**WQC**	Measured (mg/l)	Relevant Guideline (mg/l)
Br	2.168	0.01 – MCL	V	0.087	0.1 – TWQR
Be	0.005	0.004 - MCL			
Hg	0.849	0.001 – TWQR			
Se	0.092	0.05 – Cat C			

Mahudt – Reservoir (Borehole # 3) S3

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	**WQC**	Measured (mg/l)	Relevant Guideline (mg/l)
Br	2.983	0.01 – MCL	U	0.019	0.02 – MCL
TDS	1403	TWQR			
NO3	163	– MRL			
Hg	0.521	0.001 – TWQR			
Se	0.071	0.05 – Cat C			
V	0.148	0.1 – TWQR			

Salahjohn – Reservoir S4

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	**WQC**	Measured (mg/l)	Relevant Guideline (mg/l)
As	0.01	0.01 – TWQR	U	0.016	0.02 – MCL
Br	2.269	0.01 – MCL	Sr	0.684	0.1 – AV
Ni	0.025	0.02 – MRL	I	0.296	0.5 – RL
Hg	*nd	0.001 – TWQR			
Ti	0.161	0.2 – MPL			

*nd – not determined due to sample preservation technique for nitrate.

Lekkersmaak – earth dam S5

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	WQC	Measured (mg/l)	Relevant Guideline (mg/l)
As	0.025	0.01 – TWQR	I	0.227	0.5 – RL
Br	1.942	0.01 – MCL	Sr	0.208	0.1 – AV
Be	0.004	0.004 – MCL			
Cr	0.058	0.05 – TWQR			
Mn	0.23	0.05 – TWQR			
Ni	0.099	0.02 – MRL			
Hg	0.886	0.001 – TWQR			
Se	0.072	0.05 – Cat C			
Ti	0.488	0.2 – MPL			

Treinbrug - S6

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	WQC	Measured (mg/l)	Relevant Guideline (mg/l)
Br	1.648	0.01 – MCL	Ni	0.018	0.02 – MRL
Hg	0.535	0.001 – TWQR	Sr	0.158	0.1 – AV
Se	0.054	0.05 – Cat C			
Ti	0.111	0.2 – MPL			

Weir River 1- S7

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	WQC	Measured (mg/l)	Relevant Guideline (mg/l)
As	0.018	0.01 – TWQR	Ni	0.015	0.02 – MRL
Br	1.506	0.01 – MCL	Sr	0.199	0.1 – AV
Hg	0.365	0.001 – TWQR			
Se	0.13	0.05 – Cat C			
Ti	0.123	0.2 – MPL			

Lily 2- Dam (Borehole #4) S8

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	WQC	Measured (mg/l)	Relevant Guideline (mg/l)
Br	0.835	0.01 – MCL	Cr	0.037	0.05 – TWQR
Be	0.014	0.004 – MCL			
Cd	0.008	0.003 – TWQR			
Mn	0.16	0.05 – TWQR			
Ni	0.04	0.02 – MRL			
Hg	0.284	0.001 – TWQR			
Se	0.063	0.05 – Cat C			
Te	0.029	0.01 – RL			
Ti	1.792	0.2 – MPL			

Drinking trough - S9

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	WQC	Measured (mg/l)	Relevant Guideline (mg/l)
Br	1.097	0.01 – MCL	I	0.269	0.5 – RL
Cd	0.004	0.003 – TWQR	Sr	0.157	0.1 – AV
F	1.5	1 – TWQR	Mo	0.015	0.04 – RL
Hg	0.405	0.001 – TWQR			
Ti	0.119	0.2 – MPL			

Earth dam (Borehole # 4) S10

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	**WQC**	Measured (mg/l)	Relevant Guideline (mg/l)
As	0.043	0.01 – TWQR			
Br	0.786	0.01 – MCL			
Be	0.007	0.004 – MCL			
Mn	0.11	0.05 – TWQR			
Ni	0.022	0.02 – MRL			
Hg	0.24	0.001 – TWQR			
Se	0.041	0.05 – Cat C			
Ti	0.892	0.2 – MPL			

Lily 1 outflow pipe (Borehole) S11

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	**WQC**	Measured (mg/l)	Relevant Guideline (mg/l)
As	0.049	0.01 – TWQR	Mo	0.013	0.04 – RL
Br	1.854	0.01 – MCL	I	0.416	0.5 – RL
Mn	0.21	0.05 – TWQR	Sr	0.532	0.1 – AV
F	3.3	1 – TWQRL	Zn	4.14	0.1 – AV
Hg	0.197	0.001 – TWQR			
Se	0.057	0.05 – Cat C			
TDS	1139	1000 – TWQR			
Te	0.018	0.01 - RL			
Ti	0.275	0.2 – MPL			

Drinking trough – transport S12

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	**WQC**	Measured (mg/l)	Relevant Guideline (mg/l)
Br	1.554	0.01 – MCL	U	0.018	0.02 – MCL
F	1	1 – TWQR	Sr	0.21	0.1 – AV
Ni	0.018	0.02 – MRL			
Hg	0.183	0.001 – TWQR			
Se	0.097	0.05 – Cat C			
V	0.112	0.1 – TWQR			

Borehole outflow – geel enjin -S13

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	**WQC**	Measured (mg/l)	Relevant Guideline (mg/l)
As	0.023	0.01 – TWQR	I	0.243	0.5 – RL
Br	1.405	0.01 – MCL	Sr	0.452	0.1 – AV
Ni	0.029	0.02 – MRL	Zn	1.54	0.1 – AV
Hg	0.229	0.001 – TWQR			
Se	0.077	0.05 – Cat C			
Ti	0.188	0.2 – MPL			

Tank – house camp - S14

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	WQC	Measured (mg/l)	Relevant Guideline (mg/l)
As	0.031	0.01 – TWQR	Sr	0.207	0.1 – AV
Br	0.886	0.01 – MCL			
Cd	0.004	0.003 – TWQR			
Hg	0.139	0.001 – TWQR			
Se	0.081	0.05 – Cat C			
Ti	0.173	0.2 – MPL			

Borehole outflow – Next to Sable camp S15

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	WQC	Measured (mg/l)	Relevant Guideline (mg/l)
As	0.016	0.01 – TWQR	I	0.379	0.5 – RL
Br	1.895	0.01 – MCL	Sr	0.647	0.1 – AV
Be	0.005	0.004 – MCL	Zn	0.86	0.1 – AV
TDS	1040	1000 – TWQR			
Ni	0.023	0.02 – MRL			
Hg	0.193	0.001 – TWQR			
Se	0.098	0.05 – Cat C			
U	0.023	0.02 – MCL			
Te	0.012	0.01 - RL			
Ti	0.37	0.2 – MPL			

Borehole outflow – In Sable camp S16

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	WQC	Measured (mg/l)	Relevant Guideline (mg/l)
As	0.022	0.01 – TWQR	Sr	0.475	0.1 – AV
Br	1.085	0.01 – MCL			
Ni	0.033	0.02 – MRL			
Hg	0.179	0.001 – TWQR			
Se	0.036	0.05 – Cat C			
Ti	0.267	0.2 – MPL			

Gallon – Reservoir - S17

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	WQC	Measured (mg/l)	Relevant Guideline (mg/l)
Br	1.511	0.01 – MCL	I	0.392	0.5 – RL
Be	0.007	0.004 – MCL	Sr	0.4	0.1 – AV
Mn	0.1	0.05 – TWQR	U	0.016	0.02 – MCL
Hg	*nd	0.001 – TWQR	Ni	0.015	0.02 – MRL
Ti	0.233	0.2 – MPL			

Borehole outflow – Halls S18

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	**WQC**	Measured (mg/l)	Relevant Guideline (mg/l)
Br	2.366	0.01 – MCL	I	0.292	0.5 – RL
Be	0.005	0.004 – MCL	Sr	0.782	0.1 – AV
F	2.4	1 – TWQR			
Ni	0.021	0.02 – MRL			
Hg	*nd	0.001 – TWQR			
Se	0.058	0.05 – Cat C			
Ti	0.218	0.2 – MPL			

Reservoir – Ermelo Ranch S20

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	**WQC**	Measured (mg/l)	Relevant Guideline (mg/l)
As	0.019	0.01 – TWQR	Ni	0.017	0.02 – MRL
Br	1.415	0.01 – MCL	Sr	0.414	0.1 – AV
Cd	0.004	0.003 – TWQR	V	0.058	0.1 – TWQR
NO3	96	90 – TWQR			
Hg	0.632	0.001 – TWQR			
Se	0.06	0.05 – Cat C			
Ti	0.199	0.2 – MPL			

Table 6.3.4. Summary statistics for the main PHCs and COCs identified from 19 water samples.

WQC	**PHC**	**COC**	**Average (mg/L)**	**SD (mg/L)**	**Median (mg/L)**	**Range (mg/L)**	
(n) / WP	110	39				**Minimum**	**Maximum**
	5.789	2.052					
As	11	0	0.016	0.018	0.01	0	0.054
Br	19	0	1.685	0.634	1.554	0.786	2.983
Be	7	0	0.003	0.004	0.005	0	0.014
Cr	1	1	0.016	0.013	0.013	0.002	0.058
Cd	4	0	0.002	0.002	0.002	0	0.008
F	4	0	0.5	0.9	0	0	3.3
Mo	0	2	0.003	0.005	0	0	0.015
Mn	5	0	0.05	0.08	0	0	0.23
NO_3	2	0	26.8	41.7	9	1	163
Ni	9	4	0.021	0.022	0.018	0	0.099
Hg	16	0	0.484	0.448	0.325	0.139	1.91
Se	16	0	0.06	0.033	0.06	0.007	0.13
U	1	4	0.007	0.008	0.003	0	0.023
TDS	3	0	666	327	700	83	1403
Te	3	0	0.0051	0.0076	0.002	0	0.029
Ti	16	0	0.318	0.405	0.199	0.144	1.792
V	2	2	0.036	0.04	0.027	0	0.148
U	30	0	0.007	0.008	0.003	0	0.023
I	0	9	0.204	0.112	0.155	0.065	0.416
Sr	0	15	0.320	0.227	0.21	0.044	0.782
Zn	0	3	0.42	0.99	0.05	0	4.14

The highest recorded number of PHCs and COCs within a watering point was 10 and 4 respectively. All 19 watering points contained PHCs, whilst 17 contained COCs.

The most relevant correlation found was 0.722 between F and Mo (Pearson product moment r). This is significant as Mo increases F toxicity (Janse van Rensburg & Pitout, 1991). A non-significant F:TDS correlation of 0.24 was obtained, supporting previous findings (Meyer & Casey, 1999) that an inverse relationship may exist.

Results from liver samples collected from impalas (male and female specimens) on Selati and two other game reserves in the Lowveld (Ndzalama) illustrate the importance of the WQC-WQC effect. Table 6.3.5 indicates the values obtained for Cu and Se. Despite a high Se concentration in the water sampled from Selati, the liver values obtained may be interpreted as indicative of deficiency (Underwood & Suttle, 1999). The values differed significantly ($P < 0.05$) from those obtained from three other game ranches in the Lowveld, supporting the suggestion of deficiency in the Selati liver samples. A possible explanation for the seemingly contradictory results may be found when viewing the water quality results for As. The average As value obtained from the water on Selati was 0.016 mg As /L, and exceeds the recommended guideline. Much evidence exists indicating that Se is protective of As poisoning, and that high As may be a risk factor in Se deficiency (Hirunuma *et al.*, 1999), with hepatic As accumulation observed for Se deficient diets. The Cu values obtained may also indicate a Se deficiency, as liver Cu stores increase in the presence of adequate to high levels of Se (Hartman & van Ryssen, 1997). The liver values obtained support this, with lower values obtained for impala obtained from Selati (see Table 6.3.5).

Table 6.3.5 Impala liver values for Se and Cu from Selati and other Lowveld ranches.

Liver Sample	average n = 24	SD	median	minimum	maximum
Selati Se ng/g(DM)	570.48*	104.59	572	370	778
Other Lowveld ranches Se ng/g (DM)	725.36*	258.73	661	407	1352
Selati Cu mg/kg (DM)	130.12	53.89	125	53	280
Other Lowveld ranches Cu mg/kg (DM)	197.35	48.75	195	120	279

* - Significantly different at $P < 0.05$.

6.3.2.4 Discussion

The results indicate that many WQCs are present at potentially hazardous levels. The extent by which the recommended guideline limits are exceeded is significant. Many of the constituents involved have significant adverse single-dose effects, and therefore present a health hazard even to game that would normally have a beneficial dilution effect by virtue of their movement through various areas of the game ranch and resultant multiple water point intake.

The greatest hazard is presented by the constituents Hg, Se and As, as these are not only cumulative in biological tissue, but appear to be a localised geochemical anomaly. This is supported by the similar results for Br, Hg, and Se, from the outflow pipes of boreholes for samples S10, S13, S15, S16 and S18, excluding the role played by air pollution from the nearby mine. Although this may well be a significant contributing factor to total ingestion and long-term effects on groundwater quality in the area, this has yet to be determined. These samples were collected across the whole area, and as evidenced from at least two of these three PHCs being recorded in all of the samples collected, they pose risk from which most animals will not be able to gain dilution from, other than for those living within the western section that provides access to a river, and the obvious casual water obtained during the rainy season. Futhermore, the concentration ranges recorded for these three PHCs were consistent throughout.

It is noteworthy that the only high nitrate values recorded were for samples S3 and S20, both of which are high-walled circular reservoirs. Examination at the site of these reservoirs indicated heavy utilisation by elephants, with no other animals, except for giraffe, being able to access the water. Fecal matter of elephant origin was found to be present on the reservoir wall of S20, offering a possible explanation for NO_3 values.

Sample 5 was taken from an earth dam which had been fenced off for a period of one month due to repairs effected to a lion breeding camp in the adjacent vicinity. The long residence time appears to have increased some of the WQC concentrations, notably that of Cr. Although over 4 km away, a similar situation was recorded for Cr at the dam for S8, with no signs of recent animal activity observed at the site. Although difficult to model and hence predict, changes with different weather conditions, underlying soil types for natural earth dams, and utilisation by wildlife, do play a significant role in terms of water quality changes.

The adverse effects that may occur are difficult to predict due to the occurrence of so many PHCs within each water source. Some may be ameliorated due to WQC-WQC interaction, such as As-Se, but as evidenced by the liver Se results, this may precipitate a Se deficiency. Adverse effects attributable to single WQCs are well documented for most of the WQCs, with notable exceptions Tl, Te, Sb, Be and Ti. Samples S8 and S10 indicate the relationship between water pH and TDS, yielding values of 6.87 and 108, and 6.94 and 83 for pH and TDS respectively. Despite the low TDS values recorded for these samples, they still present with PHCs for many constituents with high inherent risk factors (Se, Hg, etc). The risk posed is in effect increased by the low TDS value as the palatability may improve for many game species, resulting in a higher ingestion of a single watering point.

Other correlation coefficients between groundwater constituents are evident, notably between F, Mo and TDS. The high nitrate values recorded for a few samples appear to be the direct consequence of poor water provision design, leading to fecal contamination of the water supply. It is noteworthy that water chemistry serves as a good indication of the regional geochemistry, and is suggestive in the samples collected of a high total exposure which would increase the site-specific risk factors for the PHCs recorded, via geophagia (both involuntary and voluntary) and plant matter, in addition to that ingested from water. Key risk watering points may be identified from the samples collected when used in conjunction with census data, habitat information, and linked to species tolerances. An additional area that the water quality will impact on, predominantly via the palatability influencing animal presence, absence, and movement, are the ecological norms. This influences sacrifice zones, herbaceous communities, infectious diseases, to name but a few.

6.3.3 Klaserie Area

6.3.3.1 Introduction

Samples were obtained from the Klaserie Game Reserve area in the Lowveld from 15 farms, of which 4 share an open border with the Kruger National Park. The area covered was ca. 530 km^2. In total 25 water samples were collected as part of an initial phase to gather background information on water quality in the area.

6.3.3.2 Methods

During the end of summer 1999 samples were obtained using the same procedures as described previously. A two-week survey period was conducted three months after at selected watering points in an attempt to ascertain the degree to which wildlife species utilised them. Based on these observations and statements made by rangers on the various farms, an attempt was made to arrive at a possible identification of key watering points that fell within the range for some wildlife species. As a final step, those watering points within a range were grouped according to clusters accessible to some wildlife species, and taking palatability preferences into account, and water quality, differences in risk were determined. Due to sample preservation techniques, no analyses were conducted for Hg.

6.3.3.3 Results

Klaserie -1 (24 ° 16.88S 31° 12.60E)

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	**WQC**	Measured (mg/l)	Relevant Guideline (mg/l)
Br	0.218	0.01 – MCL	Cu	0.106	0.1 – RL
Be	0.028	0.004 – MCL	Sr	0.114	0.1 – AV
Cr	0.303	0.05 – TWQR	Zn	0.135	0.1 – AV
Au	0.234	0.01 – CL			
Mn	0.737	0.05 – TWQR			
Ni	0.145	0.02 – MRL			
Sn	0.018	0.002 – MRL			
Ti	3.560	0.2 – MPL			

Klaserie -2 (24 ° 16.88S 31° 12.91E)

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	**WQC**	Measured (mg/l)	Relevant Guideline (mg/l)
As	0.016	0.01 – TWQR	V	0.031	0.1 – TWQR
Br	0.843	0.01 – MCL	Sr	0.474	0.1 – AV
F	1.21	1 – TWQR			
Au	0.267	0.01 – CL			
TDS	1642	1000 - TWQR			
Ti	0.239	0.2 – MPL			

Klaserie -3 (24 ° 16.88S 31° 13.98E)

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	**WQC**	Measured (mg/l)	Relevant Guideline (mg/l)
Br	0.243	0.01 – MCL	Cu	0.119	0.1 – RL
Be	0.031	0.004 – MCL	Sr	0.439	0.1 – AV
Cr	0.146	0.05 – TWQR	V	0.054	0.1 – TWQR
Au	0.434	0.01 – CL			
F	1.04	1 - TWQR			
Mn	0.777	0.05 - TWQR			
Ni	0.061	0.02 – MRL			
Ti	2.809	0.2 – MPL			

Klaserie -4 (24 ° 17.07S 31° 15.31E)

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	**WQC**	Measured (mg/l)	Relevant Guideline (mg/l)
Br	0.229	0.01 – MCL	As	0.009	0.01 - TWQR
Au	0.143	0.01 – CL	TDS	922	1000 - TWQR
F	1.71	1 - TWQR	Sr	0.241	0.1 – AV
			V	0.055	0.1 – AV

Klaserie -5 (24 ° 17.24S 31° 15.03E)

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	**WQC**	Measured (mg/l)	Relevant Guideline (mg/l)
As	0.017	0.01 – TWQR	Cr	0.045	0.05 – TWQR
Br	0.172	0.01 – MCL			
Au	0.283	0.01 – CL			
Mn	0.278	0.05 – TWQR			
Ti	1.365	0.2 – MPL			

Klaserie -6 (24 ° 12.34S 31° 19.72E)

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	**WQC**	Measured (mg/l)	Relevant Guideline (mg/l)
Br	0.700	0.01 – MCL	V	0.065	0.1 – AV
F	3.91	1 – TWQR	Sr	0.935	0.1 – AV
Au	0.249	0.01 – CL			
TDS	1283	1000 – TWQR			
Ti	0.234	0.2 – MPL			

Klaserie –7 (24 ° 12.48S 31° 12.62E)

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	**WQC**	Measured (mg/l)	Relevant Guideline (mg/l)
Br	0.281	0.01 – MCL	Sr	0.149	0.1 – AV
Cr	0.055	0.05 – TWQR			
Au	0.257	0.01 – CL			
Mn	0.296	0.05 - TWQR			
Ti	0.666	0.2 – MPL			

Klaserie –8 (24 ° 12.16S 31° 14.97E)

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	**WQC**	Measured (mg/l)	Relevant Guideline (mg/l)
As	0.021	0.01 - TWQR	Sr	0.853	0.1 – AV
Br	1.101	0.01 – MCL	U	0.015	0.02 - TWQR
F	6.3	1 - TWQR			
TDS	1822	1000 - TWQR			
Ti	0.304	0.2 – MPL			

Klaserie –9 (24 ° 12.42S 31° 15.25E)

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	**WQC**	Measured (mg/l)	Relevant Guideline (mg/l)
Br	0.364	0.01 – MCL	Cu	0.1	0.1 – RL
Be	0.032	0.004 – MCL	Sr	0.3	0.1 – AV
Cr	0.175	0.05 – TWQR	Zn	0.106	0.1 – AV
F	2.35	1 - TWQR			
Au	0.535	0.01 – CL			
Mn	0.834	0.05 - TWQR			
Ni	0.0668	0.02 – MRL			
Ti	3.145	0.2 – MPL			

Klaserie -11 (24 ° 14.85S 31° 16.40E)

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	**WQC**	Measured (mg/l)	Relevant Guideline (mg/l)
Br	0.413	0.01 – MCL	Cu	0.134	0.1 – RL
Be	0.02	0.004 – MCL	Sr	0.109	0.1 – AV
Cr	0.373	0.05 – TWQR	Zn	0.114	0.1 – AV
Au	0.386	0.01 – CL			
Mn	0.729	0.05 – TWQR			
Ni	0.126	0.02 – MRL			
Sn	0.005	0.002 – MRL			
Ti	3.369	0.2 – MPL			

Klaserie -12a (24 ° 12.68S 31° 19.93E)

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	**WQC**	Measured (mg/l)	Relevant Guideline (mg/l)
Br	0.392	0.01 – MCL			
F	1.19	1 – TWQR			

Klaserie -12b (24 ° 12.68S 31° 19.93E)

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	**WQC**	Measured (mg/l)	Relevant Guideline (mg/l)
Br	1.527	0.01 – MCL	Sr	1.104	0.1 – AV
Cl	1236	1000 – TWQR	Zn	0.138	0.1 – AV
Au	0.303	0.01 – CL			
TDS	2359	1000 – TWQR			
Ti	0.485	0.2 – MPL			

Klaserie -13 (24 ° 13.43S 31° 16.98E)

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	**WQC**	Measured (mg/l)	Relevant Guideline (mg/l)
Br	0.811	0.01 – MCL	Sr	0.704	0.1 – AV
F	4.2	1 – TWQR			
Au	0.213	0.01 – CL			
TDS	1793	1000 – TWQR			
Ti	0.230	0.2 – MPL			
U	0.021	0.02 – TWQR			
V	0.2	0.1 – TWQR			

Klaserie -14 (24 ° 16.87S 31° 05.49E)

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	**WQC**	Measured (mg/l)	Relevant Guideline (mg/l)
Br	0.279	0.01 – MCL	Sr	0.1	0.1 – AV
Cr	0.175	0.05 – TWQR			
Au	0.333	0.01 – CL			
Mn	0.320	0.05 - TWQR			
Ni	0.063	0.02 – MRL			
Ti	1.431	0.2 – MPL			

Klaserie -15 (24 ° 16.88S 31° 05.34E)

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	**WQC**	Measured (mg/l)	Relevant Guideline (mg/l)
Br	0.532	0.01 – MCL	Sr	0.392	0.1 – AV
Au	0.241	0.01 – CL	V	0.03	0.1 – TWQR
Ti	0.181	0.2 – MPL			

Klaserie -16 (24 ° 17.09S 31° 05.46E)

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	**WQC**	Measured (mg/l)	Relevant Guideline (mg/l)
Br	0.395	0.01 – MCL	V	0.03	0.1 – TWQR
Au	0.246	0.01 – CL	Sr	0.542	0.1 – AV
Mn	0.139	0.05 - TWQR			
Ti	0.205	0.2 – MPL			

Klaserie -17 (24 ° 17.87S 31° 17.87E)

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	**WQC**	Measured (mg/l)	Relevant Guideline (mg/l)
As	0.01	0.01 - TWQR	Se	0.018	0.02 – TWQR
Br	0.398	0.01 – MCL	Sr	0.305	0.1 – AV
Be	0.037	0.004 – MCL			
Cr	0.303	0.05 – TWQR			
Au	0.273	0.01 – CL			
Mn	0.795	0.05 - TWQR			
Ni	0.152	0.02 – MRL			
Ti	2.495	0.2 – MPL			

Klaserie -18 (24 ° 15.95S 31° 06.02E)

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	**WQC**	Measured (mg/l)	Relevant Guideline (mg/l)
Br	0.311	0.01 – MCL	Sr	0.117	0.1 – AV
Mn	0.109	0.05 - TWQR			
Ti	0.338	0.2 – MPL			

Klaserie -19 (24 ° 15.03S 31° 04.06E)

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	**WQC**	Measured (mg/l)	Relevant Guideline (mg/l)
Br	0.361	0.01 – MCL			
Be	0.004	0.004 – MCL			
Cr	0.180	0.05 – TWQR			
Au	0.245	0.01 – CL			
Mn	0.701	0.05 - TWQR			
Ni	0.077	0.02 – MRL			
Ti	2.295	0.2 – MPL			

Klaserie -20 (24 ° 14.62S 31° 04.75E)

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	**WQC**	Measured (mg/l)	Relevant Guideline (mg/l)
Br	0.422	0.01 – MCL	Sr	0.381	0.1 – AV
Mn	0.135	0.05 - TWQR	Zn	0.319	0.1 – AV
Ti	0.220	0.2 – MPL			

Klaserie -21 (24 ° 11.17S 31° 03.59E)

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	**WQC**	Measured (mg/l)	Relevant Guideline (mg/l)
Br	0.481	0.01 – MCL	Sr	0.107	0.1 – AV
Au	0.306	0.01 – CL			
Mn	0.199	0.05 - TWQR			
Ni	0.02	0.02 – MRL			
Ti	0.837	0.2 – MPL			

Klaserie -22 (24 ° 11.59S 31° 04.00E)

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	**WQC**	Measured (mg/l)	Relevant Guideline (mg/l)
Br	0.579	0.01 – MCL	Sr	0.491	0.1 – AV
Au	0.157	0.01 – CL			
Ti	0.256	0.2 – MPL			

Klaserie -23 (24 ° 03.01 S 31° 11.47E)

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	**WQC**	Measured (mg/l)	Relevant Guideline (mg/l)
Br	0.881	0.01 – MCL	Sr	0.713	0.1 – AV
Au	0.320	0.01 – CL	Zn	0.300	0.1 – AV
Mn	0.305	0.05 - TWQR			
TDS	1065	1000 – TWQR			
Ti	0.325	0.2 – MPL			

Klaserie -24 (24 ° 03.57 S 31° 11.22E)

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	**WQC**	Measured (mg/l)	Relevant Guideline (mg/l)
Br	0.425	0.01 – MCL			
Cr	0.041	0.05 – TWQR			
Au	0.266	0.01 – CL			
Mn	0.530	0.05 - TWQR			
Ti	0.659	0.2 – MPL			

Klaserie -25 (24 ° 04.95S 31° 08.52E)

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	**WQC**	Measured (mg/l)	Relevant Guideline (mg/l)
Br	0.394	0.01 – MCL	Sr	0.228	0.1 – AV
Cr	0.124	0.05 – TWQR			
F	1.08	1 – TWQR			
Au	0.119	0.01 – CL			
Mn	0.319	0.05 – TWQR			
Ni	0.034	0.02 – MRL			
Ti	1.127	0.2 – MPL			

Table 6.3.6 Description of water samples taken and species detected within 100m of in the Klaserie Area.

Sample	Description	Species present
KI 1	Clay dam – natural water	Buffalo, hippo, hyaena, impala, leopard, wildebeest, zebra
KI 2	Clay dam (borehole 1)	Elephant, hyaena, impala, rhino
KI 3	Round concrete trough	Lion, warthog, wildebeest
KI 4	Concrete trough (borehole 2)	Buffalo, warthog, wildebeest
KI 5	Clay dam – natural water	Buffalo, elephant (juv), hyaena
KI 6	Natural pan (borehole 3)	Giraffe, impala, warthog, wildebeest, zebra
KI 7	Natural pan – natural water	Buffalo, giraffe, impala, hyaena
KI 8	Natural pan (borehole 4)	Elephant, impala, lion
KI 9	Natural pan – natural water	Elephant, impala, lion, kudu
KI 11	Clay dam – natural water	Elephant, buffalo, lion, rhino
KI 12a	Borehole 5	Elephant, buffalo, lion, rhino
KI 12b	Natural pan (borehole 5)	Hyaeana, impala, warthog, zebra
KI 13	Concrete trough (borehole 6)	Buffalo, giraffe, jackal, kudu
KI 14	Clay dam – natural water	Giraffe, impala, warthog, zebra
KI 15	Concrete trough	Giraffe, hyaena, zebra
KI 16	Concrete trough (borehole 7)	Buffalo, giraffe, impala, kudu
KI 17	Clay dam – natural water	Buffalo, impala, zebra
KI 18	Clay dam – natural water	Buffalo, civit, elephant, impala, kudu, rhino, zebra
KI 19	Clay dam – natural water	Buffalo, kudu; rhino, warthog, wildebeest
KI 20	Concrete dam (borehole 8)	Hyaena
KI 21	Clay dam – natural water	Buffalo, civit, elephant, impala, giraffe, warthog
KI 22	Concrete trough (borehole 9)	Elephant, impala, rhino
KI 23	Concrete trough (borehole 10)	Impala
KI 24	Natural pan – natural water	Buffalo, elephant, giraffe, impala, zebra
KI 25	Clay dam – natural water	Buffalo, elephant, giraffe, impala, zebra

Table 6.3.7 Main PHCs and COCs recorded in the Klaserie Area from 25 samples.

WQC	PHC	COC	Average (mg/L)	SD (mg/L)	Median (mg/L)	Range (mg/L)	
(n) / WP	135	44				Minimum	Maximum
	5.4	1.1					
As	3	1	0.004	0.06	0	0	0.021
Br	25	0	0.51	0.315	0.398	0.172	0.152
Be	6	0	0.008	0.014	0	0	0.04
Cr	10	1	0.087	0.108	0.029	0	0.373
F	9	0	1.1	1.5	0.6	0	6.3
Au	21	0	0.264	0.089	0.25	0.11	0.53
Mn	16	0	0.3	0.29	0.2	0.01	0.83
Ni	9	4	0.031	0.049	0	0	0.152
TDS	7	1	654	656	343	103	2359
Ti	22	0	1.078	1.153	0.4854	0.086	3.56
V	1	6	0.022	0.042	0	0	0.2
Sr	0	21	0.363	0.3	0.3	0.06	1.104
Zn	0	6	0.07	0.08	0.03	0	0.32

The highest recorded number of PHCs and COCs within a watering point was 8 and 3 respectively. The Pearson product moment correlations obtained support previous findings (Meyer, 1998). The value obtained for F: Sr was 0.65, and between TDS : pH a value of 0.19 was obtained. The relevance of these correlations is that they have bearing on F toxicology aspects. Firstly, the low Ca values obtained are further aggravated by Sr in terms of bone mineralisation substitution, and the low TDS waters tend to be favoured by animals (palatability effect) but return a near negative correlation with pH. This will probably lead to increased F uptake from the digestive tract (Janse van Rensburg & Pitout, 1991). Table 6.3.8

provides a rough estimation of the probable intake of WQC from clustered watering points for a few wildlife species (Bothma, 1996).

Table 6.3.8 Estimation of possible ingestion (mg/d) to hazardous constituents within range clusters for some wildlife species in the south-east Klaserie area.

Species WI in L/d*	**Range – km2 diameter – (km)**	**Cluster A: Kl 1; 2; 3;4; 5**	**Cluster B: Kl 7, 8, 9, 11, 12a, 12b, 13**	**Cluster C: Kl 6**
		Total diameter = 5 km Most points within 3 km Nearest next point = 7 km	Total diameter = 7.4 km Most points within 3 km Nearest next point = 7	Total diameter = 0 km Nearest next point = 6 km
		Effective ingestion (mg/d)	Effective ingestion (mg/d)	Effective ingestion (mg/d)
Impala 2.5	66 (9)	F = 2.25 As = 0.025 Cr = 0.252 Sr = 0.667	F = 5 As = 0.015 Cr = 0.162 Sr = 1.39	****F = 8 As = 0 Cr = 0.237 Sr = 1.18
Zebra 12	186.7 (14.8)	F = 10.8 As = 0.12 Cr = 1.21 Sr = 3.2	F = 24 As = 0.06 Cr = 0.768 Sr = 6.70	****F = 38.4 As = 0 Cr = 1.14 Sr = 5.66
Buffalo 31	160 (14.2)	F = 27.9 As = 0.31 Cr = 3.13 Sr = 8.27	F = 62 As = 0.155 Cr = 1.98 Sr = 17.3	****F = 99.2 As = 0 Cr = 2.94 Sr = 14.6
Kudu 9	23.5 (5.4)	F = 8.1 As = 0.09 Cr = 0.9 Sr = 2.4	F = 18 As = 0.04 Cr = 0.576 Sr = 5.03	F = 27 As = 0. Cr = 0.73 Sr = 3.9
Bushbuck 1.5	0.6 (0.3)	**F = 2.55 – 0.45 As = 0.02 – 0 Cr = 0.219 – 0 Sr = 0.711 – 0.1	***F = 4.5 – 1.95 As = 0.01 – 0.004 Cr = 0.12 – 0.15 Sr = 0.65 – 0.75	F =5.85 As = 0 Cr = 0.01 Sr = 1.39
Warthog 3.5	1.33 (1.2)	**F = 4.02 – 0 As = 0.03 - 0 Cr = 0.03 – 0 Sr = 1.57 - 1	***F = 10.5 – 4.55 As = 0.02 – 0.01 Cr = 0.28 – 0.36 Sr = 1.51 – 1.75	F =13.6 As = 0 Cr = 0.02 Sr = 3.255

* Bothma (1996).
** Ranges possible for cluster B.
*** two clusters (7,8,9 + 11,12a,12b,13) possible.
**** one cluster (6, 7, 8, 9) possible.

The results from Table 6.3.7 provide an indication of the variable intake rates for different species based on the watering points most likely to fall within their ranges. The resultant ingestion is even more pronounced when expressed as a percentage of body weight (due to differences in water turnover rates), but the purpose of Table 6.3.7 is to illustrate the different ingestion rates possible within a watering point cluster. For example, watering point 6 presents much more of a F hazard to Kudu, bushbuck and warthog, than it does to impala, zebra or buffalo, but much less of an As and Cr hazard to Kudu, as opposed the other species. Species comparisons on this basis are required in order to rank watering points regarding their relative fitness for use for certain wildlife species. For example, it may be recommended to close point 4 and point 8 as they both fall within separate clusters which are within 3 km of other watering points, the remainder of which offer substantially better water quality. On the other hand, watering point 6 is sufficiently displaced from alternative water sources (during the winter) to warrant an alleviator treatment addition.

6.4 CONCLUSION

The results obtained from three different regions involving game ranching and conservation suggest that the WQCs present in the water source warrant attention. The concentrations of these WQCs further suggest that the norms of animal health may be adversely affected. The palatability preference of large mobile water-dependant herbivores for certain combinations of those constituents contributing to the total dissolved solid (TDS) concentration, may furthermore play a significant role in influencing animal movement. The inverse correlation found for many sources between the presence of PHCs and TDS exacerbate the situation even further, as the palatability preference leads to an increased utilisation of those watering points containing high risk constituents (see Chapter 3 – RefDoc ARF1).

The impact of increased/decreased animal movement as a result of variations in the utilisation of a watering point extend from altering habitat requirements for reproduction of certain species, such as Roan and Sable (Thrash, 1993), to ecological parameters, such as standing crop production herbaceous plant community and soil erosion. A complicating factor is the lack of a comparative norm. This challenges the condition of the wildlife taken as representative, as limiting environmental factors of a geochemical nature may affect large numbers of animals over large areas. When planning the placement of a watering point for wildlife the design and habitat are often decided upon based on aesthetic reasons. Seldom is the quality of the water being provided considered further than to perhaps test for TDS (EC). Due to the difficulties in observing the effect of potentially hazardous constituents on the health and reproduction of wildlife, knowledge of the presence of potential risks is vital if wildlife are to be managed on a successful, long-term, sustainable basis. The indirect and direct effects of the water provision on animal movement, and related ecological norms, must also be taken into account.

In the final instance, there is much a manager can do to selectively encourage/discourage the utilisation of specific sources by wildlife. Linking the factors (water palatability, design and placement of watering point) to the supplementation of licks formulated to alleviate any water quality induced trace element imbalance, deficiency or toxicity, can provide a means for utilising water sources more effectively.

CHAPTER 7

RELEVANT TECHNICAL INFORMATION REGARDING CIRRA

7.1 Programming CIRRA

CIRRA is a computer program that has been developed as an aid to the assessment of water quality used by humans and animals. It is developed to run on MS Windows 95/98 or Windows NT/2000. It is document-based where each "document" represents a water sample taken from a source where a risk assessment in terms of its quality is to made. A sample file contains all the information required to assess the quality of the water in terms dictated by research results. The evaluation module of the program portrays the application of research results in understandable terms for the fields-person to understand. This chapter describes the development of the CIRRA program and provides an insight to the underlying technologies used.

7.2 Programming Language

CIRRA is developed using Clarion, of which the current version 5 is used. Clarion has been in existence since the middle-80's in the days of MS DOS. It has taken the developers of Clarion some time to move over to MS Windows, but since 1994 TopSpeed Corporation has rolled out 5 versions of the development language with some significant improvements with each step. Although another company, called SoftVelocity, has very recently taken over Clarion from TopSpeed Corporation, the commitment shown by Clarion developers all around the world proves that Clarion is a powerful development language and will still be with us for years to come.

Two of the most important plusses of Clarion are Clarion's tight integration with a data dictionary and its use of templates, or pre-tested programming modules. The combination of the two means that, after designing a system's database and defining the referential integrity (internal relationships) between tables, the integrated development environment (IDE) invokes the templates to generate either a complete basic application or only pieces of the application. This means that a substantial amount of source code that forms part of a Clarion program (and CIRRA too) is generated by the templates, based on the data dictionary settings and values set by the programmer. The programmer however has got the ability to add source code to the program and thus change the way the program looks or behaves – very similar to other development languages like MS Visual Basic or Delphi. This gives the programmer enough time to focus on the business intended by the program instead of spending time on building screens that could otherwise easily be generated.

Clarion supports object-oriented programming, which is integrated to all aspects of a project. The tables defined in the data dictionary is available to the programmer as an object that can be used from any point in the program. The Application Builder Class library has been provided by the developers of Clarion as a set of object classes that can assist the programmer to build an application fast and to easily change the existing functionality of the program.

7.3 User Interface

The user interface refers to the windows, buttons, list boxes etc. that the user sees when working with CIRRA. CIRRA uses a multiple-document interface (MDI), which means that many windows can be opened at once. Each sample can be seen as the equivalent of a word processor document. The word processor can have many documents opened at once, just like CIRRA can have many samples opened at once. An advantage of using an MDI is that the "child" windows (or documents) visually all remain within the boundaries of the MDI-frame (the "background of CIRRA containing the menu, toolbar and status bar). If the MDI-frame is minimised, all sample windows minimise with the frame. CIRRA consists of several functional modules. Each module can be used to assess the water quality of a different area for example livestock, wildlife or domestic use of water. The user interface amongst these modules have been kept similar in order for the user to easily work with a sample from any module without getting confused. A new module can be registered from within the program and allows the user to create sample files for the applicable area.

7.4 Database

CIRRA uses the TopSpeed file format to store information. The format is very compact in size and is fast in retrieval or storage of data. A sample file (with extension .WQS) actually contains many "tables" which are virtual files placed into on physical file on disk. Sample files are created by the CIRRA user with the typical File|New action from within the program menu and because it is typically small in size, it can easily be sent to another location either by copying it onto a disk or by e-mailing it. CIRRA also contains a number of static data files (with extension .TPS) that are installed during the CIRRA installation in the program files directory. These files typically contain the reference document information that is the results of the research done which are used during the evaluation of the sample information. It is possible for specific implementations of CIRRA to change the static data file format to a number of other formats. It will be possible to implement CIRRA on most popular relational database management systems like Oracle or MS SQL Server. The changes required within the CIRRA Clarion source programs can be done in a short period of time and would not hamper any of the functionality of the program.

7.5 Distribution of CIRRA

It was decided that CIRRA would be distributed on compact disk, mainly because of its size. Currently the program can alternatively be distributed on three 3.5" disks, but the difficulties surrounding the handling of magnetic media overshadows the ease-of-use of compact disks.

The CIRRA program supplied on the compact disk contains the basic CIRRA framework, the generic application guidelines and the specific application guidelines for Livestock. Two new modules available are those for the RCLPS and WPS models as described in this report. The distribution files of these modules are small in size and can easily be provided on 3.5" disks or sent via e-mail.

7.6 Updates to CIRRA

Aside from the updating of CIRRA to accommodate current versions of the programming language (Clarion), many other changes have been effected. A few a dealt with in this section.

7.6.1 Updates to Reference Documents

Updates to the reference material as provided in sections 3.5 and 4.2 have been effected.

7.6.2 Data Capturing Guide

7.6.2.1 Motivation for developing a DCG

The Data Capturing Guide (DCG) is an additional tool developed for CIRRA. The purpose of the DCG is to aid in the collection of the required site-specific data to enable, and encourage, the user to utilise the Specific–GAL option. The detail required to depart from the Generic-GAL and execute the models residing in the Specific-GAL options available in CIRRA, are not only large, but also varied in nature. As a result, users not acquainted with some of the specialised fields might omit critical information, or simply choose to ignore the Specific-GAL option altogether. The DCG was designed to make the program more user-friendly, cost-effective, and open to a user spectrum that does not require the user to be a nutritionist, soil scientist or toxicologist.

7.6.2.2 Description

The DCG is an option available on the opening screens as the user selects the type of application, Generic or Specific, as a new sample file is being created. The option allows the user to identify the type of data that the Specific-GAL will require based on varying levels of user-defined production system detail. The DCG leads the user through the available options, so the user need only select from the list-boxes provided. As a result, the user does not need to know the type of production systems available in Dairy Farming, but can obtain the information from the farmer, or consultant. The DCG provides the user with a printed copy of the fields required to conduct a site-specific risk assessment for the selected livestock production system, and livestock type. This includes livestock detail, animal, environment and nutritional detail. It also has a default that provides general information on matters pertaining to the collection of on-site samples and data. An example of a DCG generated for Dairy Cattle is provided below. The only decisions the user would have had to make to generate the example provided would have been (1) commercial livestock production systems, and (2) livestock type = dairy cattle.

7.6.2.3 Example of DCG for Dairy Cattle

The following few pages present a partial example of a DCG generated by CIRRA.

Data Capturing Guide

Livestock Watering for Dairy Cattle

Information required for a Specific Guideline Application

On-farm collection of site-specific detail:

The following items are required when collecting site-specific data:

- A DCG (generated for the required livestock species)
- Sample containers for water, feed/plant and soil

The nearest water laboratory should be contacted for information concerning sample collection techniques, preservation and storage, Most will be able to provide pre-treated collection bottles.

For Water: Sterilised plastic sample bottles (approx. 250 ml/sample), clearly marked for identification. Further information regarding the costs and required procedures for soil, plant and water sampling may be obtained from the following institute:

Agricultural Research Council – Institute for Soil, Climate and Water
Private Bag X79
Pretoria (012) 310 2500

Where to collect the sample:

For water, feed (ration/pasture/lick) and soil, representative samples of what the animals are exposed to, and ingest, are required. In the interests of saving costs, during the initial phase only water samples collected from the drinking trough should be analysed, and should potentially hazardous constituents be found, samples from the reservoir and borehole can be analysed to ascertain potential contamination sites and treatment options.

Where to take the samples:

Most major towns and cities have laboratories capable of analysing water, plant and soil samples. The Institute for Soil, Climate and Water of the Agricultural Research Council in Pretoria offers a water package gibing information on 51 inorganic constituents. The price per package at 2000 rates is R155.00. This cost should be compared against the cost of potential damage caused to animals and equipment by water of poor quality, or water that is mismanaged.

Data Capturing Guide
Livestock Watering for Dairy Cattle
Information Required for a Sepcific Guideline Application

Sender Detail

Name [redacted]
Telephone Number [redacted]
Address [redacted]

Sample Detail

Date/time taken [redacted]
Source [redacted]

Predominant source [redacted]
Alternative Source [redacted]

Site [redacted] (e.g. borehole, reservoir)

Borehole Information
Number [redacted]
Depth [redacted] meters

Location-Latitude [redacted] degr [redacted] min [redacted] sec
Location -Longitude [redacted] degr [redacted] min [redacted] sec

Production Sytstem Detail

Breed [redacted]
Ayrshire
Crossbreeds
Friesland
Guernsey
Jersey

Production Systems [redacted]
Extensive grazing
Forage and Concentrate Feeding
Group Feeding
Individual Farming
Small Farming - Collectively owned
Small Farming - Dairy Ranching
Small Farming - Individual farmers
Total Mixed Rations

1. CIRRA

Categories [redacted]
1. Cows in mid-and late lact (FCM 10L/d)
2. Cows in mid- and late lact (FCM 15L/d)
3. Cows in mid- and late lact (FCM 20L/d)
4. 11 (FCM 60L/d)
12. Growing veal calves fed milk/milk replac
13. Large-breed growing females
14. Large-breed growing males
15. Maintenance of mature breeding bulls
16. Small-breed growing females
17. Small-breed growing males
18. Growing large-breed calves fed milk/milk repl
19. Grwoing large-breed calves fed milk + starter mix
20. Growing small-breed calves fed milk / milk repl
21. Growing small-breed calves fed milk + starter mix
22. Period - Dry
23. Period - Early Lactation
24. Period - Late Lactation
25. Period - Mid-lactation

Animal Detail

	Category No	Weight kg	DMI kg/d	TWI L/d	DMI of silage kg/d	Silage Type High moist / wilt/haylage		
______	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]

Veal [redacted] Fancy
[redacted] Conventiona

Concentrate Feeding frequency [redacted] Times/d

2. CIRRA

Data Capturing Guide
Livestock Watering for Dairy Cattle
Information Required for a Sepcific Guideline Application

Environmental Detail

Environment Type
- Arid, Semi-Arid & subtropical
- Humid, subtropical & subtropical
- Temperate, savanna & Grasslands

Average Temperature — ° C (minT+maxT/2)/week

Altitude — meters above sea level

Soil Detail

pH

Condition
- Wet
- Dry
- Shales
- Sedimentary Rocks

Soil — Collect a representative sample from a predominant grazing area. PHCs and COCS

Nutritional Detail

	Category No	Feed pelleted?	Protein	Salt %	Crude Protein

Lick Detail

Type
- Summer Mineral
- Winter Maintenance
- Production

Compositio — Category Numbers

TDN%
Protein %

Compositio — Category Numbers

P%
Salt%
Urea%
DiCa-P%
CaCO3%
NaHCO3%
MgO%

Salt Detail

Compositio — Category Numbers

Moisture%
NaCl%
Si%
SO4%
Ca%
Mg%
K%mg/kg
Zn mg/kg
Fe mg/kg
Cu mg/kg
Mn mg/kg
NO3 mg/kg
Co mg/kg
F mg/kg

Milk Replacer Fe — (mg/kg DM)

Main Forage Detail.......

Main Feed

Ration

7.7 Conclusion

In striving to improve the management of a scarce commodity, it is inevitable that a multidisciplinary approach is required. In terms of water quality, chemistry, biology, statistics, hydrology, information science, computers and technical journalism are a few of the fields of expertise required (Sanders *et al.*, 1987). When topics pertaining to animal health and human health are included, the list of fields on which one must be knowledgeable seem endless. One cannot be an expert on all the required specialities. But, to be truly effective, where diverse information types may contribute significantly to the assessments conducted regarding the fitness for use of a water source, they should be part of the assessment procedure. Presenting risk assessment modelling in a software environment allows for an non-intimidating inclusion of diverse disciplines which can cater for a wide range of educated users.

Of increasing critical importance is the need to incorporate new research findings (and forms of data provision from new advances in analytical techniques) in order to apply the new information to the central aim of correctly assessing the fitness of use of a water source within its context of usage. Once again, a software environment caters for this need.

Although primarily developed for conducting risk assessments, CIRRA also has a valuable tuition value, as it provides a means, through large help files, to serve as a source for various depths of information.

Finally, the benefit of the Internet connectivity Clarion provides CIRRA will become more apparent as co-operative research and collaborative risk assessments increase.

CHAPTER 8

CONCLUSIONS AND RECOMMENDATIONS

8.1 General conclusions

8.1.1 Rural Communal Livestock Production Systems

The project set out to incorporate two new models into the original water quality guideline index system developed (Casey *et al.*, 1998; Meyer, 1998). One of the first phases required water quality investigations in selected communities and wildlife areas to be conducted. Concurrently, applications of CIRRA were finding success in identifying potential livestock related water quality problems, and proposing solutions to them.

During the water quality investigations for livestock in the rural communal production system context, it became increasingly apparent that in many instances, the association between animal and man was a limiting factor to the successful application of CIRRA generated solutions. This was primarily due to the shared utilisation of the water source effectively prohibiting the application of chemical alleviator treatment to the water source, due to the potential for adverse effects in humans. The link between animal product quality and human health was an additional area of concern. CIRRA was initially developed for commercial livestock production systems, and the application of some alleviator treatments formulated were for the production phase of weaning to market weight. As such, an accumulation of constituents such as lead and cadmium in renal cortex tissue did not present a significant consumer health problem, as product concentrations and dilution with the total variation within the urban diet, effectively provided for sufficient safety.

This does not hold true for the rural production systems. In the first instance, the production phase is seldom as short, or well defined, as in commercial systems. Exposure periods are therefore longer, with ingestion rates typically greater due to a number of associated risk factors (e.g. temperature, moisture percentage of ration). Secondly, and possibly quantitatively more important, the nature of the diet differs in terms of input origin variability. Potentially hazardous constituents in the water may find their way into the diet of sensitive user groups, such as women of reproductive age and children, through a number of routes. These include directly via the drinking water, indirectly via food preparation and irrigation of subsistence crops with water, and indirectly via the consumption of animal products obtained from animals exposed to the water source.

A number of other routes incorporating bioaccumulation and bioconcentration may also apply, such as the consumption of aquatic organisms, and the practice of providing reverse-osmosis brine to livestock, which may find its way back into the human diet through the consumption of organs, eggs, or milk. This may be at even greater levels than those occurring naturally in water, partly due to the increased concentration of hazardous constituents in the brine, as compared to raw feed water (Schoeman, 2000), and the active transport mechanisms that may increase the concentrations thereof in milk (Krachler *et al.*, 1999). Most studies on the use of brine water for stock watering do not provide an indication of the trace element concentration in the brine, nor do they offer convincing evidence that the practice is safe for animal health. It appears as though the sentiment expressed is that if the animals survive, the water quality is acceptable. Localised geochemical anomalies may be magnified in semi-arid regions (Appleton *et al.*, 1996), and there is increasing evidence that the additional effect of geophagia, incidental and deliberate, by both animals and humans, is significant.

In the developing communities this project reports on, both for livestock and humans, dietary deficiencies in terms of quantity and quality are real challenges. The link between livestock production, animal product quality, and human nutrition, when viewed in context of the additional risk factors in rural communal production systems, takes on a more central role to the modelling of water quality guidelines for the user group. The ramifications of retaining the focus of water quality guidelines for livestock on the health of livestock, and failing to account for norm of product quality, would be grossly negligent. There is much evidence of animal products which may contain potentially hazardous concentrations of constituents with clinically accepted toxicity risks for humans, without the animal presenting with any clinical manifestations of a trace element disorder (Underwood & Suttle, 1999). As such, livestock health may not be a sufficiently accurate measure of the fitness for use of consumption products.

The above-mentioned issues do not imply that livestock products should be deemed as an unacceptable source of risk. Quite to the contrary, livestock products offer abundant and bioavailable forms of micronutrients, and calcium, iron, zinc, vitamins A and B_{12}, *if managed appropriately*. Low birth weight due to fetal malnutrition has been associated with deficient maternal intakes of iron, zinc, iodine and vitamin B_{12}, as have an increased risk for fatal infections, neuorlogic and cognitive impairment (Neumann, 1998). Not only are animal products compact and efficient sources of many of these nutrients, but they are almost the exclusive source of dietary vitamin B_{12}, and a good source of pre-formed vitamin A. The inclusion of health norms for water quality guidelines for livestock is warranted as successful production has been shown to be a valuable means of income generation for rural households.

The rural communal livestock production system model presented in this report attempts to cater for the complex requirement of balancing risk and hazard identification in the realm of environmental toxicology, with the significant role of water quality in improving the health of animals and humans. Due to the complexities of modelling relevant risk factors and the varied fields of specialisation that are addressed, achieving a guideline and risk assessment system that is manageable by a wide user audience, is best done in a software environment. Main reasons for this are access to large amounts of data, complex modelling performed, and Internet connectivity enabling sample files that represent a site-specific system to be e-mailed to persons from which specialised insight may be requested.

The water quality investigations presented in this report for several communities share a number of common observations. A high incidence of specific water quality constituents present in the water at potentially hazardous concentrations was found for all communities. Many of these communities were typified by a localised, often isolated, association between the environment, water, animals and humans. The communities had a varied spectrum of user groups, but all included sensitive user groups, namely women of reproductive age, infants and children. The valuable, and at time essential role, played by livestock was evident for most communities. Most importantly, most systems lacked the required infrastructure to allow for separate alleviator treatments formulated for livestock to be administered to the watering system.

It follows that animal data regarding risk of an environmental toxicological nature, may also be used to the benefit of identifying similar risks for humans. The localised geochemical factors shared by both animals and humans allow for some valuable information to be gained regarding the types of effects that may occur due, in varying degrees, to water quality.

The result of the water quality investigations indicated that both local and international guideline limits were exceed by large margins, and in many cases multiple potentially hazardous constituents occurred together. The drinking water quality guidelines formulated by the WHO (WHO, 1993), USEPA (USEPA, 1998), and the Department of Water Affairs and Forestry (DWA&F, 1993; 1996), are primarily based on hazard identification from single constituent exposure toxicological studies. The outcome of exposure to multiple constituents is not described. Ameliorating effects may be negligible, partial, or complete.

With this, and many other areas of uncertainty, animal health studies can provide a valuable means of determining the risk present due to potentially hazardous water quality constituents with the incorporation of significant site-specific factors. Animal health studies can provide valuable guidance to community health based studies. They afford an opportunity to gather tissue samples, not readily available from humans, for histopathological examination, and various assays, which may provide an indication of possible subchronic, subclinical, effects that may occur in humans.

Finally, as the water quality results indicate, the potential problems are not isolated occurrences, but rather localised anomalies, which have a additional problem of creating the lack of a comparative norm, as large number of animals, and humans, in an area tend to be affected. The order by which the recommended guidelines are exceeded, and the intrinsic high risk of the product system and related environment, suggest that the possible solution option within CIRRA be expanded further. The identification of points in the ingestion route between water quality and types of health effects where risk is increased, or decreased, is of great value to proposing solutions to reduce risk. In the modelling of the rural communal livestock production system, this aspect was taken into account in the setting up of different data capturing screens, and in the design of the presentation of the evaluation results. Although perhaps too complex at first glance, once familiar, these screens offer a tool for identifying, and testing, outcomes based management decisions.

8.1.2 Wildlife Production Systems

With the rapid increase in scientific investigations pertaining to game ranching, more game ranches are changing from an initial "untouched wilderness" concept to one that recognises the active-adaptive approach. There is an increased awareness relating to the profit-based business potential in game ranching. The ecological responsibility of providing water to game is also gaining recognition. The increased demand this places on management is accompanied by an increased requirement for specialist knowledge.

The effect of water quality on wildlife has typically received little attention. Most studies do not include chemical information on water quality, and when they do, it is usually inadequate and extended only to a handful of macro-element values. In the case of one National Park in South Africa, the only water quality information that existed, other than an initial borehole electrical conductivity measurement, was provided by a study in the 1970's. The constituents addressed on that occasion were still of limited value as less than a dozen were reported on. Studies elucidating the role of water quality constituents on issues such as reproductive health and immune responsive disorders are increasing, but the beginning point of such studies requires knowledge of the quality of water, spatial and temporal, as a fundamental basis.

The water quality investigations presented in this report suggest that sufficient variability in water quality constituents exist, in terms of palatability and toxicology, to require management attention. As described in the modelling section, the availability of multiple water sources, and the presence of multiple wildlife species comprising different physiological stages, makes risk assessment a fairly complex task. A software environment not only enables these complexities to be handled, but also guides the user as to the possible types of site-specific information that can be obtained. These information types will most probably find application for game ranch management decisions other than those regarding water quality.

It is hoped that this report provides sufficient water quality risk assessments to encourage managers of game ranches and conservation areas to include water quality as a pre-requisite information type required for management to bring about the successful, sustainable, existence of the ranch, or conservation area, on a sound ecological basis.

8.2 Recommendations

8.2.1 Rural Communal Livestock Production Systems

- On the basis of the potential hazardous found in the water sources sampled, it is recommended that research focus on identifying, and testing, outcomes based system manipulations that can allow for the continued use of a water source containing potentially hazardous constituents.
- The efficacy of alleviator chemical treatments administered to the water supply should be tested in the rural communal production system context.
- The effect of using brine for stock watering in the rural communal production system context on animal product quality, and animal health, should be investigated.
- It is proposed that a formal procedure be developed in which the role played by water quality in rural communal production systems be determined through a series of clearly defined steps. Recommended steps in this regard are:

1. Commencing with a risk assessment for livestock addressing health and product quality norms to identify specific potentially hazardous water quality constituents and constituents of concern;
2. Substantiating the potential risk identified in Step 1 by using clinical evaluations of herd health, animal tissue histopathology and assays for relevant constituents, geochemistry, and feed samples;
3. Formulating possible risk implications for human health on the basis of the results obtained in Step 2, incorporating direct and indirect, site-specific factors;
4. Preliminary community-based epidemiological studies to assess the risk factors present;
5. Substantiating the potential risk identified in Step 4 through community health investigations;
6. Depending on the outcome of Step 5, viable means of reducing risk in both animals and humans should be identified;
7. It is proposed that these steps form part of a formal procedure in a software program that consists of different components encompassing the fields of knowledge required. It is envisaged that such a program would enable the identification the probability of risk in potential areas to be based on geochemistry-related data, thus in effect guiding animal and veterinary scientists for step 1. The program can also contribute to the building of Provincial and National data bases by linking the relevant data capturing screen information to the relevant specialist field. The program can also accommodate frequent updates as new research evidence and procedure becomes available.

A specialist component-based software program catering for the variable types of data bases (animal, geological, hydrological, climatic, epidemiological, etc.) would aid in encouraging collaborative research, with the central theme of improving the quality of life for humans in the rural communal context, by allowing the correct detection, and management, of critical issues pertaining to water quality to be recognised and addressed.

8.2.2 Wildlife Production Systems

- It is recommended that a water quality monitoring programme be designed for the National Parks of South Africa, and that management decisions regarding water provision and the placement and design thereof, include water quality risk assessments, for wildlife health and ecological impact norms directly influenced by wildlife, as a pre-requisite to the information types on which the decision making process rests.
- It is recommended that research be conducted regarding the use of mineral licks, and other forms of supplementary feeding for wildlife, as corrective and/or alleviator treatment for water sources with potentially hazardous water quality constituent concentrations.

Possible contamination of groundwater and the environment by both production systems, although not typically intensive, should also receive attention.

Although water quality aspects for aquatic systems have, and continue to, receive attention, these monitoring programmes do not always lend themselves to conducting risk assessments for wildlife health. Those who are of the opinion that water quality for wildlife has no place in the management of wildlife not only neglect the impact thereof on wildlife health, but also on the ecological environment. Choosing not to obtain information on water quality effectively prevents a manager from managing those resources, and the wildlife that rely on them. In order to manage, measurement is a pre-requisite.

The recommendations proposed for the rural communal livestock production systems, and wildlife production systems, should be seen in context of the mission of the Department of Water Affairs and Forestry as custodian of South Africa's water resources, part of which is to "maintain the fitness for use of water on a sustained basis", with specific reference to two recognised categories of water use, namely, domestic and agricultural purposes.

CHAPTER 9
REFERENCES

Acocks, J.P.H. (1975). Veld types of South Africa. Mem. Botanical Survey of South Africa No 57.

Abdel-Rahim, A.G., Arthur, J.R. and Mills, C.F. (1985). Selenium utilisation by sheep given diets differing in sulphur and molybdenum content. *Biological Trace Element Research* 8, 145-155.

Agget, P.J. and Mills, C.F. (1996). Detection and anticipation of the risks of development of trace element-related disorders. In: Trace Elements in Human Nutrition and Health. World Health Organisation, Geneva, 289 - 308

Alloway, B.J. (1973). Copper and molybdenum in sway-back pastures. *Journal of Agricultural Science, Cambridge* 80, 521-524.

Ammerman, C.B., Fick, K.R., Hansard, S.L. and Miller, S.M. (1973). Toxicity of certain Minerals to Domestic Animals: A Review. Animal Science Research Report AL73-6, University of Florida, Gainsville.

Anke, M. (1999). Vanadium – an Essential Element for Animals and Humans? In: Favier, A.E. (ed) Trace Elements in Man and Animals – 10 – Proceedings of the Tenth International Symposium. Plenum Publishers, Evian. (in press)

Apps, P. (1999). Wild ways – Field Guide to the Behaviour of southern African Mammals. 2nd Ed. Struik Publishers. ISBN: 1 86872 443 3.

Appleton, J.D. (1992). Review of the use of regional geochemical maps for identifying areas where mineral deficiencies or excesses may affect cattle productivity in tropical countries. *British Geological Survey Technical Report* WC/92/24.

Arora, S.P., Parvinder, K., Khirwar, S.S., Chopra, R.C. and Ludri, R.S. (1975). Selenium levels in fodders and its relationship with Degnala disease. *Indian Journal of Dairy Science* 28, 249.

Arthur, J.R. and Beckett, G.J. (1994). Roles of selenium in Type I iodothyronine 5'-deiodinase and in thyroid hormone and iodine metabolism. IN: Burk, R.F. (ed.) *Selenium in Biology and Human Health.* Springer-Verlag New York Inc., New York, USA, 93 - 115

ATSDR (1989). Agency for Toxic Substances and Disease Registry. *Toxicological Profile for Selenium.* U.S.Public Health Service, U.S Department of Health and Human Services, Atlanta, GA.

Baker, D.H. and Ammerman, C.B. (1995). Zinc bioavailability. In: Ammerman, C.B., Baker, D.H. and Lewis, A.J. (eds) *Bioavailability of Nutrients For Animals.* Academic Press, New York, pp. 367-398.

Barry, T.N. Reid, T.C., Millar, K.R. and Sadler, W.A. (1981). Nutritional evaluation of kale (*Brassica oleracea*) diets 2. Copper deficiency, thyroid function and selenium status in young cattle and sheep fed kale for prolonged periods. *Journal of Agricultural Science*, Cambridge 96, 269-282.

Becker, R.B., Davis, G.K., Kirk, W.G., Glasscock, R.S., Dix, A.P.T. and Pace, J.E. (1944). "Defluosuperphosphate for Livestock" *Bull* 401-Fla. Agr. Exp. Stn., Gainesville.

Beede, D.K. (1992). *Feed Manage* 43 (6), 28.

Berg, J.M. (1990). Zinc fingers and other metal-binding domains: elements for interactions between molecules. *Journal of Biological Chemistry* 365, 6513 - 6518

Bothma, J Du P (1996). Game Ranch Management. Van Schaik Publishers. 96 - 98.

Bothma J. du P. and Walker, C. (1999). Large Carnivores of the African Savannas. J.L.van Schaik, Pretoria. ISBN 0 627 02411 4

Bowell, R.J., Warren, A. and Redmond, I. (1996). Formation of cave salts and utilization by elephants in the Mount Elgon region, Kenya. In: Appleton, J.D., Guge, R. and McCall, G.J.H. (eds), 1996, *Environmental Geochemistry and Health* Geological Society Special Publication No. 113. 63-79.

Bradley, B.D., Graber, G., Condon, R.J. and Frobish, L.T. (1983). Effects of graded levels of dietary copper on copper and iron concentration in swine tissues. *Journal of Animal Science* 56, 625-630.

Bremner, I. (1993). Metallothionein in copper deficiency and copper toxicity. In: Anke, M., Meissner, D. and Mills, C.F. (eds) *Proceedings of the Eighth International Symposium on Trace Elements in Man and Animals*. Verlag Media Touristik, Gersdorf, 507-515.

Campbell, A.G., Coup, M.R., Bishop, W.H. and Wright, D.E. (1974). Effect of elevated iron intake on the copper status of grazing cattle. *New Zealand Journal of Agricultural Research* 17, 393-399.

Canto, A.H., Nash, D. and Johnson, T.H. (1984). Toxicity of selenium in drinking water of poultry. *Nutrition Reports International* 29, 683-688.

Casey, N.H. and Meyer, J.A. (1996). Interim Water Quality Guidelines for Livestock Watering. Water Research Commission. ISBN 1 86845 225 5.

Casey, N.H., Meyer, J.A. and Coetzee, C.B. (1998a). An investigation into the quality of water for animal production livestock production with the emphasis on subterranean water and the development of a water quality guideline index system. Volume 1: Development and modelling. Report to the Water Research Commission. WRC Report No: 644/1/98. ISBN No: 1 86845 739 0

Casey, N.H., Meyer, J.A. and Coetzee, C.B. (1998b). An investigation into the quality of water for animal production livestock production with the emphasis on subterranean water and the development of a water quality guideline index system. Volume 2: Research results. Report to the Water Research Commission. WRC Report No: 644/2/98. ISBN No: 1 86845 380 4.

Casey, N.H., Meyer, J.A. and Coetzee, C.B. (1998c). An investigation into the quality of water for animal production livestock production with the emphasis on subterranean water and the development of a water quality guideline index system. Volume 3: Appendix. Report to the Water Research Commission. WRC Report No: 644/3/98. ISBN No: 1 86845 381 2.

Chakraborti. D. (1999). Arsenic groundwater contamination and sufferings of people in West Bengal-India and Bangladesh. In: Favier, A.E. (ed) Trace Elements in Man and Animals – 10 – Proceedings of the Tenth International Symposium. Plenum Publishers, Evian. (in press)

Chatterlee, A., Das, D., Mandal, B.K., Chowduhury, T.R., Samanta, G. and Chakrborti, D. (1995). Arsenic in ground water in six districts of West Bengal, India: The biggest arsenic calamity in the world. *Analyst*, 120, 643 - 653

Clark, R.G., Wright, D.F., Millar, K.R. and Rowland, J.D. (1989). Reference curves to diagnose cobalt deficiency in sheep using liver and serum vitamin B12 levels. *New Zealand Veterinary Journal* 37, 1-11.

Coppock, R.W., Wagner, W.C. and Reynolds, R.D. (1988). Migration of lead in a glass-lined, bottom-loading silo. *Veterinary and Human Toxicology* 30, 458 - 459

Cousins, R.B. (1996). Zinc. In: Filer, L.J. and Ziegler, E.E. (eds) *Present Knowledge in Nutrition*, 7[th] edn. International Life Science Institute-Nutrition Foundation, Washington, DC.

Cummings, T.R. (1989). Natural Ground-water Quality in Michigan: 1974 – 1987. United States Geological Survey, Denver, CO: Open-file Report 89 – 259. 50.

DWA&F (1993). Department of Water Affairs and Forestry: South African Water Quality Guidelines (second edition). Volume 4: Agricultural Use: Livestock Watering.

DWA&F (1996). Department of Water Affairs and Forestry: South African Water Quality Guidelines (second edition). Volume 4: Agricultural Use: Livestock Watering.

Danckwerts, J.E. and Teague, W.R. (1989). *Veld management in the Eastern Cape*. Department of Agricultural Development, Pretoria.

Darnley, A.G., Bjorklund, A., Bolbiken, B., Gustavsson, N. and Koval. P. (1995). *A Global Geochemical Database, Recommendation for International Geochemical Mapping*. Final Report for ICGP Project 259, UNESCO, Paris.

Davidson, W.B. and Kennedy, D.G. (1993). Synthesis of [^{75}Se] selenoproteins is greater in selenium-deficient sheep. *Journal of Nutrition* 123, 689-694.

Dean, H.T. (1945). On the epidemiology of fluorine and dental caries. In: Gies, W.J. (ed) *Fluorine in Dental Public Health*. Academy of Medicine, New York, 19 - 30

Denton, D.A. (1967). "Salt appetite, Handbook of Physiology 1" *Am. Physiol. Soc*., Washington, D.C.

Dickson, J. and Bond, M.P. (1974). Cobalt toxicity in cattle. *Australian Veterinary Journal* 50, 236

Dick, A.T. and Bull, L.B. (1945). Some preliminary observations on the effect of molybdenum on copper metabolism in herbivorous animals. *Australian Veterinary Journal* 21, 70-72.

Eloff, F.C. (1973). Water use by the Kalahari Lion *Panthera leo vernayi*. Koedoe, 16: 149-154.

Enomoto, S. (1999). Transfers of trace elements from the placenta to the fetus of pregnant rat by using the multitracer technique. In: Favier, A.E. (ed) Trace Elements in Man and Animals – 10 – Proceedings of the Tenth International Symposium. Plenum Publishers, Evian. (in press)

Ferguson, W.S., Lewis, A.H. and Watson, S.J. (1938). Action of molybdenum in nutrition of milking cattle. *Nature, UK* 141, 553.

Ferguson, W.S., Lewis, A.H. and Watson, S.J. (1943). The teart pastures of Somerset.1. The cause and cure of teartness. *Journal of Agricultural Science* 33, 44-51.

Fuge, R. (1996). Geochemistry of iodine in relation to iodine deficiency diseases. In: Appleton, J D, Fuge, R and McCall, G J H (eds) 1996. *Environmental Geochemistry and Health*. Geological Society Special Publication No. 113, 201-212

Grace, N.D. (1973). Effect of high dietary Mn levels on the growth rate and the level of mineral elements in the plasma and soft tissues of sheep. *New Zealand Journal of Agricultural Research*. 16, 177-180.

Grace, N.D. and Lee, J. (1990). Effect of Co, Cu, Fe, Mn Mo, Se and Zn supplementation on the elemental content of soft tissues and bone in sheep grazing rye grass/white clover pasture. *New Zealand Journal of Agricultural Research* 33, 635-647.

Grace, N.D., Clark, R.G. and Mortleman, L. (1986). Hepatic storage of vitamin B12 by the pregnant ewe and foetus during the third trimester. *New Zealand Journal of Agricultural Research* 29, 231-232.

Grace, N.D. and Suttle, N.F. (1979). Some effects of sulphur intake on molybdenum metabolism in sheep. *British Journal of Nutrition* 41, 125 - 136

Green, B., Anderson, J. and Whateley, T. (1984). Water and sodium turnover and estimated food consumption in free-living lions (*Panthera leo*) and spotted hyaenas (Crocuta crocuta). *Journal of Mammalogy*, 65 (4): 593-599.

Halverson, A.W. and Monty, K.J. (1960). An effect of dietary sulfate on selenium poisoning in the rat. *Journal of Nutrition* 70, 100-102.

Hartman, F and van Ryssen, J.B.J. (1997). Metabolism of selenium and copper in sheep with and without sodium bicarbonate supplementation. *Journal of Agricultural Science, Cambridge* 128, 357-364.

Healy, W.B. (1973). Nutritional aspects of soil ingestion by grazing animals. In: Butler, G.W. & Bailey, R.W. (eds) *Chemistry and Biochemistry of Herbage* Vol. 1. Academic, London, 567 – 588

Healy, W.B., Rankin, P.C. and Watts, H.M. (1974). Effect of soil contamination on the element composition of herbage. *New Zealand Journal of Agricultural Research* 17, 59 – 61.

Henry, P.R. and Ammerman, C.B. (1995). Selenium bioavailability, In: Ammerman, CB., Baker, D.H. and Lewis, A.J. (eds) *Bioavailability of Nutrients for Animals*. Academic Press, New York, pp. 303-331.

Hetzel, B.S. and Welby, M.C. (1997). Iodine. In: O'Dell, B.L. and Sunde, R.A. (eds) Handbook of Nutritionally Essential Mineral Elements. Marcel Dekker, New York 557 - 582

Hillman, D. and Curtis, A.R. (1980). Chronic iodine toxicity in dairy cattle: blood chemistry, leukocytes and milk iodine. *Journal of Dairy Science* 63, 55-63.

Hirumnuma, R. (1999). Distribution of Selenium, Arsenic, Iron and Scandium in Selenium-deficient rats using the multitracer technique. In: Favier, A.E. (ed) Trace Elements in Man and Animals – 10 – Proceedings of the Tenth International Symposium. Plenum Publishers, Evian. (in press)

House, W.A. and Welch, R.M. (1989). Bioavailability of and interactions between zinc and selenium in rats fed wheat grain intrinsically labelled with ^{65}Zn and ^{75}Se. *Journal of Nutrition* 119, 916-921.

Hsu, F.S., Krook, L., Pond, W.G. and Duncan, J.R. (1975). Interactions of dietary calcium with toxic levels of lead and zinc in pigs. *Journal of Nutrition* 105, 112-118.

Howes, A.D. and Dyer, I.A. (1971). Diet and supplemental mineral effects on manganese metabolism in newborn calves. *Journal of Animal Science* 32, 141-145.

Huheey, J.E., Keiter, E.A. and Keiter, R.L. (1993). Inorganic Chemistry: Principles of structure and reactivity, 4th Ed. Harper Collins, New York, USA. ISBN 0-06-042995-X.

ISCW (1998). Institute for Soil Climate and Water. *Agricultural Research Council. Water Analysis Division. Pretoria R.S.A.*

Ivanov, V.N. (1999). Experimental molygdenosis is the risk factor in the development of atherosclerosis. In: Favier, A.E. (ed) Trace Elements in Man and Animals – 10 – Proceedings of the Tenth International Symposium. Plenum Publishers, Evian. (in press)

Janse van Rensburg, S.D. and Pitout, M.J. (1991). Fluoried metabolisme:'n oorsig. Geneeskunde – Sept, 17 - 25

Jarvis, S.C. and Austin, A.R. (1983). Soil and plant factors limiting the availability of copper to a beef suckler herd. *Journal of Agricultural Science, Cambridge* 101, 39-46.

Johnson, P.E., Lykken, G.I. and Kortnta, E.D. (1991). Absorption and biological half-life in humans of intrinsic and extrinsic ^{54}Mn tracers from foods of plant origin. *Journal of Nutrition* 121, 711-716.

Jumba, I.O., Suttle, N.F., Hunter, E.A. and Wandiga, S.O. (1996). Effects of botanical composition, soil origin and composition on mineral concentrations in dry season pastures in western Kenya. In: Appleton, J.D., Guge, R. and McCall, G.J.H. (eds), *Environmental Geochemistry and Health* Geological Society Special Publication No. 113. 39-45.

Kempster, PL, Hattingh, WHJ and van Vliet, HR (1985). Summarised Water Quality Criteria. Dept of Agriculture and Water Affairs, Hydrological Research Institute. Technical Report TR 108.

Kent, G. and Bahu, R.M. (1979). Iron overload. In: MacSween, R,N.M., Anthony, P.P. and Schewr, P.J. (eds) *Pathology of the Liver*. Churchill Livingstone, Edinburgh, 148-163.

King, J.C. (1999). Recommended dietary intakes for trace elements: New trends. In: Favier, A.E. (ed) Trace Elements in Man and Animals – 10 – Proceedings of the Tenth International Symposium. Plenum Publishers, Evian. Plenum Publishers (in press)

Knight, M.H., Knight-Eloff, A.K. and Bornman, J.J. (1988). The importance of borehole waer and lick sites to Kalahari ungulates. *J.Arid Environ.* 15: 269 – 281.

Knight, M.H. (1989). Importance of borehole water to doves and sandgrouse in the semi-arid southern Kalahari. *S. Afr. Tydskr. Natuurnav.* 19(1) 1-5.

Koenig, K.M., Rode, L.M., Cohen, R.D.H. and Buckley, W.T. (1997). Effects of diet and chemical form of selenium on selenium metabolism in sheep. Journal of Animal Science 75, 817-827.

Krachler, M. (1999). Trace element transfer from the mother to the newborn – Investigations on triplets of colostrum, maternal and umbilical cord sera.. In: Favier, A.E. (ed) Trace Elements in Man and Animals – 10 – Proceedings of the Tenth International Symposium. Plenum Publishers, Evian. (in press)

Kul'kova, J., Bremner, K., McGaw, B.A., Reid, M. and Beattie, J.H. (1993). Mercury-zinc interactions in marginal zinc deficiency. In: Anke, M., Meissner, D. and Mills, C.F. (eds) *Proceedings of the Eighth International Symposium on Trace Elements in Man and Animals*. Verlag Media Touristik, Gersdorf, 635-637.

Langlands, J.P., Donald, G.E., Bowles, J.E. and Smith, A.J. (1990). Selenium supplements for grazing sheep. 1. A comparison between soluble salts and other forms of supplement. *Animal Feed Science and Technology* 28, 1-13.

Leach, R.M., Jr, Rosenblum, C.I., Amman, M.J. and Burdette, J. (1990). Broiler chicks fed low-calcium diets. 2. Increased sensitivity to copper toxicity. *Poultry Science* 69, 1905-1910.

Lonnerdal, B. (1999). Nutrition during pregancy and lactation: effect on milk trace elements In: Favier, A.E. (ed) Trace Elements in Man and Animals – 10 – Proceedings of the Tenth International Symposium. Plenum Publishers, Evian. (in press)

Louw, G.N. (1984). Water deprivation in herbivores under arid conditions. In: Herbivore Nutrition in the Subtropics and Topics. (Eds) Gilchirst, F.M.C. & Mackie, R.I. 106-126. The Science Press. Johannesburg.

McDowell, L.R. (1985). Nutrition of Grazing Ruminants in Warm Climates. Academic Press, N.Y.

McDowell, L.R. (1992). "Minerals in Animal and Human Nutrition." Academic Press, San Dieago, 524.

McDowell, L.R. and Conrad, J.H. (1986). Mineral supplementation for cattle in the tropics. *Agriculture International*, 38, 50 - 54

McDowell, L.R., Conrad, J.H. and Hembry, F.G. (1993). Minerals for Grazing Ruminants in Tropical Regions, 2[nd] Edn. Animal Science Department, University of Florida, Gainsville, USA.

McDowell, L.R. (1996). In: Proceedings: Free-Choice mineral supplements for grazing sheep in developing countries. *Aust. Centre for Int. Agric. Res.*, Canberra, 81

McMichael, A.J. (1993). Planetary Overload. Global environmental change and the health of the human species. *Cambridge University Press.*

McDowell, L.R. (1997). Minerals for Grazing Ruminants in Tropical Regions. 3[rd] Edition. Institute of Food and Agricultural Sciences, University of Florida. *Bulletin.*

Meneses, A., Batra, T.R. and Hidiroglou, M. (1994). Vitamin E and selenium in milk of ewes. *Canadian Journal of Animal Science* 71, 567-569.

Meyer, J.A. (1992). *Potentially toxic variable in water for livestock and the physiological impact of fluoride and total dissolved solids on sheep, MSc thesis. Univ. of Pretoria. South Africa.*

Meyer, J.A. (1998). *Modelling for the Prediction of Water Quality Guidelines for Livestock in South Africa. Ph.D. Thesis Univ. of Pretoria. South Afrifca.*

Meyer, J.A. (1999). Water quality for wildlife. *South African Veterinary Association. Wildlife Group Newsletter: Hooo-hooo.* 3(4) 10-15.

Meyer, J.A. and Casey, N.H. (1999). *Selenium and fluoride toxicology - water quality guidelines for Dohne Merino Sheep in southern Africa. In: Favier, A.E. (ed) Trace Elements in Man and Animals – 10 – Proceedings of the Tenth International Symposium. Plenum Publishers, Evian (in press).*

Meyer, J.A., Casey, N.H. and Coetzee, C.B. (1997). Water quality guidelines for livestock watering in southern Africa. *Water SA* 23:1:7-12.

Meyer, J.A., Casey, N.H. and Myburgh, J. (2000). The influence of geochemistry on health risks to animals and humans in geographically localised livestock production systems. Proceedings of the 38[th] Congress of the South African Society of Animal Scientists. KwaZulu-Natal. 109-110.

Mills, M.G.L. (1978). The diet of the brown hyaena *Hyaena brunnea* in the southern Kalahari. Koedoe, 21: 125-149.

Mills, C.F. (1996). Geochemical aspects of the aetiology of trace element related diseases. In: Appleton, J.D., Fuge, R. and McCall, G.J.H. (eds), 1996, *Environmental Geochemistry and Health* Geological Society Special Publication No. 113.

Minson, D.J. (1990). *Forage in Ruminant Nutrition*. Academic Press, New York, 382-395.

Mitchell, R.L. (1957). The trace element content of plants. *Research, UK* 10, 357-362.

Nechay, B.R. (1984). Mechanisms of action of vanadium. *Annual Reviews of Pharmacology and Toxicology* 24, 501 - 524

Nelson, T.S., Daniels, L.B., Hall, J.R. and Shields, L.G. (1976). Hydrolysis of natural phytate phosphorus in the digestive tract of calves. *Journal of Animal Science* 42, 1509 – 1512.

Neser, J.A., De Vries, M.A., De Vries, M., Van der Merwe, A.J., Loock, A.D., Smith, H.J.C., Van der Vyver, F.H., Elsenbroek, J.H. and Delport, R (1997). Enzootic geophagia and hepatitis of calves and lambs and the possible role of manganese poisoning. AFMA Matrix (Sept), 5 - 6

Neumann, C.G. (1998). Role of Animal Source Foods in Improving Diet Quality and Micronutrient Content and Contribution to Child, Health, Growth and Development. In: *Symposium on Human Nutrition and Livestock in the Developing World.* Miller, A (ed) Heifer Project International. Arkansas, USA. 9 - 18

NRC, (1996). Nutrient requirements of beef cattle. Seventh Revised Ed. National Academy of Sciences. Washington, DC

Ockerse, T. (1953). Chronic endemic dental fluorosis in Kenya, East Africa. *British Dental Journal*, 95, 57 - 60

Ohta, H. (1999).Effects of daily cadmium intake on bone metabolism and renal function in rats. In: Favier, A.E. (ed) Trace Elements in Man and Animals – 10 – Proceedings of the Tenth International Symposium. Plenum Publishers, Evian. (in press)

Ottoboni, M.A. (1984). The Dose makes the Poison. Vincente Books, USA. 77 - 88

Parr, R.M., Crawley, H., Abdulla, M., Iyengar, G.B. and Kampulainen, J. (1992). *Human dietary intakes of the trace elements: a global literature survey, mainly for the period 1970 – 1991.* International Atomic Energy Agency, Vienna.

Phillips, D.I.W., Nelson, M., Barker, D.J.P., Morris, J.A. and Wood, T.J. (1988). Iodine in milk and the incidence of thryotoxicosis in England. *Clinical Endocrinology* 28, 61-66.

Piasek. M. (1999). Low iron diet and cadmium exposure disrupt steroidogenesis in the rat. In: Favier, A.E. (ed) Trace Elements in Man and Animals – 10 – Proceedings of the Tenth International Symposium. Plenum Publishers, Evian. (in press)

Plant, J.A., Hale, M. and Ridgway, J. (1988). Developments in regional geochemistry for mineral exploration. *Transactions of the Institute of Mining and Metallurgy*, 97, B116-B140.

Plant J. A., Baldock, J.W. and Smith, B. (1996). The role of geochemistry in environmental and epidemiological studies in developing countries: a review. In: Appleton, J D, Fuge, R and McCall, G J H (eds) 1996. *Environmental Geochemistry and Health.* Geological Society Special Publication No. 113, 7-22.

Porterfield, W.W. (1984). Inorganic chemistry, a unified approach. Addison Wesley Publishing Co., Reading Massachusetts, USA.

Puls, R (1994). *Mineral levels in animal health: Diagnostic Data. Serpa Int., Canada.*

Quality of Domestic Water Supplies (1998). Published by the Department of Water Affairs and Forestry, The Department of Health, and the Water Research Commission. 65 -95.

Reid, R.L., Baker, C.S. and Vona, L.C. (1984). Effects of magnesium sulphate supplementation and fertilisation on quality and mineral utilisation of timothy hays by sheep. *Journal of Animal Science* 59, 1403 - 1410

Richardson, P.R.K (1987). Food consumption and seasonal variation in the diet of the aardwolf *Proteles cristatus* in southern Africa. *Seitschrift fur Saugetierkunde*, 52(5):
307-325.

Rosa, I.V. (1980). Dietary phosphorus and trace element interrelationships in ruminants. Ph.D. Dissertation, Univ. of Florida, Gainesville

Rosa, I.V., Ammerman, C.B. and Henry, P.R. (1986). Interrelationships of dietary copper, zinc and iron on performance and tissue mineral concentration in sheep. *Nutrition Reports International* 34, 893-902.

Sargent, T., Linfoot, J.A. and Isaac, E.L. (1966). Whole body counting of ^{47}Ca and ^{85}Sr in the study of bone diseases. In: Clinical uses of whole-body counting. Proceedings of a Panel, Vienna. International Atomic Energy Agency. 187 – 212.

Schoeman, J (2000). Reverse osmosis and brine water. Membrane and Ion Exchange Technology. Environmentek. CSIR. South Africa (personal comm.)

Silanpaa, M. (1982). Micronutrient and the Nutrient Status of Soils. a Global Study. FAO Soils Bulletin, 48, Rome

Skinner, J.D., Van Aarde, R.J. and Van Jaarsveld, A.S. (1984) Adaptations in three species of large mammals (*Antidorcas marsupialis*, *Hystrix africaeaustralis* and *Hyaena brunnea*) to arid environments. *South African Journal of Zoology*, 19: 82-86.

Smith, R (1988). *Water Quality Criteria for Livestock Watering and Human Consumption. CSIR: Division of Water Technology. Project No. 670 21 70 9.*

Smith, J.W., Tokach, M.D., Goodband, R.D., Nelsson, J.L. and Richert, B.T. (1997). Effects of the interrelationship between zinc oxide and copper sulphate on growth performance of early weaned pigs. *Journal of Animal Science* 75, 1861-1866.

Smart, M.E., Cohen, R., Christensen, D.A. and Williams, C.M. (1986). The effects of sulphate removal from the drinking water on the plasma and liver copper and zinc concentrations of beef cows and their calves. *Canadian Journal of Animal Science* 66, 669-680.

Smith, J.W., Tokach, M.D., Goodband, R.D., Nelsson, J.L. and Richert, B.T. (1997). Effects of the interrelationship between zinc oxide and copper sulphate on growth performance of early weaned pigs. *Journal of Animal Science* 75, 1861-1866.

Sposito, G. (1989). The Environmental Chemistry of Aluminium. CRC, Boca Raton, Florida.

Suttle, N.F. (1991). The interactions between copper, molybdenum and sulphur in ruminant nutrition. Annual Review of Nutrition 11, 121-140.

Suttle, N.F. (1996). Non-dietary influences on mineral requirements of sheep. In: Masters, D.G. and White, C.L. (eds) *Detection and Treatment of Mineral Nutrition Problems in Sheep.* ACIAR Monograph 37, Canberra, 31-44

Suttle, N.F., Alloway, B.J. and Thornton, I. (1975). An effect of soil ingestion on the utilization of dietary copper by sheep. *Journal of Agricultural Science, Cambridge, UK*, 84, 249 - 254

Suttle, N.F. and Mills, C.F. (1996). Studies of the toxicity of copper to pigs. 1. Effects of oral supplements of zinc and iron slats on the development of copper toxicosis. *British Journal of Nutrition* 20, 135-148.

Suttle, N.F., MacPherson, A., Phillips, P. and Wright, C.C. (1999). The influence of trace elements status on the pre-weaning growth of lambs on improved hill pastures in Scotland. I. Copper, molybdenum, sulphur and iron. *Journal of Agricultural Science, Cambridge*.

TEMA 10, 1999. In: Proceedings of Trace Elements in Man and Animal, 10[th] Symposium, Evian, May 3–7.

Theiler, A., Green, H.H. and Du Toit, P.J. (1924). *Unions S. Afr. J.Dep.Agric.* 8, 460.

Thrash, I. (1993). Implications of providing water for indigenous large herbivores in the Transvaal Lowveld. Ph.D. Thesis. University of Pretoria. South Africa.

Toens, P.D., Stadler, W. and Wullschleger, N.J. (1998). The association of groundwater chemistry and geology with atypical lymphocytes (as a biological indicator) in the Pofadder area, North Western Cape, South Africa. Report to the Water Research Commission. WRC Report No: 839/1/98. ISBN No: 1 86845 446 0.

Trescases, J.J. (1992). Chemical weathering. In: Butt, C.R.M. & Zeegers, H. (eds) Regolith Exploration Geochemistry in Tropical and Subtropical Terrains. Handbook of Geochemistry, Elsevier, Amsterdam, 25-40.

USEPA (1986). U.S. Environmental Protection Agency. *Final Draft for the Drinking Water Criteria Document for Selenium.* Criteria and Standards Division. Office of Drinking Water, Washington, D.C.

USEPA (1998). Domestic Drinking Water Quality Criteria. National Technical Information Service. (Revised July 1998). United States Environmental Protection Agency, Washington DC, EPA.

US Geological Survey (1984). Water Quality Issues in National Water Summary 1983, Hydrologic Events and Issues. Water Supply Paper 2250, Washington DC.

Underwood, E.J. (1981). Manganese. In: *Mineral Nutrition of Livestock.* Commonwealth Agricultural Bureauz, Farnham Royal, Slough, UK. 170 – 195.

Underwood, E.J. and Suttle, N.F. (1999). The Mineral Nutrition of Livestock. 3rd edition. CAB International. ISBN 0 85199 128 9.17 - 66.

Van Niekerk, B.D.H. and Jacobs, G.A. (1985). Protein energy and phosphorus supplementation of cattle fed low-quality roughage. *South African Journal of Animal Science* 15, 133 - 136

Van Ryssen, J.B.J., Bradfield, G.D., Ban Malsen, S. and De Villiers, J.F. (1992). Response to selenium supplementation of sheep grazing cultivated pastures in the Mildlands of Natal. *J.S.Afr.Vet.Assoc.* 63, 148.

Van Ryssen, J.B.J. (1996). The selenium concentration of feedstuffs in South Africa. AFMA MATRIX Vol 5(2). 3-5.

Webb, J.S. (1964). Geochemistry and life. *New Scientist*, **23**, 504-507.

Wedeking, K.J., Titgemeyer, E.C., Twardock, R. and Baker, D.H. (1991). Phosphorus but not calcium affects manganese absorption and turnover in chicks. *Journal of Nutrition* 121, 1776-1786.

White, C.L., Robson, A.D. and Fisher, H.M. (1981). Variation in the nitrogen, sulfur, selenium, cobalt, manganese, copper and zinc contents of grain from wheat and two lupin species grown in a Mediterranean climate. *Australian Journal of Agricultural Research* 32, 47-57.

White, C.L., Masters, D.G., Peter, D.W., Purser, D.B., Roe, S.P. and Barnes, M. (1992). A multi-element supplement for grazing sheep. I: Intake, mineral status and production response. *Australian Journal of Agricultural Research*. 43, 795 – 808.

Whitelaw, A., Russel, A.J.F., Armstrong, R.H., Evans, C.C. and Fawcett, A.R. (1983). Studies in the prophylaxis of induced copper deficiency in sheep grazing reseeded hill pastures. *Animal Production* 37, 441-448.

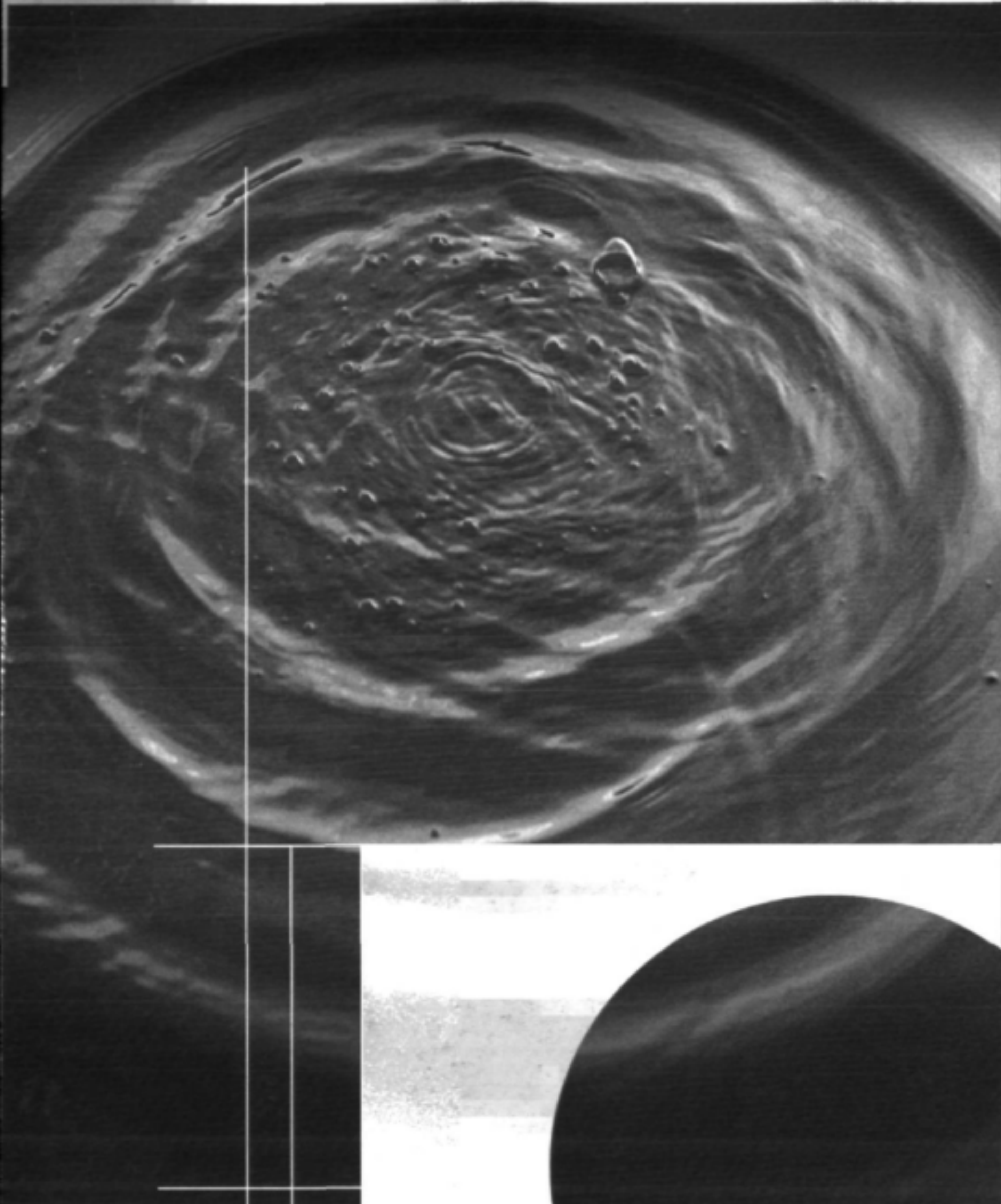
WHO (1984). World Health Organisation. Guidelines for Drinking Water Quality: Volume 2: Health Criteria and Other Supporting Information. WHO, Geneva.

WHO (1988). World Health Organisation. Urbanisation and its implications for child health: potential for action. WHO, Geneva

WHO (1993). World Health Organisation. Geneva. Guidelines for drinking-water. Volume 2. 55-77

WHO (1996). World Health Organisation. *Trace elements in human nutrition and health*. WHO, Geneva

Winter, C.T. (1985). The water quality of waterholes utilised by game in the Etosha National Park. *Madoqua* 12: 145-153.



Water Research Commission

PO Box 824, Pretoria, 0001, South Africa

Tel: +27 12 330 0340, Fax: +27 12 331 2565

Web: http://www.wrc.org.za

1868457133